TRANSPORTATION RESEARCH RECORD 629

Pedestrian Controls, Bicycle Facilities, Driver Research, and System Safety

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1977

Transportation Research Record 629
Price $3.60
Edited for TRB by Susan L. Lang

subject areas
51 highway safety
52 road user characteristics
53 traffic control and operations
84 urban transportation systems

Transportation Research Board publications are available by ordering directly from the board. They may also be obtained on a regular basis through organizational or individual supporting membership in the board; members or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Notice

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Pedestrian controls, bicycle facilities, driver research, and system safety.

(Transportation research record; 629)
Includes bibliographical references.
1. Traffic safety–Research–United States–Congresses. 2. Pedestrians–Congresses. 3. Cycling paths–Congresses. I. Title. II. Series.
TE7.H5 no. 629 [HE5614.2] 380.5'08s [614.8'62]
ISBN 0-309-02657-1 78-1602

Sponsorship of the Papers in This Transportation Research Record

Sponsorship is indicated by a footnote at the end of each report. The organizational units and officers and members are as of December 31, 1976.

Contents

Selection of Pedestrian Signal Phasing

C. M. Abrams and S. A. Smith, JHK and Associates, Alexandria, Virginia

This paper presents a methodology for selecting alternate schemes for pedestrian signal phasing. The types of pedestrian phasing studied include (a) combined pedestrian-vehicle interval, (b) early release of pedestrians with respect to vehicles, (c) late release of pedestrians with respect to vehicles, and (d) scramble timing. Each alternative is weighed in terms of its impact on the safety of the pedestrian and on the delay to both pedestrians and vehicles. The results of the study indicate that the combined pedestrian-vehicle interval will almost always minimize overall pedestrian and vehicle delay. The only exception occurs for the case in which a pedestrian-vehicle conflict causes long queues of vehicles to form in a right-turning lane (or left-turning lane on a one-way street). In that case, the use of late release or scramble timing is preferable. Scramble timing is capable of increasing pedestrian safety by completely separating pedestrian and vehicular movements; however, this benefit is canceled if pedestrian compliance is low. The early release of pedestrians does not appear to significantly improve pedestrian safety and will always increase total delay at the intersection. A methodology for selecting the phasing for given pedestrian volumes and vehicle-turning movements is presented.

The combined pedestrian-vehicle interval is the most common form of pedestrian signal phasing in use today, and it is defined in a manual (1) as "a signal phasing wherein pedestrians may use certain crosswalks and vehicles are permitted to turn across these crosswalks." At most crosswalks, the necessity to share green time leads to conflicts between pedestrians and right- or left-turning vehicles. The signal phases that have been used in the past are designed to partially or fully separate the movements of pedestrians and vehicles. This paper discusses the practicality of using phasing schemes other than the combined pedestrian-vehicle interval. The research on which this paper is based was performed as part of a broader study that encompassed a number of areas in addition to pedestrian signal timing (2). The procedures that are too detailed to be treated in this paper are referenced for further information.

TYPES OF PHASING

Three basic schemes for pedestrian signal phasing were examined as alternatives to the combined pedestrian-vehicle interval. These schemes included two semiexclusive pedestrian phases and one totally exclusive pedestrian phase and are listed below:

1. Early release of pedestrians with respect to vehicles,
2. Late release of pedestrians with respect to vehicles, and
3. Scramble timing.

The early release of pedestrians is designed to allow pedestrians to leave the curb before the vehicles turn right. Through vehicles are allowed to proceed normally. The object of this type of signal phasing is to allow the pedestrians who travel in the same direction as the vehicles to pass the zone of conflict before the vehicles turn right. Thus, the pedestrians from the opposite end of the crosswalk enter the zone of conflict shortly after the vehicles are released. (This situation will vary, depending on street width.) In this case, the pedestrians are better equipped to react to the movement of right-turning vehicles because they have direct eye contact with the vehicles. However, this type of signal phasing necessitates a separate signal indication for right-turning vehicles. The length of this early release interval is generally in the range of 5 to 10 s.

The late release of pedestrians is defined as holding the pedestrians at the curb until several vehicles turn right and pass the crosswalk. The logic behind this type of signal phasing is to permit several vehicles to turn before there is a pedestrian conflict. This situation increases the capacity of the right-turning lane and reduces the vehicle delay. It would be desirable, although not necessary, to provide a green arrow for right turns for the initial vehicle interval. This arrow would then revert to the normal green indication several seconds before the pedestrian WALK sign informs the vehicles that they no longer have the right-of-way. The late release interval could be as short as 7 s or much longer, depending on the cycle length and time required for the minimum WALK and clearance intervals.

The use of scramble timing provides an exclusive signal phase so that pedestrians can cross the intersection from all directions, including the diagonal. Currently, the most frequent use of scramble timing occurs in shopping and business districts where pedestrian volumes are high and at school crossings where safety is of utmost concern. The exclusive phase is normally timed with a 7-s WALK interval, and a minimum clearance interval is timed by using a walking speed of 1.22 m/s (4.0 ft/s), which covers the distance between the diagonally opposite curbs.

STUDY APPROACH

The study approach was to evaluate these three types of pedestrian signal phasing in terms of pedestrian and vehicle delay and safety. The delay and safety effects of these types of phasing were then compared to the effects of a combined pedestrian-vehicle interval.

For both early and late release, a hypothetical location that is typical of an intersection in a central business district (CBD) was used to develop the values for vehicle and pedestrian delay. The delay impacts of scramble timing were examined for a hypothetical intersection that was best suited for the use of scramble timing. A special study that used time-lapse photography was conducted for the delay analyses. For the safety analysis, a pedestrian compliance study was performed for late release phasing, and compliance trends were observed for scramble timing.

DATA COLLECTION

The data required for the analysis of the schemes for pedestrian signal phasing included studies of vehicle delay, pedestrian arrival rates at intersections, pedestrian delay, and pedestrian compliance. These are briefly discussed below.

The impact of phasing on vehicle delay was determined by developing a relation between right-turning vehicle delay and pedestrian volume on the crosswalk. Although some studies concerning this relation have been performed, none were sufficiently detailed for use in this analysis. Consequently, a field study that used time-lapse photography was undertaken for this project. For the purpose of this study, delay was defined as the difference between the time required for a right-turning movement with pedestrians in the crosswalk and the time required for a right-turning movement without pedestrians in the crosswalk. Thus, this definition of delay does not include any effect of the traffic signal itself.

Films from the cities of Washington, D.C.; Cambridge, Massachusetts; Phoenix, Arizona; and Akron, Ohio, were used. The data base included 68 h of approach that translated into approximately 2000 h of right-turning vehicles for a wide range of pedestrian volumes. The specific data collection and analysis procedures are found in another report (2). The delay relation that evolved from this study is shown in Figure 1. This relation is applied to intersection approaches where the intersecting street is less than 18.3 m (60 ft) wide, i.e., the parallel crosswalk is less than 18.3 m (60 ft) long.

The analysis of pedestrian delay required a preliminary study of pedestrian arrival rates at intersection crosswalks. The details of this study can also be found in another report (2). Briefly, it was found that the arrival rate of pedestrians at a signalized intersection crosswalk is highest during and just before the WALK interval. This rate drops off to approximately half the rate of the former after the flashing DONT WALK sign is displayed because the pedestrians who wish to reach the diagonal curb have a choice of streets to cross. To minimize their delay, the pedestrians will cross from the crosswalk that is displaying or will soon display the WALK interval. The arrival rate of pedestrians at a crosswalk that was assumed for computing the pedestrian delay in this study is shown in Figure 2.

Other data collection included a field study in Sioux City, Iowa, to observe pedestrian compliance at late release installations. For over 10 years, late release has been used at many of the intersections in downtown Sioux City. Most of these late release phasings are at intersections on one-way streets. These installations use a right-turn arrow for vehicles that is displayed for all but the last 2 to 3 s of the total interval for the late release of pedestrians (9 to 10 s). The pedestrian compliance rates at scramble-timing installations in Washington, D.C., were also used. No field studies were made at locations where the phasing for the early release of pedestrians is used.

EARLY PEDESTRIAN RELEASE

Analysis

The delay analysis for the early release phasing was performed under several assumptions. The characteristics of the intersection and the assumptions include the following:

1. Perfect pedestrian compliance,
2. The pedestrian arrival distribution shown in Figure 2,
3. The distribution of right-turning vehicle delays shown in Figure 1,
4. A 3-s headway for right-turning vehicles and a 2-s headway for through vehicles at saturation flow,
5. A 15.9-m (52-ft) crosswalk,
6. An 80-s cycle with a 50-50 split,
7. All right-lane vehicles in the queue at the beginning of green, and
8. Various combinations of through and right-turning vehicles to simulate the total range of difference in delay between early release and standard timing.

A 7-s interval for early release of pedestrians (vehicles are stopped in the right-turning lane during this time) was also used. The signal timing that results from the above assumptions is shown in Figure 3.

The specific analysis procedures used in computing vehicle and pedestrian delay can be found in another report (2). Basically, pedestrian delay was computed for pedestrian volumes of between 2 and 20 pedestrians/cycle. The delay for right-turning vehicles resulting from pedestrians was computed for a range of 2 to 8 vehicles/cycle and between 2 and 20 pedestrians/cycle who crossed the street into which the vehicles were turning. Two different arrival patterns for through and right-turning vehicles in the right lane were examined: one favored early release, and the other favored standard timing.

Results

The results of the delay analysis in person-seconds per cycle for the two arrival patterns are given in Table 1. The pedestrian delay does not increase with the early release of pedestrians, since the length of the WALK interval is the same as that with standard timing. Overall, and in comparison with standard phasing, early pedestrian release will always result in additional total person delay at an intersection.

LATE PEDESTRIAN RELEASE

Analysis

The analysis of vehicle and pedestrian delay resulting from the late release of pedestrians was conducted in much the same way as the early release analysis. The timing diagram for late release and its relation to standard timing is also shown in Figure 3. The same intersection characteristics and assumptions were used for late release as had been used for early release. A 7-s advance green for right-turning vehicles that is relative to the pedestrian WALK interval was also used. This interval permits 2 to 3 vehicles to turn right before the pedestrians are released. Similar to the analysis of the early release, the vehicle-delay analysis was performed for two different arrival patterns; one favored late release, and the other favored standard phasing.

The analysis of the pedestrian compliance data collected in Sioux City consisted of determining the percentage of pedestrians who begin to cross during each pedestrian interval. Of particular interest was the percentage of pedestrians who begin to cross during the late release interval.

Results

The results of the delay analysis for various pedestrian and vehicle volume levels are given in Table 2. The total delay is always increased by the use of late release for low volumes of vehicles; however, the results for higher volumes are mixed. Thus, it appears that, for the case in which almost all vehicles are making right turns and pedestrian volumes are heavy, the use of late release significantly reduces the vehicle delay. This is the case because the first several vehicles are allowed to proceed in an unobstructed manner. The use of late release also increases the capacity of the right-turning lane to some extent by concentrating pedestrian movements into a shorter period of time, which increases the time available for free vehicle movement. The potential increase in the capacity of the right-turning lane would be even more significant, if a longer late release interval were used. Thus, one application of late release phasing would be to alleviate a congestion problem in the right-turning lane.

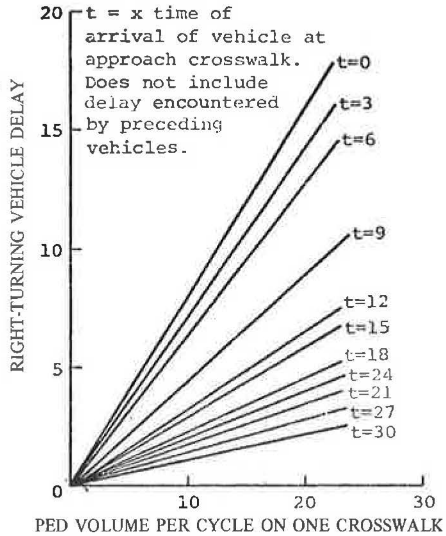


Figure 1. Relation between pedestrian volume and right-turning vehicle delay.

Note: 1 m = 3.3 ft.
These curves apply only to those crosswalks that are less than 18.3 m long.

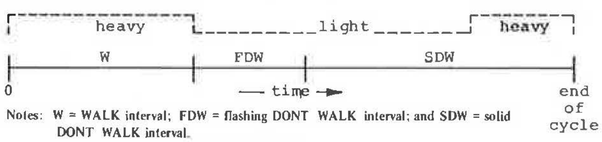


Figure 2. Typical distribution of pedestrian arrival at an intersection crosswalk.

Notes: W = WALK interval; FDW = flashing DONT WALK interval; and SDW = solid DONT WALK interval.
Light arrival rate = 0.5 x heavy arrival rate.

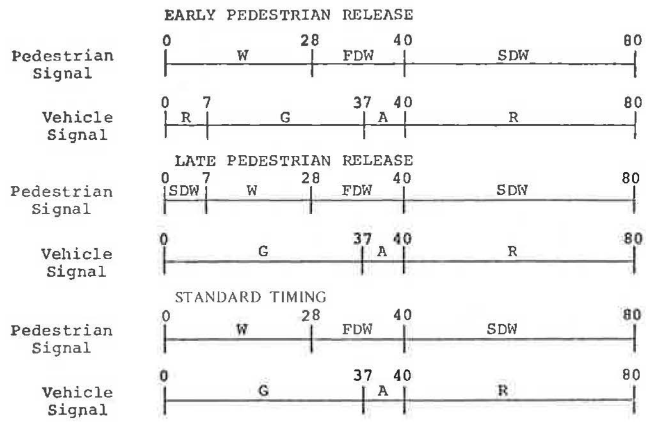
The capacity of the right-turning lane that exists with late release timing can be approximated by the following formula:

$$LRC = LRT - 3 + x \quad (1)$$

where

LRC = late release capacity per cycle (number of vehicles),
LRT = time allocated to the pedestrian late release interval (seconds),

Figure 3. Timing used in the analysis of early and late release of pedestrians.



Notes: W = WALK interval; FDW = flashing DONT WALK interval; SDW = solid DONT WALK interval;
G = green indication; A = amber indication; and R = red indication.
Numbers indicate time (seconds) from beginning of the cycle.

Table 1. Increase in delay from early release timing over standard timing.

		Vehicle Delay (person-s/cycle)								Total Delay (person-s/cycle)							
		2 Veh/Cycle		4 Veh/Cycle		6 Veh/Cycle		8 Veh/Cycle		2 Veh/Cycle		4 Veh/Cycle		6 Veh/Cycle		8 Veh/Cycle	
Pedestrian Volume per Cycle	Pedestrian Delay (person-s)	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
0	–	21	0	42	0	63	0	84	0	21	0	42	0	63	0	84	0
2	0	18	0	36	0	54	0	72	0	18	0	36	0	54	0	72	0
5	0	18	0	36	0	54	0	72	0	18	0	36	0	54	0	72	0
10	0	15	0	30	0	45	0	60	0	15	0	30	0	45	0	60	0
20	0	12	0	24	0	36	0	48	0	12	0	24	0	36	0	48	0

Notes: Based on vehicle occupancy rate of 1.5 persons/vehicle.
Maximum possible increase in vehicle delay for early release versus standard timing occurs when the first vehicle turns right and the remaining vehicles go through the intersection. Minimum increase occurs when at least the first three vehicles and possibly all vehicles go through the intersection.

Table 2. Increase in delay from late release timing over standard timing.

		Vehicle Delay (person-s/cycle)								Total Delay (person-s/cycle)							
		2 Veh/Cycle		4 Veh/Cycle		6 Veh/Cycle		8 Veh/Cycle		2 Veh/Cycle		4 Veh/Cycle		6 Veh/Cycle		8 Veh/Cycle	
Pedestrian Volume per Cycle	Pedestrian Delay (person-s)	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	9	0	-8	2	-20	6	-32	12	-44	9	1	11	-11	15	-23	21	-35
5	21	0	-15	3	-36	12	-57	21	-78	21	6	24	-15	33	-36	42	-57
10	41	0	-29	5	-68	21	-107	42	-146	41	12	46	-27	62	-66	83	-105
20	83	0	-53	8	-139	26	-185	165	-312	83	30	91	-56	109	-102	248	-229

Notes: Based on vehicle occupancy rate of 1.5 persons/vehicle.
Maximum possible increase in vehicle delay for late release versus standard timing occurs when the first three vehicles go through the intersection and the remainder turn right. Minimum increase (maximum decrease) occurs when the first three vehicles turn right and the remainder go through the intersection.
Negative sign indicates that vehicle delay decreased with late release.

3 = approximate average vehicle headway for right turns, and
x = capacity of remainder of the phase after pedestrian release (number of vehicles).

The value of x depends on the time allocated to the WALK and clearance interval and on the pedestrian volume. The approximate capacity of the right-turning lane for a range of interval times and pedestrian volumes that was developed for this study is based on the delay curves shown in Figure 1. These capacity values for an exclusive right-turning lane are given in Table 3.

The results of the compliance study in Sioux City, Iowa, indicate that most pedestrians comply with the late release interval. At the locations studied, only about 3 percent of all pedestrians began their crossing in the 9 to 10-s late release interval.

It is difficult to judge the effect of the late release phasing on pedestrian behavior in other cities without actually installing such a system. Late release phasing has been used in Sioux City over a long time period and in a number of locations so that both the pedestrian and driver are quite familiar with its operation, which possibly contributes to the high compliance rate. However, if such installations were introduced in other cities, the acclimation period would probably be long. If a new installation is used for late release phasing, signs should be placed at the crosswalk to inform pedestrians that they cannot leave immediately with the vehicle green phase.

SCRAMBLE TIMING

Analysis

The analysis of the delay difference between scramble and standard timing was designed by using conditions favorable to scramble timing. Previous research suggests that these conditions include high pedestrian volumes, low through-vehicle volume, heavy right-turn volumes, and narrow street widths (3). Specifically, the following assumptions were used:

1. Perfect pedestrian compliance;
2. Uniform pedestrian arrivals for scramble timing and the distribution shown in Figure 2 for standard pedestrian timing;
3. A 12.2-m (40-ft) street with parking on both sides, which allows one lane of traffic in each direction;
4. An 80-s cycle with a 50-50 split;
5. A 3-s average headway for right-turning vehicles at saturation flow;
6. All vehicles making right turns, and
7. Cycles with 8 vehicles/cycle and 20 pedestrians/cycle.

The timing schemes analyzed for scramble and standard phasing are shown in Figure 4.

The analysis of pedestrian delay was based on a ratio of 2:1 of pedestrians using the parallel crosswalk to those using the diagonal crosswalk. This ratio represented the travel characteristics at several scramble-timed locations in Washington, D.C. For this example, the 20 pedestrians/cycle translate into 13 pedestrians using the parallel crosswalk and 7 pedestrians using the diagonal crosswalk. For the non-scramble timing alternative, the pedestrians desiring to cross diagonally were presumed to use the WALK intervals on which they would incur the least delay.

The difference in vehicle delay between scramble and standard timing was assessed by using two arrival patterns. One pattern was based on the uniform arrival of vehicles, and the other was based on all vehicles in a platoon arriving at the beginning of the green phase. Such conditions are uncommon in everyday experience, but probably form the two extremes of possible arrival patterns.

Results

The results of the vehicle and pedestrian delay analyses for the given assumptions are presented below:

1. The pedestrian delay under scramble timing was 650 person·s compared with the 200 person·s for standard timing, an increase of over 200 percent;
2. The vehicle delay for the uniform arrival assumption was reduced with scramble timing by 300 person·s/cycle; and
3. The vehicle delay for the platoon arrival assumption was reduced with scramble timing by 400 person·s/cycle.

The large increase in pedestrian delay is primarily due to the additional delay encountered by pedestrians on the parallel crosswalks. However, the results also indicate that the delay is increased not only for those using the parallel crosswalks but also for those using the diagonal crosswalks. Thus, the use of scramble timing is at a distinct disadvantage with respect to pedestrian delay.

Although vehicle delay was reduced for the assumptions used, it should be emphasized that these combinations of intersection and traffic characteristics are favorable to the use of scramble timing. It is rare that such conditions exist in reality, particularly with such a high turning percentage. A lower turning percentage or lower traffic volume would reduce the vehicle delay advantages of scramble timing substantially. If fewer vehicles turn, or if the street is wider, then the use of scramble timing would more than likely increase vehicle delay rather than reduce it.

The prime advantage of scramble timing would accrue to vehicles by increasing the capacity of the right-turning lane under the conditions of heavy pedestrian and right-turning vehicle volumes. For cases in which a queueing problem exists in the right-turning lane, the use of scramble timing may be a means for alleviating this problem and would be particularly useful when such problems exist for both vehicle phases. The use of late release may be more applicable for the cases in which queueing problems exist for only one phase.

Despite its drawbacks and from the standpoint of delay, the use of scramble timing does have a number of possible applications because of its safety features. Under the assumption that the scramble-timing indications are obeyed, the use of scramble timing can completely separate pedestrian and vehicle movements, thereby reducing the potential for pedestrian accidents. If violations are frequent, the use of scramble timing may be more of a safety hazard than an accident prevention measure. Observations of pedestrians at several scramble-timing locations revealed that violations are more frequent at narrower streets, which is the geometric criterion for which scramble timing is the most applicable. Most of these violations were found to occur during the vehicle phase that is normally used by pedestrians under standard timing. A lack of right-turning maneuvers generally encourages the most violations at these locations.

Scramble timing and similar exclusive pedestrian phases have been widely applied to school crossings, and justifiably so, regardless of their impact on delay. Crossing guards are sometimes present at these locations to supplement the signal. Scramble timing may also be helpful at T-intersections where vehicles from the side street must turn and, in so doing, either reduce the gaps available to pedestrians or incur substantial delay themselves. If scramble timing is selected for use at an intersection, it is usually desirable to provide it on a pedestrian-actuated basis.

Table 3. Capacity of an exclusive right-turning lane by pedestrian volume in crosswalk during a cycle.

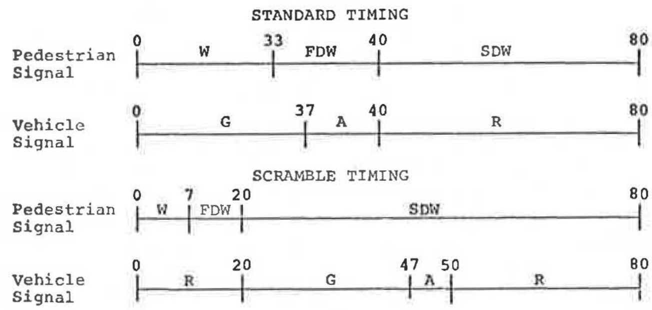
Green Phase Time (s)	Number of Vehicles: 0 Pedestrians	2 Pedestrians	5 Pedestrians	10 Pedestrians	20 Pedestrians
20	6	5	4	3	2
25	8	6	5	4	2
30	10	7	6	5	3
35	11	9	8	6	4
40	13	12	10	7	5
45	15	13	11	9	6
50	16	15	13	11	8
55	18	17	15	12	10
60	20	18	16	14	11

Notes: 1 m = 3.3 ft.
The data are applicable only for the case in which the exit crosswalk is less than 18.3 m (60 ft) long.

SELECTION OF PEDESTRIAN SIGNAL PHASING

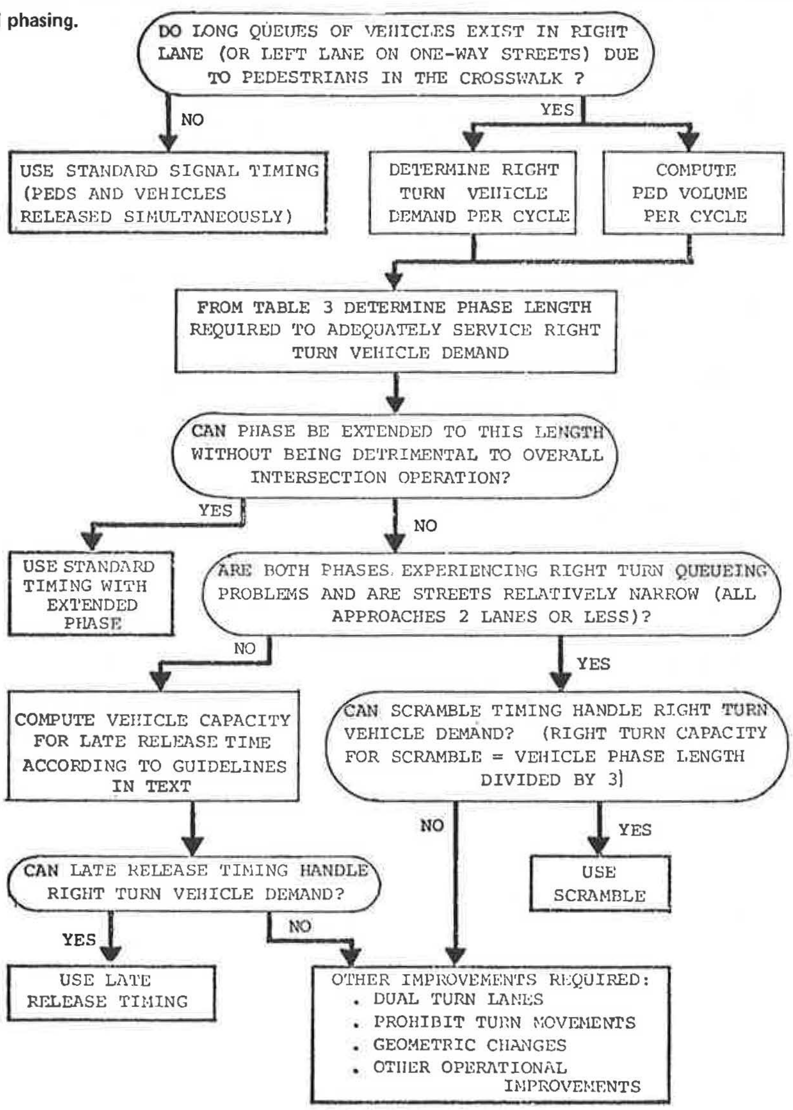
The methodology for selecting pedestrian signal phasing is shown in Figure 5. This flow chart is formulated primarily on the basis of pedestrian and vehicle delay. Safety justification for the various types of phasing is discussed below.

Figure 4. Timing alternatives evaluated for standard and scramble timing.



Notes: G = green indication; A = amber indication; R = red indication; W = WALK interval; FDW = flashing DONT WALK interval; and SDW = solid DONT WALK interval.
Numbers indicate time (seconds) from the beginning of the cycle.

Figure 5. Selection of pedestrian signal phasing.



The principles on which the methodology is based are

1. Standard pedestrian phasing (combined vehicle-pedestrian phase) almost always minimizes total intersection delay;
2. Early release of pedestrians always increases overall intersection delay;
3. Late release of pedestrians can be used to alleviate a capacity problem in the right-turning lane, but this phasing should only be used when such a problem exists; and
4. Scramble timing is best used, from the perspective of delay, when both phases are experiencing queueing problems in the right-turning lane because of pedestrian conflicts and relatively narrow street widths.

The decision for selecting the appropriate phasing scheme begins by determining whether a problem of vehicle queueing in the right-turning lane exists for any hour because of vehicle-pedestrian conflict. This condition will usually require heavy pedestrian and right-turning vehicle volumes. If this condition does not exist, delay considerations dictate that standard timing be used. If this condition does exist then the pedestrian volume per cycle should be computed and the demand for right-turning vehicles estimated. The phase length required to service the right-turning vehicle demand under standard timing can be determined by using Table 3. If the phase can be extended to that length, standard timing should be used.

If standard timing is unable to service the right-turning vehicle demand, then other phasing schemes should be examined. If both phases are experiencing queueing problems, scramble timing is suited for these conditions. If only one phase is experiencing problems, then the late pedestrian release should be used. The capacity in the right-turning lane for both scramble timing and late release can be determined by using the methodologies shown in Figure 5. If neither scheme solves the problem, then the situation will have to be tolerated or other solutions such as dual-turning lanes, turn prohibitions, or geometric changes will be required.

To select the appropriate type of signal phasing, one must consider safety as well as delay. Scramble timing would appear to be the safest type of phasing because vehicle and pedestrian movements are completely separated. However, the level of safety afforded to pedestrians is contingent on the degree of compliance with the signal indications as previously discussed.

Scramble timing may have some application to intersections where the characteristics of the pedestrian population require special consideration. For example, it may be used at locations where there are many elderly pedestrians or young school pedestrians. These locations should be carefully selected so that the violation rates do not increase or that serious traffic congestion results.

CONCLUSIONS

1. The early release of pedestrians significantly increases vehicle delay without reducing pedestrian delay. It may provide some measure of additional safety, but the benefits were not precisely determined in this study.
2. The late release of pedestrians tends to increase the overall delay at intersections (sum of vehicle and pedestrian delay) at most traffic volume levels. However, for a vehicle queue that consistently exists in a right-turning lane, late release is a good means for increasing the capacity of that lane, and, with certain combinations of pedestrian and vehicle volumes, late release will reduce the overall delay at intersections.
3. Compliance with the late release of pedestrians in Sioux City was remarkably high with less than 3 percent of pedestrians in violation. However, it is expected that, if a late release installation is provided in a city where this has not been used, pedestrian acceptance and the resultant compliance may be low. In this case, it is recommended that signs be provided to inform pedestrians that they are not permitted to begin their crossing with vehicles.
4. Scramble timing always increases pedestrian delay. For the example used in this study, pedestrian delay was increased by over 200 percent.
5. Scramble timing may be able to increase the capacity in the right-turning lanes; however, its use will increase delay on the through lanes. The delay effects are minimized if the streets are narrow and the right-turning volumes are high.
6. Scramble timing creates an exclusive pedestrian phase that, if obeyed, can completely eliminate pedestrian-vehicle conflicts, thus improving the level of safety. However, in this study, it was observed that violation rates for scramble timing were generally higher on narrow streets, which is the most suitable condition from the delay perspective.

ACKNOWLEDGMENTS

The work described in this paper was performed under a contract entitled, "Urban Intersection Improvements for Pedestrian Safety," sponsored by the Federal Highway Administration of the U.S. Department of Transportation. We wish to thank Douglas Robertson, who was with BioTechnology, Inc. at the time of this research, and Julie Fee of the Federal Highway Administration of the U.S. Department of Transportation for their constructive reviews of this work. Gratitude is also expressed to the Sioux City Traffic Engineering Department for its assistance in performing the field studies for late release phasing. The opinions, findings, and conclusions expressed in this paper are ours and not necessarily those of the sponsor.

REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, U.S. Department of Transportation, 1971.
2. C. M. Abrams and S. A. Smith. Urban Intersection Improvements for Pedestrian Safety: Signal Timing for the Pedestrian. Federal Highway Administration, U.S. Department of Transportation, Vol. 3, Aug. 1976.
3. R. D. Dier. Pedestrian Scramble Control. Traffic Engineering, Aug. 1954, pp. 413-414.

Publication of this paper sponsored by Committee on Pedestrians.

Pedestrian Delay and Pedestrian Signal Warrants

G. F. King, KLD Associates, Inc., Huntington Station, New York

Previously determined analytical relations are applied to compute the expected pedestrian delay from the pedestrian signal warrant in the current Manual on Uniform Traffic Control Devices.

A traffic signal warrant can be a set of specifications that define the boundary between two regions. In one of these regions, the installation of signal control will lead to better service for that portion of the traffic stream that is of interest. In the other regions, the converse will also hold true. The concept of better service manifests itself by reducing the average or maximum delay: a reduction in the probability of stops or a reduction in accident potential. This paper is concerned with using pedestrian delay as the boundary criterion in traffic signal warrants.

CURRENT PEDESTRIAN WARRANT

The following traffic signal warrant in the Manual on Uniform Traffic Control Devices (MUTCD) (7) is based on pedestrian demand:

For each hour in an 8-h period, a minimum of 150 pedestrians, in any one crosswalk, must cross a traffic stream that has a minimum of 600 vehicles/h in an undivided roadway, or 1000 vehicles/h in a divided roadway. These values can be reduced by 30 percent if the 85th percentile speed exceeds 65 km/h (40 mph) or if the location lies within the area that is built up in an isolated community that has a population of less than 10 000.

The 1954 revisions to the 1948 edition of the MUTCD specified a total of 250 pedestrians/h (i.e., independent of the number of crosswalks) who must oppose 600 vehicles/h. There was no difference in this value for divided highways. The mean speed of traffic had to exceed 24 km/h (15 mph). As defined for rural areas, these values could be reduced by 50 percent if the average approach speed exceeded 49 km/h (30 mph). Furthermore, the 1954 set of warrants allowed pedestrians to be added, on a one-to-one basis, to the cross-street volume, which was required for qualification under the interruption of continuous traffic warrant. Thus, signals could be justified if, for urban areas with an average approach speed of 32 km/h (20 mph), there were 75 units (pedestrians and vehicles) crossing a main street that has a 750-vehicle volume. For rural conditions and approach speeds exceeding 57 km/h (35 mph), the corresponding minimum values were 50 units and a street with a 500-vehicle volume.

The 1948 edition of the MUTCD specified the same numerical values. However, these values were determined on the basis of the average volume over any 8-h period instead of being determined for each hour in an 8-h period. For the 1954 version, these values are equivalent to a de facto increase of approximately 14 percent in required minimum volumes (2), which is relative to the 1948 version.

As indicated, the pedestrian warrant has required higher volumes over the years. Not unexpectedly, this increase has reduced the applicability of the pedestrian warrant. From a survey of current practices (3), it was found that, out of a total of 12 780 traffic signal installations made by the responding jurisdictions, only 171 or 1.3 percent were justified by the pedestrian volume warrant. The pedestrian component of the traffic stream was also considered, and it entered into the 506 (4.0 percent) new signals justified under the school crossing warrant. Some consideration of pedestrians may have also entered into the 1243 (9.7 percent) signal installations under the combination warrant.

Previously developed analytical formulations, based mainly on the queuing theory, were used to develop the delay implications of the current pedestrian warrant and the possible warrant formulations that are based on reasonable threshold values for delay.

ANALYTICAL MODEL

The main rationale underlying a pedestrian warrant is to determine those traffic flow conditions that are characterized by inadequate gaps in the traffic stream that affect the safe passage of pedestrians. This rationale implies a concomitant reasonable threshold of delay for pedestrians. If this threshold is violated, then it is necessary to introduce traffic control devices that create a sufficient number of adequate gaps artifically. These traffic control devices (primarily traffic signals) will, in turn, generate vehicle delay, which must be related to the time savings afforded the pedestrians. The initial analysis is made in terms of an isolated, midblock crossing so that confounding, due to change in delay of cross-street vehicle traffic, can be eliminated.

The primary theoretical analysis of pedestrian delay was made by Tanner (4). Tanner used an exponential arrival distribution that was justified for an isolated location to derive the following formulation for the delay of a randomly arriving pedestrian:

$$P(T) = \sum_{s=0}^{r+1} [(-1)^s e^{-sNI} N^s (T - sI + I)^s]/s! + \sum_{s=1}^{r+1} [(-1)^s e^{-sNI} N^{s-1} (T - sI + I)^{s-1}]/(s-1)! \quad (1)$$

where

P(T) = probability (delay > T),
I = required gap,
N = vehicles arriving per unit time, and
r = largest integer ≤ T/I.

Figure 1 shows the mean of this distribution, which is a function of volume, for the various values of I. As given by Tanner (4), this mean has been calculated from

$$E(D) = (e^{NI} - NI - 1)/N \quad (2)$$

Tanner checked this formulation against field data, and it can be used at the 0.05 level except for extremely small values of T. Tanner attributes this exception to pedestrians' disinclination to immediately accept otherwise satisfactory lags.

ANALYSIS OF CURRENT PEDESTRIAN WARRANT

A rational pedestrian warrant should be based on the following considerations:

1. An acceptable level of average pedestrian delay;
2. A tolerable level of maximum, i.e., 95th percentile, pedestrian delay; and
3. An equitable allocation of total delay between the pedestrian and vehicle components of the traffic stream.

Before proceeding to the development of a suggested pedestrian warrant, one must analyze the current pedestrian warrant in light of the above criteria.

As given in the MUTCD (1), Figure 2 shows P(T) for the following typical conditions:

1. Vehicle volume = 600 vehicles/h;
2. Pedestrian walking speed = 1 m/s (3.5 ft/s); and
3. Street width = 12 m (40 ft).

For an isolated and uncontrolled location that is under

Figure 1. Mean pedestrian delay.

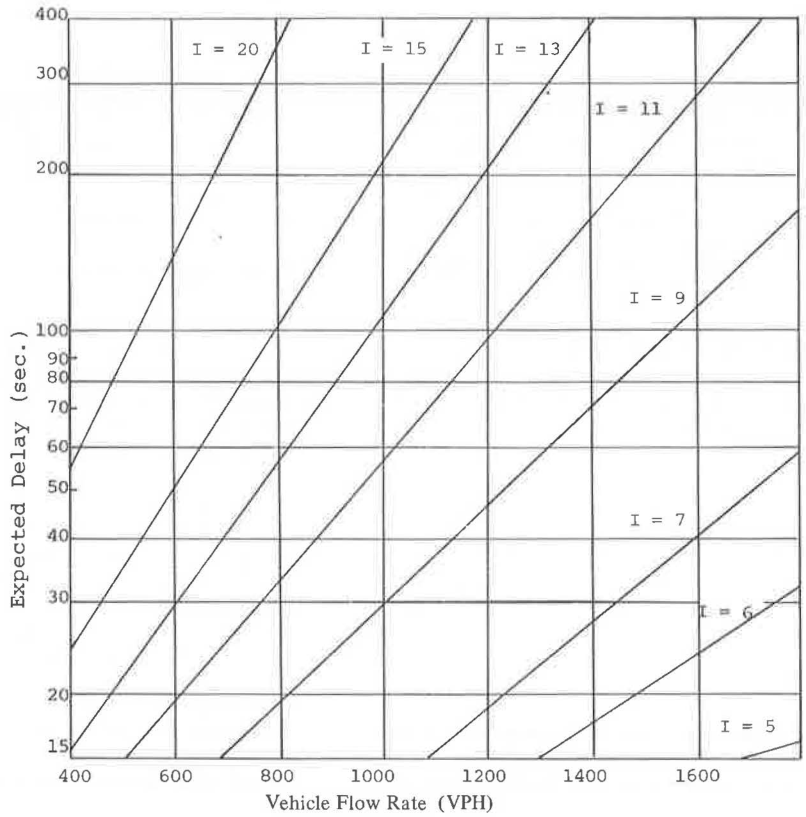
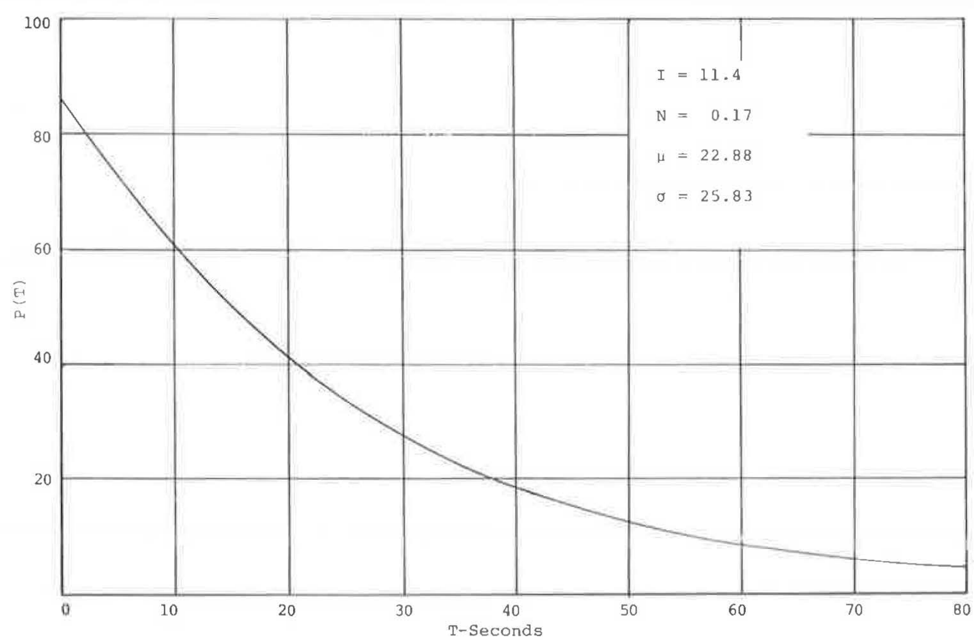


Figure 2. Pedestrian delay probability.



the assumption of exponential arrivals, the mean delay for each arriving pedestrian is 22.9 s. Since this approach accounts only for a single pedestrian, the analysis must be extended to consider a number of pedestrians. For a pedestrian volume of 150/h, the pedestrian accumulation during the mean waiting time of 22.9 s, under the assumption of Poisson arrival, will exceed 5 only 0.1 percent of the time. Since 5 or more pedestrians can easily cross abreast, no additional gap is required. Heavier pedestrian volume, nonrandom arrival, or group arrival may change this situation.

The current warrant conditions of 600 vehicles and 150 pedestrians imply a total pedestrian delay, in the absence of signal control, of 57.2 person·min/h. Long delays to pedestrians will accrue as follows: for a delay of >45 s, 23 pedestrians/h; >60 s, 13 pedestrians/h; and >80 s, 6 pedestrians/h.

For the specific case analyzed, that is, a 12.2-m (40-ft) road and a 1.1-m/s (3.5-ft/s) walking speed, the existing warrant is shown to be equivalent to a mean pedestrian delay of 22.9 s and a 95th percentile delay of 75 s. After a signal is installed, these delay times become a function of the cycle length and split. For a 60-s cycle with a 5-s walking interval, the average pedestrian delay is approximately 25.2 s, and the 95th percentile pedestrian delay is approximately 52 s.

The condition of equalizing delay between pedestrians and passengers in vehicles was analyzed to investigate the validity of adopting this condition as a criterion for specifying a pedestrian warrant. It was found that, for all vehicle flow rates below the saturation level, the average pedestrian delay without signals was always higher than the average vehicle delay with signals. Furthermore, the criterion itself is suspect. Since the pedestrians are exposed to the elements, it is unreasonable to subject them to the same levels of delay as those who are comfortably ensconced in vehicles. Consequently, this criterion was eliminated.

DEVELOPMENT OF PROPOSED PEDESTRIAN WARRANT

For purposes of developing a pedestrian warrant, we selected 30 s as an acceptable level of mean pedestrian delay and 60 s as a tolerable level of maximum (i.e., 95th percentile) delay. The selection of the 95th percentile value as tolerable (rather than the 85th percentile) reflects the exposure of pedestrians to the elements, their relatively unpredictable behavior, and the pedestrians' exposure to accidents of increased severity. These values are suggested on the basis of a review of literature (5, 6).

Three different possible behavior patterns can be postulated for pedestrians crossing a bidirectional roadway:

1. The pedestrian crosses whenever he or she perceives an acceptable gap in both directions of travel;
2. The pedestrian crosses whenever he or she perceives an acceptable gap in the near stream of traffic, which is in anticipation of a subsequent acceptable gap in the far stream; and
3. The pedestrian crosses whenever he or she perceives an acceptable gap in the near stream of traffic and waits on the median of the divided roadway for an acceptable gap in the far stream.

Patterns 1 and 2 apply to undivided highways. Based on field observations, Tanner concluded that pattern 1 appeared more frequently than pattern 2. Pattern 3 is common for divided highways when the median provides an adequate refuge.

Figure 3 shows the computed mean pedestrian delay contours for various vehicle flow rates and values of accepted gaps. If the pedestrian walking speed is 1.1 m/s (3.5 ft/s) and a single lane is assumed to be 3.7 m (12 ft) wide, then the following combinations will yield an average pedestrian delay of 30 s.

Number of Lanes	Divided Roadways	Total Vehicle Flow	Number of Lanes	Divided Roadways	Total Vehicle Flow
2	No	1440	4	Yes	2080
3	No	800	6	Yes	1100
4	No	525			

The second warrant criterion postulated states that the 95th percentile delay to pedestrians should not exceed 60 s. This delay can be computed by using Equation 1. A slight complication is introduced in the case of divided roadways. Although the mean pedestrian delay for divided highways is twice the mean delay for each roadway, assuming a 50-50 directional split, the same methodology cannot be used in determining the percentile points of the distribution. The distribution of pedestrian crossing times for a divided roadway is the sum of the two individual distributions. Since these distributions are identical, the joint distribution is the convolution of the crossing distribution with itself. Figure 4 shows the 95th percentile of pedestrian delay for both divided and undivided roadways as a function of vehicle volume (Q_v) and acceptable gap size (I). Note that the values of I and Q_v for the divided highway case apply for a single roadway. From this value the following table that gives the various combinations for a 95th percentile delay of 60 s has been constructed.

Number of Lanes	Divided Roadways	Total Vehicle Flow	Number of Lanes	Divided Roadways	Total Vehicle Flow
2	No	1160	4	Yes	1860
3	No	625	6	Yes	960
4	No	390			

Figure 5 shows the application of a 30-s mean pedestrian delay and a tolerable 60-s pedestrian delay (95th percentile).

It can be seen that the criterion of tolerable pedestrian delay governs throughout. This criterion is independent of pedestrian volume (Q_p). Since the use of signals would not be considered at extremely low pedestrian flow levels, a lower limit of pedestrian hourly demand must be set. The current MUTCD sets this figure at 150 pedestrians/h. Box (5) based his derivation on a proposed Canadian warrant and suggested a minimum of 60 pedestrians/h, as long as these pedestrians incur a total delay of 1.0 h. The pedestrian flows that produce a total delay of 1.0 h were determined from Equation 2 and are plotted in Figure 6.

A minimum volume of 90 pedestrians/h was suggested in a proposed pedestrian signal warrant in Ireland (6). The current MUTCD implies in the interruption of continuous traffic warrant that delay to 100 or more traffic units/h may justify signals. It is, therefore, suggested that a proposed pedestrian warrant be subject to two different lower bounds: (a) an aggregate pedestrian delay of 1 h/h and (b) a minimum pedestrian volume of 100/h.

PROPOSED PEDESTRIAN WARRANT

A proposed pedestrian warrant for the undivided highway case is shown in Figure 7. The graph shows the measured value of traffic flow and the required value for an accepted gap (I). When approach speeds exceed 64 km/h (40 mph), the required value of I should be increased by 1 s to reflect the increased difficulty in identifying an appropriate gap. The accepted gap (I) is the time necessary to cross the roadway at the prevailing pedestrian walking speed. This speed is generally between 0.9 and 1.2 m/s (3.0 and 4.0 ft/s) in the United States (7); however, values as high as 1.5 m/s (5 ft/s) are used in other areas (8).

The minimum pedestrian volume that warrants a signal is read, and, if the actual pedestrian volume exceeds this value, a signal is warranted. The W-scale, which is also shown in Figure 7, can be used if a walking speed of 1 m/s (3.5 ft/s) is assumed. This warrant

Figure 3. Mean pedestrian delay contours.

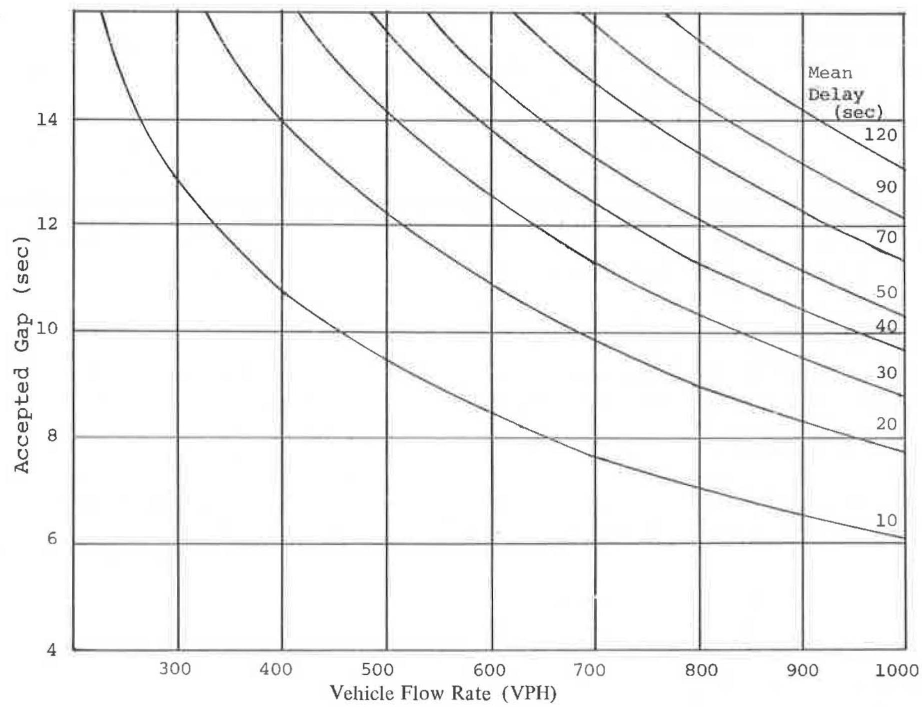
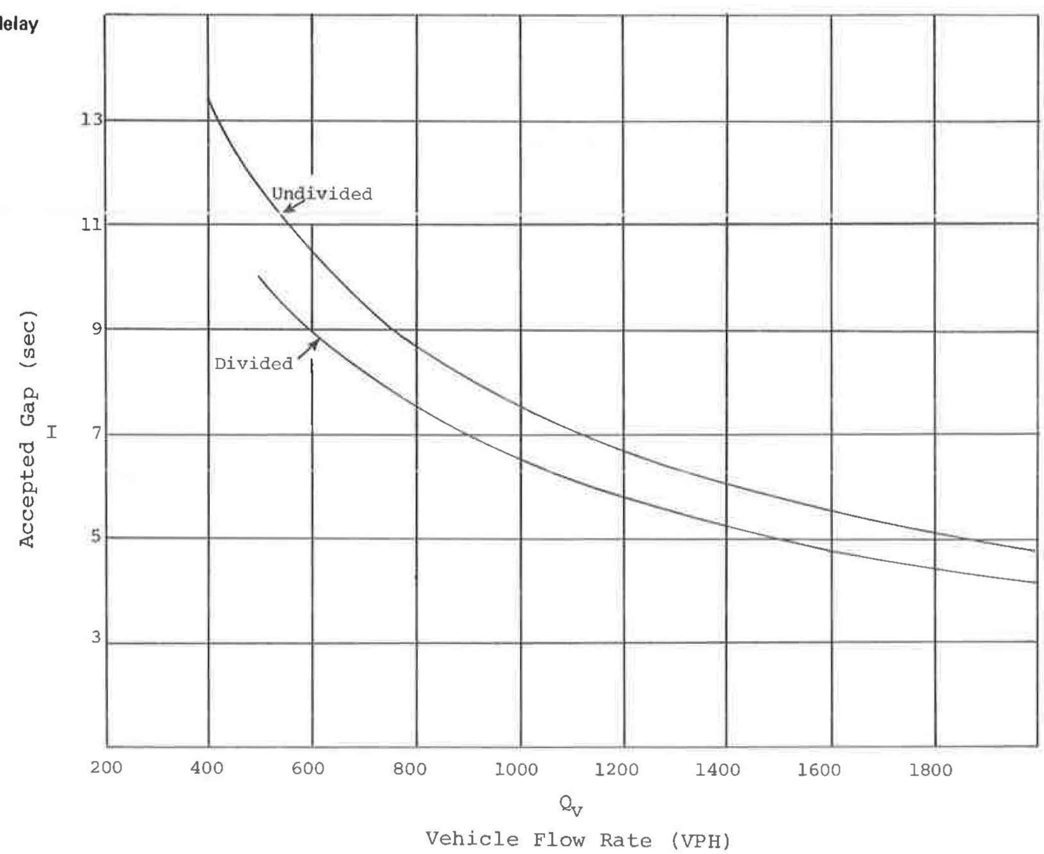


Figure 4. 95th percentile of delay distribution.



curve was constructed by superimposing the 95th percentile delay curve that applies for hourly pedestrian volumes exceeding 200 and the 1-h aggregate delay curves for lower pedestrian volumes.

The curves shown in Figure 8 apply to divided highways. These curves are based on the assumption of approximately equal directional traffic volume split and do not apply for the case in which the split is markedly unbalanced. For the purposes of this warrant, a divided highway is defined as one with a center median (either curbed or painted) that is wide enough to accommodate the maximum (i.e., 95th percentile) pedestrian platoon. If these curves for the specification of the pedestrian signal warrant are to be applied, a lower bound of 500 and 1000 vehicles/h for undivided highways and divided highways respectively has been used.

Figure 5. Two pedestrian warrant criteria.

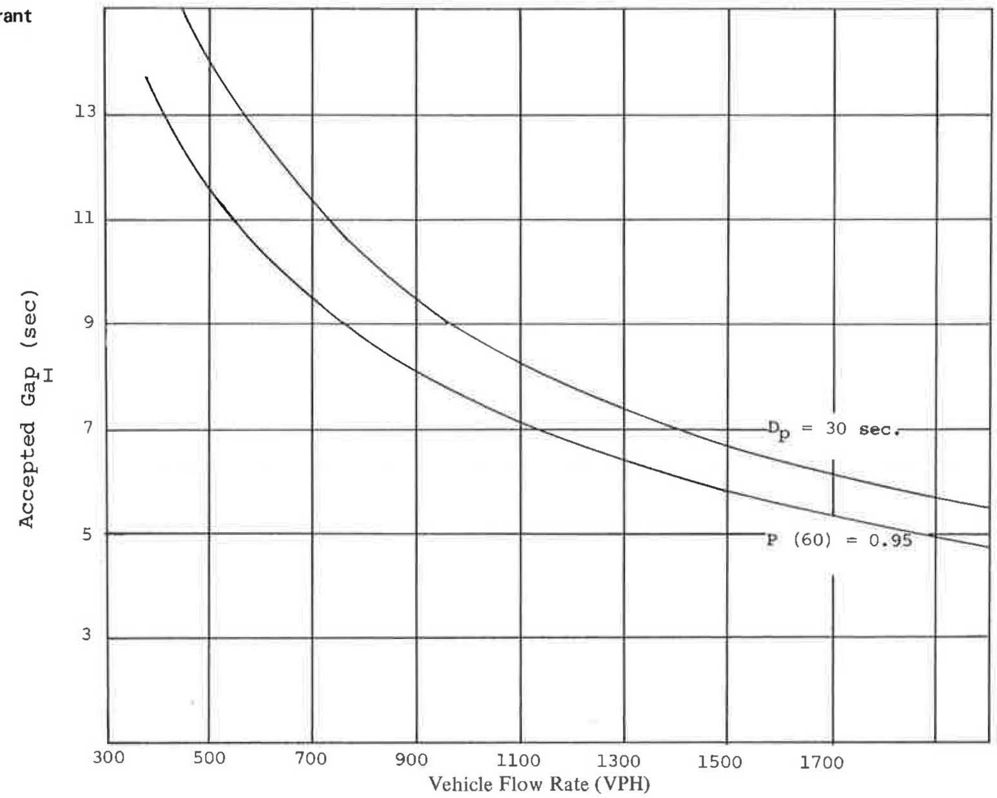
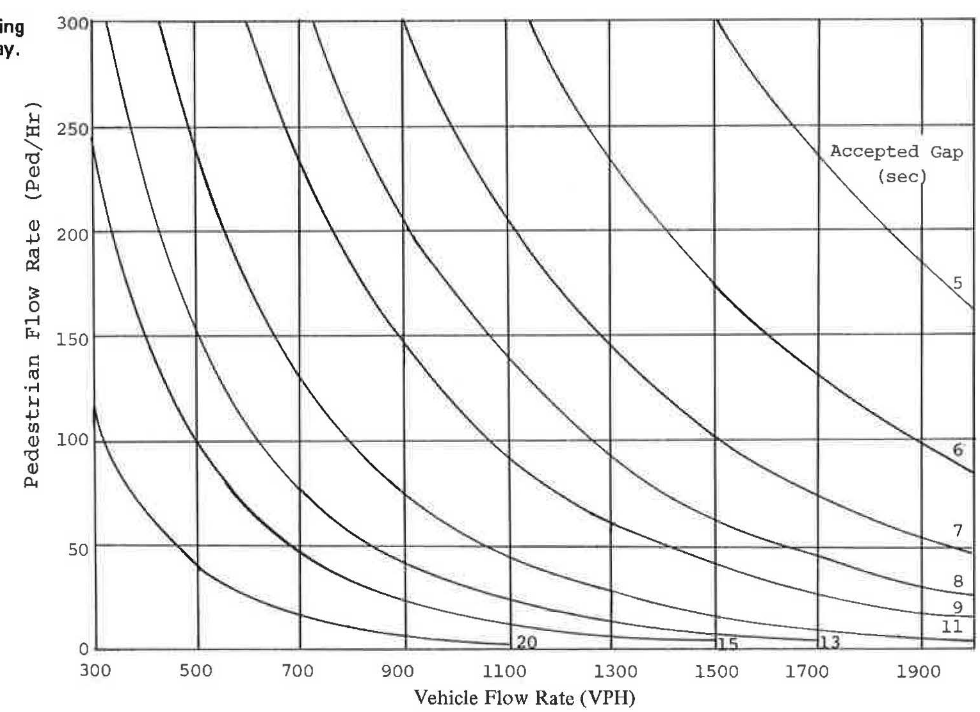


Figure 6. Volume levels producing 1.0 h/h aggregate pedestrian delay.



DISCUSSION OF WARRANTS

Thus far, the analysis has addressed the pedestrian delay that has occurred while pedestrians wait for acceptable gaps in traffic. However, by a strict interpretation of Chapter 11, Article V of the Uniform Vehicle Code (9), a pedestrian may force an adequate gap in traffic at any unsignalized intersection or marked midblock crosswalk as long as a minimum, natural gap that is sufficient for a driver to yield or stop occurs. In certain jurisdictions such as California, this rule is strictly interpreted. The result of such a rule will be the acceptance of much shorter gaps by pedestrians, thus reducing the nonsignalized pedestrian delay.

This phenomenon of preemption by pedestrians has led to the adoption of maximum pedestrian volume criteria in those jurisdictions such as the United Kingdom where some type of pedestrian priority rule is in effect at designated crossings. It has been found that signals can be justified at volumes in excess of 360 pedestrians/h to reduce vehicle delay (10).

The explicit assumptions of isolated intersections (i.e., random arrivals) at a midblock pedestrian location should be kept in mind when evaluating these proposed warrants. Although the proposed warrant applies to this set of conditions, it can be extended, in general,

Figure 7. Proposed pedestrian signal warrant for an undivided highway.

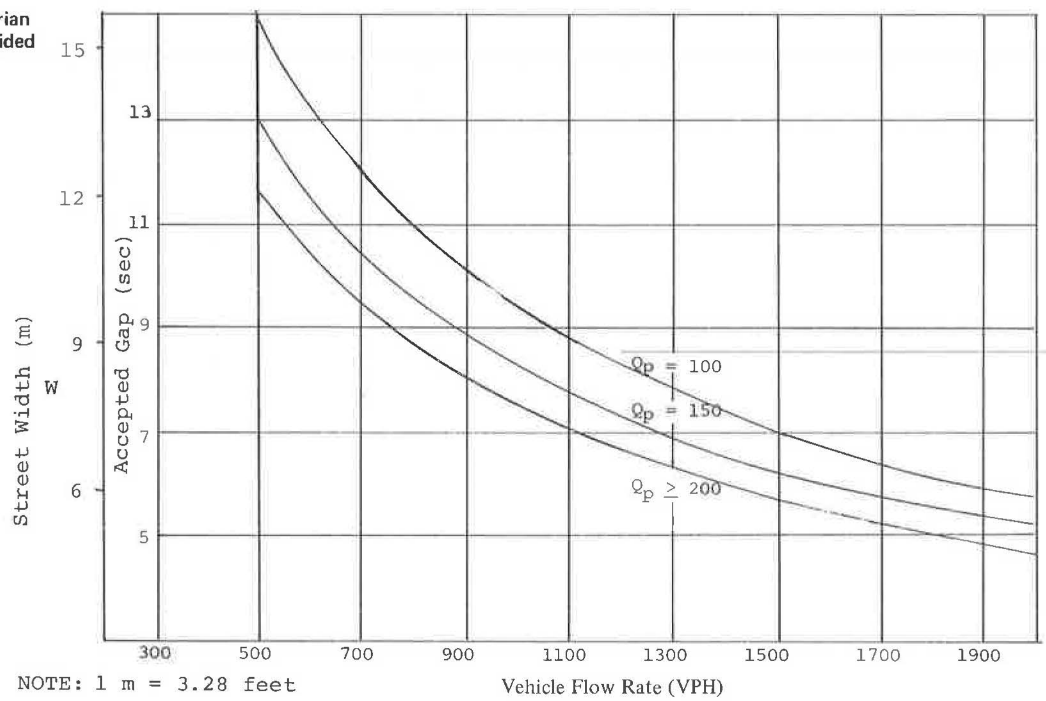
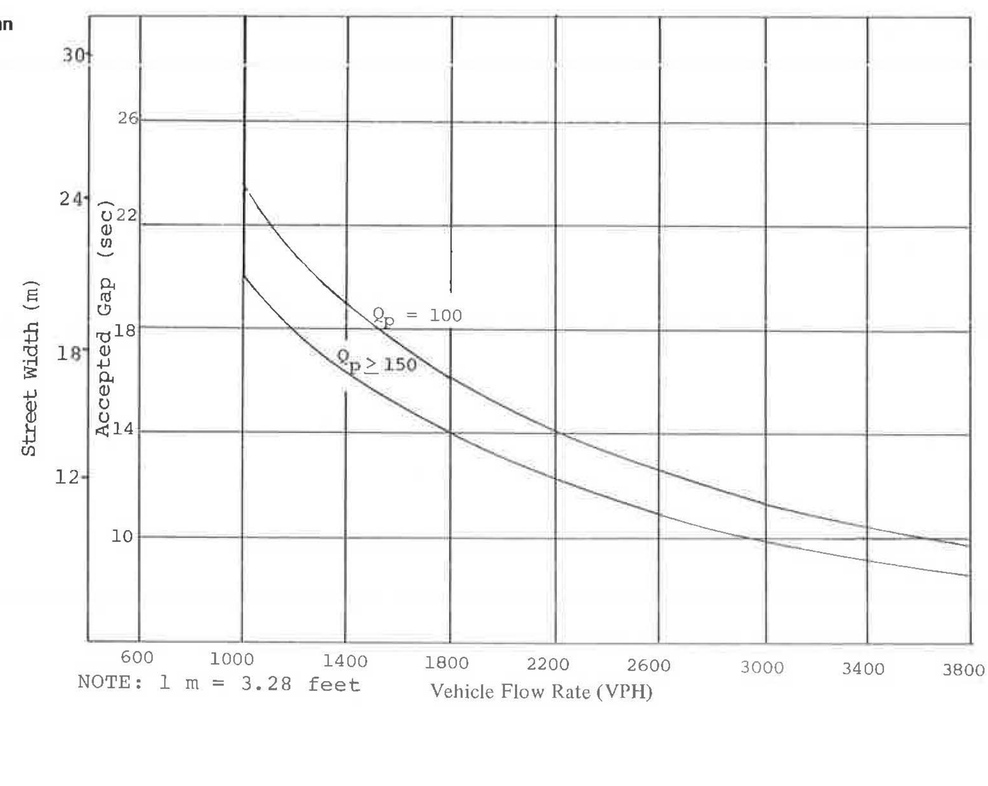


Figure 8. Proposed pedestrian signal warrant for a divided highway.



to crosswalks at intersections. Tolerable pedestrian delay is the prime criterion on which the proposed warrant is based, and such delay is essentially independent of the crosswalk location. It is recognized that at an intersection a pedestrian must contend not only with cross traffic but also with turning vehicles. Those vehicles turning from the cross streets will be few in number; however, since these intersections require a signal, they will have failed to satisfy the warrants for vehicle volume.

The numerical warrants for both midblock and intersection locations are presented in Figures 7 and 8. Before signals are installed, these warrants should be met or exceeded for 4 h on an average weekday. Alternatively, the warrant could be met or exceeded for 10 h on any weekend if at least 3 h are on the day with lighter volumes. These periods have been selected to correspond to those used for other warrants developed (3) and reflect the typical peaking characteristics of urban traffic.

All signals installed under this warrant should be provided with pedestrian signal heads and pedestrian push-button detectors. Normally these signals should not be flashed. If installed at an intersection location, the installation should be at least semiactuated for side-street traffic. A pedestrian signal installed at an intersection and meeting only the weekend requirements should be fully actuated.

ACKNOWLEDGMENT

This work was sponsored by the American Association of State Highway and Transportation Officials in cooperation with the Federal Highway Administration of the U.S. Department of Transportation and was conducted in the National Cooperative Highway Research Program that is administered by the Transportation Research Board of the National Research Council.

The opinions and conclusions expressed or implied in the report are ours and not necessarily those of the Transportation Research Board, the National Academy of Sciences, the Federal Highway Administration, the U.S. Department of Transportation, the American Association of State Highway and Transportation Officials, or the individual states participating in the National Cooperative Highway Research Program.

REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, U.S. Department of Transportation, 1971.
2. L. J. Pignataro. Traffic Engineering Theory and Practice. Prentice-Hall, Englewood Cliffs, N.J., 1973.
3. E. Lieberman, G. F. King, and R. Goldblatt. Traffic Signal Warrants. KLD Associates, Inc., Huntington Station, N.Y., 1976; Final Rept., NCHRP Project 3-20(1).
4. J. C. Tanner. The Delay to Pedestrians Crossing a Road. Biometrika, Vol. 38, 1951, pp. 382-392.
5. P. C. Box and W. A. Alroth. Assembly Analysis and Application of Data on Warrants for Traffic Control Signals. Prepared for the Signal Committee, National Joint Committee on Uniform Traffic Control Devices, unpublished, March 1967.
6. F. Simons. Warrants for the Installation of Pedestrian Crossing Facilities. The National Institute for Physical Planning and Construction Research, Dublin, Ireland, 1970.
7. J. E. Baerwald, ed. Transportation and Traffic Engineering Handbook. Prentice-Hall, Englewood Cliffs, N.J., 1976.
8. Research on Road Safety. Department of Scientific and Industrial Research, Her Majesty's Stationery Office, London, 1963.
9. Uniform Vehicle Code. National Committee on Uniform Traffic Laws and Ordinances, Washington, D.C., 1968.
10. R. T. Underwood. Tentative Warrants for the Installation of Pedestrian Crossings. Victoria County Roads Board, Res. Memo. 13, 1957.

Publication of this paper sponsored by Committee on Pedestrians.

Knowledge and Perceptions of Young Pedestrians

Martin L. Reiss, BioTechnology, Inc., Falls Church, Virginia

The progress of a research study on school-age pedestrians has been previously reported in a paper that dealt with the behavior of drivers in relation to the existing signing at four school sites in three states. That research study has now been completed, and this paper deals primarily with the findings regarding youngsters in the 5 to 14-year-old age group. Data are provided on the accident experience of the young pedestrians and on their behavior, attitudes, and knowledge. Students in sections of the eastern United States were observed walking to school and were then surveyed on their pedestrian behavior and knowledge. Significant differences by age groupings were noted for both the accident data and knowledge responses.

This paper describes a school walking-trip study that was undertaken during the summer of 1973 and completed in the spring of 1975 with the publication of a walking-trip guidebook. The study objective was to develop guidelines for the protection of young pedestrians (ages 5 to 14 years) walking to and from school. These guidelines were based on field surveys of the young pedestrian and the driver regarding designated school zones and specific school-crossing protective devices. The guidelines are described in detail in a companion report (1).

Two sources of information were used to define problems and develop guidelines for safety programs: a review of literature that included accident data and surveys of the knowledge and stated behavior of young pedestrians and of the knowledge and observed behavior of drivers. The accident data were primarily gathered from an urban area and used to determine the magnitude of school-trip accidents and the specific ages of the young pedestrians involved. The student survey was conducted in several states at urban, suburban, and rural schools. The survey techniques used were developed through a series of pilot tests. Materials for kindergarten students were pictorial and involved a story-line approach. Third, sixth, and eighth graders were queried by a self-administered survey that incorporated pictorials and other graphics.

Separate driver surveys were conducted at four school sites in three states. The techniques used for the collection of driver data were developed through a series of pilot tests. The driver was interviewed in his or her vehicle after having driven through the school zone. Driver perception of existing signing was tested, and driver speed through the school area was recorded. The survey format used recall items (free response) rather than recognition items (multiple choice). The driver surveys are not addressed in this paper, and the interested researcher is directed to another report (2).

ACCIDENT PROBLEM

National Accident Data

A report by the National Safety Council (3) provides some general data on the motor vehicle accidents that occurred in 1973, including those accidents that involved school-age pedestrians. Of the 16.6 million U.S. motor vehicle accidents in 1973, there were an estimated 300 000 accidents that involved pedestrians (250 000 urban and 50 000 rural). The age distribution of pedestrians in accidents is provided in terms of a subpopulation of an estimated 120 000 injury accidents. Within this group, there were 58 000 or 48 percent injury accidents to young pedestrians under 15 years of age. Analysis of the pedestrian accident distribution by increments of 10 years of age indicates that the 5 to 14-year-old population represents 38 percent of all pedestrian accidents, and this population has almost four times the number of accidents that any other age group has (3).

Through use of National Safety Council statistics (3), several calculations may be made to provide a rough indication of the accident frequency for school-age pedestrians. Of the estimated 300 000 pedestrian accidents occurring in 1973, there were an estimated 114 000 (38 percent) school-age pedestrian accidents.

Urban Accident Data

Knoblauch (4) provides detailed accident data on 2044 pedestrian accidents from six study cities (Akron and Toledo, Ohio; Miami, Florida; New York City, New York; San Diego, California; and Washington, D.C.). This study indicated that pedestrians between 5 and 14 years of age represented 34 percent of the pedestrian accident data base. The period between 2:00 and 4:00 p.m. represented the highest accident time period for this population. This age group was most likely to become involved in an accident (a) on a weekday, (b) in the first lane of a two-lane road, (c) in a residential area, (d) in an area without traffic controls, and (e) with a car going straight. This age group was also involved in accidents when (a) they did not cross at an intersection or crosswalk (midblock), (b) the driver's vision was blocked by a parked vehicle, (c) the pedestrian was running, and (d) the pedestrian was crossing from behind a parked vehicle.

School Walking-Trip Accidents

For the accident population in Knoblauch's study only the information recorded in Toledo, Ohio, noted whether school was the trip origin or destination for each young-pedestrian accident occurring in 1973. Young pedestrians (5 to 14 years) accounted for 135 of the 285 pedestrians struck by vehicles for cases in which supplementary accident forms were completed by the researchers. It was noted that 43 percent of the young pedestrians were struck between the hours of 8 and 9 a.m., 12 and 1 p.m., and 2 and 4 p.m. These time periods are the basis for most of the calculations of the school-trip pedestrian accidents. The Toledo forms indicated that an actual 17 percent of the young-pedestrian accidents occurred when the students were en route to and from school.

These data are in agreement with previous studies that indicate that 10 to 20 percent of young-pedestrian accidents (5, 6, 7) occur during the school walking trip. When applied to national data, these limits show that the magnitude of the school walking-trip accidents is approximately 10 000 to 20 000 annually for young pedestrians. Most young-pedestrian accidents (80 to 90 percent) occur after school hours near the child's home and within a block of it (5, 6, 7).

In England, Grayson (8) found that, for a group of 420 pedestrians, the journey purpose for 24 percent of the 5 to 9-year-olds in pedestrian accidents and 27 percent of the 10 to 14-year-olds in pedestrian accidents was to or from school (8).

A study (5) was performed by the American Automobile Association (AAA) that provided an age distribution of the students in 1910 school-trip pedestrian accidents. Through these figures and the public school enrollment figures for each age provided by the U.S. Department of Commerce (9), it is possible to calculate a school-trip, accident involvement rate for each age between 5 and 14 years. The analysis reveals that there is a near-monotonic relation between the age and the accident involvement rate for the 5 to 14-year-old population. The youngest students are considerably overrepresented in the school-trip accident data, and the oldest students are underrepresented (Figure 1). The accident rate can be calculated by dividing the percentage of the pedestrian accident population represented in a specific age group by the percentage of the school-age population in that group. For example, the 5-year-olds represent 12.8 percent of the AAA 5 to 14-year-old school-trip accident population. Of the 5 to 14-year-old population enrolled in public schools, the 5-year-olds represent 7 percent. Thus, the school-trip accident involvement rate for 5-year-olds is 1.83 (12.8 ÷ 7).

Young-Pedestrian Exposure and Actions

One hypothesis for the overinvolvement of the youngest pedestrians is their degree of exposure to vehicles as pedestrians; however, this does not prove to be the case. Two studies comparing pedestrian exposure and accident data are those by Routledge and others (10, 11). The analysis of young pedestrians who were observed during a 20-min period after school showed a highly significant increase in exposure (road crossings and traffic density encountered) with age. The risk per road crossing and risk per encounter with a car decrease with age as does the accident involvement rate.

Several studies have characterized the activities of young pedestrians involved in accidents. Marks (12) describes the most frequent actions (comprising over 68 percent of the young-pedestrian accidents) in decreasing order: darting into the street, crossing midblock, and playing in the street. Knoblauch (4) indicates that the most prevalent young-pedestrian actions are as follows:

Action	Action by Age (%) 5 to 9	10 to 14
Darting out	42	31
Dashing from intersection	17	18
Dashing from midblock	16	7

Other recurring characteristics involved in accidents in this study are children running, pedestrians not crossing at intersection or crosswalk, and drivers' or pedestrians' vision blocked.

Accident Causation

Although there are many characteristic conditions under which accidents occur, there is little knowledge regarding why these accidents happen. Several previously mentioned studies have suggested various hypotheses for young students' accident proclivities.

Sandels (13, 14), in describing studies performed in Sweden, suggests that the average child does not attain the requisite degree of maturity as a pedestrian until the child is between the ages of 9 and 12. Sandels points out that (a) the diminutive stature of children makes it difficult for them to judge a traffic stiuation; (b) children are incapable of distributing their attention because they concentrate on one thing at a time—often play—or take a vague overall impression; (c) they cannot distinguish between right and left; (d) they have difficulty discriminating the direction of sound; and (e) many children believe the safest way to cross a street is to run. In England, Backett (15) compared 100 children who were pedestrian accident victims with 100 children who were not involved in accidents. The control group was chosen so that both groups were similar in age, sex, school, neighborhood, social class, and distance walked to school. The accident victims differed significantly from their controls by having less parental supervision and by coming from homes and neighborhoods that had fewer play areas. Similar findings were made by Read and Backett and others (15, 16). The following results of the student survey may assist future researchers in analyzing the factors that make almost every accident unique.

STUDENT SURVEY

Development of Survey

A survey of students from primary and secondary schools was devised to provide some basic facts with respect to the students' stated school walking-trip behavior and knowledge that relates to school-trip safety. The objectives of these surveys were to (a) identify the students' knowledge that needs modification; (b) identify the students' behaviors that need modification; and (c) identify the procedures for modification of knowledge and behaviors. The questions addressed by the student survey were as follows.

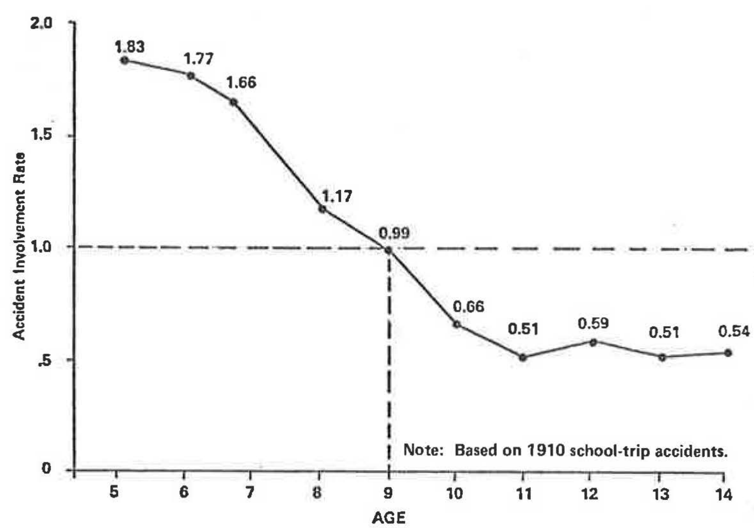
1. What do students know about traffic control devices?
2. What fears do students have in reference to traffic?
3. How do students select their route to school?
4. How do students cross the street?

Based on previous research and on the pattern of young-pedestrian accidents, items addressing each of the above topic areas were generated. Through a series of six pilot tests, the subject matter was shaped into an efficient instrument for soliciting the information required. After each pretest session, a complete review was made. Techniques were devised and items reworded to make the survey clear to children of various ages. Response alternatives were adjusted to include those responses actually used by the children.

The iterative process used in the pilot testing phase resulted in the following modifications being incorporated in the final survey form.

1. The survey was divided into two formats: one for younger children (individual administration) and one for older children (group administration);
2. The questions were portrayed by pictures, a card sorting technique was used for cases in which several choices among response alternatives were desired, and pictorial stickers were used as a mode of response;
3. The wording was changed to use the vocabulary of the children in items and response alternatives; and
4. Stories and familiar situations were used to avoid the possibility of threatening the children.

Figure 1. School-trip pedestrian accident involvement rate of students by age.



Data Collection Methodology

Data were collected on 933 students at schools in Montgomery and Howard counties in Maryland, Fairfax and Prince William counties in Virginia, and New York City. This sample represents students from urban, suburban, and rural schools. The population of interest to this study is school children between the ages of 5 and 14. The student survey was aimed at those students in this age group who walk to school. This group was represented by students in kindergarten (age 5 to 6), third grade (age 8 to 9), sixth grade (age 11 to 12), and eighth grade (age 13 to 14). A minimum requirement of 50 students from each grade was set for urban and suburban schools. In most instances, more than 50 students were surveyed because the questionnaire was administered in the classroom and the class size was generally in the range of 28 to 30 students, which necessitated two administrations per grade per school.

The rural subsample was taken at a school that only included grades one through five. A group of 52 students from third grade was surveyed, and a smaller group of students from fifth grade was tested to provide some basis of comparison by age. Since very few rural students walk to school, transportation mode was not used as a selective criterion for this subsample (Table 1).

To collect data from urban, suburban, and rural segments of the population, officials of several school systems were contacted. The schools chosen met the following criteria:

1. There was a high percentage of walking students;
2. There were an adequate number of students enrolled in the school; and
3. There was voluntary cooperation between the principal and school staff and the researchers in the planning and conducting of the surveys.

In all, 11 schools were selected for the survey sites. A follow-up meeting with the principal of each school was held to ascertain information about the background characteristics of the student body and the surrounding area. Questions such as how far the students had to walk to get to school, whether the students were exposed to major intersections, and what type of areas the students came through with respect to traffic and traffic control devices were asked. This meeting was also used to determine the best date and time for survey administration.

Group interviews were administered in the classroom to about 20 to 30 children in each group. An administrator read the questions aloud while one or two proctors (depending on the size and age of the group) circulated throughout the room to answer questions and check the children's understanding of the procedures (answering each question and checking only one answer per question). The teacher was asked to stay in the classroom during the survey administration. The same administrators interviewed the children in kindergarden individually. In most cases, this interviewing was done outside the classroom so that other children did not hear the questions and so that the child being interviewed was not distracted.

Table 1. Percentage of students in each grade.

Type of Area	Grade K	Grade 3	Grade 5	Grade 6	Grade 8	Total
Urban	4	9	0	9	6	28
Suburban	15	16	0	16	17	64
Rural	0	5	3	0	0	8
Total	19	30	3	25	23	100

Note: N = 933.

RESULTS

Comparisons by Location, Grade, and Sex

In Appendix A of the study final report (2), the knowledge and behavioral survey items of 115 students are compared on the basis of where the student lives, the grade of the student, and the sex of the student. This section represents some of the highlights from that analysis. All the comparisons between groups described in this section were found to be statistically significant at the 0.05 level (two tail). A Z-test of uncorrelated portions was used to test differences. The information (2) should prove useful in the design of future accident-reduction programs, particularly for those programs that orient specific treatments (educational and public information) for different audiences (location, age, and sex).

The results indicate that male students are more likely to travel to school alone and are willing to take more risks than female students. Also, male students are more likely to

1. Go to school alone,
2. Choose a school route because it is the shortest,
3. Run across the street when there is a break in traffic,
4. Cross when the traffic signal facing them is red,
5. Indicate that nothing happens to a child when struck, and
6. Think it is safer to run rather than walk across the street.

However, female students are more likely to

1. Choose a school route because their parents took them that way,
2. Go a different way if told to do so by parents or if the route was safer, and
3. Consider the unprotected corner as the safest crossing location.

In general, the pattern of responses indicates a progression of understanding and capability from the kindergarten to the eighth grade students. The youngest students have less walking exposure, particularly alone, and usually cross at protected locations where there are crossing guards. These students generally do not relate to or indicate an understanding of traffic control devices and safety techniques other than crossing guards.

In relation to younger students, older students (sixth and eighth grade) are more likely to

1. Walk to school;
2. Walk alone;
3. Take the shortest route;
4. Cross streets without guards;
5. Be fearful when it is dark;
6. Take greater risks such as crossing in the middle of the block or running across the street when there is a break in traffic.
7. Cross at crosswalks;
8. Pick the traffic signal as the safest place to cross; and
9. Take a different route only if friends do.

On the other hand, younger students (kindergarten and third grade) are more likely to

1. Take the school bus or be driven by car;
2. Be taken by parents;
3. Take the route that avoids traffic;
4. Cross three or more streets with guards;
5. Be fearful when there are no safety patrols or guards;
6. Cross when the traffic signal facing them is red;
7. Cross at unprotected corners;
8. Pick a crossing with guards as the safest location; and
9. Take a different route to school if told to do so by parents or school officials.

Some comparisons by location have been made in the discussion of general results. In relation to suburban and urban students, rural students are more likely to

1. Cross the street when the traffic signal facing them is red, and
2. Cross the street at an unprotected midblock location.

In relation to suburban and rural students, urban students are more likely to

1. Wait for a traffic light before crossing a street,
2. Run out into the street if no cars are coming or if cars are moving slowly, and
3. Cross the street at an unprotected corner.

In relation to urban and rural students, suburban students are more likely to

1. Run out into the street if they dropped something (ball or paper) in the street,
2. Choose a location where there is a guard because it is the safest place to cross, and
3. Cross at three or more streets where there are crossing guards.

The pattern of responses indicates a progression in pedestrian capability from the kindergarten to the eighth grade students. Several pictorial questions illustrated this capability dramatically. The percentages of kindergarten, third grade, sixth grade, and eighth grade students who indicated that an unmarked corner or a midblock location was safer for crossing than a corner with a marked crosswalk were 43, 21.5, 10, and 9 respectively.

Another indication of the progression of understanding with age was the fact that, throughout the grades covered in the survey, a group of children whose number decreased with age said they would cross the street when the traffic signal facing them was red. The percentages of kindergarten, third grade, sixth grade, and eighth grade students who indicated they would cross when the traffic signal facing them was red were 47.5, 42.3, 26.9, and 23.3 respectively.

A special field study was conducted to verify the findings that concerned traffic signals. The study consisted of two parts. First, a class of 20 students was administered the traffic signal items in a classroom setting. Second, the students were taken by a researcher to a signal-controlled intersection adjacent to the school. At this intersection, the students were asked to face the researcher with their backs to the intersection. They remained standing in this position until the researcher said, "Turn around, look at the traffic light, and tell me when you would cross this street." One-half of the students were asked to turn so that they could view the signal on the red interval, and the other half viewed the signal on the green interval. The students indicated the point in the cycle when they would cross and did not give a color response.

The McNemar test of significance (17), for cases in which subjects are observed twice, was used to test the null hypothesis: The proportion of subjects choosing either green or red as the appropriate traffic signal interval during which to cross the street is not different for the written test and field situations. Through use of the 0.05 probability level, no significant difference was detected between responses in the classroom and field situations. Based on the results from the comparison between the classroom and field traffic signal responses, it appears plausible that the pictorial questionnaire item reflects the school childrens' responses to traffic signals in the real world. It is suggested that other researchers replicate this field study and vary the location (urban, suburban, rural) as well as the age groups tested.

Figure 2 shows the responses of all those students (882) who provided information on their age, how they got to school, and the color of the traffic signal facing them when they would cross the street. It can be seen that, as age increases, a greater proportion of the students will cross on the green signal. This relation between the students' increased knowledge of traffic control devices and age closely matches the decreasing rate of student involvement in accidents: There is a near-monotonic relation between age and accident involvement. Although the students' proclivity toward risk-taking (taking the shortest route, crossing in the middle of the block, running across when there is a break in traffic, running into the road) increases with age, the accident data indicate that this situation may be offset by knowledge of when and how to take risks. This is particularly true in light of the finding of Routledge and others (10, 11) that children's exposure to traffic as pedestrians (going to and from school in England) increases with age between the ages of 5 and 10 years.

The percentage distribution by age of those walking students who would cross when the traffic signal facing them is red has been plotted against the school walking-trip accident involvement rate by age and is shown in Figure 3. This figure is similar to the plots made by Routledge and others (10, 11) that compared risk per road crossing and risk per encounter with a car by young-pedestrian age.

For the youngest students, the accident risk and lack of knowledge concerning traffic control devices should be considered in relation to how those children choose their school routes and who can influence their choices. The survey responses to questions on route choice and route change indicate an increasing independence from parents and an increasing influence of peer group pressure. The percentage of kindergarteners who said their parents had recommended or taken them on their route to school was 61.5. In comparison, the percentages of third, sixth, and eighth grades were 49.3, 26.1, and 7.7 respectively. The most frequent response of the sixth and eighth graders was that they chose their route because it was the shortest.

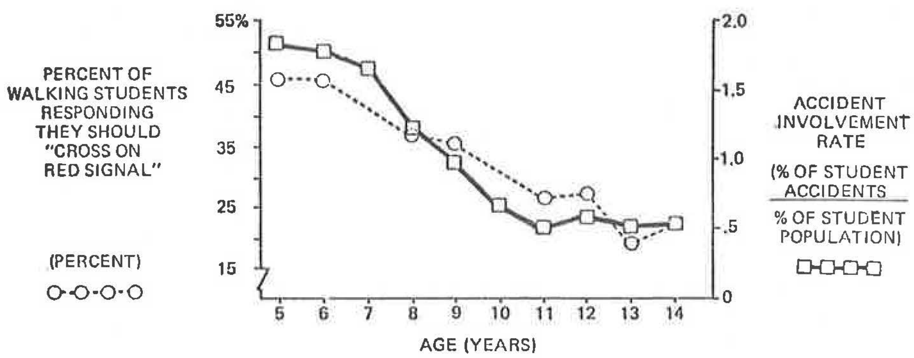
Similarly, the percentages of kindergarten and eighth grade students who would change their route if their parents told them to do so were 83.8 and 65.2 respectively. The percentages of kindergarten and eighth grade students who said they would change their route if told to by the school were 72 and 41 respectively. The percentages of kindergarten, third, sixth, and eighth grade students who would change their route if friends went another way were 50, 79, 39, and 66 respectively. In the pilot test, when all the students' responses were tape recorded, the percentage of third graders who said nothing would make them change their route was 50. In contrast, the

Figure 2. Respondents' means of transport to school and indication of traffic signal color when crossing, by age.

Means of Transport	Walk			School Bus			City Bus		Train	Car		Bike		Total
Color of Traffic Signal When Student "Would" Cross	R	Y	G	R	Y	G	R	G	R	R	G	R	G	
Age (Yrs.)														
5	34	1	39	2	1	7				13	8			105
6	23	3	24	7		3	1			5	5			71
8	36		61	11	1	4				15	12			140
9	31	1	55	11	1	10	1		1	7	8	3	2	131
11	24		66	10		2				4	14	1	3	124
12	26	1	68	1				1		5	4	1	6	113
13	18	2	76							1	5	1	1	104
14	20		69			1				1	2	1		94
														882

Key: Red, Yellow, Green

Figure 3. Comparison of student national accident involvement rate and surveyed traffic signal knowledge.



sixth graders in the pilot test most often said they would take a different route if their friends did.

CONCLUSIONS

Significantly more younger students (who need the most help) than older students indicated they would change their route if told to do so by their parents. These results appear to indicate differing influences on the routes of the students at various age levels and may have implications for channels of information to promote change. For example, the parents may be the most useful channel of information for the younger children, while the peer group may have more influence on the older children. A broad safety program (1) that involves traffic engineers, parents, educators, police, Parent-Teachers Association, and the public communications media as well as the students may be effective in reducing shcool walking-trip accidents if applied through a long-range, broad-based program. For the interested reader, the two student surveys and accompanying art work can be found in Appendix A of the final report (2).

ACKNOWLEDGMENT

This paper is based on a study for the Federal Highway Administration of the U.S. Department of Transportation. The opinions, findings, and conclusions are mine and are not necessarily those of the sponsoring agency.

REFERENCES

1. A. E. Shinder, H. D. Robertson, and M. L. Reiss. School Trip Safety and Urban Play Areas: Guidelines for the Development of Safe Walking Trip Maps. BioTechnology, Inc., Falls Church, Va.; Federal Highway Administration, U.S. Department of Transportation, FHWA-RD-75-108, May 1975.
2. M. L. Reiss. School Trip Safety and Urban Play Areas: Student and Driver Perception of School Trip Safety. BioTechnology, Inc., Falls Church, Va.; Federal Highway Administration, U.S. Department of Transportation, FHWA-RD-75-105, June 1975.
3. Accident Facts. National Safety Council, Chicago, 1974.
4. R. L. Knoblauch. Urban Pedestrian Accident Countermeasures Experimental Evaluation: Accident Studies. BioTechnology, Inc., Falls Church, Va., Vol. 2; National Highway Traffic Safety Administration and Federal Highway Administration, U.S. Department of Transportation, Feb. 1975.
5. Pedestrian Safety Report. American Automobile Association, Vol. 1, No. 1, 1968.
6. The Child in Detroit Traffic. Traffic Safety Bureau, Detroit Police Department, 1963.
7. The Child in Detroit Traffic. Traffic Safety Bureau, Detroit Police Department, 1968.
8. G. B. Grayson. The Hampshire Child Pedestrian Accident Study. U.K. Transport and Road Research Laboratory, Crowthorne, England, unpublished manuscript, 1972.
9. Statistical Abstract of the United States. Bureau of the Census, U.S. Department of Commerce, 1972.
10. D. A. Routledge, R. Repetto-Wright, and C. I. Howarth. A Comparison of Children's Exposure to Risk as Pedestrians. Ergonomics, Vol. 17, No. 5, 1974, pp. 623-638.
11. D. A. Routledge, R. Repetto-Wright, and C. I.

Howarth. The Exposure of Young Children to Accident Risk as Pedestrians. Ergonomics, Vol. 17, No. 4, 1974, pp. 457-480.
12. H. Marks. Child Pedestrian Safety: A Realistic Approach. Traffic Engineering, Vol. 25, 1957, pp. 13-19.
13. S. Sandels. Young Children's Ability to Understand Traffic Education. International Federation of Pedestrians, Bulletin 8, 1969.
14. S. Sandels. Young Children in Traffic. British Journal of Educational Psychology, Vol. 40, 1970, pp. 111-116.
15. E. M. Backett and A. M. Johnston. Social Patterns of Road Accidents to Children: Some Characteristics of Vulnerable Families. British Medical Journal, Feb. 14, 1959, pp. 409-413.
16. J. H. Read and others. The Epidemiology and Prevention of Traffic Accidents Involving Child Pedestrians. Canadian Medical Association Journal, Vol. 89, Oct. 5, 1963, pp. 687-701.
17. W. J. Conover. Practical Nonparametric Statistics. Wiley, New York, 1971.

Publication of this paper sponsored by Committee on Pedestrians.

Abridgment

Pedestrian Signal Displays: An Evaluation of Word Message and Operation

H. Douglas Robertson, BioTechnology, Inc., Falls Church, Virginia

In 1974, a study was initiated by the Federal Highway Administration to define the problems associated with pedestrians crossing at urban intersections and to evaluate remedial measures aimed at reducing or eliminating these problems. The results of the problem identification phase of the study (1, 2) indicated that pedestrian signal displays were the source of several problems and that certain improvements in the displays could result in a higher level of compliance, safer pedestrian behavior, and better user understanding.

Two problem areas are addressed in the research described here. One problem involved the display of the pedestrian clearance interval. Pedestrians complained that there was not enough WALK (W) time to complete their crossing. They did not understand that a clearance interval was provided for them to complete their crossing before traffic was released. Additionally, some 15 percent of pedestrians hit by vehicles at signalized intersections were crossing against the signal. At 71 percent of 38 site pairs (intersections) that were matched by high and low occurrence of pedestrian accidents in Washington, D.C., the percentage of pedestrians who started crossing during the clearance display was greater than that at the high-accident location. Finally, 40 percent of the pedestrians observed crossing against the pedestrian signal started on the clearance indication, which is the flashing DONT WALK (FDW).

The second problem area centered on the effectiveness of flashing the W indication to warn pedestrians that vehicles might be turning through their crosswalk. A study by D'Angelo in 1973 (3) showed that pedestrians did not understand the intended meaning of flashing WALK (FW) and that an educational campaign produced no change in pedestrian crossing behavior. Observations in the earlier phase of this project confirmed that there was no significant difference in compliance between locations with FW and locations with steady W. The accident data indicated that turning vehicles represented a serious safety hazard to pedestrians. Approximately 25 percent of pedestrian accidents at intersections involved turning vehicles.

STUDY METHODOLOGY

Three experimental conditions were devised to address these two problem areas. In all cases, the experimental condition was compared to the current recommended Manual on Uniform Traffic Control Devices (MUTCD) standard. Experiment 1 compared a steady DONT WALK (DW) clearance indication to the standard FDW clearance indication. The hypothesis was that, if pedestrians were not shown a distinct clearance-interval indication, compliance would increase, undesirable behaviors would decrease, and the need to understand the clearance interval would be eliminated, i.e., W means it is safe to cross, and DW means it is not safe to cross. However, this hypothesis contained a possible flaw. Would the pedestrian understand what to do if he started on the W and the signal changed to DW while he was still in the street?

Experiment 2 was designed to address this question and consisted of a DONT START (DS) message in place of the DW message. The operation was the same as the experimental condition in experiment 1, i.e., a steady DS indication during the clearance and prohibited intervals. The hypothesis was that, when the DS message was displayed, pedestrians already in the street would continue their crossing while those still on the curb would not start their crossing.

Experiment 3 dealt with the second problem area and compared steady W to FW. The objective was to determine whether pedestrians understood the intended meaning of FW and steady W and whether pedestrians behaved differently with the two displays. Figure 1 shows the experimental design.

All three experiments were conducted simultaneously in Buffalo, New York, and Phoenix, Arizona. A before and after study design was employed. Each experiment was conducted at two different test intersections (one central urban and one suburban) in each of the two cities, i.e., 4 intersections/experiment. A 2-month acclimation period was allowed after installation of the experimental condition. One exception was that experiment 3 in Buffalo was reversed in the before and after sequence because the normal operation in Buffalo was a steady W. All of the test sites operated on two-phase, fixed-time control, and turning movements were permitted at all sites.

The three types of variables measured were observed pedestrian behavior, pedestrian compliance, and user understanding. In phase 1 of the project, a set of hazard-related pedestrian behaviors was developed. These behaviors occurred more frequently at high-accident intersections than at similar low-accident intersections and included the following:

1. Backup movement (B)—Pedestrian momentarily reverses his or her direction of travel in the traffic lane or the pedestrian hesitates in response to a vehicle in a traffic lane;
2. Moving vehicle (MV)—Through traffic is moving through the crosswalk while a pedestrian is in a traffic lane;
3. Turning vehicle (TV)—Pedestrian is in the path and within 6.1 m (20 ft) of a turning vehicle;
4. Vehicle hazard (VH)—Pedestrian enters a traffic lane when a through vehicle that is unrestricted by a traffic control device is approaching in that lane within one block of the pedestrian;
5. Running vehicle hazard conflict (RVH)—Pedestrian runs in a traffic lane in response to a VH; and
6. Running turning vehicle conflict (RTV)—Pedestrian runs in a traffic lane in response to a TV or TV potential.

The second type of variable measured was the pedestrian compliance observed at the signal display. In addition to recording the number of pedestrians starting on the clearance interval, starting on the prohibited interval, and anticipating the signal, the distribution of these occurrences was also recorded.

The third type of variable measured was the user's understanding of the signal display. A survey was made of pedestrians who used the crossings when the above described observations were taken. Three days were spent at each site pair for each experimental condition during the before and after study in each of the two cities.

The evaluation of each experimental signal display, when compared to the base condition, was based on the following criteria:

1. A significant change in the occurrence of one or more of the observed pedestrian behaviors;
2. A significant difference in the types of pedestrian violations and the distributions of those violations over time; and
3. Responses from the user survey with respect to the meaning of the indications and perceived actions required by the indications.

DATA ANALYSIS

The analysis of data was designed to reflect the three evaluation areas of understanding, compliance, and behavior. Within each of these areas, a statistical comparison that contrasted the experimental and standard signal was performed. These analyses were based on standard psychometric procedures, and all statistical tests were evaluated at the 0.01 level (two-tail). The analysis of data on signal understanding consisted of a series of Z-tests that were used to compare the percentage of pedestrians who correctly identified the meaning of the various signal displays under investigation.

The analysis of the compliance data consisted of two sequential steps. First, an overall test of the compliance distributions that were obtained under different signal conditions was performed by using χ^2 with a $2 \times n$ design, where n = the number of intervals timed. Second, the results of this test determined if there was a significant difference between the distribution of crossings under different signal conditions. In the event that such a difference was detected, a series of Z-tests was conducted to isolate the particular time interval in the cycle that showed a significant shift. The behavioral data were analyzed by comparing the proportion of pedestrians involved in each of the target behaviors. The proportions of each behavior occurring under the different signal displays were tested by using the Z-test.

Experiment 1: FDW Versus Steady DW

The results of experiment 1 are given in Table 1. Almost no behavioral differences were found. In Phoenix, the three behaviors showing a slight significant difference occurred in less than 2 percent of the 3000 observed crossings.

The compliance data were summarized in two ways. First, the proportion of pedestrians leaving the curb during the W indication (in compliance with the signal) was noted. Highly significant differences were found at one intersection in each of the two cities. In Buffalo the before case (FDW) was favored (compliance was 10.5 percent higher), while in Phoenix the after case (DW) was favored (compliance was 8 percent higher). No significant differences were found at the other intersections for each city. Combining the two sites in each city resulted in the same trend but a lower level of significance. Thus, the improvement shown by steady DW in Phoenix appears to be offset by the findings in Buffalo. In general, compliance ranged from 8 to 32 and from 65 to 89 percent in Buffalo and Phoenix respectively.

Second, the compliance data were summarized and tested by comparing the proportion of pedestrians leaving the curb during the clearance interval. The hypothesis was that fewer pedestrians would leave the curb during the DW clearance then during the FDW clearance. At one site in Buffalo, the hypothesis proved correct at the 0.05 level of significance (a reduction of 9.1 percent). At the remaining sites, there were no significant differences. In general, pedestrians leaving the curb during the clearance interval ranged from 10.0 to 20.4 and from 3.7 to 20.7 percent in Buffalo and Phoenix respectively.

Some 400 pedestrians were surveyed to obtain user-understanding data (50 pedestrians/site/before and after condition). The questions asked pertaining to the clearance interval are given in Table 1. No significant differences were found in the responses to question 1 for either city. Of the responses to question 1, an average of 91 percent were correct across both cities. In other words, most pedestrians understood that they should not leave the curb on either FDW or DW. The answers to question 2 (what would the pedestrian do if after he or she left the curb the clearance indication changed to FDW or DW) produced mixed results. In Buffalo, the combined correct responses (i.e., to continue across) for both sites were significant at the 0.05 level in favor of the FDW clearance indication (59.1 percent before compared to 42.6 percent after). In Phoenix, the correct responses at one site and at both sites combined were significant at the 0.05 level in favor of the steady DW clearance indication. At the one site, correct responses ranged from 74 to 90 percent for the before and after cases respectively. With both sites combined, the correct responses went from 79 to 91 percent for the before and after cases respectively.

The differences between cities were considerable. In Phoenix, pedestrians exhibited both a higher compliance

Figure 1. Displays for experiments 1, 2, and 3.

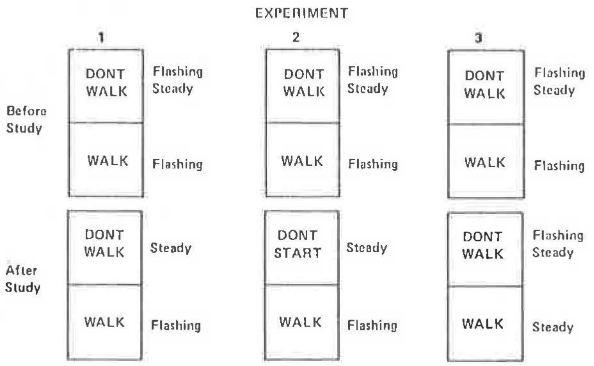


Table 1. Summary of results for experiment 1: steady DW (after) versus FDW (before).

Item	Buffalo Site 1	Buffalo Site 2	Buffalo Sites 1 and 2	Phoenix Site 5	Phoenix Site 6	Phoenix Sites 5 and 6
Behavior						
B	nc	nc	nc	A*	nc	nc
RTV	nc	nc	nc	nc	nc	B*
MV	nc	nc	nc	nc	nc	nc
TV	nc	nc	nc	nc	nc	nc
RVH	nc	nc	nc	nc	nc	nc
VH	nc	nc	nc	nc	A*	nc
Compliance						
Leaving curb on walk	B**	nc	B*	A**	nc	A*
Leaving curb on clearance	nc	A*	nc	nc	nc	nc
Understanding						
Question 1[a]	nc	nc	nc	nc	nc	nc
Question 2[b]	nc	nc	B*	nc	A*	A*

Note: A = significant difference in favor of after (experimental) condition; B = significant difference in favor of before (MUTCD standard) condition; nc = no significant difference between before and after conditions; * = significant at the 0.05 level; and ** = significant at the 0.01 level.

[a] If you are at the curb, what should you do if you see the FDW or DW indication?
[b] If you had just started to cross the street and you saw the FDW or DW indication, what should you do?

Table 2. Summary of results for experiment 2: steady DS (after) versus FDW (before).

Item	Buffalo Site 3	Buffalo Site 4	Buffalo Sites 3 and 4	Phoenix Site 1	Phoenix Site 2	Phoenix Sites 1 and 2
Behavior						
B	nc	nc	nc	nc	nc	nc
RTV	nc	nc	nc	nc	nc	nc
MV	nc	nc	nc	nc	nc	nc
TV	nc	nc	nc	nc	A**	A*
RVH	nc	nc	nc	nc	nc	nc
VH	nc	nc	nc	nc	nc	nc
Compliance						
Leaving curb on walk	nc	nc	nc	nc	A*	nc
Leaving curb on clearance	nc	nc	nc	nc	nc	nc
Understanding						
Question 1[a]	nc	A**	nc	nc	nc	A*
Question 2[b]	nc	nc	nc	nc	nc	nc

Note: A = significant difference in favor of after (experimental) condition; B = significant difference in favor of before (MUTCD standard) condition; nc = no significant difference between before and after conditions; * = significant at the 0.05 level; and ** = significant at the 0.01 level.

[a] If you are at the curb, what should you do if you see the FDW or DS indication?
[b] If you had just started to cross the street and you saw the FDW or DS indication, what should you do?

with and a better understanding of pedestrian signal indications. In Buffalo, the number of significant differences was fewer than in Phoenix. Pedestrians did not react differently to the change in clearance indications. The responses to a question about when it would be safe to leave the curb (the correct answer is on the W indication) implied that some 21 percent of the respondents either do not understand pedestrian signals or do not bother to use them as an aid in crossing the street.

Experiment 2: FDW Versus Steady DS

The results of experiment 2 are given in Table 2. No significant differences in behaviors occurred in either city except at one site in Phoenix. At that site, TV conflicts were reduced from 23.5 to 14.5 percent, which favored the DS display. This difference was significant at the 0.01 level and contributed largely to the difference for the combined data from both Phoenix sites to be significant at the 0.05 level. TV conflicts were approximately 8 percent higher in Phoenix than in Buffalo, even though the proportion of TVs in Phoenix was about 2 percent lower than that in Buffalo.

Only one significant difference was found in the compliance data. At one site in Phoenix, the compliance increased from 80.9 to 87.8 percent (significant at the 0.05 level), thus favoring the DS message. This difference was not sufficient to cause the combined data from both sites to be significantly different. No significant difference was found in the proportion of pedestrians (approximately 11 and 8 percent in Phoenix and Buffalo respectively) leaving the curb during the clearance interval. In general, compliance ranged from 39 to 49 and from 81 to 88 percent in Buffalo and in Phoenix respectively. Thus compliance was greater at the experiment 2 sites than at the experiment 1 sites in both cities.

The survey questions in experiment 2 were the same as those asked in experiment 1, and again 400 pedestrians were surveyed. A highly significant (at the 0.01 level) increase in correct responses to question 1 (82 to 98 percent) was found at one site in Buffalo, thus favoring the after case. In Phoenix, the difference was not significant at either site, but was significant at the 0.05 level for the two sites combined, which also favored the

Table 3. Summary of results for experiment 3: steady W (after) versus FW (before).

Item	Buffalo Site 5	Buffalo Site 6	Buffalo Sites 5 and 6	Phoenix Site 3	Phoenix Site 4	Phoenix Sites 3 and 4
Behavior						
B	B**	B**	B**	nc	nc	nc
RTV	B*	nc	B**	nc	nc	nc
MV	nc	nc	nc	nc	nc	nc
TV	nc	B*	B**	nc	nc	nc
RVH	nc	nc	nc	nc	nc	nc
VH	nc	B**	B**	nc	nc	nc
Compliance						
Leaving curb on walk	B**	nc	B**	A**	nc	A**
Leaving curb on clearance	nc	nc	nc	A*	nc	A*
Understanding						
Question 3[a]	nc	nc	nc	nc	nc	nc
Turn expectancy, percent[b]	49.5	41.4	45.5	35.0	44.0	39.5

Note: A = significant difference in favor of after (experimental) condition; B = significant difference in favor of before (MUTCD standard) condition; nc = no significant difference between before and after conditions; * = significant at the 0.05 level; and ** = significant at the 0.01 level.

[a] At some intersections, the W signal flashes, at some, it does not. What does the flashing (nonflashing) W signal mean at this intersection?
[b] The percentage of pedestrians that would expect vehicles to be turning into their crosswalk if they started their crossing on the W indication.

after case (an increase in correct responses from 84 to 91 percent). No significant differences were found in the responses to question 2 in either city; thus the hypothesis that DS would be better understood as a clearance display was not sustained. As in experiment 1, the differences between cities were great at the experiment 2 sites. Compliance in Phoenix was nearly twice as high as that in Buffalo. The pedestrian understanding of signal indications also remained higher in Phoenix than in Buffalo.

Experiment 3: FW Versus Steady W

The results of experiment 3 are given in Table 3. As given in that table, a number of differences were found in the Buffalo behavioral data, whereas no significant differences were found in the Phoenix behavioral data. All of the differences in the Buffalo data favored the before (FW) case. The most significant results were that hesitations, vehicle hazards, and turning vehicle conflicts were reduced by 13, 6, and 4 percent respectively.

Significant differences were also apparent in the compliance data. As in experiment 1, the differences in pedestrians leaving the curb on the W indication were offsetting. In Buffalo, the before case was favored (compliance decreased 19 percent) and in Phoenix the after case was favored (compliance increased 8 percent). The same trends held when data from both sites in each city were combined. Compliance at these sites ranged from 21 to 40 and from 78 to 93 percent in Buffalo and Phoenix respectively. The proportion of pedestrians leaving the curb during the clearance indication (FDW) was not expected to change because the indication was the same in both the before and after cases. This expectation held true except at one site in Phoenix where a difference at the 0.05 level was found.

The most significant finding in this experiment was from the understanding data. Of the 400 pedestrians surveyed, only 2.5 percent understood the intended meaning of FW and steady W. Less than half of the pedestrians in both cities said that they would expect vehicles to be turning into the crosswalk during the W interval, even though turning vehicles in both cities made up one-fourth of the total traffic passing through the intersection when all turns were permitted. As mentioned earlier, turning vehicle conflicts dropped in Buffalo (4.0 to 0.4 percent) and remained the same for both the before and after cases in Phoenix (approximately 16 percent).

The trends in compliance differences between cities remained consistent with the trends in experiments 1 and 2. The behavioral differences found in Buffalo are not easily explained. The before and after sequence was reversed in Buffalo for this experiment, but there was a 2-month acclimation period to reduce or eliminate the novelty effect. There was no novelty effect apparent in the behavioral data for the other two experiments, and they were conducted simultaneously with this experiment.

CONCLUSIONS

1. A steady DW clearance display appears to have the same effectiveness as an FDW clearance display. There is not sufficient evidence to say that a steady clearance is better than a flashing clearance.
2. The DS message offers little or no improvement over the current DW message.
3. FW is not an effective means of warning pedestrians about turning vehicles.
4. Based on pedestrians' stated expectancy in regard to TVs, there is a need to make pedestrians more aware of TVs.
5. Pedestrians' observance of pedestrian signals varies somewhat from intersection to intersection and greatly from city to city.
6. The pedestrian behaviors used may be sensitive enough to reflect the responses of pedestrians to the subtle changes made in these experiments.

ACKNOWLEDGMENT

The conclusions stated here are mine and do not necessarily reflect the opinions of the Federal Highway Administration or the U.S. Department of Transportation.

REFERENCES

1. H. D. Robertson, W. G. Berger, and R. F. Pain. Urban Intersection Improvements for Pedestrian Safety. Volume II: Identification of Safety and Operational Problems at Intersections. BioTechnology, Inc., Falls Church, Va., May 29, 1975.
2. H. D. Robertson. Urban Intersection: The Problems of Sharing Space. Traffic Engineering, Arlington, Va., Feb. 1976.
3. J. D. D'Angelo. The Effects of a Flashing Walk Education Program on Pedestrian Crossing Characteristics. Department of Civil Engineering, Univ. of Pennsylvania, College Park, June 1973.

Publication of this paper sponsored by Committee on Pedestrians.

Abridgment

A Method for Estimating Pedestrian Volume in a Central Business District

Jahanbakhsh Behnam, Department of Civil Engineering, Marquette University
Bharat G. Patel, Spicer Engineering Company, Saginaw, Michigan

In the past decade, significant efforts have been directed toward improving the accessibility and revitalization of the central business district (CBD) in many large metropolitan areas. The ingenious concepts that emerged have been used to achieve economic goals as well as to satisfy the demand for CBD accessibility in many urban transportation developments. In spite of these successful developments, the most vital element of urban transportation, namely pedestrian movement, has been treated incomprehensively in many transportation studies. The importance of pedestrian circulation in the CBD area has not been recognized even though transportation by foot is the only efficient means of internal circulation for many short trips in the heart of the downtown area.

The innovative design and construction of pedestrian facilities or planning of such facilities requires a comprehensive knowledge of pedestrian traffic flow and behavior of pedestrian circulation in the CBD area. If the pedestrian facilities are planned to be built on vague assumptions and inadequate technical documentation, then the demand for such facilities will not be estimated accurately. Underestimation of pedestrian flow will lead to poor design in urban areas and the creation of discomfort among the users. On the other hand, if the facility is built on the basis of a highly overestimated pedestrian demand, then the funds used are wasted because they could have been used for other purposeful urban projects. Based on this rationale, scientific methods are vital to forecast the pedestrian volume in urban areas.

The primary purpose of this study was to develop a simple quantitative model that could be used by various planning and engineering staff of an urban government for predicting the pedestrian volume from land use data in the core of the CBD. The study design placed a special emphasis on the selection of variables that could be quantified and obtained without difficulty from the existing data bank of a city.

BACKGROUND

A limited number of studies have attempted to develop models for determining pedestrian volume in CBD areas. One of the studies related to this research has been conducted by Pushkarev and Zupan (1) in midtown Manhattan. The technique of regression analysis was used to establish a relation between instantaneous numbers of pedestrians on a street (dependent variable) and walkways, office space, retail stores, and restaurants (independent variables). The distance from the nearest transit station, an additional independent variable, was used in this study to represent the geographical distribution of opportunities for making trips. The data for this study were collected by aerial photography. However, one disadvantage of this technique was that counts could not include pedestrians walking through covered areas or areas concealed from view.

There are several problems involved in this study that deserve some attention. First, the study does not establish a direct relation between pedestrian volume and land use data. Second, the collection of data for geographical distribution and walkways many not be a simple task in many cases. Third, the cost of using aerial photography for pedestrian data and for the other two independent variables previously mentioned is generally beyond the financial capability of many cities. Although the study is of significance in the understanding of pedestrian circulation in the CBD area, it does not lend itself as a practical tool that could normally be used at a city level.

The conventional gravity model technique is applied to forecast pedestrian volume in the Toronto area. The study reported by Ness and others (2) employed gravity models to develop predictive tools for the journey to work and lunch-hour pedestrian circulation demands in the CBD area. The prediction model for pedestrian volume for the journey to work was developed relative to the location of transportation terminals and offices by dividing the CBD area into office zones. Pedestrian links were coded for CBD, depending on street configuration and office centroids. According to the study (2), "The inputs to the gravity model were the generation and attraction rates of office and transportation zone, a family of friction factors, and a set of minimum-path walking trees from all office centroids to all transportation zones." Similarly, the gravity model was used for the noon-hour circulation. Since the attraction rate was unknown, the minimum path was not calibrated by a usual approach. The calibration was completed on the basis of walking time, waiting time at intersections, street attractiveness, and a turn penalty. The simulation techniques were employed for the latter part of this study. The study will probably provide an accurate prediction of pedestrian circulation; however, the technique is difficult and the cost involved is high.

Haas and Morrall (3) have conducted a survey of pedestrian tunnels between all major buildings and parking lots of Carleton University, Ottawa, Canada. The objective was to develop a pedestrian demand model for future design criteria. Data had been collected by an origin-destination questionnaire survey. Screen-line counts and walking time-distance surveys were made for the calibration of the model. Screen-line counts were taken at the peak hour for all links. According to this study, "The walking time-distance measurements were obtained by using a floating pedestrian technique, similar to the floating car method often used in conventional traffic studies." The peak hour for the design was determined from the schedule of university classes. Trips were assigned to the network system (considering interzonal transfers) by a computer assignment program from the results of this survey.

LAND USE VARIABLES

Previous studies have shown that the relation between pedestrian traffic and influencing variables can be best studied by quantitative analysis. It is important to choose those variables that could be quantifiable and readily obtainable for the study. Thus, the following variables were chosen.

1. Commercial space (x_1) refers to the spaces used for retail stores, shopping areas, inns, restaurants, and other similar commercial activities that take place in the CBD area.
2. Office space (x_2) refers to the spaces used for governmental offices, professional offices, banks, and other financial institutions located in the study area.
3. Cultural and entertainment space (x_3) refers to the spaces associated with museums, historical sites, theaters, parks, educational institutions, and other similar activities located in the CBD.
4. Manufacturing space (x_4) refers to all spaces used for small-scale industries in the CBD area.
5. Residential space (x_5) refers to all spaces used for residential purposes in the study area.
6. Parking space (x_6) refers to parking spaces in the CBD area of the city and includes all parking lots and multistory parking garages used for parking purposes.
7. Vacant space (x_7) refers to the spaces that are allocated for some activity but were not used at the time of the land use survey and includes vacant spaces in the buildings and vacant lots found in each block.
8. Storage and maintenance space (x_8) refers to the spaces used for storage and maintenance purposes.

The variables described above are the independent variables, and the pedestrian volume per hour per block was the dependent variable used for developing the proposed models.

DATA COLLECTION

The pedestrian survey was conducted during the summers of 1971 through 1973 by field observers stationed at each midblock location within the defined area of study. The study area was divided into several numbers of loops of varying size, and each loop contained several blocks that were assigned to an observer. The procedure required that each observer count pedestrians in each loop for a period of 1 h at intervals of 6-min counts for each midblock station. Thus, the observer stationed at the midblock of a street counted the number of pedestrians who used the sidewalk in two directions for 6 min. After completing the 6-min count, the observer moved to the next station to continue the counting process. The loops were designed in such a manner that normally an observer could cover all stations in a loop within 1 h, which included the time it took the observer to relocate from one station to another. If the coverage of stations in a loop took an observer less than 1 h, the observer was instructed not to initiate a new count until the completion of a full hour. Manual mechanical counters were used in this study, and the survey was conducted between 6:00 a.m. and 6:00 p.m. during weekdays.

The pedestrian volumes for each sidewalk were derived from the data that were compiled by field measurement. The pedestrian volumes per hour were derived and expanded from the 6-min counts. For example, the pedestrian volume at the noon hour was obtained by multiplying the 6-min counts by a factor of 10. Likewise, the average volume per hour for each sidewalk was computed by dividing the total observed volumes per hour by the total survey time.

The land use data for this study were collected from the files of the Milwaukee Department of City Development. The department retains current detailed data on various aspects of land use that were suitable for the purpose of this study.

FORMULATION OF MODELS

A stepwise regression technique was used to discriminate and enter into the model the most significant land use variables that influenced the pedestrian volume. The computer enters variables in single steps from best to worst provided that they meet the preestablished statistical criteria. The variable that explains the greatest amount of variance in the dependent variable will enter first, and the variable that explains the greatest amount of variance in conjunction with the first variable will enter second. In other words, the variable that explains the greatest amount of variance unexplained by the variables already in the equation enters the equation in each step. This process continues until all variables with significant F-values are in the equation.

The statistical criterion used in developing the models was based on an F-level of significance of 0.05 for a variable to be included or excluded from the models.

Several potential models, linear and nonlinear, were applied to the data before the final models were selected. Since the noon hour was considered the peak pedestrian circulation period, the pedestrian volume during this period and the associated land use data were analyzed separately by the use of potential models. Similarly, the average pedestrian volume per hour and associated land use data were also applied to the potential models. This grouping was used to investigate the significance of noon-hour pedestrian circulation for the development and selection of the final model. Thus, two sets of equations were developed for each category and the best model was selected from each group. For this analysis, the final models for noon-hour pedestrian volume (model 1) and average pedestrian volume per hour (model 2) are shown below in Equations 1 and 2 respectively:

$$\ln \hat{Y} = 5.128 + 0.000\,004\,03\, x_1 + 0.000\,001\,99\, x_2 + 0.053\,8 \ln x_3 + 0.056\,0 \ln x_7 + 0.038\,9 \ln x_8 \quad (1)$$

$$\ln \hat{Y} = 5.159 + 0.000\,003\,57\, x_1 + 0.000\,001\,90\, x_2 + 0.032\,2 \ln x_3 + 0.034\,2 \ln x_5 + 0.038\,2 \ln x_7 + 0.035\,9 \ln x_8 \quad (2)$$

where R = 0.739 and 0.764 and S_e = 0.726 and 0.568 for Equations 1 and 2 respectively.

EVALUATION OF MODELS

The statistical evaluation of these two models indicated that the models selected were good predictors of pedestrian volume and will provide relatively accurate results. The coefficient of multiple determination showed that approximately 60 percent of the variation in pedestrian volume is explained by land use variables. Further examination of Equations 1 and 2 indicates that the significant independent variables in both models are identical except for the residential land use variable (x_5) that was included in model 2. Also, the coefficient of correlation and the standard error of estimate displayed by each model are similar.

The coefficients of correlation derived for the models were statistically tested by comparing them to the critical values obtained from the statistical handbook (4) at the 0.01 level of significance. The critical values were 0.439 and 0.444 for models 1 and 2 respectively. Thus, the correlation coefficients were found to be highly significant for both models.

Further investigations were made to determine how the derived models compared in accuracy and what percentage of error should be expected to result if the models were used for prediction purposes. Since the models predict only total pedestrian volume for the entire block, a method was employed to compute the pedestrian volume for each sidewalk of the blocks. This approach was based on the ratio concept, and it was assumed that the current ratio of pedestrian volume on each side of the block to its total pedestrian volume will remain relatively stable through the years. Hence, the percentage of error for the entire block and each sidewalk of the block was computed by comparing the observed values to those calculated from the models. The results are given in Table 1. The typical blocks were chosen to provide a representative sample of volume variation for each condition previously mentioned. Generally, the percentage of error for model 2 is lower than that for model 1. Although model 2 has similar statistical characteristics and a fewer number of variables than model 1, the latter model produces errors that are somewhat lower, and thus model 1 would be the more suitable model to use for prediction purposes.

APPLICATION OF MODELS

The models developed during the conduct of this study have various practical applications in traffic engineering, transportation planning, and the design of pedestrian walkways in urban areas. Since the data required for these models can be collected simply and without high

Table 1. Percentages of error for observed and estimated pedestrian volumes on block sides and on total block.

		Side 1			Side 2			Side 3			Side 4			Total		
Model	Block	Observed	Estimated	Error	Observed	Estimated	Error	Observed	Estimated	Error	Observed	Estimated	Error	Observed	Estimated	Error
1	8	1180	857	-27.4	130	95	-26.9	60	44	-26.7	20	15	-25.0	1390	1011	-27.3
	11	3550	2519	-29.1	240	171	-28.8	200	142	-29.0	160	114	-28.8	4150	2946	-29.0
	96	40	42	+4.8	100	105	+4.8	20	21	+4.8	0	0	—	160	168	+4.8
	148	140	86	-38.6	10	6	-40.0	180	110	-38.9	150	92	-38.7	480	294	-38.8
	127	130	219	+40.6	80	135	+40.7	90	151	+40.4	70	118	+40.7	370	623	+40.6
2	8	843	661	-21.5	134	105	-21.6	40	31	-22.5	89	69	-22.5	1106	866	-21.6
	11	1768	1451	-17.9	283	233	-17.7	157	128	-18.5	159	130	-18.2	2367	1942	-17.9
	96	28	31	+9.7	47	53	+11.3	34	38	+10.5	46	52	+11.5	155	174	+10.9
	148	0	0	—	44	47	+6.4	118	127	+7.1	0	0	—	162	174	+6.9
	127	141	216	+34.7	43	66	+34.9	104	159	+34.6	106	162	+34.6	394	603	+34.8

Table 2. Example data for a 1990 forecast of pedestrian volumes on each sidewalk of a rectangular block.

Sidewalk	Existing (V)	Ratio (r)	Pedestrians per Hour ($\hat{Y}$)	Estimated ($\hat{V}$)
V_1	70	0.1186	734	87
V_2	240	0.4068	734	299
V_3	120	0.2034	734	149
V_4	160	0.2712	734	199

cost, the models have significant values in the field of transportation engineering. The following example of an application of the models in practice is presented to show the use of the derived models.

For example, consider a rectangular block that is located in the CBD area and has an existing pedestrian volume (pedestrians per hour) on each sidewalk as given in Table 2. The 1990 forecast of land use within the block is as follows:

Use	Amount (m^2)	Use	Amount (m^2)
x_1	3251.6	x_5	1207.7
x_2	3948.4	x_7	1022.0
x_3	929.0	x_8	1394.0

The average pedestrian volume per hour in 1990 ($\hat{Y}$) can be obtained by using Equation 2. Therefore, Ln $\hat{Y}$ = 6.599 and $\hat{Y}$ = 734.

The estimated volume can be distributed to each sidewalk of the block by the ratios (r) derived by dividing the total volume (V_t) of 590 pedestrians by the volumes on each sidewalk (V_1, V_2, V_3, and V_4). These ratios are also given in Table 2. Thus, the 1990 pedestrian volumes per hour ($\hat{V}$) for each sidewalk are obtained by the following equation and the values are given in Table 2.

$$\hat{V} = r(\hat{Y}) \quad (3)$$

These volumes may be used for planning, design, or evaluating the sidewalk level of service in the CBD area. Obviously, the models could be used for a variety of purposes in studying and planning the pedestrian circulation in the core of downtown.

LIMITATIONS OF MODELS

The data for this study were gathered in the CBD of Milwaukee, which is unique in its urban formation compared with other U.S. cities. This city is considered medium-sized and is an automobile-oriented urban community with a reasonable supply of parking space at a relatively moderate cost. The primary transit system currently in operation is a bus system that serves the metropolitan area of Milwaukee, and no major transit terminal exists in the CBD area except for the conventional bus stops. Thus, the models developed in this study represent the characteristics of the urban CBD in Milwaukee and its land use patterns in the CBD in relation to the pedestrian flow. These factors may be different for other cities.

Geographical factors are also important items that should be considered in the development and use of these models. Each region comprises groups of people who have characteristics, life-styles, and land use patterns that may be completely different from those of the CBD in Milwaukee. Thus, for those areas where the transit system and walking are a common form of transportation other variables may warrant consideration. The regions with mild climates and an elderly population will have a high pedestrian flow with different pedestrian characteristics and generations.

The models developed here contain terms with a natural logarithm of land use variables that may assume a zero value for certain blocks. This condition should not pose any difficulty in the computation process of the models. Since a zero value for any variable implies that the specific land use variable would not contribute to any flow of pedestrians, the value of unity should be used to avoid undefined terms, and, in the meantime, eliminate the effect of the variable from the model.

Last, the temporal nature of the regression model should be acknowledged for the purpose of clarification. The variables used in the development of these models may change periodically by urban renewal, change in allocation of space for different activities, and catastrophical events such as fire and earthquake. Therefore, the models should be updated and modified to preserve accuracy and stability in the estimation process.

CONCLUSIONS

The analysis of pedestrian volume and land use data produced two simple pedestrian-forecasting models for the CBD area. The models developed have significant advantages in terms of the data collection method and use of the models in practice. The data collection procedure employed for this study is less sophisticated than other collection procedures, but it is economically feasible and provides for reasonably accurate inputs for use in the models. The land use data needed for forecasting purposes can be obtained from city planning agencies without significant difficulty or cost in many U.S. cities.

The models have a wide range of applications in the field of transportation engineering such as planning, traffic engineering, and design of pedestrian facilities. The application of the models in practice was demonstrated by an example problem in this paper. The models were tested statistically, and there were no reasons to believe that the models would not provide reasonably accurate results. However, the models developed were based on the data collected in Milwaukee, which is a medium-sized city. The walking habits, degree of transit usage, composition of land use, and other factors may generate a different format of pedestrian models in other cities. Nevertheless, the models should provide a reasonably accurate forecast in CBDs of other cities that have synoptic characteristics.

Further research is needed to develop and study similar models for other cities and low-density areas. A possible approach would be to collect comprehensive and nationwide data that can be used to develop models for various classifications (low and high-density areas and small and large cities) in which the accuracy and validity of each model can be determined and compared with certainty. The results of this type of research may then provide a set or a unified model that may be used under various geographical and land use conditions for the estimation of pedestrian volumes.

ACKNOWLEDGMENT

The pedestrian data for this study were collected by the Milwaukee Bureau of Traffic Engineering and Electrical Services under the direction of David A. Kuemmel. The land use data were provided by the Milwaukee Department of City Development. The conclusions and views expressed in this report do not reflect the opinions of the above cooperating agencies.

REFERENCES

1. B. Pushkarev and J. M. Zupan. Pedestrian Travel Demand. HRB, Highway Research Record 355, 1971, pp. 37-53.
2. M. P. Ness, J. F. Morrall, and B. G. Hutchinson. An Analysis of Central Business District Pedestrian Circulation Patterns. HRB, Highway Research Record 283, 1969, pp. 11-18.
3. R. C. G. Haas and J. F. Morrall. Circulation Through a Tunnel Network. Traffic Quarterly, April 1967.
4. D. B. Owen. Handbook of Statistical Tables. Addision-Wesley, Reading, Mass.

Publication of this paper is sponsored by Committee on Pedestrians.

Abridgment

Accident Data Base for Urban Pedestrians

Richard L. Knoblauch, BioTechnology, Inc., Falls Church, Virginia

The transportation safety community has been aware of the extent of the national pedestrian accident problem for many years. There are approximately 400 000 injuries and nearly 10 000 fatalities annually. The U.S. Department of Transportation became actively involved in determining the nature of the problem in 1969, when it funded a project to investigate urban pedestrian accidents. This project (1) identified the recurring accident patterns or accident types involved in urban pedestrian accidents. Since that time, similar research efforts have successfully identified the recurring behavioral antecedents in rural and suburban (2) as well as freeway pedestrian accidents (3).

The accident typology is the basis for developing countermeasures that are designed to affect the behavioral antecedents of the various accident types. A previous report (4) described the establishment of a pedestrian accident data system in several cities. The information in the regular police report was combined with information provided on a special supplementary form so that a type could be established for each accident. The resulting data base is used to evaluate the effectiveness of various countermeasures that reduce the occurrence of specific accident types in a pre- and post-experimental-control paradigm.

The purpose of this paper is to provide a profile of the accident experience; it is not intended to be analytical.

METHODOLOGICAL PROCEDURES

Each type of target accident has associated predisposing and precipitating factors. The effectiveness of a given countermeasure can be evaluated by ascertaining whether the reported accidents could be target types for that countermeasure. Thus, a number of items required for the pedestrian accident data were developed to determine the types of accidents that occur. These items included a combination of items already on the police accident report form and certain additional items needed to determine each accident type. Figure 1 shows the list of required data items formatted as a master coding form.

The police accident report forms in each city were analyzed to see which required data items were routinely collected. Thus, it was possible to identify the additional items to be collected in a supplementary form. Figure 2 is a typical supplementary data collection form that was used by one of the seven cities in the study.

Intrinsic in the design of the data items was the concept of identifying an accident according to a particular accident type by the presence or absence of certain select descriptors. It was possible to determine which type of accident a particular accident most closely resembled by using the information contained on the master coding form. A sorting logic taxonomy was programmed and tested during this project (Figure 3). In addition, all accidents were coded manually so that a subjective (manual coding) and an objective (machine-programmed) accident type was assigned for each accident.

RESULTS

The primary purpose of this data collection effort was to provide before and after accident data for a variety of long-term countermeasure evaluation projects. However, a great deal of interesting and potentially useful information has been collected on nearly 6000 accidents. The data base is briefly described below.

The data base consists of data from seven cities for the 3-year period of 1973 through 1975. The distribution of the entire accident sample by time of day revealed a curve that is characteristic of the urban pe-

Figure 1. Master coding form for pedestrian accident summary.

Coder ______
Date ______

MASTER CODING FORM: PEDESTRIAN ACCIDENT SUMMARY

Card Number 1

CITY: 01 Akron 02 Columbus 03 Miami 04 New York City 05 San Diego 06 San Jose 07 Toledo 08 D.C. . . . 2,3

ACCIDENT NUMBER: Code Police Accident Report No., Justify Left . . . 4-10

DATE: Code Month (11, 12) Day (13, 14) Year (15, 16) . . . 11-12, 13-14, 15-16

TIME: Military Time (18-21) DAY OF WEEK: 22-1 Sun 22-2 Mon 22-3 Tue 22-4 Wed 22-5 Thur 22-6 Fri 22-7 Sat 18-21,22

DRIVER–AGE: (23, 24) DRIVER–SEX: 25-1 Male 25-2 Female 25-3 Hit and Run . . . 23-24, 25

PEDESTRIAN–AGE: (26, 27) PEDESTRIAN–SEX: 28-1 Male 28-2 Female . . . 26-27,28

PEDESTRIANS INJURED: Code no. of injured peds. in Col. 29. Complete separate form for each ped. . . . 29

INJURY SEVERITY: 30-1 Fatal 30-2 Serious 30-3 Moderate 30-4 Slight 30-5 None . . . 30

LIGHT CONDITIONS: 31-1 Daylight 31-2 Dawn or Dusk 31-3 Dark . . . 31

WEATHER CONDITIONS: 32-1 Clear or Cloudy 32-2 Rain 32-3 Snow or Sleet 32-4 Fog or Mist 32-5 Other ______ 32

ROADWAY CONDITIONS: 33-1 Dry 33-2 Wet 33-3 Snow, Ice or Mud 33-4 Other ______ 33

TYPE OF VEHICLE: 34-1 Car 34-2 Taxi 34-3 Bus 34-4 Truck 34-5 Other ______ 34

TYPE OF ROAD: 35-1 Two-way 35-2 One-way 35-3 Divided 35-4 Expressway 35-5 Other ______ 35

TYPE OF AREA: 36-1 Resid. 36-2 Comm. 36-3 Indust. 36-4 Undev. 36-5 School 36-6 #1,2 36-7 #1,3 36-8 #2,3 36-9 Other ______ 36

TRAFFIC CONTROL: 37-1 Red,Green,Amber Signal 37-2 Stop or Yield Sign 37-3 None 37-4 Other ______ 37

THE VEHICLE WAS: 39-1 Proceeding Straight 39-2 Backing 39-3 Turning Right 39-4 Turning Left
39-5 "U" Turning 39-6 Stopped in Traffic 39-7 Starting in Traffic 39-8 Stopping or Slowing . . . 39
40-1 Entering or Leaving Parking Space 40-2 Other ______ 40

THE ACCIDENT OCCURRED: 41-1 At an intersection 41-2 Not at an intersection . . . 41
42-1 In a marked crosswalk 42-2 In an unmarked crosswalk 42-3 Not in a crosswalk . . . 42
43-1 With the street lights on 43-2 With a pedestrian signal present 43-3 #1,2 . . . 43

NUMBER OF TRAFFIC LANES: Code no. of traffic lanes, do not include parking lanes . . . 44

THE PEDESTRIAN WAS STRUCK: 45-1 In the 1st traffic lane entered 45-4 In the 4th traffic lane entered 45-7 In the parking lane
45-2 In the 2nd traffic lane entered 45-5 In the 5th traffic lane entered 45-8 While not in the roadway
45-3 In the 3rd traffic lane entered 45-6 After crossing more than 5 lanes . . . 45

THE DRIVERS VISION WAS BLOCKED BY: 46-1 Standing traffic 46-2 A parked vehicle 46-3 A bus at a bus stop 46-4 Other ______ 46

THE DRIVER: 47-1 Did attempt evasive action,swerved or braked to avoid pedestrian . . . 47
49-1 Was attending to traffic and failed to see pedestrian 50-1 Was under the influence of alcohol or drugs . . . 49,50
51-1 Was exceeding the speed limit 52-1 Was engaged in a turning or merging maneuver . . . 51,52
53-1 Made an improper turn 54-1 Disobeyed a sign or signal . . . 53,54

THE PEDESTRIAN CROSSED: 55-1 From behind a parked vehicle 56-1 Against the signal . . . 55,56
57-1 At a bus stop In front of the bus 57-2 At a bus stop Behind the bus 58-1 In front of standing traffic. 57,58

THE PEDESTRIAN WAS: 59-1 Running 60-1 Going to or from an ice cream truck or vendor . . . 59,60
61-1 Crossing with other pedestrians 62-1 Not attempting to cross the roadway . . . 61,62
63-1 Getting in or out of vehicle 64-1 Not aware that the vehicle was backing up . . . 63,64

THE PEDESTRIAN: 65-1 Appeared suddenly in the path of the vehicle 66-1 Walked or ran into the vehicle . . . 65,66
67-1 Was working on or pushing a vehicle 68-1 Was working in roadway 68-2 Was playing in roadway . . . 67,68
69-1 Attempted evasive action to avoid the vehicle 70-1 Was under the influence of alcohol or drugs . . . 69,70

ACCIDENT TYPE: Subjective typing by Coder . . . 76,77

DEGREE OF CERTAINTY IN ACCIDENT TYPING: 78-1 Positive 78-2 Reasonably Certain 78-3 Uncertain . . . 78

ACCIDENT TYPE: Objective typing by Sorting Program (Coder; leave blank) . . . 79,80

Card No.	Ident.	ACCIDENT LOCATION: House Number	ON: Street Name	St.,Rd. Etc.	Feet	N.S. E.W.	At or of	Street Name	St.,Rd. Etc.	Quadrant or Area	Type
2	Same as Card 1										Same as Card 1

Figure 2. Supplementary form for Akron, Ohio.

Accident Number ______ (4-10) Time of collision ______ (18-21)

Date of collision ______ (11-16) Form completed by ______ (Officer)

SUPPLEMENTARY PEDESTRIAN DATA

- To be completed for all pedestrian injury accidents
- Check all responses that apply
- Forward through normal channels with the regular accident report form
- The following information is being collected for research purposes only

TYPE OF ROAD:
- 35-1 ☐ City street
- 35-2 ☐ One-way city street
- 35-3 ☐ Divided roadway
- 35-4 ☐ Controlled access highway
- 35-5 ☐ Other, specify ______
- 35-6 ☐ Underpass
- 35-8 ☐ Bridge
- 37-7 ☐ Overpass
- 35-9 ☐ Tunnel

TYPE OF AREA:
- 36-1 ☐ Residential
- 36-2 ☐ Business
- 36-3 ☐ Industrial
- 36-9 ☐ Other, specify ______
- 36-4 ☐ Undeveloped
- 36-5 ☐ School
- 36-9 ☐ Parkway

THE ACCIDENT OCCURRED:
- 42-1 ☐ In a marked crosswalk
- 42-2 ☐ In an unmarked crosswalk
- 42-3 ☐ Not in a crosswalk
- 43-1 ☐ With the street lights on
- 43-2 ☐ With a pedestrian signal ("Walk, Don't Walk") present

NUMBER OF TRAFFIC LANES: 44- ⎵ Indicate the total number of traffic lanes in both directions (do not include parking lanes)

THE PEDESTRIAN WAS STRUCK:
- 45-1 ☐ In the 1st traffic lane entered
- 45-2 ☐ In the 2nd traffic lane entered
- 45-3 ☐ In the 3rd traffic lane entered
- 45-4 ☐ In the 4th traffic lane entered
- 45-5 ☐ In the 5th traffic lane entered
- 45-6 ☐ After crossing more than 5 lanes
- 45-7 ☐ In the parking lane
- 45-8 ☐ While not in the roadway

THE DRIVER'S VISION WAS BLOCKED BY:
- 46-1 ☐ Standing traffic
- 46-3 ☐ A bus at a bus stop
- 46-2 ☐ A parked vehicle
- 46-4 ☐ Other, specify ______

THE DRIVER:
- 47-1 ☐ Did attempt evasive action, swerved or braked to avoid the pedestrian
- 49-1 ☐ Was attending to oncoming traffic and failed to see the pedestrian

THE PEDESTRIAN CROSSED:
- 55-1 ☐ From behind a parked vehicle
- 56-1 ☐ Against the signal
- 57-1 ☐ At a bus stop in front of the bus
- 57-2 ☐ At a bus stop behind the bus
- 58-1 ☐ In front of standing traffic

THE PEDESTRIAN WAS:
- 59-1 ☐ Running
- 60-1 ☐ Going to or from an ice cream truck or vendor
- 61-1 ☐ Crossing with other pedestrians
- 62-1 ☐ Not attempting to cross the roadway
- 64-1 ☐ Not aware that the vehicle was backing up

THE PEDESTRIAN:
- 65-1 ☐ Appeared suddenly in the path of the vehicle (the driver's detection of the pedestrian was hampered by visual obstruction and/or by the pedestrian's unexpected movement)
- 66-1 ☐ Walked or ran into the vehicle (cases where the pedestrian impacts the vehicle rather than the vehicle striking the pedestrian)

OTHER NOTES OR COMMENTS: ______

COMPLETE FORM FOR EACH PEDESTRIAN ACCIDENT

destrian accident pattern. The percentages of accidents that occurred between 2:00 and 8:00 p.m. and that occurred during daylight lighting conditions were 53 and 68 respectively. The age distributions of the pedestrians involved were also typical. The 5 to 9-year group (21 percent) was encountered most frequently, and the total percentage of 14 years old or younger was 42.

The weather was clear or cloudy for 88 percent of the accidents. It was raining and snowing or sleeting in 9 and 1 percent of the accidents respectively. The roadway was dry, wet, and snow-, ice-, or mud-covered in 84, 13, and 1 percent of the accidents respectively.

Most of the collision vehicles (80 percent) were passenger cars, and trucks, buses, and taxis were involved in 9, 2, and 1 percent of the accidents respectively. Since 10 percent of the accidents involved hit-and-run vehicles, it is not surprising that vehicle type was unknown in 3 percent of the cases.

Although 74 percent of the accidents occurred on two-way surface streets, there were also occurrences on one-way streets, divided highways, and expressways for 9, 4, and 2 percent of the accidents respectively. Most frequently, the roadways were two-lane and four-lane for 41 and 29 percent of the accidents respectively. The accidents occurred most frequently in residential (39 percent) and commercial (26 percent) areas. Most of the accidents did not occur at an intersection (56 percent). Although 40 percent of the accidents occurred at or within 15.2 m (50 ft) of an intersection, only 16 per-

Figure 3. Sorting program logic for typing of accidents.

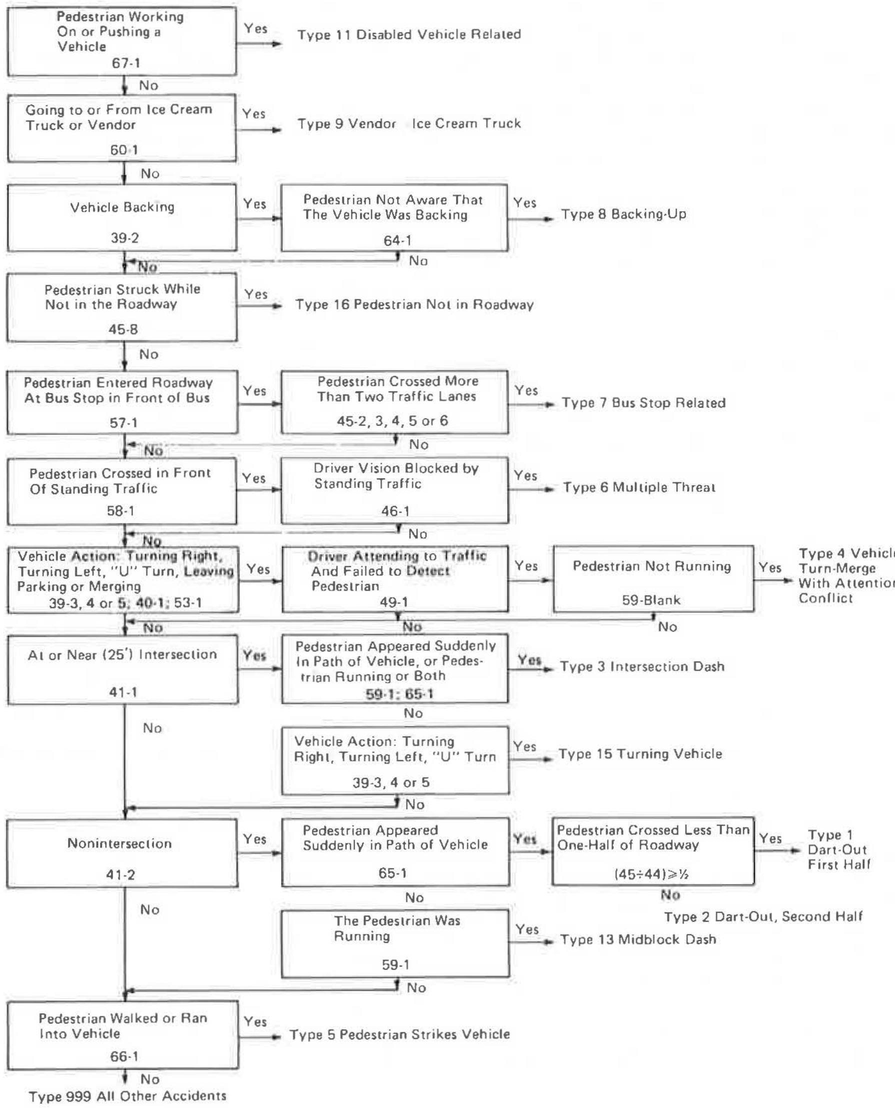


Table 1. Coding, percentage, and description of accident type.

Code	Percentage of Accidents	Accident Type: Name	Accident Type: Description
01	19	Dart-out, first half	Pedestrian crossed the street less than half-way at a location other than an intersection (short-time exposure)
02	9	Dart-out, second half	Pedestrian crossed the street more than half-way at a location other than an intersection (short-time exposure)
03	17	Intersection dash	Pedestrian ran across the street at an intersection (short-time exposure)
04	2	Turning vehicle and driver-attention conflict	Driver attended to traffic rather than pedestrian when turning (not 15)
05	5	Pedestrian strikes vehicle	Pedestrian walked or ran into a vehicle (no other information and not 01, 02, 03, 04, 09, 13, or 15)
06	2	Multiple-vehicle threat	Pedestrian was struck by vehicle traveling in the same direction as other vehicles that were stopped for pedestrian
07	1	Bus stop-related	Pedestrian was struck when crossing in front of a bus or standing at a bus stop
08	2	Backing-up vehicle	Pedestrian who was not clearly aware of vehicle movement was struck by a backing-up vehicle
09	1	Vendor/ice cream truck-related	Pedestrian was struck when going to or from a vendor vehicle on the street
10	3	Unusual circumstances	One-of-a kind occurrences that cannot be corrected by countermeasures
11	1	Disabled vehicle-related	Pedestrian was struck when working on or next to a disabled vehicle
12	3	Result of automobile-automobile crash	Pedestrian was struck by vehicle(s) as a result of automobile-automobile crash
13	7	Midblock dash	Pedestrian ran across street at a location other than an intersection (not a short-time exposure, 01 or 02)
14	1	Trapped	Pedestrian was struck when the light changed and the traffic started to move (not 06)
15	7	Turning vehicle	Pedestrian was struck by a turning vehicle (no attention conflict documentation, and not running or 04)
16	4	Pedestrian not in roadway	Pedestrian was struck at a location other than the roadway, including cases in which the vehicle went out of control (not 08, 11, or 12)
—	19	Uncoded	Accidents such as big wheels, skateboards, and pedacycles do not fit into any of the above categories. Other examples are cases in which the pedestrian is hitchhiking, walking along the roadway, or not attempting to cross the roadway

cent occurred in marked crosswalks and 14 percent occurred in unmarked crosswalks. Two-thirds (67 percent) of the sites had no traffic controls, but 22 percent of the sites had a red, green, and amber signal. Only 5 percent of the sites had a pedestrian signal. Although many of the accidents occurred at intersections, the vehicle actions were typically proceeding straight (73 percent).

Although the driver's vision of the pedestrian was not specifically indicated as blocked in 74 percent of the accidents, parked cars and standing traffic were visual obstructions in 13 percent and 5 percent of the accidents respectively. Several other driver-related characteristics were coded as follows: (a) drivers attempting evasive action (40 percent), (b) drivers engaged in a turning or merging maneuver (12 percent), (c) drivers attending to traffic and not seeing pedestrian (11 percent), (d) drivers under the influence of alcohol or drugs (3 percent), (e) drivers exceeding the speed limit (2 percent), and (f) drivers disobeying a sign or signal (1 percent).

Pedestrian behaviors were indicated for a number of variables that include the following.

Variable	Percent
Appearing suddenly in path of vehicle	44
Running	39
Walking or running into vehicle	17
Under the influence of alcohol or drugs	6

The accident-based countermeasure evaluations are aimed at detecting a change in the occurrence of specific target-accident types. Definitions were developed for a number of different accident types. There were 16 accident types developed and, when these were combined with those accidents that could not be coded, a total of 17 categories were identified as given in Table 1. As also given in Table 1, dart-outs and dashes of various kinds accounted for a total of 52 percent of the accidents.

In addition to the coding personnel who assigned each accident to a subjective accident type, automated procedures were developed to assign each accident to an objective accident type by using the taxonomy shown in Figure 3. Correlations were computed between the coder-assigned subjective code and the computer-assigned objective code. The correlations were high for all the accidents in the 1973 and 1974 sample (0.9754 and 0.9519 respectively).

REFERENCES

1. M. D. Snyder and R. L. Knoblauch. Pedestrian Safety: The Identification of Precipitating Factors and Possible Countermeasures. Operations Research, Inc., Vols. I-II, Final Rept., Jan. 1975; National Highway Traffic Safety Administration, U.S. Department of Transportation,
2. R. L. Knoblauch and W. Moore, Jr. Causative Factors and Countermeasures for Rural and Suburban Pedestrian Accidents. BioTechnology, Inc., Falls Church, Va., March 1976; National Highway Traffic Safety Administration and Federal Highway Administration, U.S. Department of Transportation.
3. R. L. Knoblauch, W. Moore, Jr., and P. R. Schmitz. Causative Factors and Countermeasures for Freeway Pedestrian Accidents. BioTechnology, Inc., Falls Church, Va., June 1976; National Highway Traffic Safety Administration and Federal Highway Administration, U.S. Department of Transportation.
4. R. L. Knoblauch and others. Urban Pedestrian Accident Countermeasures Experimental Evaluation: Accident Studies. BioTechnology, Inc., Falls Church, Va., Vol II, Final Rept., Feb. 1975; National Highway Safety Administration and Federal Highway Administration, U.S. Department of Transportation.

Publication of this paper sponsored by Committee on Pedestrians.

Bicycle Transportation for Downtown Work Trips: A Case Study in Davis, California

Donna Y. Lott, Bicycle Research Associates, Davis, California
Timothy J. Tardiff, University of California, Davis
Dale F. Lott, Bicycle Research Associates and University of California, Davis

Although there has been increasing interest in using the bicycle as a transportation mode, little is known about travel decisions that involve the bicycle, especially in U.S. cities. This paper discusses the development of modal-choice models that include the bicycle. The data used consist of a sample of 802 downtown workers in Davis, California. Age, sex, occupation, student status, and distance between workplace and residence were examined in relation to modal selection. Age and trip distance appeared to be negatively related to bicycle usage. The rate of bicycle use as a mode of transportation was lower for managers and those employed in areas such as transportation, utilities, communications, finance, real estate, and insurance than for workers employed in other areas. To analyze the contribution of these factors, we used a methodology that had been developed in disaggregate-behavioral, travel-demand studies to develop our alternative modal-choice models. Sequential binary and multinomial logit choice models were tested. The resulting models were satisfactory for exploratory purposes since many of the independent variables were useful in explaining modal choice. The results indicate that future work is needed to extend the models to other areas and to include those independent variables that are policy-sensitive. As a result, these models can be used in transportation planning to assist in making decisions relevant to bicycle use.

Main street is usually crammed with automobiles. The automobiles fill every possible place to park along the curbs, and drivers must wait in long queues to get through the next intersection. There are a lot of drawbacks in this situation. First, there are fewer visitors to businesses and governmental offices because the visitors must spend time looking for a place to leave their automobiles. The visitors also expend their emotional goodwill while waiting in the queues and competing for parking spaces. Second, everyone must breathe air that is substantially deteriorated by the admixture of noxious fumes from tailpipes, and the fact that the fossil fuels that make noxious fumes are finite and are rapidly declining does not lessen the discomfort.

Still, main street would not be main street without all those people. In most areas in the United States, the automobile is the only significant mode that is used to get people where they want to go. The search for alternative modes of transportation has progressed since the drawbacks of automobile use have been recognized. One of the many alternatives that is currently undergoing considerable evaluation is the bicycle.

In contrast to many of the mass or personal transit vehicles that are currently envisioned as alternatives to the automobile, bicycles are eminently state of the art. Bicycles are easy to make, fix, and operate. Moreover, they are easily accommodated, are inexpensive, and efficient, and rely primarily on renewable sources of energy. Bicycles are slower than cars, but a high percentage of trips currently made in the United States, especially to the downtown area, are well within their range. Despite all of these advantages, bicycles are still not seen on most main streets. Many people are arguing today that, if facilities were provided for bicycles, then people would ride them. However, will people ride bicycles if the facilities are provided?

The purpose of this paper is to discuss bicycle use in Davis, California, where there are well-established bicycle facilities. The response of citizens in Davis to using bicycles for work-trip travel indicates that, in this case, the citizens make substantial use of bicycles and their facilities. The percentage of bicycle riders for work trips in Davis exceeds the percentage of bus riders in many urban areas with strong transit systems.

Davis is a university-oriented city of about 30 000 in the central valley of California. Traditionally, a major transportation mode in Davis is the bicycle (12, 13). When growth and consequent competition with automobiles began to threaten the continuance of this tradition, a number of facilities and programs aimed at preserving the role of bicycles were established and have been in operation for several years. Consequently, it was possible to obtain the citizens' behavioral response to these facilities. Although the city of Davis possesses many special characteristics, e.g., its university orientation, terrain, and climate, the information gathered from this city gives some indication of what might be expected if similar facilities were provided in other locations.

PREVIOUS BICYCLE STUDIES

Recently, bicycle transportation has received popular and research attention. It has become apparent that bicycle transportation is a possible alternative for solving the problems of immobility, traffic congestion, air pollution, and energy shortages. However, there has been little research on the actual reasons why people choose bicycles as a transportation mode. Most research has been devoted to either the physical design of bikeway facilities or the discussion of the public-planning processes that include the location of bicycle facilities (3, 9). The state of knowledge regarding bicycle use is characterized more by what is not known than by what is known (5).

Although there has been little systematic effort in specifying the determinants for bicycle use, there have been a few studies that suggest some factors that might be related to bicycle use. Ohrn (10) made assumptions about a number of factors that might affect bicycle modal choice from a study in the Minneapolis-St. Paul area. Among the factors assumed to be important were flexibility of schedule, distance of trip, age of person, cost of parking, need for cargo storage, congestion of traffic, quality of facilities, and availability of transit. The specific nature of the assumed effects was not determined empirically, but assumptions were made on the magnitude of such effects. It was assumed that only a few people would use bicycles for work trips and trips longer than 3.2 km (2 miles). The assumption concerning the work-trip purpose seems to be contradicted by the experience in Davis and results from at least one other study.

Hansen and Hansen (5) found that the work trip was one of the strongest attractors for bicycle use in Uppsala, Sweden. In a 1971 survey, it was found that over 20 percent of all work trips were made by bicycle, and about 12 percent of all trips were bicycle trips, indicating that more importance is given to bicycles as a work-trip mode than any other mode.

Two studies took an economic approach to explain the choice between the bicycle and the automobile (4, 6). That is, it was assumed that the essential factors for explaining modal choice were trip costs and travel times. The latter factor was converted to monetary units by assuming a particular factor for the value of time. In both studies, assumptions were made about the comparative times and costs of the bicycle and automobile; however, this information was not derived by observing actual choices. The assumptions were used to analyze several hypothetical situations. It was concluded that, in most cases, the automobile is more likely to be chosen on strictly economic grounds. Since the trip times and costs were assumed to be a function of distance in both studies, the economic assumptions can be used indirectly by considering distance explicitly as suggested in other studies. This approach is taken in this study.

McGuire (9) suggested several factors that might be determinants for bicycle modal choice. Although these factors were not tested empirically, they are similar to those suggested in previously mentioned studies. These factors include trip distance, trip purpose, route quality, travel time, trip cost, age, sex, weather, and environmental pollution. It was further suggested that the approach used in disaggregate-behavioral models involving other modal choices might be useful for the bicycle case.

The disaggregate approach (11) has been thoroughly studied in the past, primarily in reference to the automobile as a modal choice. The key hypothesis is that individuals make their choice among modes probabilistically as a function of (a) characteristics of the modes in question such as time and cost; (b) characteristics of the individuals making the choice; and (c) interactions between individuals and modal characteristics, i.e., attitudes and perceptions of travel modes. Probably, the most common model of this nature is one in which the choice process is assumed to involve a trade-off between the time savings of a faster, more expensive mode and the cost savings of a slower, less expensive mode. It is apparent that the assumptions inherent in the disaggregate approach could be extended to include the bicycle as a possible alternative for a particular trip.

Such an extension was made by Ben-Akiva and Richards

(2) in a study of modal choice for work trips in the Netherlands. Among the modes included in a multinomial-logit, modal-choice model were automobile, bicycle, bus, train, moped, and walking. Since the conventional approach used in previous binary modal-choice studies was also used in this study, the key characteristics of the modes are trip times and costs.

The review of previous studies indicated that there are assumptions about the important determinants for bicycle use as a transportation mode but there is little concrete evidence that verifies these assumptions. This condition is especially true for U.S. cities where the bicycle has only recently been recognized as a viable transportation mode. This paper describes some of the data collected in Davis; the importance of various factors that affect the choice of using bicycles for commuting can be tested from these data.

BICYCLE-COMMUTING STUDY IN DAVIS

Data

Information on the use of bicycles was collected in October 1974 as part of a survey sponsored by the Davis Chamber of Commerce to determine the number of parking spaces normally used by people in the downtown area. One of us participated in expanding the survey to include data on transportation modes used for work trips to the downtown area. The downtown area is one of two major employment centers in Davis. The other center is the University of California, Davis.

Questionnaires were distributed to all downtown employees by the 168 employers. A total of 1413 persons were said to be employed in March 1974 in the area. The eventual rate of return was high. There were 1049 downtown workers (74 percent) who returned information on their usual transportation modes and parking locations. Failure to fill out or return the questionnaire seemed to be correlated with (a) employers who experienced difficulty getting part-time workers to return their questionnaires and (b) employees who did not fill out a questionnaire because they did not arrive by automobile and felt the study was not relevant to them. Since both these categories of workers showed an above-average incidence of using bicycles as their transportation mode, there is reason to believe that the reported rate of bicycle usage is an underestimate of the actual rate. Unfortunately, it does not seem possible to give a useful estimate of the magnitude of the underestimate.

In analyzing the degree of bicycle use as a transportation mode in the population that did respond, we considered only the incidence in the area where this mode would most likely be used. In this case, it was easy to discriminate between residents and nonresidents of Davis. This corresponds to the areas where bicycle use is likely because Davis has no significant unincorporated residential areas that are within range for using bicycles and it is 17.7 km (11 miles) from the nearest area where nonresident workers might live. There were 802 questionnaires returned from local residents.

These data are reported and analyzed in two stages. The first stage is a simple description (tabular) extracted from the survey data, and we did not attempt to make a statistical evaluation of these data in this section. Second, the development of modal-choice models is analyzed. Since these two stages have slightly different goals, the variables are defined or categorized slightly differently in the description as compared to the analysis. These differences are identified at the appropriate points in the text.

For the first step in this stage, the overall contribution of various modes of transportation for work travel to downtown Davis is reported. Table 1 gives the number and percentage of respondents who use the various modes or combinations of modes. An individual is assigned to a category if the mode(s) in the category was used at least once a week.

Although the automobile is the dominant mode, the bicycle is used for a substantial proportion of work trips. About 25 percent of the respondents use the bicycle at least once a week, and more than 6 percent of the respondents walk at least once a week. Therefore, non-motor-vehicle modes are important for work trips in Davis. The following is the relative contribution to transportation of each of the three principal modes: automobile, bicycle, and walk. The role of each is described by the number of work trips made per week and the number of work-trip kilometers traveled per week (1 km = 0.6 mile).

Transportation Mode	Kilometers Traveled per Week		Trips Made per Week	
	Number	Percent	Number	Percent
Automobile	7422	83	2879	77
Bicycle	1347	15	671	18
Walking	182	2	188	5
Total	8951	100	3738	100

The motor-vehicle mode of transportation accounted for a greater percentage of the total kilometers traveled than of the total trips made. Thus, there appears to be a difference in the length of trips by the different modes. To facilitate comparisons of the distances traveled by each mode, we sorted the respondents into three classes that correspond with the mode most frequently used. Those choosing automobiles as their most frequent mode had the longest trip distance [$\bar{x}$ = 2.85 km (1.77 miles)]; those choosing bicycles as their most frequent mode had the second longest trip distance [$\bar{x}$ = 2.12 km (1.32 miles)]; and those choosing walking as their most frequent mode had the shortest trip distance [$\bar{x}$ = 1.27 km (0.79 mile)]. Each group was paired with each of the other groups by using a Student's t-test to evaluate the reliability of the observed differences. All differences proved reliable as follows:

Item	t-Test	df	p
Automobile versus bicycle	6.11	651	<0.001
Automobile versus walking	7.89	557	<0.001
Bicycle versus walking	4.39	180	<0.001

In addition to the fact that trips of different length are normally made by each mode, the frequency of bicycling among those who chose to bicycle at all is slightly influenced by the length of the trip. Shorter trips were made more often. This relation is given below (1 km = 0.6 mile).

Number of Days per Week	Number of Bicyclists	Mean Distance (km)	Number of Days per Week	Number of Bicyclists	Mean Distance (km)
1	28	2.78	5	39	2.12
2	39	2.17	6	11	1.58
3	39	2.40	7	2	0.93
4	35	2.08			

These two lines of evidence converge in support of the view that work-trip length is a predictor of bicycle use as a transportation mode.

Age is also regarded as an important variable that affects the choice of bicycles as a transportation mode. This relation is described by classifying the three groups according to their most frequently used transportation mode and according to their ages, which are divided into seven classifications. These data are given in Table 2.

Since workers under age 24 are more likely to ride bicycles to work than other workers are, and since students are an important subgroup in that age classification, we determined whether the relation between student status and modal choice was a function of student status or student age. When age was controlled, student status did not appear to be related to bicycle use.

The final predictors of bicycle use for work trips were job title and type of employment of the workers. The classifications used for this analysis were those used by the U.S. Bureau of the Census for job titles and employment categories. These categories were used because they reflect socioeconomic similarity and because information about the work force in any community is available to that community through the census description. Table 3 reports the number and percentage of bicyclists by type of employment and job title. Bicycle use as a mode of transportation was substantially lower for the managerial group than for the other group. The rate of bicycle use as a mode of transportation is lower for workers in areas such as transportation, utilities, communications, real estate, finance, and insurance than for workers in the other areas.

Table 1. Downtown commuter modal choice of Davis workers by sex and student status.

Transportation Mode	Student		Nonstudent		Total	
	Male	Female	Male	Female	Number	Percent
Automobile only	36	29	235	205	505	63.0
Automobile-car pool	1	0	4	6	11	1.4
Automobile-walking	3	4	4	7	18	2.2
Automobile-motorcycle	0	1	1	0	2	0.2
Bicycle only	8	19	20	27	74	9.2
Bicycle-automobile	18	13	46	34	111	13.8
Bicycle-car pool	1	0	3	4	8	1.0
Bicycle-walking	0	1	3	2	6	0.7
Bicycle-motorcycle	1	0	0	0	1	0.1
Walking only	5	2	9	12	28	3.5
Car pool only	1	0	4	11	16	2.0
Bus only	1	0	0	1	2	0.7
Motorcycle only	2	0	4	1	7	0.9
Other	3	1	5	4	13	1.6
Total	80	70	338	314	802	100.0

Table 2. Most frequent modal choice by age classification.

Age Group	Automobile		Bicycle		Walking		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
<18	17	58.6	10	34.5	2	6.9	29	4.3
18 to 25	133	60.2	72	32.6	16	7.2	221	32.4
25 to 35	161	76.7	37	17.6	12	5.7	210	30.8
35 to 45	98	87.5	13	11.6	1	0.9	112	16.4
45 to 55	63	86.3	7	9.6	3	4.1	73	10.7
55 to 65	25	86.2	0	0.0	4	13.8	29	4.3
65 to 74	6	75.0	0	0.0	2	25.0	8	1.2
Total	503	73.8	139	20.4	40	5.9	682	100.0

Table 3. Number and percentage of bicyclists by type of employment and job title.

Item	Number of Respondents	Ride at Least Once per Week	
		Number	Percent
Type of employment			
Transportation, utilities, and communications	58	7	12
Government	164	43	26
Services	130	36	28
Finance, real estate, and insurance	130	19	15
Retail trade	195	60	31
Bar and cafe	115	35	30
Total	792	200	25
Job title			
Professional and technical	168	48	29
Managerial	105	12	11
Sales worker	143	46	32
Clerical and cashier	188	49	26
Service worker	122	31	25
Laborer	60	13	22
Total	786	199	25

Modeling Analysis

The previous section indicates that several of the variables suggested by previous researchers might be useful for explaining the choice of bicycles as a transportation mode. Although these separate bivariate relations are informative, a multivariate analysis of the contribution of the independent variables to modal choice would account for possible intercorrelations among the independent variables. This analysis was done by constructing binary and multinomial-logit, modal-choice models that use the independent variables described below.

Since facility quality and weather condition data were not available for the study in Davis, they were not used as variables. Also, it was thought that these variables might not affect the work-trip travel in Davis for two reasons. First, the bicycle lanes and paths established in Davis make all trips to the core area equally feasible; thus facilities were not a variable. Second, the weather conditions for commuting trips are not as important as the weather conditions for other trips.

Undoubtedly, weather conditions influence the frequency of bicycling throughout the year; however, our goal, in this stage of the study, was to emphasize the characteristics of the situation that accounted for choices among a population all of whom were subject to the same weather considerations.

The variables available are divided into characteristics of the trip and characteristics of the individuals making the trip. Trip distance is the variable in the first class. There are two measures of trip distance. The first is an estimate of home-to-work distance that is reported by each respondent. Home and work addresses were also reported by the respondents. Therefore, the home-to-work distance was also determined by measuring it.

Distance is widely thought to be an important variable in determining the use of bicycles as a transportation mode. It can be assumed to have a direct effect on modal choice. Alternatively, since data on the times and costs for the alternative modes were not available, the distance variable can be used as a surrogate for a generalized price variable (1). Generalized price is a function of time and cost, and both of these variables are related to trip distance. Hence, distance should be related to generalized price (4, 6).

The remaining independent variables are characteristics of the trip makers. These variables are sex, age, and occupation, which measures the socioeconomic status. For the purposes of this analysis, the job title classification system of the Bureau of the Census was simplified to include five categories:

1. Professional and technical,
2. Managerial,
3. Sales,
4. Clerical and cashier, and
5. Blue collar (combination of laborers and service workers).

Each classification has roughly equal numbers of respondents.

Modal-Choice Models

The data given in Table 1 indicate that the work trips in Davis can be assigned to three major modes with little loss of information. These modes are motor vehicle, bicycle, and walking. The first category includes automobiles, car pools, and motorcycles. The last two categories are aggregated to yield a motor or non-motor-vehicle modal-choice situation. Therefore, modal-choice models can be developed that include either two or three alternative modes.

The inclusion of only Davis residents in the sample carries with it the implicit assumption that all employees in Davis have a viable choice among the three modes. This assumption might be unrealistic for those respondents who are captive to one of the work-trip modes; however, no information was available to screen those respondents. Therefore, the results should be interpreted in light of this assumption.

The use of modeling techniques developed in behavioral modal-choice studies is useful in developing the bicycle modal-choice model. Specifically, logit analysis is used. The logit model is used to model either the two or three-alternative situation described above. In the former case, it is assumed that the individual's first decision is to use a motor vehicle or a nonmotor vehicle. Once the decision between the broader classifications is made, a specific mode is selected within the chosen classification. For purposes of this analysis, the choice between walking and bicycling is of interest. Two binary models were developed for the modal choice of motor or non-motor vehicle and the bicycle-walking modal choice. This approach is a variation of McFadden's maximum model (8, 14). The model for three alternatives assumes that the choice among the three modes is made simultaneously rather than in a hierarchical manner. Consequently, the multinomial-logit model is used.

The independent variables used in the models were defined earlier. Not all the variables examined in the descriptive section were considered in the modeling analysis, but the variables that were included correspond with some of the most important variables found in traditional modal-choice studies. Of special interest is the preliminary finding that involves the occupation variable; i.e., only particular categories appeared to be related to bicycle modal choice. This finding suggests that dummy variables be used to represent occupation. Since there are five categories, four dummy variables are necessary. In addition, it is possible to use both the respondent's perceived home-to-work distance and the measured distance. Separate models that use the alternative distance measures are also developed. The independent variables are as follows:

Symbol	Definition
PDIS	Home to work distance that is perceived by respondent
MDIS	Home to work distance that is measured
DOC1	Occupation dummy 1 equals one if the respondent is a manager; other occupation equals zero
DOC2	Occupation dummy 2 equals one if the respondent is a sales worker; other occupation equals zero
DOC3	Occupation dummy 3 equals one if the respondent is a clerical or cashier worker; other occupation equals zero
DOC4	Occupation dummy 4 equals one if the respondent is a blue collar worker; other occupation equals zero
AGE	Respondent's age in years
SEX	Equals one for males and two for females

The models can be represented symbolically, and the hierarchical binary approach is used to estimate the following equations:

$$P(\text{motor vehicle}) = \exp[L_1(x)]/\{1 + \exp[L_1(x)]\} \quad (1)$$

where $L_1(x)$ is a linear function of the independent variables given above. The second model in the set is

$$P(\text{bike}) = \exp[L_2(x)]/\{1 + \exp[L_2(x)]\} \quad (2)$$

where $L_2(x)$ is a second linear function of the independent variables.

The simultaneous three-alternative model can be represented by the following equations:

$$P(\text{motor vehicle}) = \exp[L_3(x)]/\{\exp[L_3(x)] + \exp[L_4(x)] + 1\} \quad (3)$$

$$P(\text{bike}) = \exp[L_4(x)]/\{\exp[L_3(x)] + \exp[L_4(x)] + 1\} \quad (4)$$

$$P(\text{walk}) = 1/\{\exp[L_3(x)] + \exp[L_4(x)] + 1\} \quad (5)$$

where $L_3(x)$ and $L_4(x)$ are two additional linear functions of the independent variables.

The linear functions in all of the alternative models are of the following forms:

$$L_i(x) = a_{0i} + a_{1i}\text{DIS} + a_{2i}\text{DOC1} + a_{3i}\text{DOC2} + a_{4i}\text{DOC3} + a_{5i}\text{DOC4} + a_{6i}\text{AGE} + a_{7i}\text{SEX} \quad (6)$$

where the a_{ji} are coefficients.

The coefficients of the linear functions are interpreted in a manner similar to that of the standard regression coefficient. That is, the magnitude of the coefficient indicates how the linear function changes with a unit change in the corresponding independent variable, and the ratio of the coefficient to its standard error yields a t-statistic that is used to test whether the coefficient is significantly different from zero (the critical values are 1.96 for the 0.05 level and 2.57 for the 0.01 level for two-tailed testing in large samples).

The coefficient values of the dummy variables indicate how much the given linear function for a person from a particular occupational category differs from the linear function of a person in the professional category, if all the independent variables are the same. For example, if the coefficient of DOC1 is negative, then the linear function for a managerial worker is smaller than the linear function of a professional worker with a difference of a_{21}.

The linear functions are inserted into one of the equations (1 through 5) to estimate the probability of a given individual selecting a particular mode or category of modes. These individual probabilities are conceptually similar to the aggregate modal splits for the entire population. As the linear function in the numerator of Equations 1 through 4 increases, the corresponding probability will also increase. Therefore, an increase in a variable in the appropriate linear function that has a positive coefficient will also increase the corresponding probability, and an increase with a negative coefficient will decrease the corresponding probability. For example, if the coefficient for the managerial dummy variable is significantly positive in the first linear function, then managerial workers are more likely to use motor-vehicle modes than professional workers are. Similarly, if the distance variable has a positive coefficient, then individuals with longer work trips are more likely to use a motor-vehicle mode. This will be the case if everything else in the linear function remains equal.

The three-alternative model is different from the usual approach to the multinomial-logit model. In these applications, there are separate characteristics of attributes that correspond to each alternative. In the current model, alternatives are distinguished by separate linear functions. In interpreting the linear functions, the walking mode is treated as the base case. Thus, the generalized price interpretation of distance is informative.

Table 4. Coefficients and standard errors of linear functions for the binary and three-alternative models.

	Binary Model								Three-Alternative Model							
	$L_1(\bar{x})$				$L_2(\bar{x})$				$L_3(\bar{x})$				$L_4(\bar{x})$			
	PDIS		MDIS		PDIS		MDIS		PDIS		MDIS		PDIS		MDIS	
Item	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Variable																
PDIS	1.00[a]	0.060			2.60[a]	0.26			3.60[a]	0.24			2.91[a]	0.24		
MDIS			1.15[a]	0.070			2.44[a]	0.25			3.34[a]	0.22			2.55[a]	0.23
DOC1	0.61[a]	0.18	0.55[a]	0.19	-0.19	0.51	0.18	0.53	0.47	0.44	0.47	0.45	-0.17	0.46	-0.12	0.48
DOC2	-0.16	0.14	-0.34[b]	0.14	-1.83[a]	0.44	-1.73[a]	0.43	-1.20[a]	0.38	-1.53[a]	0.37	-1.25[a]	0.39	-1.44[a]	0.38
DOC3	-0.200	0.14	-0.12	0.14	-1.17[a]	0.44	-1.16[a]	0.43	-0.98[b]	0.39	-1.13[a]	0.38	-1.14[a]	0.40	-1.19[a]	0.39
DOC4	0.079	0.14	0.12	0.14	-0.99[b]	0.43	-0.96[b]	0.42	-0.61	0.38	-0.81[b]	0.37	-0.92[b]	0.39	-1.19[a]	0.38
AGE	0.033[a]	0.0045	0.036[a]	0.0046	-0.075[a]	0.011	-0.063[a]	0.0099	-0.030[a]	0.0077	-0.018[b]	0.0073	-0.086[a]	0.0091	-0.077[a]	0.0088
SEX	-0.013	0.097	0.060	0.10	0.34	0.24	0.38	0.24	-0.21	0.20	0.032	0.20	-0.078	0.21	-0.021	0.21
Constant	-1.29[a]	0.25	-1.68[a]	0.26	1.58[b]	0.62	1.29[b]	0.62	0.66	0.53	0.47	0.52	2.07[a]	0.57	2.25[a]	0.55
Number	691		646		227		221		691		646		691		646	
ρ^2	0.15		0.14		0.32		0.29		0.19		0.18		0.19		0.18	

Note: $\rho^2 = 1 - L^*(\beta)/L^*(c)$, where $L^*(\beta)$ is the logarithm of the likelihood function at convergence and $L^*(c)$ is the logarithm of the likelihood function when all the coefficients of the independent variables, excluding the constant, are zero.

[a]Signifcant at $p < 0.01$. [b]Significant at $p < 0.05$.

Table 5. Prior modal split for linear functions.

Linear Function	Mode	Trips With PDIS Number	Trips With PDIS Percent	Trips With MDIS Number	Trips With MDIS Percent
$L_1(\bar{x})$	Motor vehicle	2615	77	2418	76
	Nonmotor vehicle	800	23	774	24
$L_2(\bar{x})$	Bicycle	628	79	605	78
	Walking	172	21	169	22
$L_3(\bar{x})$ and $L_4(\bar{x})$	Motor vehicle	2615	77	2418	76
	Bicycle	628	18	605	19
	Walking	172	5	169	5

The distance coefficient of the linear function corresponding to the motor-vehicle mode can be thought of as the scaling factor that converts distance to the generalized price difference between the motor vehicle and walking modes. A similar interpretation can be placed on the distance coefficient of the other linear function with respect to the generalized price difference between the bicycle and walking modes. In this way, the particular attributes of the modes such as generalized prices are approximated by distance and its coefficients. This interpretation makes the present approach similar to previous applications.

Although the sequential binary model and the simultaneous three-alternative model both generate two separate linear functions, it is likely that the functions will be different for the two approaches. These functions are different because the approaches assume different choice mechanisms and are calibrated differently: The sequential binary model involves the estimation of two separate models while the three-alternative model estimates the two linear functions simultaneously.

Data were collected on the number of weekly work trips by various modes; therefore, repeated observations were made for each respondent. As given in Table 1, there are a substantial number of people who use a combination of modes. Thus, for the logit models, sample size is increased by treating each trip as a separate observation. For example, a respondent who made three automobile trips, one bicycle trip, and one walking trip would contribute five observations.

RESULTS

Table 4 gives the coefficients and standard errors of linear functions for the binary and three-alternative models. The two equations considered are the perceived distance variable and the measured distance variable. Table 5 gives the prior modal split for the linear functions. Fewer than 802 cases were used to estimate these models. This reduction in sample size is due to data missing on the key variables and the inclusion of only the motor-vehicle, bicycle, and walking modes.

Several general conclusions emerge from the estimation of the models. First, although the perceived distance variable yields slightly stronger models than does the measured distance variable, the overall similarity of the corresponding models is striking. This similarity is not surprising since there is a strong correlation between measured and perceived distance in the sample.

Second, the importance of distance and age hypothesized in earlier studies and suggested by the tabular description of these data is confirmed by the multivariate analysis. These two variables are strongly significant in all models. On the other hand, the sex variable is statistically insignificant in all cases.

The remaining conclusions deal with some specific features of the alternative models. In the sequential binary models, motor-vehicle users tend to have longer trips, be in the managerial occupation category, and be older. Within the non-motor-vehicle category, bicycle users tend to have longer trips, are less likely to be sales workers, clerks and cashiers, or blue collar workers, and are more likely to be younger than the walkers.

It is apparent that the independent variables have different effects in determining the sequential choice processes. The role of age is reversed in the two cases. Also, the managerial category is the major distinction in the motor or non-motor-vehicle modal choice. However, in the bicycle-walking choice, three other categories generate different trip patterns and the managerial category is not statistically significantly different from the professional category.

The simultaneous three-alternative models given in Table 4 can be interpreted by regarding the linear functions as distinguishing motor-vehicle users from walkers and bicycle users from walkers respectively. The results here are qualitatively similar to the bicycle-walking model also given in Table 4. That is, both motor-vehicle users and bicycle users are distinguished from walkers in that they tend to have longer trips, are less likely to be sales workers, clerks and cashiers, or blue collar workers, and tend to be younger. For this model, the difference between motor-vehicle drivers and bicyclists can be determined by comparing the respective linear functions given in Table 4.

The most interesting difference between the linear functions in Table 4 is the larger coefficient for distance in the function corresponding to motor-vehicle users. This difference is consistent with the generalized price interpretation, since it appears reasonable that the generalized price difference between automobile use and walking would be larger for a given distance than the difference between bicycling and walking.

In assessing the relative merits of the sequential binary models versus the simultaneous three-alternative models, it is possible to use the fact that overall the likelihood functions for the sequential models are equal to the sum of the likelihood functions for the two binary models constituting the sequence (1). By using this criterion, we found that the simultaneous models have a slightly better overall statistical fit than do the sequential models. The slight statistical difference, together with the qualitative similarity of the alternative-choice structures, leads to the conclusion that the data do not indicate a clear-cut preference for either approach. This fact and the additional observation that the simultaneous approach was much more expensive computationally might indicate a practical advantage for the sequential binary approach.

In theoretical terms, the determination of whether the sequential binary or simultaneous three-alternative approach is superior depends on how validly each approach models the actual decision processes. The former model assumes a hierarchical process and that alternatives within broad categories are more similar than alternatives in different categories. In this case, people are assumed to make a choice between motor and non-motor-vehicle modes; therefore, the bicycle and walking modes are more similar to each other than either is to the motor-vehicle modes. The simultaneous three-alternative model assumes a single decision among alternatives that are equally similar (or different).

Since the empirical results indicate a qualitative similarity among the alternative approaches and the results are similar in statistical strength, the current results do not indicate a clear-cut preference for either hypothesis. However, both are based on particular decision rules and the results should be interpreted in this light.

SUMMARY AND CONCLUSIONS

This paper described the role of the bicycle as a transportation mode to work in Davis, California, and discussed the development of alternative, logit-choice models for determining bicycle use. The description of the role of the bicycle revealed that a substantial percentage of the trips were made by bicycle and that for trips up to 3.2 km (1.5 miles) the bicycle was readily accepted as a transportation mode by this segment of the general travel population under these conditions. There are a number of reasons for being cautious in using these results to forecast rates of bicycle usage in other areas or among other groups. First, the sample is probably not representative of the general travel population; Davis has several unusual attributes. Even here, the sample did not include workers at the university, which is a larger employment center than the downtown area is and has a heavier rate of bicycle users for work trips. Further, Davis has well-established bicycle facilities. Quantitative projections of riding rates among downtown workers made on the basis of the data reported here will be accurate in places that are similar to Davis. For such towns without well-established bicycle facilities, the model might estimate the ultimate potential for bicycle use as a transportation modal choice by downtown workers rather than the immediately obtainable results. The extension of the model, in quantitative terms, to areas not similar to Davis should await some data on usage under different circumstances. In the meantime, the identification of variables that are related to and not related to the use of bicycles for work trips may prove helpful in making decisions about relative rates of usage by subpopulations in other areas.

The major contribution of the development of the alternative, logit-choice models for bicycle use as a transportation mode appears to be in two cases. First, some of the variables that were assumed to be important in bicycle modal choice by other researchers were tested and found to be generally useful. Second, this study is one of the first attempts to model bicycle use from data taken from an American city. The results seem to indicate that behavioral-demand modeling was extended successfully in this case.

A feature of the model that limits its practical usefulness is the fact that none of the independent variables are easily controlled by transportation decision makers. For this reason, an improved model might include variables such as modal travel times and costs and route quality, which can be changed through transportation policies. The effect of the quality of available bicycle routes on overall modal choice would be especially useful here. As mentioned earlier, this variable was not available in this study because of the uniform quality of Davis bikeway facilities. However, such a variable might be important for improving models on bicycle policy analysis. Finally, bicycle modal choice is influenced by certain sociological variables (7). Inclusion of more variables of this type would also strengthen the models. All of these influences on modal choices might also bear on modal choice at the level of purchase. The unusually low number of two-car families in Davis may be a reflection of the operation of these influences. Unfortunately, our data do not illuminate this issue.

Therefore, the results indicate that there is potential for incorporating information on bicycle use in transportation planning models. Further work to develop models in other areas and to make such models more policy-sensitive could generate valuable planning tools that could be used for effectively allocating resources for bicycle transportation.

ACKNOWLEDGMENTS

This paper reports studies undertaken in connection with a research effort conducted by De Leuw, Cather and Company under contract to the Federal Highway Administration of the U.S. Department of Transportation. Findings and conclusions expressed herein are ours and not those of the sponsoring agency.

REFERENCES

1. M. E. Ben-Akiva. Structure of Passenger Travel Demand Models. Department of Civil Engineering, Massachusetts Institute of Technology, PhD dissertation, 1973.
2. M. E. Ben-Akiva and M. G. Richards. Disaggregate Multimodal Model for Work Trips in the Netherlands. TRB, Transportation Research Record 569, 1976, pp. 107-123.
3. Bikeways: State of the Art. De Leuw, Cather and Company, Final Rept, 1974; Federal Highway Administration, U.S. Department of Transportation.
4. M. Everett. Commuter Demand for Bicycle Transportation in the United States. Traffic Quarterly, Vol. 28, No. 4, 1974, pp. 585-601.
5. S. Hansen and P. Hansen. Problems in Integrating Bicycle Travel Into the Urban Transportation Planning Process. TRB, Transportation Research

Record 570, 1976, pp. 24-29.
6. E. Hirst. Bicycles, Cars and Energy. Traffic Quarterly, Vol. 28, No. 4, 1974, pp. 573-584.
7. D. Y. Lott and D. F. Lott. Quantitative Description of Downtown Commuting by Bicycle in Davis, California, and Some Geographic and Demographic Determinants of Commuter Mode Split. Bicycle Research Associates, Davis, Calif., 1975.
8. D. McFadden. Economic Applications of Psychological Choice Models. Travel Demand Forecasting Project, Univ. of California, Berkeley, working paper 7519, 1975.
9. P. B. McGuire. The Bicycle as a Mode of Transportation: Analysis and Planning Process Considerations. Department of Urban and Regional Planning, Univ. of Iowa, 1973.
10. C. E. Ohrn. Predicting the Type and Volume of Purposeful Bicycle Trips. TRB, Transportation Research Record 570, 1976, pp. 14-18.
11. P. R. Stopher and A. H. Meyberg, eds. Behavioral Demand Modeling and Valuation of Travel Time. TRB, Special Rept. 149, 1974.
12. R. Sommer and D. F. Lott. Bikeways in Action: The Davis Experience. Congressional Record, Vol. 117, No. 53, 1971.
13. R. Sommer and D. F. Lott. Behavioral Evaluation of a Bikeway System. Department of Psychology, Univ. of California, Davis, 1974.
14. K. Train and D. McFadden. The Measurement of Urban Travel Demand II. Travel Demand Forecasting Project, Univ. of California, Berkeley, working paper 7515, 1975.

Publication of this paper sponsored by Committee on Bicycling and Bicycle Facilities.

Citizen Participation in Planning and Designing Bikeways

Wesley Lum, Federal Highway Administration, U.S. Department of Transportation

The United States has recently experienced a sharp resurgence in bicycling activities. Public agencies are actively planning and constructing bicycle facilities. However, these facilities may have some adverse as well as beneficial community impacts. More citizen participation in the planning of bikeways can help provide better facilities. Several citizen participation techniques are discussed, and an example of a bikeway planning program that incorporates citizen participation is also presented. The use of these techniques can help provide safer, more efficient, effective, and compatible bikeway systems.

The United States has experienced a sharp resurgence in bicycling activities that has brought into view the potential usefulness of bicycling for transportation—a usefulness that bicycling has known in many foreign countries. In response to the increase in bicycling, many bicycle facilities are being planned and constructed. Unfortunately, environmental impact analysis and citizen participation have not been adequately considered in the planning of many bicycle facilities.

From the experience of highway planners in 1950 through 1960, the importance of adequately incorporating environmental impacts into the planning of major transportation projects, especially in urban areas, was revealed. Moreover, planners found that it was difficult to adequately incorporate qualitative impacts and information into the analysis and decision-making process. Consequently, methods of citizen participation were implemented to acquire better planning information and produce more compatible, effective, and desirable transportation facilities.

The impacts of bicycle facilities are not as great as the impacts of highways. However, if bicycling is to be a safe and effective means of transportation that is compatible with the nature and goals of the community, the environmental impacts of bicycle facilities should be analyzed, and the citizens affected should participate in the bikeway planning process. Bikeways have both potentially adverse and potentially beneficial impacts. Some of the adverse impacts are bicycle and motor-vehicle conflicts in traffic, loss of privacy to residents along the bikeway, decrease in business activity caused by bikeways eliminating street parking, replacement expenses for storm-sewer inlet grates, and expenses for major construction and maintenance. The beneficial impacts from bicycle use are providing an inexpensive short-range mode of transportation that is practical in good weather, reducing traffic congestion and air pollution, promoting a healthy activity, and creating a friendly, prosperous community atmosphere. Environmental analysis has shown that there is a potential for both adverse and beneficial impacts associated with bikeways. However, the degree of significance of these impacts cannot be completely determined. Bicycling is in its infancy in the United States, and this prohibits or hinders the gathering of significant data for determining demand, potential conflict, noise pollution, and other factors relevant to bikeway impacts. Although some impacts could be quantified by experimentation (e.g., delay to motorists caused by bicyclists in the roadway), most other impacts are not quantifiable because of the relative lack of experience with bikeways and the uncertainty of the popularity of bicycling, the values of the community, and the interaction of bikeways in communities.

COSTS AND BENEFITS OF CITIZEN PARTICIPATION

The agencies responsible for bikeway planning and implementation (including construction and maintenance) are typically traffic, public works, and planning departments. These agencies should be aware of the potential impacts that bikeways could have on communities and may be able to minimize certain impacts by design and route considerations. However, many of these impacts cannot be quantitatively measured but are still critical to an effective, environmentally compatible bikeway system. Failure to consider all the adverse impacts adequately can result in dissatisfied citizens with or without a project.

Thus, citizen participation in the planning process can provide a valuable input toward the environmental impact analysis and the planning of an effective bikeway system that is compatible with the environment and complementary to the community and community systems (i.e., the existing transportation system). There are many ways in which citizen participation can be implemented. (Those most applicable to bikeway planning are discussed in a later section.) Generally, the benefits that can come from citizen participation in the planning of their community systems can be described as follows.

1. Mobilization of idle resources (1)—In cities where there is a shortage of funds to perform tasks needed in the planning of bikeways, citizens can be mobilized to provide the people power for these tasks.

2. Use of sources of knowledge (1)—Citizens who represent various professions as well as levels of society and the community can and should provide corrective feedback to the planning professionals. This feedback can be achieved through various surveys, community meetings, and citizen committees.

3. Affirmation of the democratic process (1)—The American urban political culture is described by Colcord (2) as having three distinct characteristics: high value of local autonomy, direct participation in decision making by the elected officials, and direct participation in decision making by private civic leadership. The results of citizen participation can be described as people power (3).

4. Improvement in the quality of decisions (1)—The participation of the community in the planning process can enable all points of view to be considered and analyzed for their impacts. Those impacts that are most adverse to the citizens can be minimized and the benefits can be maximized (4).

5. Recognition of goals and priorities that affect citizens (5)—Citizen participation can enhance the likelihood of the agencies' successes and also their responsiveness to community values (6).

Unfortunately, effective citizen participation is difficult to champion (1), and there are many costs or disadvantages associated with it. These disadvantages are discussed below.

1. Increase of separatism—Citizen participation tends to intensify the disparities that exist between citizen groups and between professional planners and citizen groups (5, 7). However, if managed properly, the process can be one of cooperation rather than antagonism (7).

2. Greater cost with less efficiency (5, 8)—Citizen participation requires more money and time from the agencies and their personnel respectively. The planning process usually becomes more complicated through consideration of alternatives, feedback loops, and larger numbers of people working in it. Consequently, it takes longer for the process to be completed.

3. Increase of influence of some citizen groups (3)—It has been difficult to properly measure the influence of the different groups involved or concerned with the project. This problem is partly due to the difficulty in maintaining citizen participation through the planning process of a project. Only those groups who have the highest stake (usually the most to lose) are active at any one particular moment. If this problem is to be counteracted, then nonreactive techniques of measuring are needed. (These techniques are discussed in the section on surveys.)

4. Incompatibility with the merit system and professionalism (3)—In the general case of citizen participation, the civil servant should play a subordinate role to politicians and citizen groups (2, 9). However, a new approach to professionalism in the transportation planning area is being promoted and practiced in certain highway planning projects in which the highway planner acts as a facilitator or coordinator-catalyst by his or her relation with the citizens and the highway planning department.

The costs associated with effective citizen participation in planning are substantial. However, these costs are small when compared to the potential costs of not implementing citizen participation (i.e., the potential costs to residents along a bikeway route or the potential costs to victims of bicycle and motor-vehicle accidents). Irate citizen groups may even stop or reverse the plans for and construction of planned bikeways because of insufficient participation from citizens. Citizen participation increases the likelihood that the agencies' actions will be in consonance with community values and that there can be substantial, effective agreement on a course of action that is feasible, equitable, and desirable (10).

COMMUNITY PARTICIPATION TECHNIQUES

There are a number of techniques available to the traffic engineer or transportation planner who wishes to obtain citizen involvement in planning a bikeway system. Many of these techniques have been applied to other planning projects such as those dealing with regional transportation systems and local street uses. Other techniques have had application in various fields, while a few have had little or no application in real situations.

This section discusses some of these techniques. The characteristics of bikeways and bikeway planning that should be considered when applying these techniques are

1. Bikeways are an intrusion into a neighborhood,
2. Bikeways are uncommon and difficult to visualize,
3. The degree of impacts to the environment is unknown,
4. Bicyclists do not often follow rules of the road, and
5. Bikeways are for recreational and transportation purposes.

The particular combination of techniques used for a community would depend on the characteristics of that community. Each community will have its own peculiarities or problems to which certain techniques would apply while others would be inappropriate.

As expressed by Manheim (10), the objective would be to "achieve substantial, effective agreement on a course of action that is feasible, equitable, and desirable." The planners must assess each community's needs and desires when selecting the techniques that would help the community realize its goal. However, it should be remembered that implementation of certain citizen participation techniques may entail more expense than could be justified for a bikeway planning program. The program may not warrant the hiring of professionals on a long-term, full-time basis in the area of citizen participation. On the other hand, other planning areas such as community redevelopment and highways are in need of more citizen participation and may be able to absorb a substantial portion of the efforts of such professionals. In any case, cities should take advantage of all available information (i.e., environmental impact reports) that can be used in their own efforts.

The city should follow certain guidelines in their interaction with citizens. These guidelines apply to all techniques and to all phases of the planning process (10) as follows:

1. Determine a decision-making process,
2. Establish and maintain credibility (honesty),
3. Establish and maintain open channels of communication,
4. Depolarize interests (strive for consensus), and
5. Establish the facts.

ADVISORY COMMITTEES

Citizen advisory committees are formed for the purpose of representing the public (10). The function of the committee is to advise the city (officials and staff) in their decision making. If the public is to be represented fairly, then the committee should have balanced representation from the community. In the case of an advisory committee on bikeways and bicycle facilities, the committee should have, at the minimum, representatives from business, residential, and education sectors and from bicycle-concern groups (both young and old and serious and recreational). I believe that members of the committee, who represent the community, should have knowledge of community values and bicycle facilities and systems. Knowledge of community values should be a crucial factor in the selection criteria for committee members. An understanding of bicycling can be acquired through studying references supplied by the city. Nonetheless, a thorough and previous knowledge of the state of the art for bicycling will help the committee understand the bikeway problems and render it better able to advise. Well-informed community representatives on the committee could act as resource persons to the city about the community and to the community about bicycling.

The committee could be vested with various degrees of power. Arnstein (3) discusses various levels of the citizen participation ladder in which citizens and citizens' committees can be given a range of power that varies from tokenism to citizen control. Zuccotti (11) presents the pros and cons of giving local community boards (of New York City, in this case) more power (i.e., veto power) over regional commissions. However, for the use of a citywide bicycle advisory committee, it is felt that the role of advisor to the decision makers, that is, to the planning commission or the city council, is sufficient, since these decision makers are also representatives of the community.

The committee can be given strength by its association with the city structure. If the committee were appointed by the council, the city would have more impetus for following committee recommendations. The committee should have the power to request that studies be made by the city (for example, gathering additional bikeway studies).

The several methods of selecting the citizen advisory committee include selection by the mayor, by the city council, by a planning commission, or through solicitation of volunteers. There are two concepts implicit in the formation of advisory committees: (a) The duly selected or appointed officials do not fully represent the public, and (b) a body selected for the express purpose of being representative of the public will be representative (10). Manheim argues that since the history of citizen advisory committees indicates that an appointed committee can be no more representative than the appointing body, and since the membership of the committee, to be fully representative, should be open to all citizens, then the city could forgo the committee by "simply making the effort to interact with all the interests" (10). On the other hand, the city can and should delegate responsibilities to the committee; thus a better response is obtained (12).

The frequency of meetings for the committee should be in response to the evaluations and the recommendations requested by the city. Committee members should also individually attend working meetings.

SURVEYS AND QUESTIONNAIRES

One of the best ways to evaluate community values is by questionnaire surveys of the public (13, 14, 15, 16). In a questionnaire, it is possible for the planner to obtain data on the community that would be most helpful in the bikeway planning process. However, careful planning of the questionnaire is critical for ensuring the quality of data. Leading questions can often result in misleading results (3). For example, if the question is, "Are you in favor of pleasant bikeways?" then this may result in a survey concluding that a majority of those surveyed are in favor of bikeways. Actually, the question to be useful should be asked in several questions, such as

1. Are you in favor of bikeways in your community?
2. Are you in favor of bikeways on your street?
3. How extensive should they be? Circle areas that should be connected by a bikeway system: schools parks downtown factories shopping center
4. How should a bikeway system be financed?
5. How much should the bikeway system cost?

The answers to the preceding questions would give the planner better information on the type of bikeway the community desires.

The planner may want to conduct several surveys to obtain the most helpful type of information. For example, if the planner wishes to use the ideas of the bicyclists in preliminary planning and those of the general public in the final plans, questionnaires to bicycle enthusiasts may be different from questionnaires to the general public. Since meaningful results from children are difficult to obtain because of their lack of maturity and impressionable nature, questionnaires to schools may require a different approach than those submitted to the public.

One can expect bias in the results of the questionnaire survey. These biases (16) are derived from errors by the subject (the awareness of being tested and the role selection), by the investigator (sex, age, nationality of interviewer, or interviewer's change in procedure), or by sampling imperfections (population restrictions and stability over time or area). In view of the complexity of questionnaire techniques, it is recommended (16) that the agency use professionals in that field to plan and conduct the survey(s).

The expense of the questionnaire survey may prompt the use of other types of surveys for validation of results or a less expensive method for obtaining the results. Some surveys that may be helpful in bikeway planning are bicycle counts on streets or at schools and parks, street-parked cars, off-street parking, accident records, complaints, bicycle retail sales, bicycle store maintenance volume, and presence of litter.

RANGE OF ALTERNATIVES

Citizens find it difficult to participate in activities in which they do not see a vested interest. In addition, citizen participation appears to be stronger (at least emotionally) when the citizen has something to lose. To help initiate and maintain good response from citizens, the agency should present a range of alternatives as early in the planning process as possible. Once the citizens can see their potential interest in a project, whether it be for or against, their participation will be easier to maintain. Their selection of certain alternatives over others will also give the agency more insight into the values of the community (10).

In bikeway planning, it is important to present a range of alternatives (especially those that concern routes) to the community so that all the potentially concerned citizens can see and protect their interests early in the planning stage. The following list of alternatives are presented in chronological planning order for the bikeway system:

1. Routes or corridors,
2. Origins and destinations (bike traffic generators),
3. Type of facility (route, lane, or path),
4. Intersections, and
5. Combinations that include the null set.

COST/BENEFIT ANALYSIS

Cost/benefit studies used in early transportation studies are finding limited use in the decision-making process of today's society. The problems with the cost/benefit method stem mainly from the inability to properly quantify social values and environmental effects with respect to each other and with physical costs. Typically, a cost/benefit analysis for a highway route compared the costs of construction, relocation, maintenance, and right-of-way to the benefits of time and fuel saved over time. Often, the planners recommending the route with the best cost/benefit ratio would meet substantial citizen opposition on the basis of environmental or social values, which many times resulted in a completely different alignment and, according to studies, higher cost/benefit ratios.

In the case of conflict between the goals of two or more groups, i.e., costs and benefits for one group are not the same as those for another group, the traditional method of maximizing benefits to society by the cost/benefit analysis does not fairly account for the costs. According to Berry and Steiker (17), the maximizing of the net goal for society can place unfair costs on some parties. Although bargaining between parties appears to be a logical approach to determining a fair distribution of costs, those authors doubted that the results would be fair because certain groups often hold an unfair advantage over other groups. Their only hope rested in the tradition that publicly argued and decided cases would establish generally acceptable policies.

For the planning of bikeways in which many costs and benefits are not measurable, the cost/benefit analysis is even more limited in its application. However, the analysis does provide a medium for dialogue (18), especially when comparing construction and maintenance costs of alternatives.

In addition, the city can augment its environmental and cost/benefit analysis by applying multiple-objective, multiclient concepts such as goals-achievement matrix and planning balance sheet that measure or consider all gains and losses in matrix form (19). Another method of evaluating community consequences to alternatives that may be used is value analysis. This method differs from the cost/benefit and goal-matrix methods in that it assumes that an attitude is developed during the planning process (4).

PROJECT ILLUSTRATIONS

A problem with bikeway planning is that bikeways are uncommon. To most citizens, talking about types of bikeways and intersection crossings and their impacts does not give a clear picture of the bikeway. Thus, the citizens' level of involvement or understanding of the problems is limited. Engineering drawings of the bikeway are too complicated for the average person to understand (10, 20). If the communication between agency and community on the planning of bikeways is to be assisted, then the bikeways in their various forms should be shown at least pictorially, if not on location.

Artistic renderings are commonly used to illustrate a new project for the community. However, too often the finished product does not turn out to be quite like the pretty drawing. Architects have used scale models as well as drawings to illustrate their projects. The use of models gives the viewer more perspective on the project, but the model may also be too pretty. Photographic representations of projects have recently been used to illustrate new community projects (21, 22). The California Department of Transportation uses retouched community photos to show residents what the freeway will look like in their community. Although this method exhibits less perspective than the scale models, it does give a truer representation of the project in the community.

Recently, a potentially effective method of using photographs in alternative selection has been tried experimentally by planners. The method involves comparing touched-up photographs of various project alternatives (22). This method of photocomparison has been used at large and small working meetings. The pictures are displayed from a slide projector for large meetings and from prints for small meetings. The photographic display of alternatives provides the citizens with the information necessary to formulate problems and to select from alternative solutions. Also, the citizen groups usually worked through their differences to reach a consensus and relied on each other to provide the information needed to understand the problems. One important conclusion from the experiment was that interdisciplinary teams were essential for both research and practice of urban decision making.

Other uses of photography include slide libraries—one is being collected to aid bikeway planners by the International Urban Bikeway Design Collaborative—and bikeway movies. But probably the best way to illustrate bikeways is to actually see them. Unfortunately, this can be done only if there are bikeways available for seeing. The agency could send a few citizens to a city like Davis, California, and while this method could be rather expensive, it would give a good perspective and feeling for what bikeways are actually like.

WORKING MEETINGS

Working meetings usually consist of a small group of professionals, who are involved with the planning of the project, meeting with a group of residents (10). These meetings are usually limited to from 15 to 20 participants, since larger meetings restrict the involvement of some community members. The purpose of these meetings is to provide an environment for professionals and citizens to interact.

There are several ways to conduct the meeting, and they should all be used, when appropriate, throughout the planning phases of a project. The early phases may be informational for both the citizens and the agencies. Later phases will probably take the form of planning, designing, and financing the project. For example, a meeting in the early phases may take the form of role playing or charrette whereas in the later stages a meeting may consist of dialectical scanning and alternative selection.

To avoid interpersonal conflicts, the participants should focus on the subject of the discussion rather than on personalities. Also, agency personnel should be related to the planning and designing aspect of the project rather than the decision aspects of the project. This situation is desirable from two points of view: (a) to obtain better planning and (b) to avoid confrontation and ultimatums (10).

The meetings require flexible hours for professionals, since they are often held in the evenings to accommodate the workday hours of the residents. The meetings should be held in places where it is most comfortable and convenient for residents, e.g., residents' homes (10). Youngsters should also be involved at these meetings since they account for a substantial proportion of the bicyclists. Arrangements for meetings may be conducted through local service and community organizations such as Parent Teacher's Association, Rotary Club, League of Women Voters, Sierra Club, and League of American Wheelmen.

Meetings should be recorded (i.e., taped or minutes taken), and copies of the records should be made available to the public. Follow-up meetings and action are essential to the success of these meetings. Again, the degree of citizen power is dependent on the responsiveness of the agency to the public.

Role Playing

Role playing may be used early in the planning process by everyone concerned with the project (i.e., planners and citizens). The process of advocating a different role helps people appreciate the fact that others see a given situation from a perspective different from their own because each group operates under a different set of needs and constraints (10). This technique can help create empathy and compromise between conflicting interests. An analysis of the underlying reasons for different views leads to dialectical scanning, which is discussed later.

Charette

A charette is an intensive brainstorming process that produces plans within a strict, usually short, time period (10). This activity should be open to all community and agency members. However, participants of each charette should be of similar opinions (i.e., bicycle club members and residents of a street) or the charette may result in confrontations and criticisms rather than expressions of ideas.

Unless the charette is considering rather specific plans (i.e., alternate routes), the participants' involvement is usually not deep (10). As a minimum, the preliminary bikeway system such as the corridors and destinations (modes) should be presented in the charette process.

Dialectical Scanning

Dialectical scanning is a process that allows human interaction. The objective of this process is to focus on discussion and review of particular issues in which there is conflict so that these issues may be singled out for debate. This method, discussed in a recent article by Hudson, Wachs, and Schofer (18), incorporates local impact evaluation of large-scale urban systems and seems readily applicable to small or medium-scale urban systems such as bikeways.

Dialectical scanning may involve only a blackboard and a recorder to jot down important points of the discussion. If used in the working meetings, the process first identifies critical points of disagreement and conflict and then attempts to resolve the differences by looking at the nature of the contradictions and selecting a form of analysis appropriate for each issue. Most conflicts will stem from factual misunderstandings, differences in assumptions about cause and effect relations, and differences in values (18). The process provides for a deeper analysis of the problems that arise between conflicting interests, which may not be appreciated through role playing. Dialectical scanning can be conducted in working meetings of conflicting interest groups and can help planners analyze citizen values.

Community Advocate

The city should provide the community with any requested information that is related directly or indirectly to a public project. The city's responsibility to the public includes acting as a facilitator and a coordinator-catalyst, described by Fielding (4). However, if the community desires the professional assistance of an advocate and funds can be made available, the city should provide the necessary funds to hire a community advocate. Although the city can provide professional assistance in areas such as traffic impact and public works assistance, the community may need special assistance in other areas such as social or health impacts. Also, the community may not trust the agency or may need assistance or leadership with their plans. In these situations, a community advocate should be provided through agency funds and should have full cooperation from agency resources.

Difficulty arises, however, when two or more conflicting interest groups are involved with the project. Should advocates be provided for each interest group or should a mediator attempt to resolve the differences? The advocate does not eliminate the need for community members to interact. There is still a need for working meetings.

Mediating Between Groups

It is more than likely that there will be different interest groups involved in bikeway planning. These groups with different goals may have conflicting views on the bikeway plan. The agency could act as, or hire, a mediator in these situations in which the groups are unable to reach a consensus. Although this aspect of the planning process is very important it is beyond the scope of this paper.

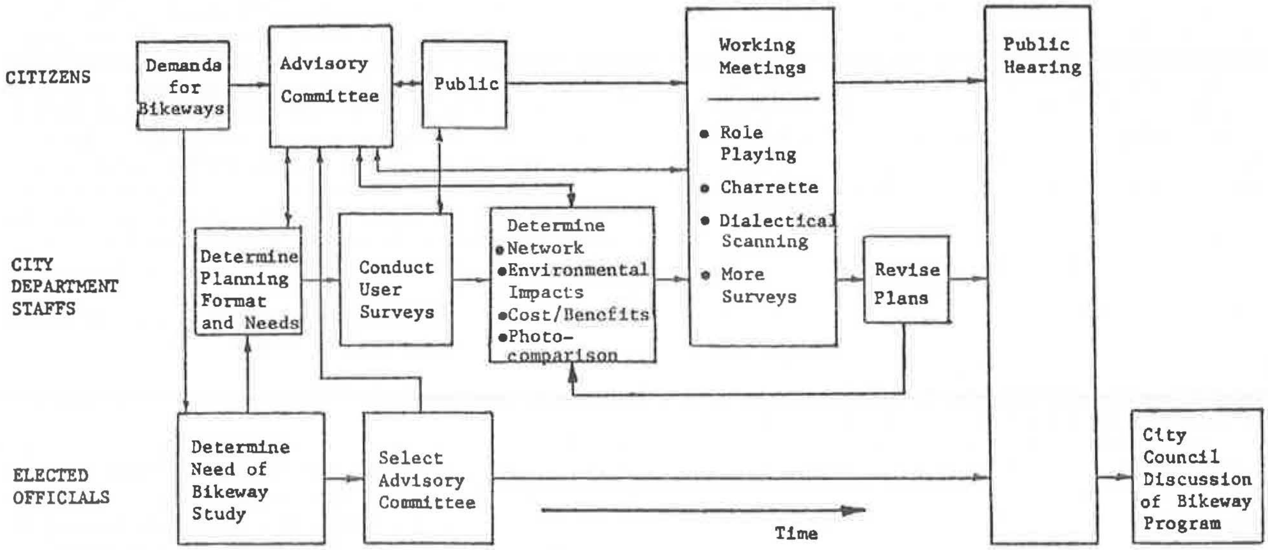
PUBLIC HEARINGS

The initial citizen participation technique employed by government and prescribed by law was the public hearing on a project. It is at such meetings that projects obtain formal rejection or approval from the planning commission or city council. Hence, all interested parties are allowed to voice their opinions on the project before a decision is made.

However, when the concerned parties are not aware of the important details of a project or surprising information is revealed at these meetings, these sessions are often turned into stages for confrontations between conflicting interests. Situations like these could be avoided by discussing the problems at the working meetings (20).

Public hearings often fail to represent those groups who are least well served (13, 15, 20, 23). Many people are intimidated by the formal proceedings while others

Figure 1. Bikeway planning program.



use them to their advantage. The agency can structure its planning process to accommodate those not well served or intimidated by formal proceedings; thus equitable participation by all parties is allowed. The results could be realized by using the public hearing for the summation of the planning process, which would lead to a formal ratification or rejection.

BIKEWAY PLANNING PROGRAM

Figure 1 shows the bikeway planning program and represents one way in which citizens can be involved in the planning process. The interaction among citizens, city staff, and city officials is shown. Citizen inputs are channeled into certain areas in which information, advice, or feedback is needed by the city.

For this example the decision to make a bikeway study is made by the elected officials in response to citizen demands. The elected officials then notify the city staff and the public, and the staff determines the planning strategy and needs. Meanwhile, the officials select a citizen advisory committee that provides advice and information to the city staff and officials.

The city, with the assistance of this committee, surveys the user population (bicyclists) of the community (i.e., bicycle clubs, registered bicycle owners, and schools) to obtain basic information such as potential demand, routes, and traffic generators. Once the results of the surveys are determined, the city designs and plans a bikeway system and alternatives to meet the demand. Cost/benefit and environmental impacts of the plans are analyzed, and illustrations of the plans are prepared.

The city then conducts working meetings with the citizens (including the committee) to introduce the plans (environmental impact reports, cost/benefit analyses, and photocomparisons) and to obtain initial reactions (through role playing and charrette). Analysis of the system alternatives by citizens is obtained through techniques such as dialectical scanning, debates, studies, requests for information, and general public surveys.

With the citizen feedback from the working meetings and the committees, the city then revises the bikeway system, possibly by narrowing the number of alternatives. New or revised analyses of environmental impacts and costs and benefits are made. The new plans are then introduced to the citizens at working meetings for feedback. This loop is continued until the city feels that it has achieved "substantial, effective agreement on a course of action that is feasible, equitable, and desirable" (10). At this time the plans are presented in a public hearing, and recommendations are taken to the city officials for a final decision.

SUMMARY

Various techniques of citizen participation are discussed for their application toward obtaining better information on environmental impacts and for the preparation of bikeway plans that are compatible with the desires of the community. Although citizen advisory committees represent the public to the city officials, public surveys can be used to give a better evaluation of the values of the community. When citizens are presented a range of alternatives that are accompanied with environmental impact and cost/benefit analyses, vested interests are realized and facts are obtained about the proposed project. Various methods of education (role-playing, charette) and interaction (dialectical scanning) are most applicable to the community's efforts in bikeway planning. This report can be used by the general public as well as the city government as a reference in future bikeway planning endeavors.

REFERENCES

1. E. S. Cahn and J. C. Cahn. Maximum Feasible Participation: A General Overview. In Citizen Participation: Effecting Community Change (E. S. Cahn and B. A. Passett, eds.), Praeger, New York, 1971, pp. 9-66.
2. F. C. Colcord, Jr. Transportation and the Political Culture. HRB, Highway Research Record 356, 1971, pp. 32-42.
3. S. R. Arnstein. A Ladder of Citizen Participation. AIP Journal, Vol. 35, No. 4, July 1969, pp. 216-224.
4. G. J. Fielding. Structuring Citizen Involvement in Freeway Planning. HRB, Highway Research Record 380, 1972, pp. 23-36.
5. J. B. Mason and C. T. Moore. Development of Guides for Community Acceptance of Highway Location, Development, and Construction. HRB, Highway Research Record 356, 1971, pp. 43-54.

6. H. Bleiker, J. H. Suhrbier, and M. L. Manheim. Community Interaction as an Integral Part of the Highway Decision-Making Process. HRB, Highway Research Record 356, 1971, pp. 12-25.
7. E. A. France. Effects of Citizen Participation in Governmental Decision Making. HRB, Highway Research Record 356, 1971, pp. 1-5.
8. H. H. Hyman. Planning With Citizens: Two Styles. AIP Journal, Vol. 35, No. 2, March 1969, pp. 105-112.
9. A. T. Reno. Interaction Procedures in the Transportation Systems Planning Process. HRB, Highway Research Record 394, 1972, pp. 1-10.
10. M. L. Manheim and others. Community Values in Highway Location and Design: A Procedural Guide. Urban Systems Laboratory, Massachusetts Institute of Technology, Rept. 71-4, Sept. 1971, pp. XIV, V1-V68.
11. J. E. Zuccotti. Planning With Neighborhoods: An Approach to Reality. City Almanac, Vol. 9, No. 4, Dec. 1974, pp. 1-11.
12. A. T. Germano and others. The Emerging Needs of Bicycle Transportation. HRB, Highway Research Record 436, 1973, pp. 8-17.
13. K. M. Travis and S. C. Plog. Community Involvement in Transportation Planning: A New Approach. HRB, Highway Research Record 380, 1972, pp. 8-13.
14. E. N. Thomas and J. L. Schofer. Strategies for the Evaluation of Alternate Transportation Plans. NCHRP, Rept. 96, 1970.
15. M. M. Webber. Alternate Styles for Citizen Participation in Transport Planning. HRB, Highway Research Record 356, 1971, pp. 6-11.
16. E. Webb and others. Unobtrusive Measures: Nonreactive Research in the Social Sciences. Rand McNally, Chicago, 1966, pp. 1-27.
17. D. Berry and G. Steiker. The Concept of Justice in Regional Planning: Justice as Fairness. AIP Journal, Vol. 40, No. 6, Nov. 1974, pp. 414-421.
18. B. M. Hudson, M. Wachs, and J. L. Schofer. Local Impact Evaluation in the Design of Large-Scale Urban Systems. AIP Journal, Vol. 40, No. 4, July 1974, pp. 255-265.
19. N. Lichfield. Evaluation Methodology of Urban and Regional Plans: A Review. Regional Studies, Vol. 4, 1970, pp. 151-165.
20. L. E. Walton, Jr., and J. R. Saroff. Proposed Strategy for Public Hearings. HRB, Highway Research Record 356, 1971, pp. 26-31.
21. K. H. Craik. The Comprehension of the Everyday Physical Environment. AIP Journal, Vol. 34, No. 1, Jan. 1968, pp. 29-37.
22. J. E. Grigsby III and B. Campbell. A New Role for Planners: Working With Community Residents in Formulating Alternative Plans for Street Patterns: Before Decision Making. Transportation, Vol. 1, No. 2, Aug. 1972, pp. 125-150.
23. R. Yukubousky. Citizen Participation in Transportation Planning: A Selected Bibliography. Planning and Research Bureau, New York State Department of Transportation, Rept. TR080820, Feb. 1973.

Publication of this paper sponsored by Committee on Bicycling and Bicycle Facilities.

Evaluating the Impact of Weather on Bicycle Use

Susan Hanson, Department of Geography and Department of Sociology, State University of New York, Buffalo
Perry Hanson, Department of Geography, State University of New York, Buffalo

Weather is one factor that is believed to have a significant impact on bicycle use as a transportation mode. This paper presents a method for exploring the sensitivity of two types of bicycle use to variable weather conditions. The results of studies such as this one can be used in conjunction with previous findings to estimate the proportion of present-day automobile travel that could be transferred to bicycle travel, if appropriate bicycle facilities are provided. The study uses travel data collected in Uppsala, Sweden, over a 39-day period in the spring of 1971. The daily proportion of bicycle travel for discretionary purposes and journey to work is compared to daily weather data. Correlation and regression analyses were used to assess the impact of weather on bicycle use. The study indicates that temperature and cloud coverage do affect the proportion of daily travel made by bicycle and that the weather variables have a different impact on each of the two types of bicycle travel. The study also examines the alternative modes used on the days when little travel is done by bicycle. The study reveals that a larger proportion of travel to work is done by bicycle than of travel for discretionary purposes regardless of weather conditions. When the temperature is below freezing, between 20 and 25 percent of all trips to work are made by bicycle.

During the past few years there has been a growing realization among transportation planners that the bicycle has a great deal of promise as a viable mode for urban transportation (1). As an inexpensive, energy-efficient, nonpolluting, quiet, healthful means of transportation, the bicycle is becoming an increasingly attractive alternative, or at least a supplement, to the automobile for substantial portions of intraurban travel. However, when the potential of the bicycle is discussed as a transportation mode, the issue of the weather is inevitably advanced as a major deterrent to using bicycles as a serious transportation alternative. The usual argument, which has been unexamined, is that people cannot or will not ride bicycles when weather conditions are too cold, too hot, too wet, or too icy, and, therefore, investments in bicycle facilities in areas where there is a susceptibility to any of these conditions are unwise, since the facilities will essentially be unused when the weather is unsuitable.

The purpose of this paper is to present a method for empirically examining the impact of daily weather conditions on the use of the bicycle as an urban transportation mode. For such an endeavor, three questions in particular need to be addressed.

1. How does the weather affect the volume of discretionary travel done by bicycles in comparison to other modes?
2. How does the weather affect modal choice on the principal form of nondiscretionary travel, the work trip?
3. What modes do bicyclists use when they do not use their bicycles?

Considerable work is required on the relation between weather conditions and bicycle use before the demand for intraurban bicycle travel can be predicted.

PREDICTING DEMAND FOR BICYCLE FACILITIES

In an earlier paper, we pointed out the need for safe bicycle facilities in urban areas, the desirability of being able to measure the latent demand for such facilities, and the difficulty in measuring the demand given the current lack of information on bicycle use in comparison to other urban transportation modes (2). Others have also noted the problems associated with predicting future levels of bicycle travel and have undertaken studies to estimate current and future levels of bicycle use (3, 4). For example, Ohrn used origin-destination data from Minneapolis-St. Paul to estimate the number of trips that could be made by bicycle. His assumption was that a certain proportion of trips under 3.2 km (2 miles), currently made by other modes, would be transferred to bicycle trips, if safe bicycle facilities were installed (3).

In a similar vein, we have attempted to investigate the potential demand for bicycle travel by first examining the existing level of bicycle use in a city without any special provisions for bicycle travel. Then, by using the empirically established parameters of bicycle use, we found the proportion of travel currently done by automobile or bus that could be transferred to bicycles, if bicycling was made safer and more convenient by a system of bikeways and safe parking places (5). To calculate the volume of bicycle travel that could result from modal switching, we assumed that no trip will be transferred from automobile or bus to bicycle, if (a) the distance to be covered is too great, (b) the traveler has to transport other people or bulky packages, or (c) the weather is too unpleasant. By using the disaggregate data set described below, we found that 96 percent of all bicycle movements were under 3 km (1.86 miles) in length and that 96 percent of all bicycle movements were made by unaccompanied persons (5). We then found the proportion of automobile and bus movements that were both under 3 km (1.86 miles) and unaccompanied, and proposed that on the basis solely of distance and accompaniment, these movements could be transferred to bicycles.

This paper represents an effort to extend our previous work by investigating the impact of weather conditions on the demand for bicycle travel in our study area. When combined with our earlier findings, the results should help to provide a fuller picture of the extent to which the bicycle could be used for travel that is currently done by other modes. However, the intent here is not to provide results that are universally applicable, but rather to illustrate a method for assessing the impact of weather conditions on the demand for bicycle travel.

WEATHER AND BICYCLE USE

Although poor weather conditions are often cited as evidence against the viability of the bicycle as a real transportation mode, there has been, to our knowledge, no empirical investigation of modal use as a function of weather conditions. Only one study (6) has explicitly considered, from a normative viewpoint, the impact of weather on bicycle ridership. Based on the assumptions that a bicycle could be ridden on any day when (a) there was no snow or ice on the roads and (b) there was not more than 12.7 mm (0.5 in) of precipitation, Hirsch (6) concluded that bicycles could be used in Philadelphia for 310 days during a year (or 85 percent of the year). The Philadelphia study represents a start towards assessing the impact of weather on the demand for bicycle travel, and similar studies could easily be carried out for other cities that have different climates and weather conditions.

But before a rash of such studies is undertaken, it would seem useful to weigh the validity of the assumptions underlying the Philadelphia study and to establish empirically the weather conditions that a majority of bicyclists find intolerable. We need to know how sensitive bicycle use is to varying weather conditions and whether there are thresholds of temperature and precipitation that dramatically affect levels of bicycle ridership. Moreover, if unsuitable weather conditions are found to reduce bicycle use, then we need to know how the other components of the transportation system are affected; that is, we need to know what modes absorb the bicyclists who abandon use of their bicycles in bad weather. An additional consideration that should be explicitly recognized by any empirical investigation is the fact that weather conditions may well affect different types of bicycle use differentially.

There are at least two kinds of bicycle travel that could be expected to be affected by day to day seasonal fluctuations in the weather. One of these concerns discretionary travel. Discretionary travel is travel undertaken at the option of the individual and is inherently flexible in terms of the timing of trips as well as the choice of destination. In general, social, shopping, recreational, and personal business trips are all forms of discretionary travel. We could anticipate that the volume of discretionary travel might be responsive to weather conditions in that bad weather might reduce the number of discretionary trips made by all modes. We might also expect the proportion of discretionary travel made by bicycle to be particularly sensitive to weather conditions; if this is the case, bad weather would bring a reduction in discretionary bicycle trips and would mean that such trips would be either not made at all, postponed, or made by other modes.

The other aspect of bicycle use that is likely to be affected by weather conditions concerns nondiscretionary travel. Nondiscretionary travel is essentially travel that lacks flexibility in timing and choice of destination; trips to work and school are the principal forms of this type of movement. Since the work trip must be made at about the same time every weekday, the volume of nondiscretionary travel should remain invariant under different weather conditions. However, we could expect modal choice on the journey to work to be related to prevailing weather conditions. Since we have documented elsewhere the importance of the bicycle for the work trip (2, 5), it would seem particularly relevant to investigate how sensitive commuter bicycle use is to varying weather conditions and what alternative modes, if any, are used when the weather is poor.

The method that is proposed here for examining the impact of weather on levels of bicycle use involves the use of a travel diary. A travel diary is used by respondents to record, for some extended period of time, the details of all out-of-home travel. This method enables the researchers to distinguish between discretionary and nondiscretionary travel and also permits a comparison of bicycle use with the use of other modes. If the travel data are to be compared, then daily weather records are also required that include information on temperature, precipitation, cloud coverage, and snow and ice accumulations. Ideally, these travel and weather data should be collected for 1-week periods at monthly intervals throughout the year. Unfortunately, no such ideal data set exists; therefore, the data that come closest to meeting the requirements set forth were gathered from the Uppsala survey in Sweden.

UPPSALA SURVEY

Carried out in the spring of 1971, the Uppsala household travel survey collected longitudinal, disaggregate travel data on the daily intraurban movements of some 300 households. Uppsala is a medium-sized city with a population of about 120 000 and is located 80 km (50 miles) northwest of Stockholm. At the time of the study, the city had no special facilities for bicycles, although about 75 percent of the households owned at least one adult bicycle and over 11 percent of all the person movements made within the city were made by bicycle (2). When only vehicular travel is considered, the bicycle accounts for 18 percent of all movements within the urbanized area.

The Uppsala study provides the best existing data source for evaluating intraurban bicycle use and comparing it to other modes. For a period of 35 consecutive days, the adult members (defined as those over 16 years of age) of the sample households recorded all movements made outside the residence. In this study, a trip was a series of movements that began and terminated at the residence; one or more locations could be visited in the course of a trip, and each interruption on the journey is referred to as a stop. For each stop on each trip, the panel members recorded the time of arrival and departure, the location of the destination, the purpose of the stop, and the mode of travel used for the trip. A detailed description of the design and methodology of the study can be found in Marble, Hanson, and Hanson (7).

In addition to the travel data, detailed weather records were kept during the study period. Readings on a number of variables that included temperature, precipitation, cloud coverage, pressure, and wind force were made daily at 7 a.m., 1 p.m., and 7 p.m. The amount of snow on the ground was recorded once a day; snow was present for only the first 6 days of the study. To ease the logistics of monitoring the 300 households in which travel diaries were being kept, the researchers divided the sample into 5 streams, each of which started keeping travel records on 5 different consecutive days. With this staggered start and staggered finish, the study extended over a 39-d period from March 29 to May 3. Since the study was conducted during this portion of the early spring, weather conditions varied considerably over the 39 days of observation. The temperatures ranged from -4°C to 18°C (25°F to 65°F). The precipitation recorded for a single day was up to 84 mm (3.2 in), and the snow coverage recorded for a given day was a maximum of 8.0 cm (3.2 in). In the following analysis, the travel data are compared to only the temperature, precipitation, and snow and cloud coverage weather variables.

IMPACT OF WEATHER ON VOLUME OF DISCRETIONARY TRAVEL

The 300 households included in the Uppsala sample represent a disproportionately stratified random sample, stratified on the basis of stage in the life cycle. The effects of weather on the volume of discretionary travel were examined by using a subset of 92 households that was representative of the population in Uppsala. Although a considerable amount of discretionary travel is undertaken in conjunction with the journey to work (8), the analysis in this section focuses on only the discretionary travel that is not associated with the work trip; in other words, discretionary stops that occur on trips in which there is a stop at the workplace are excluded. The volume of travel is measured by the number of stops per day (days 1 through 4 and 36 through 39 are appropriately weighted to correct for the fact that all sample households were not reporting on those days), and these travel data are compared to the temperature and cloud coverage data at 1 p.m. The weather conditions were noted and taken at that time because it represents the daily weather conditions. The precipitation data used throughout the analysis are the total daily precipitation.

The relations among the number of stops per day and the temperature, daily precipitation, and cloud coverage at 1 p.m. were examined to see if weather conditions had any effect on the volume of discretionary travel. The results clearly indicate that the number of discretionary stops made by all modes is insensitive to weather conditions; that is, the daily volume of discretionary travel is not related to temperature, precipitation, or cloud coverage. The correlation coefficients (r) show the lack of any significant relations among the number of discretionary stops per day and the temperature at 1 p.m. (-0.24), the daily precipitation (0.09), and the cloud coverage at 1 p.m. (0.01).

However, when the percentage of daily discretionary stops made by bicycle is examined, a significant relation (0.62) between bicycle use and temperature at 1 p.m. is evident (Figure 1). When the midday temperature rises, a larger proportion of daily discretionary travel is done by bicycle. The relation appears to be linear, and there are no threshold temperatures evident for bicycle use within the range of temperatures that prevailed during the study period. As shown in Figure 1, there is very little discretionary travel done by bicycle when the temperature is below 1° C (34° F).

In contrast to the relatively strong impact of temperature on bicycle ridership for nonwork travel, cloud coverage and precipitation were found to have no significant effect on the proportion of discretionary stops made by bicycle. A weak relation was found between the percentage of discretionary stops by bicycle and cloud coverage (-0.14). Unfortunately, there were only 7 days during the study when more than a trace of precipitation was recorded. Therefore, these results must be taken as entirely preliminary, but the correlation analysis shows only a weak relation between the percentage of discretionary stops made by bicycle and precipitation (-0.11). Since there were only 6 days with snow coverage, the effect of snow on the ground was also difficult to assess. However, on the days when there was snow on the ground, less than 5 percent of discretionary travel was done by bicycle. The conclusion must be that, within the range of early spring weather conditions observed, only temperature has a visible impact on the use of the bicycle for discretionary travel. Firmer conclusions must rest on data gathered at appropriate intervals throughout the year rather than on only one season.

Since we know that discretionary trip making as a whole is not affected by temperature, we must next ask what alternative means of travel are used when low temperatures bring reduced levels of bicycle use. This question is addressed by examining the relation between the daily proportion of bicycle travel and the daily proportion of travel by other modes. The results indicate that no single mode is exclusively used by bicyclists when bad weather prevails. As the daily proportion of discretionary travel by bicycle riders decreases, the daily proportions of discretionary travel by bus rider, automobile driver, and automobile passenger all increase, as one would expect. The relations, although they are all significant, are not extraordinarily strong but are of approximately the same magnitude. The correlation coefficients are -0.27 for the relation between the percentage of discretionary stops for bicycle rider and bus rider, -0.23 for bicycle rider and automobile driver, and -0.33 for rider and automobile passenger. Evidently, in the city under study, the bicyclists use all three modes as a substitute for the bicycle.

IMPACT OF WEATHER ON MODAL CHOICE FOR JOURNEY TO WORK

Unlike discretionary travel that can be postponed or simply not undertaken, the journey to work must be made daily by those who work on a regular basis. Furthermore, there is generally little flexibility in the timing of the journey to and from work. As a result, if inclement weather greets the prospective morning commuter, the only travel decision he or she is really free to make (aside from the route to be taken) is the mode of travel to be used. We have established elsewhere (5) the importance of the bicycle in Uppsala as a transportation mode to work; over half (53.2 percent) of all bicycle stops were made at the workplace, and 20 percent of all stops at the workplace were made by bicycle. But how sensitive to weather conditions is the use of the bicycle for this purpose?

This question was answered by examining the travel records of all full-time employed persons in the original sample and by examining their modal choice for journey to work in light of the weather data. Only work trips made on regular weekdays were included (weekends and holidays were excluded), and only the first daily arrival at the workplace was considered. This data base was used to compute the percentage of stops made by each mode for each of 27 d and to compare the weather data taken at 7 a.m. and 7 p.m. Generally speaking, if a person is going to decide to ride a bicycle to work, the decision will be made in the early morning and will be based on the observable morning weather conditions as well as the reported weather prognosis for the rest of the day. Since we did not have the daily morning weather forecasts, we used the actual weather data taken at 7 p.m. as the best available surrogate for the expected early evening weather conditions.

As expected, the correlation coefficient for the number of stops at the workplace is totally unrelated to either the temperature at 7 a.m. (-0.001) or the cloud coverage at 7 a.m. (-0.06). The use of the bicycle for the work trip, however, is sensitive to both of these weather variables. The percentage of daily journeys to work by bicycle increases as a function of increasing temperature at 7 a.m. (0.45) and decreases as a function of greater morning cloud coverage (-0.42). The relation, shown in Figure 2, between commuter bicycle use and early morning temperature is interesting to compare with the relation portrayed in Figure 1 between discretionary bicycle use and midday temperature. The most striking difference is that there is a markedly higher average daily proportion of bicycle travel for the journey to work than for discretionary travel. On the average, only 4.3 percent of daily discretionary travel is done by bicycle, while the average daily percentage of work journeys made by bicycle is 26.7! Also, a visual comparison of the regression lines in Figures 1 and 2 shows a steeper slope in Figure 1, which indicates that the percentage of discretionary travel made by bicycle increases more rapidly as a function of rising temperatures than that of travel to work. Thus, bicycle use for the journey to work is less sensitive to temperature than bicycle use for nonwork purposes is. It is also evident from Figure 2 that even when the temperature hovers around the freezing point, a substantial portion (between 20 and 25 percent) of all travel to work is made by bicycle. Furthermore, commuter bicycle use is affected little by snow on the ground; on those 5 workdays when there was snow, the bicycle accounted for between 16 and 29 percent of the daily work trips.

The fact that the proportion of daily commuter travel by bicycle is related to cloud coverage at 7 a.m. is another departure from the findings described earlier that concern the impact of weather on discretionary travel by bicycle. Although bicycle use for nonwork travel was found to be unrelated to cloud coverage, a moderately strong inverse relation exists between bicycle use for journey to work and early morning cloud coverage. A possible explanation lies in the fact, previously mentioned, that, although the work-trip modal-choice decision is made in the early morning, estimates of early evening weather conditions are also taken into consideration, and the heavier the morning clouds, the greater the estimated probability of poor weather later in the day. Since discretionary trips are usually of a much shorter duration than work trips, the prospective traveler has only to make relatively short-term weather predictions. Thus, people are willing to embark on a discretionary bicycle trip in cloudy weather when it seems apparent that no marked weather change will occur within the estimated time span of the trip. But selecting a mode for the work trip involves longer range amateur weather forecasting, and therefore people are reluctant to ride a bicycle to work when morning clouds seem to portend afternoon or evening rain. In fact, the appearance of clouds seldom actually produced precipitation.

Since rain was recorded for only a few nonholiday weekdays (only three) during the study period, the impact of precipitation on commuter bicycle use unfortunately cannot be evaluated. However, the argument that estimated evening weather conditions play a role in the morning modal-choice process is supported by the correlations found between the percentage of daily work trips by bicycle and the temperature at 7 p.m. (0.48) and the cloud coverage at 7 p.m. (-0.32). These relations could be expected, at least in part, on the basis of the positive correlations between morning and evening temperature and morning and evening cloud coverage. Table 1 gives a summary of these relations. But, the fact that commuter bicycle use is more strongly related to morning cloud coverage than to evening cloud coverage seems to indicate that the decision to ride a bicycle to work is dependent on the individual's (often erroneous) appraisal of daily weather and its development.

Since bicycle use for the journey to work does vary considerably from day to day (Figure 2), even though the number of work trips remains relatively stable over time, the question arises concerning what other modes are used on the days when the proportion of commuter trips made by bicycle is low. As was done for discretionary travel, the daily proportion of work trips made by each mode was calculated and compared to the percentage of daily work trips made by bicycle. The results indicate that the strongest inverse relation exists between the percentage of daily commuter travel by bicycle and the percentage of commuter travel by bus (-0.52). However, significant correlations were also found between bicycle use and the other modes: automobile passenger (-0.36), walking (-0.36), and automobile driver (-0.25). Thus, again, a variety of alternatives is used by bicyclists when bicycles are not used, but the results indicate that a reduction in bicycle use is more strongly re-

Figure 1. Bicycle use for discretionary travel as a function of midday temperature.

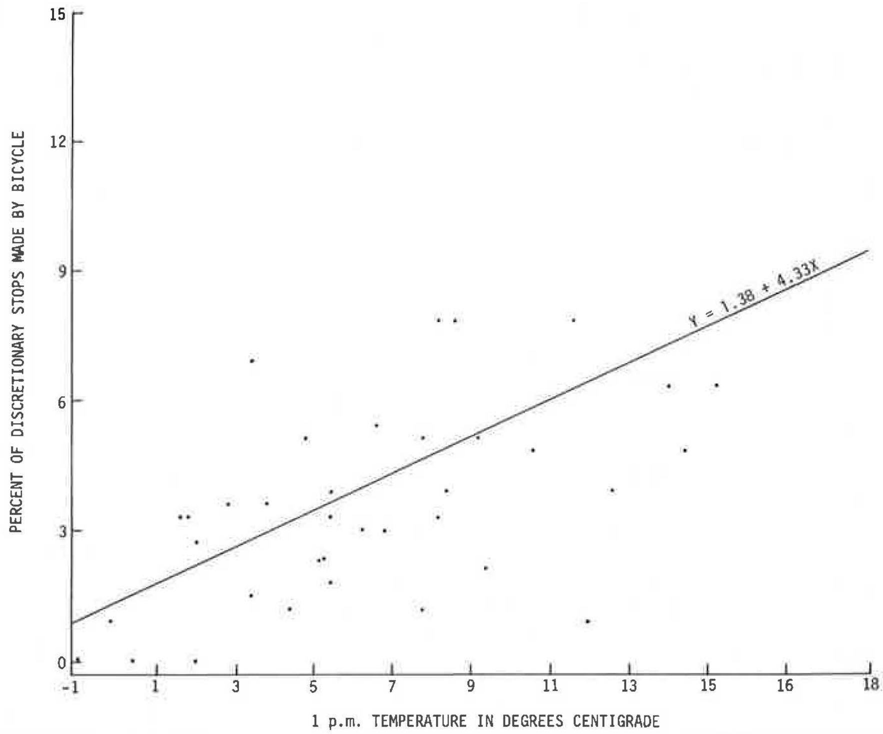


Figure 2. Bicycle use for journey to work as a function of early morning temperature.

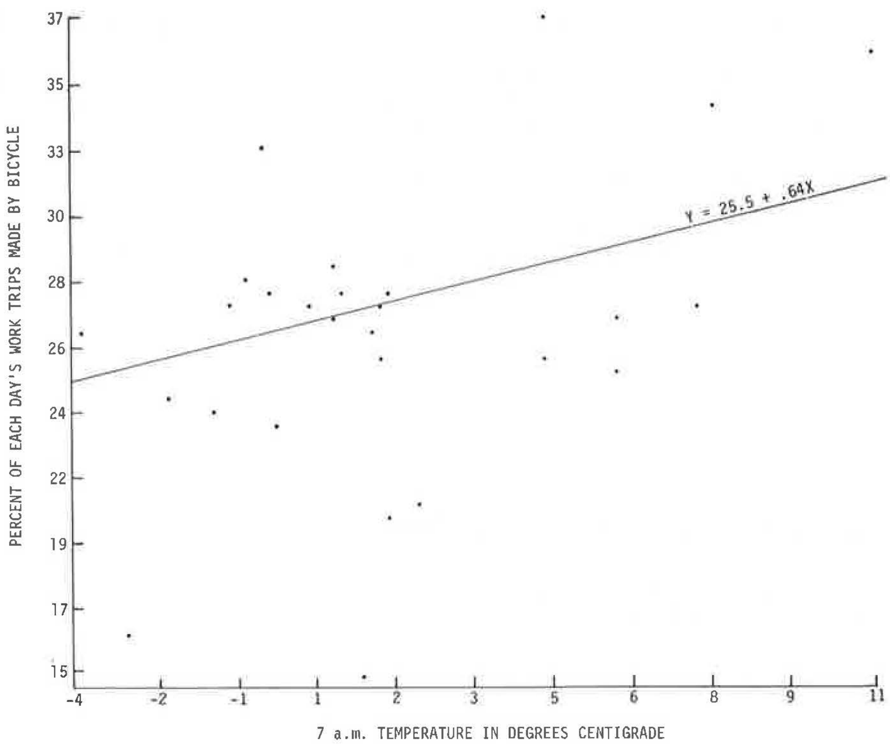


Table 1. Correlation coefficients for selected weather variables and bicycle use on the journey to work, March 29 to May 3, 1971.

Item	Temperature		Cloud Coverage		Percentage of Daily Work Trips by Bicycle
	7 a.m.	7 p.m.	7 a.m.	7 p.m.	
Temperature					
7 a.m.	1.00	—	—	—	—
7 p.m.	0.78	1.00	—	—	—
Cloud coverage					
7.a.m.	0.01	-0.12	1.00	—	—
7 p.m.	0.06	0.13	0.45	1.00	—
Percentage of daily work trips by bicycle	0.45	0.48	-0.42	-0.32	1.00

lated to an increase in the bus, walking, and automobile passenger modes than to an increase in the automobile driver mode. While it is unlikely that this is due to the individual's lack of access to an automobile (5), it may reflect the person's desire or need to leave the automobile at home for use by another household member.

CONCLUSIONS

The results of this study indicate that further empirical investigations of this nature should prove fruitful. If appropriate data were available for time periods throughout the year, we could gain considerable insight into the way in which daily weather conditions impact the demand for bicycle travel. Although the data on which this exploratory study was based were limited, they did afford a glimpse of the kinds of processes that can and should be uncovered, if we are to understand the relation between weather and bicycle use.

The expectation at the outset was that weather conditions would have some impact on the use of the bicycle as an urban transportation mode. Although the dearth of rainy days during the study period precluded any meaningful insight into the impact of precipitation on bicycle use, this paper has shown that both temperature and cloud coverage are related to the proportion of daily travel done by bicycle in the study area. Perhaps more important is the finding that weather affects bicycle ridership differentially in accordance with the type of travel in question; discretionary travel by bicycle is more sensitive to temperature changes and less sensitive to cloud coverage than bicycle use for the journey to work is. This paper has also shown that several different modes of transportation are used as alternatives to the bicycle on days when bicycle ridership is low. Finally, although bicycle use does decline with falling temperatures, a substantial portion of travel to work is done by bicycle even when temperatures are below freezing. It is apparent that for the work trip, in particular, people can and will use bicycle facilities (if they are provided) under variable weather conditions. It appears that attitudes constitute a more formidable deterrent to bicycle use than the weather does.

ACKNOWLEDGMENTS

This work was supported in part by a grant from the National Science Foundation. Special thanks are given to Rebecca Somers for drafting the figures.

REFERENCES

1. The Bicycle as a Transportation Mode. TRB, Transportation Research Record 570, 1976, pp. 1-45.
2. S. Hanson and P. Hanson. Problems in Integrating Bicycle Travel Into the Urban Transportation Planning Process. TRB, Transportation Research Record 570, 1976, pp. 24-30.
3. C. E. Ohrn. Predicting the Type and Volume of Purposeful Bicycle Trips. TRB, Transportation Research Record 570, 1976, pp. 14-18.
4. Long Range Bikeway Program. Madison Department of Transportation, Wisconsin, 1975.
5. S. Hanson and P. Hanson. Planning for Bicycles in Urban Transportation. Proc., Intersociety Conference and Exposition on Transportation, Institute of Electronic and Electrical Engineers, New York, 1976.
6. R. B. Hirsch. Facilities and Services Needed to Support Bicycle Commuting Into Center City Philadelphia. Philadelphia Bicycle Coalition Rept., 1973; U.S. Environmental Protection Agency.
7. D. Marble, P. Hanson, and S. Hanson. The Uppsala Household Travel Study: Design and Methodology. Geografiska Annaler, Series B, in preparation.
8. S. Hanson. The Structure of the Work-Trip in Intra-Urban Travel Behavior. Paper presented at the North Atlantic Treaty Organization Conference on Transportation and Urban Life, Munich, Oct. 1975.

Publication of this paper sponsored by Committee on Bicycling and Bicycle Facilities.

Abridgment

Development of a Bicycle Accident Rate in Arizona

Richard G. Perreault, Judson S. Matthias, and Mary R. Anderson, Arizona State University

The climate in Arizona allows bicycling to be a year-round activity in the most populous areas of the state. The number of accidents in the state has increased from 383 in 1967 to 1124 in 1975. More than 90 percent of these accidents occurred in urban areas. In the last few years, the growing concern and previous lack of planning have motivated state and local authorities to conduct extensive surveys and to finance research for recommendations and solutions to this problem. Data are now categorically collected and stored at state and local levels for analyzing the location, probable cause, time of day, and conditions at the time of the accident. Extensive surveys have yielded data such as predicted ownership, location, and usage of bicycles. Projected bicycle usage and projected accidents indicate that solutions to the growing accident problem must be found.

STATEMENT OF PROBLEM

Statistics frequently used to measure effectiveness are the number of accidents or injuries occurring in a defined area during a specified time. These statistics are compared with previous results or with results from other areas. This method does not account for changes in usage nor trends that may have influenced the results. A rate relating bicycle usage with the number of accidents occurring during a specified time span or for a specified area would be a more meaningful statistic.

SCOPE OF STUDY

This study encompasses only reported accidents that involve bicycles and motor vehicles in Arizona. The availability of data limits the rate analysis to the period of January 1973 through December 1975 (1).

Although the bicycle accident problem is increasing each year, no literature equating accidents as a function of usage is found. Statistical reports present the increase of bicycle accidents as a percentage of accidents in previous years, and the majority of other consulted literature pertains to the design and implementation of bikeway systems. Most statistical accident reports present data on the number of injuries and deaths attributed to bicycle accidents. One report (2) did attempt to develop a relation between bicycle accident deaths and the number of pedal-cycles in use. However, this rate does not equate the accidents with usage.

STUDY AREA

Approximately 70 percent of the population in Arizona live in urban areas where populations exceed 10 000 people, and over 90 percent of all bicycle accidents occur in these urban areas. The state was divided into two major categories. Cities with a population exceeding 10 000 were classified as urban, and all other areas and communities were classified as rural. Accident summaries for 1973 to 1975 for the state, urban and rural areas, and major cities of interest are given in Table 1.

DEVELOPMENT OF BICYCLE USAGE

In November 1972, the Behavior Research Center of Phoenix conducted a survey of 1041 randomly selected households throughout Arizona. The results of this survey were used by Bivens and Associates (3) to help determine bicycle usage in the state. Some of the findings of this survey are given below.

Round Trips per Week	Percent State	Urban	Rural
1 to 2	30	30	26
3 to 4	16	16	22
5	21	24	8
6 to 9	18	17	22
>10	15	13	22
Total	100	100	100

Item	State	Urban	Rural
Percent			
Households owning bicycles	51	54	42
Bicycle owners riding bicycles	90	91	87
Average number of bicycles in households owning bicycles	2.13	2.20	1.90

We used the above percentage of round-trip data to develop a trip generation formula per rider. The percentage of riders is multiplied by the average number of trips per week to find the number of trips per week the average rider takes. For instance, the average rider in the state takes 4.91 round trips per week as follows:

$$\text{number of trips per week per rider} = [0.3(1.5) + 0.16(3.5) + 0.21(5) + 0.18(7.5) + 0.15(10)] = 4.91 \quad (1)$$

The definition of a trip used in this report is a one-way trip; therefore, the average state rider makes 9.8 trips/week or 510.6 trips/year. Similarly, the average urban bicycle rider makes 9.6 trips/week or 497.6 trips/year.

Bicycle Accident Rate

The objective of this study is to develop a relation between the number of bicycle accidents that occur in a defined area for a specific time period and the bicycle usage for that time period. Calculating this rate for the same area for different time periods produced a standard or measure from which trends can be developed. These rates can also be used to compare trends in other areas. The units for the bicycle accident rate (BAR) used in this study are the number of accidents that occur per 1 000 000 bicycle trips.

From the 1970 census data, there were an average of 3.208 persons/household in Arizona. For this study, the assumption is made that the household size remains constant. From this assumption and the population figure, the number of trips per year in the state and in the urban and rural areas can be readily calculated by using the bicycle-ownership information. The bicycle usage summary for 1975 is given as follows:

Item	State	Urban	Rural
Population	2 224 000	1 522 708	701 292
Households	693 267	474 660	218 607
Riders	677 786	513 145	164 641
Trips per year	346 104 643	255 361 478	120 743 165

From the above information, it is possible to develop rates for the number of injuries and fatalities that occur each year.

BAR and Accident Projections

To accurately develop the regression equations for the state and the city of Tempe, we used accident data and population estimates for 1970 through 1975 to calculate the BARs for each year as shown in Table 2.

We used these BARs to derive the following regression equations for Arizona and for Tempe respectively.

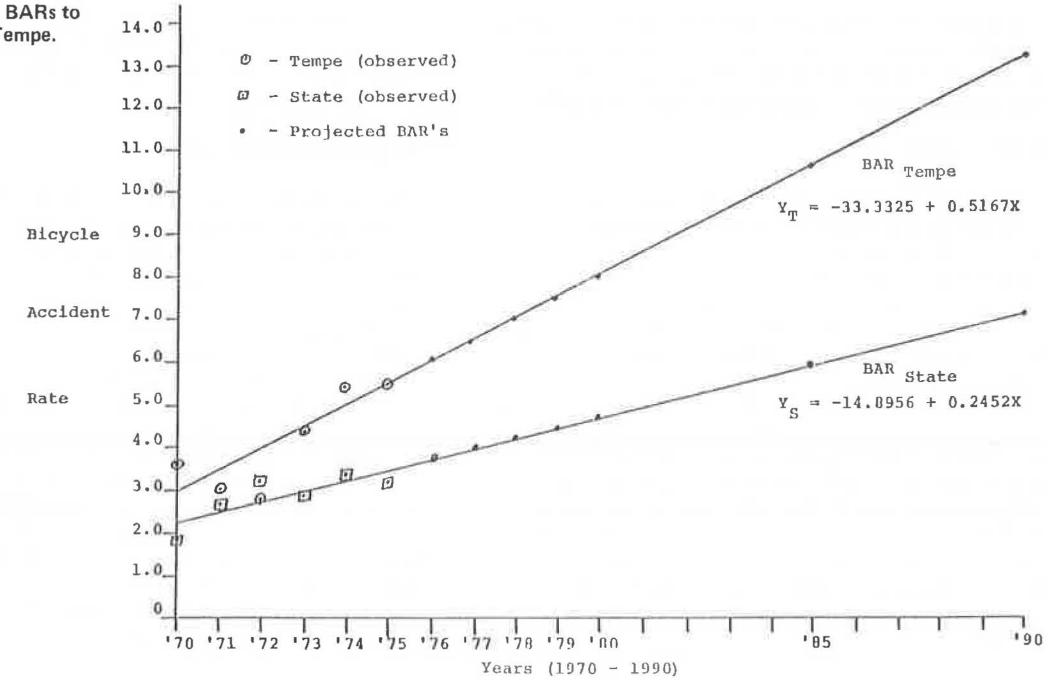
Table 1. Summary of bicycle accidents and BARs in Arizona.

	Number of Accidents			Bicycle Accident Rate		
Location	1973	1974	1975	1973	1974	1975
Arizona	942	1130	1124	2.9201	3.3616	3.2476
Urban	864	1045	1053	3.6219	4.2087	4.1236
Rural	78	85	71	0.9279	0.9676	0.5880
Phoenix	410	441	453	3.8159	3.9854	4.0435
Tucson	155	198	160	3.1660	4.0198	3.2166
Tempe	59	79	86	4.3553	5.3901	5.5184

Table 2. BARs for Arizona and Tempe from 1970 through 1975 and projected for 1980 and 1990.

	Number of Accidents		Bicycle Accident Rate	
Year	Arizona	Tempe	Arizona	Tempe
1970	524	38	1.8965	3.6021
1971	773	35	2.6576	3.0674
1972	979	35	3.2047	2.8216
1973	942	59	2.9201	4.3550
1974	1130	79	3.3616	5.3901
1975	1124	86	3.2476	5.5184
1980	1943	151	4.7204	8.0035
1990	3773	324	7.1724	13.1705

Figure 1. Projection of BARs to 1990 for Arizona and Tempe.



$$Y_S = -14.8956 + 0.2452X \quad (2)$$

$$Y_T = -33.3325 + 0.5167X \quad (3)$$

where Y_s and Y_T are the predicted BARs for Arizona and Tempe respectively, and X is the year of the predicted BAR. Table 2 also gives the predicted BARs and the number of accidents to be expected for 1980 and 1990 if bicycling conditions remain constant and if future population estimates are realized. The projection of Arizona and Tempe BARs is shown in Figure 1.

ANALYSIS AND APPLICATION OF BARs

As given in Table 1, the majority of bicycle accidents occur in urban areas, and the number of accidents is increasing yearly. Phoenix and Tucson appear to be the least safe cities for riding bicycles. In the last 3 years, 44 percent of the urban accidents occurred in Phoenix and Tucson; however, 65 percent of the urban population is located in these two cities. The BARs for Phoenix and Tucson are actually lower than the urban BARs for 1974 and 1975. By using the BARs, it is possible to develop trends and determine where the problem is increasing.

The importance of the BAR is not in the quantitative value calculated but rather in the trends that the BAR exemplifies. The techniques presented in this study can also be used to categorically calculate rates for bicycle accidents by age of rider, by time of day, and by the number of injuries or fatalities resulting from the accidents.

In large metropolitan areas such as Phoenix and Tucson, it may be desirable to further delineate the city into sectors and to study trends that occur within the city. By using this procedure, it is possible to determine which areas need emphasis and to recommend to the city management where projects and programs are needed. In this manner, the priority of efforts can be determined. At the state or regional level, this procedure can also be used to develop trends and measure the effectiveness of ongoing programs.

Administrators can use the BARs and statistical analyses as supportive information when requesting funds for improvement programs. The BAR is a statistical tool, and the use of it can be tailored to the needs of the state or community.

CONCLUSIONS AND RECOMMENDATIONS

The BAR is a better measure for developing trends than the present use of percentages. It has been shown in this study that the cities experiencing the majority of accidents are not necessarily in those areas where the bicycle accident problem is increasing.

1. The BAR is representative of the relation between the number of bicycle accidents and bicycle usage.
2. The bicycle accident problem is increasing in urban areas and decreasing in rural areas.
3. Metropolitan urban areas collectively have more of a bicycle accident problem than the separate urban areas.
4. If current trends continue and conditions remain constant, bicycle accidents will triple in the state of Arizona and quadruple in Tempe by 1990.
5. Better bicycle safety programs are needed.
6. Further study and research of the bicycle accident rate are warranted.

Bicycle accident data have become more standardized and available; however, little effort has been made to accurately determine bicycle usage. Currently, there is no method for accurately determining bicycle ownership. One method to help determine usage would be mandatory registration of bicycles.

The validity of future projections can be increased by using a larger sample or by expanding the number of years used to make the projection. Further collection of data will yield a larger sample from which the projections can be made. It is recommended that future studies consider individual cities that have an increase in or higher than average bicycle accident rates.

REFERENCES

1. Traffic Accident Listing: Pedalcyclist Accidents

From January 1, 1973, Through December 31, 1975. Arizona Department of Transportation, Phoenix, Computer printout from Safety Project Services, Jan. 27, 1976.
2. Robbins, E. O., II. A Study of Cyclist Behavior and Characteristics on the College Avenue Bikeway. Arizona State Univ., Engineering Rept., Dec. 1974.
3. Final Review Draft of the Arizona Bicycle and Foot Path Study. Bivens and Associates, Inc., Phoenix, Feb. 15, 1973.

Publication of this paper sponsored by Committee on Bicycling and Bicycle Facilities.

Effect of Bicycle Lane Usage on Vehicles in the Adjacent Lane

Stephen B. Loop, Idaho Transportation Department, Boise
Robert D. Layton, Department of Civil Engineering, Oregon State University

This paper presents an approach for investigating the effect of bicycles in a bicycle lane on the characteristics of the traffic stream in the adjacent lane. Previous work related to this subject is reviewed, and a possible model to analyze the impact of bicycles on level of service is proposed. The model uses the difference in vehicle speed with and without the presence of bicycles. The application of this model to capacity analysis is discussed, and a program of expansion and testing is recommended. The method of data collection employed is presented. A limited data set from a field study is analyzed, and the results are tested for statistical significance. The results of this analysis indicate that there is a measurable reduction in speeds with bicycles present and reinforce the need for further study.

Bicycle sales in the United States more than doubled between 1968 and 1973. In the same period, automobile sales increased approximately 14 percent. In 1973, bicycle sales totaled 15.3 million while automobile sales were only 11.4 million. The Bicycle Institute of America reports that in 1969 only 15 percent of all bicycle riders were adults. However, one year later, adult bicycle ridership doubled to 30 percent. It is estimated that there is one bicycle for every two people in the United States (1).

Numerous surveys have indicated that a latent demand for bicycle commuting exists that is not realized because of the lack of adequate facilities (2). One survey (3) indicates that the majority of those persons who use on-street bicycle lanes are commuters, but the survey included only cities in which there were universities.

Increased use of bicycles is frequently advocated as a strategy to limit the increase in motor vehicle traffic. If one assumes that there is an increase in the number of bicyclists who use the streets, then the reduction in vehicle trips represented must be compared to the decrease in roadway vehicle capacity that is caused by the presence of bicycles. The primary situations that affect capacity include bicyclists riding in the traffic stream and bicyclists riding in adjacent striped bicycle lanes. In the first situation, the bicycle affects the traffic stream characteristics in a manner similar to the presence of trucks, buses, and turning vehicles. The effect on roadway capacity in the second situation results from both the effects of traffic stream characteristics and a reduction in the physical dimensions of the facility.

There has not been sufficient study devoted to this topic. Currently, it is difficult to provide more than a qualitative assessment of the impact that the large increase in bicycle use has had on roadway vehicle capacity. There are no quantitative adjustment factors that can be applied to a capacity relation to account for the presence of bicycles.

PURPOSE AND SCOPE OF STUDY

The purpose of this paper is to provide insight into the effect that the presence of bicycles in bicycle lanes has on the level of service on urban streets. The characteristics studied include the effect of street width, the interaction of vehicle and bicycle volumes, and the influence of weather. The reduction in approach width that results from the presence of a striped bicycle lane is taken into account by using accepted capacity analysis techniques. The problem of right-turning vehicles that cross through a bicycle lane and left-turning bicyclists who cross through the lanes is not dealt with in this study.

The data and discussion presented here are intended to describe a possible methodology of capacity analysis that would account for the presence of bicycles in bicycle lanes. Data were collected along bicycle lanes in Eugene, Oregon, under conditions with and without bicycles. The results are compared with data from a previous study in West Lafayette, Indiana. Inferences are made from the data collected, and possible applications to capacity analysis are explored. These inferences and applications are only preliminary in nature and are intended to stimulate further study that is more comprehensive in nature.

REVIEW OF PREVIOUS WORK

A literature search was conducted to determine the nature and extent of previous research in this area. The results of that search are included in an unpublished annotated bibliography (4). The articles on the location of bikeways primarily discuss the characteristics of streets that are compatible with bicycle lanes or the problems of locating streets where bicycle lanes would be most used. The articles dealing with operations are primarily concerned with the means for preventing automobiles from intruding into bicycle lanes and for dealing with the signing and traffic control problems within bicycle lanes.

Two articles were found that touched on this subject. The first by Smith (5) discussed the reduction in capacity on a street because of lane width reduction that results from a bicycle lane. The effects of bicycle lane usage on traffic flow in the adjacent lane were studied by Jilla at Purdue University (6). The two variables chosen as indicators were the difference in mean speed and the difference in lateral displacement of vehicles in the adjacent lane, which results from the presence of bicycles. The data presented represent a good source for comparison purposes, and basic concepts were used to design this study.

PROPOSED MODEL

The level of service provided by a facility is described in part by the speed of operation and the volume present. It is suggested that the difference in mean speed that results from the presence of bicycles would be a legitimate indicator of the change in level of service. For purposes of the proposed model, the relation between speed and volume is expressed in terms of density of flow as follows:

$$\text{Density} = (\text{vehicles/kilometer}) = [\text{volume(vehicles/hour)}] \div [\text{speed(kilometers/hour)}] \quad (1)$$

The density of vehicles measures the freedom that vehicles have to maneuver. Because of the requirement of greater headways at higher operating speeds, the relation between speed and volume at a given level of service is not linear. This relation is shown in Figure 1. However, for the small range of speeds and at the lower speeds considered in this model, the error is negligible.

Assuming that the volume of traffic that desires to pass through a given route remains constant, the change in density could be calculated as follows:

$$\text{Change in density} = \Delta(\text{vehicles/kilometer}) = [Q(Sp_A - Sp_B)] \div [(Sp_A)(Sp_B)] \quad (2)$$

where

Q = flow rate (vehicles per hour),
Sp_A = mean vehicle speed without bicycles present, and
Sp_B = mean vehicle speed with bicycles present.

Conversely, the reduction in volume necessary to maintain a constant density and thereby level of service could be found by using the following:

$$\text{Reduction in volume} = \Delta(\text{vehicles/hour}) = Q_A\,[(Sp_B/Sp_A) - 1] \quad (3)$$

where Q_A = flow rate (vehicles per hour) without bicycles present.

The volume of vehicles present is expected to influence the amount of speed reduction that is caused by the presence of bicycles. As the volume of vehicles increases, the relative ease of a motorist to respond to an external factor (the bicyclist) is reduced. Therefore, the expected differences in mean speed should be related to the volume of vehicles present. Also, since the change in speed is a result of the interaction between vehicles and bicycles, the total volume of vehicles present must be known. And, since the change in speed is a result of the interaction between vehicles and bicycles, the total volume of both bicycles and vehicles, during the study period, must be known to reflect the number of interactions. Other factors that must be included in the data set for capacity analysis are the weather conditions, the width of the bicycle lane, and the character and width of the street.

The reduction in speed that results from the presence of bicycles reflects the impact on the level of service and may ultimately permit estimation of the reduction in capacity (or service volume) for the uninterrupted traffic flow that is created by bicycle lanes. As shown in this study and previous research, the bicycle in a bicycle lane may reduce vehicle speed significantly. As the volume of bicycles and vehicles increases, more interaction between bicycles and vehicles occurs. The reduction in vehicle speed may be a function of the normal speed of operation and the frequency of these interactions, i.e., the bicycle-vehicle interactions per kilometer in 1 h. The frequency of bicycle-vehicle interactions is given as follows:

$$\text{Frequency of interactions} = \text{vehicle}^2(\text{kilometers/hour}) = [(Q_V)(Q_B)/(S_V)(S_B)]\,[(S_V - S_B)] \quad (4)$$

where

Q_V = vehicular volume (vehicles per hour),
Q_B = bicycle volume (bicycles per hour),
S_V = traffic stream speed (kilometers per hour), and
S_B = bicycle mean speed (kilometers per hour).

Since the data base is limited, it is difficult to quantify the impact on street capacity. The presence of bicycles in a separate parallel lane may reduce the traffic stream speeds up to about 10 percent on streets where the average speed is about 48 km/h (30 mph). The greatest speed reduction occurs when traffic volumes are low, and, consequently, speeds are high. Unless bicycle volumes are also high, the driver can accelerate to the normal speed of operation after passing the bicycle, which only temporarily reduces the level of service.

For higher traffic volumes, normal operating speeds are lower, and the reduction in speed that is created by the presence of bicycles is small. At high traffic volumes (1000 to 1700 vehicles/h/lane), any reduction in the speed of a vehicle would influence the vehicles behind it and consequently the level of service. In this and other research (6), speed reductions of the magnitude found at higher traffic volumes of 1.5 to 3 km/h (1 to 2 mph) would be expected to alter the service volume level very little.

The relative importance of street width reduction on capacity, in relation to the effect of the level of usage of the bicycle lane that would cause the reduction, depends on the character of the street. For example, on High Street in Eugene, Oregon, as given by the Highway Capacity Manual, the reduction in capacity because of a narrower street width is about 20 percent. The reduction in street width should not be considered alone; the number of lanes and the lane widths should also be considered in capacity analysis, as suggested by Smith (5). In this example, lane widths of 3.51 m (11.5 ft) are provided for cases in which 1.52 m (5 ft) of the street is used as a bicycle lane. Although the original lane widths were 4.27 m (14 ft), lane widths that are greater than 3.66 m (12 ft) would contribute very little to an increase in capacity. Therefore, a capacity reduction of 20 percent for lanes that are 0.15 m (0.05 ft) narrower than 3.66 m (12 ft) appears unreasonably large (Figure 2).

The effect of street width in reducing capacity is more pronounced and well-defined on streets where a reduction in the number of lanes accompanies the reduction in street width. For example, an 11.58-m (38-ft), three-lane, one-way street with a 2.44-m (8-ft) parking lane would be reduced to a 7.62-m (25-ft) width for traffic movement, if a 1.52-m (5-ft) bicycle lane were added. Thus, this addition of a bicycle lane would permit only two 3.81-m

(12.5-ft) vehicle traffic lanes. The reduction in capacity based on analysis by using the Highway Capacity Manual would be about 20 percent. With a reduction in the number of lanes, the reduction in capacity is probably greater than 20 percent. Even though the lanes are increased from 3.05 m (10 ft) to 3.81 m (12.5 ft), the loss of a lane would seem to be of greater influence than the difference in lane width. However, if the parking lane were replaced by a 1.52-m (5-ft) bicycle lane, a 10 percent increase in capacity would be realized, based on the additional 0.91 m (3 ft) of width for vehicles; the effect of the presence of bicycles is ignored.

Relations that describe the effects of the level of usage of an adjacent bicycle lane on the capacity of arterial streets and highways are shown in Figure 3. This discussion is for uninterrupted traffic flow conditions and moderate speeds of about 72 km/h (45 mph). For the conditions represented by region A, the service volume of the adjacent traffic lane is not affected by the presence of the bicycle lane. The volume of vehicles and the volume of bicycles are both low. The speed of a vehicle would be significantly reduced by the presence of a bicycle, but there would be few bicycle-vehicle interactions with the small number of bicycles and vehicles present. Consequently, the driver could accelerate to the normal operating speed, after passing the bicyclist, with little or no effect on the other vehicles in the traffic stream.

The service volume in region B with low-vehicle volumes and high-bicycle volumes may be reduced a little because the normal operating speeds would be reduced by the presence of bicycles. The quantity of bicycles present, an average of one bicycle for every 120 to 150 m (400 to 500 ft) for a bicycle volume of 200 bicycles/h, would not permit recovery to the normal higher speeds of operation. The density of the traffic stream would be unchanged, and, consequently, there would be a reduction in service volume.

For region C conditions, that is, high vehicular volumes and fewer bicycles, a small reduction in service volume would be expected. The lower speeds of operation for high-volume conditions would be reduced further by the presence of bicycles. With the high vehicular volumes, a vehicle that is slowed by the presence of a bicycle would also slow the traffic behind the vehicle. However, since the change in speed would be small, there would be little reduction in service volume. At capacity, the vehicles in the traffic stream have no freedom to maneuver; thus, the lateral friction created by bicycles would have little effect, unless the traffic lanes and the bicycle lanes were narrow.

As the volume of bicycles increases with high-traffic volumes, shown as region D in Figure 3, the additional bicycle-vehicle interactions do not have much of an added effect. If the vehicles at high volumes are slowed down, the vehicles in the traffic stream behind them will also slow down. The presence of additional bicycles would not further slow these trailing vehicles.

The region in Figure 3 shown by the cross-hatching represents conditions in which the greatest effect on capacity may be found. At these volumes, the operation of individual vehicles influences other vehicles in the traffic stream; however, individual vehicles are not completely restricted in their operations. Figure 4 shows a model of the relations for the capacity reduction factors that may be expected under various vehicle and bicycle volume conditions. These factors must be further modified when applied in capacity analysis to take account of the nearness of the bicycles to the vehicles in the traffic stream. Effect of nearness to traffic stream has not been investigated here; however, the findings of the Purdue study (6) indicate its importance.

As shown in Figure 4, the reduction in formal operating speeds would have the greatest effect on the reduction in capacity. In the center of this figure, which is the area of greatest bicycle influence, the location of the reduction factor would be a function of the frequency of interactions and the normal operating speeds. On the right side of the figure, the dominating influence of flow near capacity would control conditions.

The quantification of these reduction factors will require a coordinated data collection and analysis program. Once developed, these factors could be used in existing capacity analysis procedures.

COLLECTION OF DATA

It was decided that data would be needed to supplement the data currently available to determine if bicycles significantly affect the level of service on urban streets. The city of Eugene was chosen as the study site because of its extensive system of bicycle lanes. There is also a large segment of students at the University of Oregon who commute by bicycle. Three specific sites were chosen that were based on three criteria: the volume of bicycles, the volume of automobiles, and the character of the street. Two of the streets chosen are one-way with parking on one side and a bicycle lane on the opposite side. One of the streets is inbound toward the central business district and the other is outbound. The third street is two-way with parking on both sides and bicycle lanes on both sides between the parking lane and travel lane. The point where the data were collected is adjacent to the campus. In all cases, the bicycle lanes are 1.52 m (5 ft). Vicinity maps for the three sites are shown in Figure 5.

Method

There are three major areas of concern in the collection of data. These include equipment, procedures, and classification scheme.

The equipment used was a hand-held radar speed meter. It was chosen because of its ease of operation and quick set-up time. It also has the advantage of being totally inconspicuous to the vehicle operator, thus eliminating the possibility of the sampling procedure affecting the characteristics of the population being sampled. The model of equipment used provided a direct and instantaneous read-out of speed for each vehicle desired. Therefore, the speeds were logged continuously. It also allowed the data to be stratified prior to taking the sample. The total number of vehicles and bicycles passing by the checkpoint during each sampling period was tallied.

For the procedure, sites were chosen that provided an opportunity to park in an inconspicuous location. When possible, parking lots were used; otherwise a street location between two parked cars was used. A special effort was made to eliminate any bias that would result from the physical attributes of the locations such as automobiles in platoon, automobiles slowing down to make a turn, and vehicles approaching a stop light.

The classification scheme is as follows. The population of vehicles was divided into two categories before the sampling process began: the case in which a bicycle is not present, and the case in which a bicycle is present. Because of the limited number occurring in the second category, 100 percent of the speeds were sampled. Since the population is stratified for the purpose of comparing the mean speeds in each category, the sample was not allocated by proportional or optimal methods.

Figure 1. Relation between density and level of service.

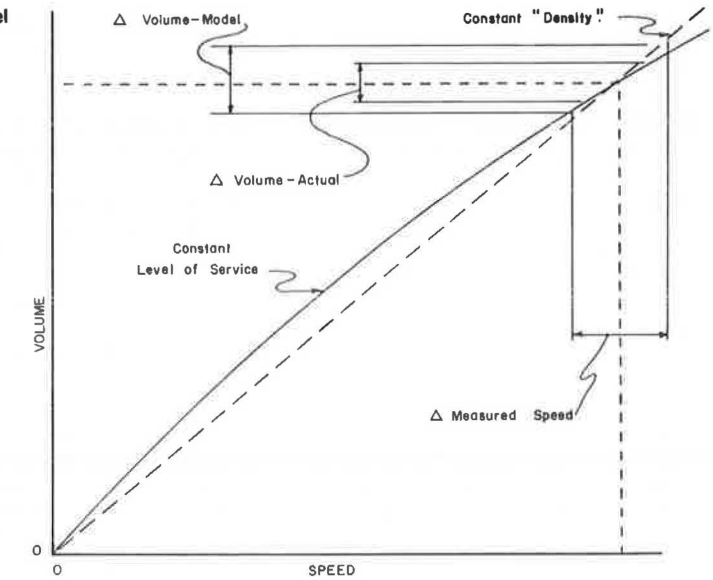
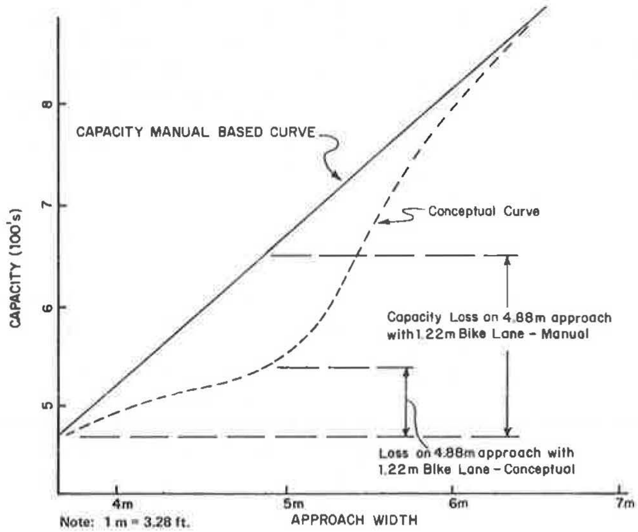


Figure 2. Capacity loss due to physical presence of bicycle lane.



Note: 1 m = 3.28 ft.

Figure 4. Model of capacity reduction factors for bicycle lane effects.

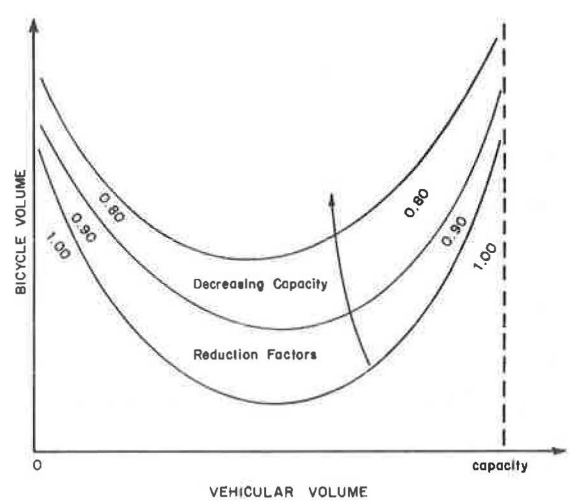


Figure 3. Effect of bicycle volumes on level of service.

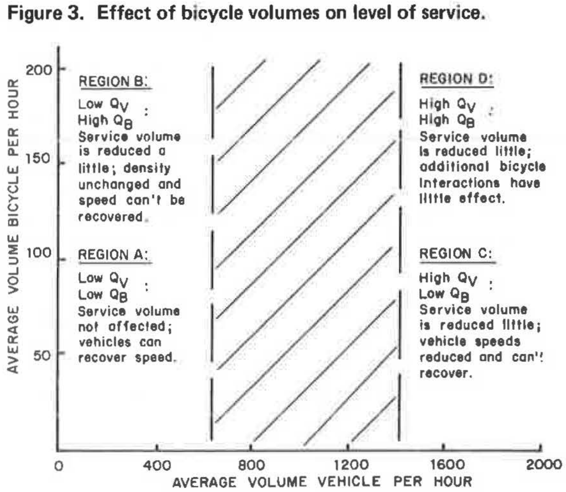
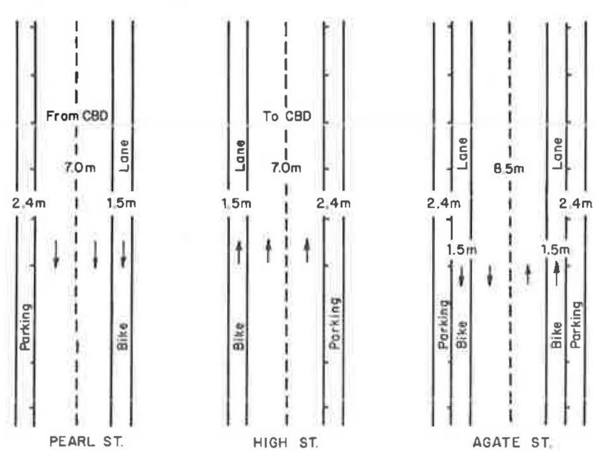


Figure 5. Sampling sites.



Note: 1m = 3.28 ft.

Statistical Analysis

An estimate of the mean speed with the desired degree of accuracy was obtained by calculating a minimum sample size. The expected range of speeds was taken into consideration, and a maximum difference between the population mean and the sample mean of 0.6 km (1 mile) was considered acceptable. The level of significance in testing the data was 10 percent. Based on data from other speed studies, the standard deviation was assumed to equal 2.48 km/h (4 mph). Therefore, the minimum sample size required to meet the above criteria was calculated by using the following formula:

$$n = (z_\alpha / 2^\sigma)/e \qquad (5)$$

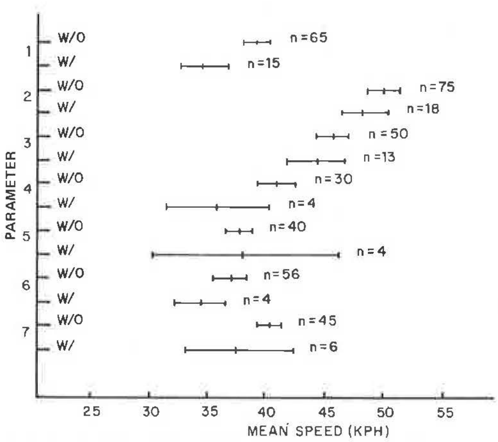
where

n = required sample size,
z = estimated standard deviation of the population [1.645 (α = 0.10)], and
e = maximum error desired.

The minimum value of n calculated to provide a statistically significant sample is about 43.

Confidence limits were established for each of the sample means. Since the value of n was less than 100,

Figure 6. Confidence intervals for mean speeds.



Notes: 1 kph = 0.6 mph; W = with bicycles present, and W/o = without bicycles present.

the Student's t-statistic was used instead of the z-statistic for a standard normal distribution. The formula to calculate the confidence limits (CL) is as follows:

$$CL = x \pm \{[t(\alpha/2, \sigma)](s/n)\} \qquad (6)$$

where

x = sample mean,
$t(\alpha/2, \sigma)$ = Student's t-statistic,
s = standard deviation of sample, and
n = size of sample.

The differences in means between the various cases were tested by using the two-tailed Student's t-distribution. The null hypothesis was that the population means for the two cases were equal. This was tested at the 10 percent significance level.

ANALYSIS OF DATA

The data were analyzed to anwer the following questions. The first question asked if there was a significant difference in speed as a result of the presence of bicycles. A negative answer would have indicated that the effect of bicycles on the level of service is limited. The second question considered the effect of the different weather conditions present during the survey period. Comparisons were made between rainy and nonrainy weather for the two cases by using the same time of day and location for both cases. The results of the comparisons were used by analyzing the effect of the number of vehicles per hour and the number of bicycles per hour on the number of interactions per hour between vehicles and bicycles. Because of the limited number of occurrences of some of the penomena, the results that are derived may have limited validity.

Comparisons of Mean Speeds

Standard parameters were calculated for each of the speed samples. These include the sample mean and the standard deviation. Confidence intervals of 90 percent were calculated for each sample. These intervals are shown in Figure 6. It can be seen that the desired accuracy of plus-or-minus 1.61 km/h (1 mph) is not achieved in many of the samples. This occurs primarily in the case for a bicycle present on days of inclement weather.

A test was made to determine the significance of the

Table 1. Comparison of means for vehicle speeds for bicycles present versus not present and for rain versus no rain.

Sample	Street	Weather	$\bar{X}_1$	$\bar{X}_2$	$s(x_{1i})$	$s(x_{2i})$	n_1	n_2	t-statistic	ν	$t_{(\alpha/2,\nu)}$	Reject
Bicycles versus no bicycles[a]												
1	Pearl	Cloudy	39.40	35.41	5.68	5.41	65	15	2.47	78	1.666	Yes
2	Agate	Cloudy	49.89	48.18	7.16	5.28	75	18	0.94	91	1.664	No
3	Pearl	Cloudy	45.71	44.19	5.89	5.12	50	13	0.84	61	1.671	No
4	High	Rainy	40.99	36.21	5.41	3.83	30	4	1.70	32	1.695	Yes
5	Pearl	Rainy	37.95	38.22	3.60	6.61	40	4	-0.14	42	1.683	No
6	Pearl	Rainy	37.53	35.00	6.20	2.03	56	4	0.81	58	1.672	No
7	Pearl	Rainy	40.35	38.09	4.26	5.54	45	6	1.17	49	1.678	No
8[b]	Pearl	Rainy	38.54	37.24	5.10	5.01	141	14	0.91	153	1.645	No
Rain versus no rain[c]												
1[d]	Pearl	–	39.40	37.52	5.68	6.20	65	56	1.72	119	1.658	Yes
2[e]	Agate	–	35.41	33.80	5.41	2.03	15	4	0.14	17	1.740	No

Notes: 1 km/h = 0.62 mph.

[a] $\bar{X}_1$ = speed of vehicles without bicycles present and $\bar{X}_2$ = speed of vehicles with bicycles present.

[b] Sample 8 is the total of samples 5, 6, and 7.

[c] $\bar{X}_1$ = speed of vehicles in dry weather and $\bar{X}_2$ = speed of vehicles in rainy weather.

[d] Sample 1 is taken from the population of vehicles without bicycles present.

[e] Sample 2 is taken from the population of vehicles with bicycles present.

difference between the means for the two cases, that is, speed without bicycles present versus speed with bicycles present for each sample. The hypothesis test was conducted at a 10 percent level of significance for the null hypothesis in which the true difference between the population means is zero. The Student's t-statistic was used because of the small size of the samples. As given in Table 1, there was a significant difference in only two of the samples.

There is a decrease in the mean speed differences as the vehicular average hour volume (AHV) increases. A mean speed difference of 4.83 km/h (3.0 mph) for the bicycle present versus the bicycle not present cases is found when the AHV is 340 vehicles. When the volume increases to 890 and 914 vehicles/h, the speed differences of 2.25 km/h (1.4 mph) and 2.42 km/h (1.5 mph) respectively are smaller.

The test to determine whether there is a significant difference between the vehicle speeds on a rainy and a nonrainy day is given in Table 1. There is a significant difference at the 10 percent level with no bicycle present between speeds on rainy days and speeds on nonrainy days. However, in the second case with bicycles present, the difference in mean speeds on rainy days versus mean speeds on nonrainy days is not significant at the 10 percent level. Thus, data from the second case tend to support the fact that the difference in speed between the two cases was greater on dry days than on rainy days.

RESULTS AND CONCLUSIONS

The purpose of this study was to investigate the effect of bicycle lanes on the level of service on urban street systems. A model of capacity effects based on reductions in vehicle speeds was suggested. A large cross section of bicycle lanes across the nation must be sampled to get sufficient data for this purpose. There are five main results from this study, and they are as follows:

1. There appears to be a small decrease in mean vehicle speed as a result of the presence of bicycles.
2. During rainy weather, the mean speed of vehicles is reduced because of the climatic conditions; therefore, the presence of bicycles does not noticeably affect mean speed.
3. The amount of reduction tends to decrease slightly; i.e., it is inversely proportional to an increase in vehicle AHV. This may be a result of drivers having less freedom to respond to outside influences.
4. There is less reduction in speed on wider streets since there is more room for lateral movement. Thus, if there is sufficient room, motorists will move away from the lane, and the decrease in speed will not be noticeable.
5. The reduction in capacity may be a function of the frequency of bicycle-vehicle interactions and speed of operation. Further data collection and analysis are needed to quantify this relation.

ACKNOWLEDGMENTS

Special thanks are due to Alva Williams of the city of Eugene, Oregon, for his assistance in data collection and especially for loan of his radar equipment. Thanks are also due to Harry A. Burns, Jr., of Gainesville, Florida; R. Gary Hicks of Oregon State University; and William Tebeau of the Oregon State Highway Division of the Department of Transportation for making available material that is in their personal libraries. This research was made possible by a graduate fellowship from the Federal Highway Administration of the U.S. Department of Transportation and the cooperation of the Oregon Department of Transportation. Preparation of the final manuscript was assisted by the Idaho Department of Transportation.

REFERENCES

1. Bicycling in Tennessee: Inventory of Users, Facilities, and Programs. Barton-Aschman Associates, Inc., Minneapolis, Sept. 1974.
2. Mesa Bicycle Study. City of Mesa, Arizona, 1974.
3. B. Kroll and R. Sommer. Bicyclist's Response to Urban Bikeways. AIP Journal, Vol. 42, No. 1, Jan. 1975.
4. S. B. Loop. Bicycle Transportation: An Annotated Bibliography. Department of Civil Engineering, Oregon State Univ., unpublished rept., 1976.
5. D. T. Smith, Jr. Research on Safety and Location Criteria for Bicycle Facilities. De Leuw, Cather and Co., San Francisco, Dec. 1973.
6. R. J. Jilla. Effects of Bicycle Lanes on Traffic Flow. School of Civil Engineering, Purdue Univ., Joint Highway Res. Project JHRP-74-10, Dec. 1974.

Publication of this paper sponsored by Committee on Bicycling and Bicycle Facilities.

An Experimental Study of the Defensive Driving Course

Ronald M. Weiers, School of Business, Indiana University of Pennsylvania

This study employed the systems concept that the overall success of a social product results from a combination of adoption rate and effectiveness and that product design improvement involves the generation of an attractive alternate product design, which is evaluated and compared with the conventional design on the basis of appropriate adoption rate and effectiveness measures. Group interviews and preliminary marketing research that involved actual and potential consumers of a defensive driving course were used to identify a number of salient course characteristics. The scope of the study was limited by confining the investigation to a single important course di-

mension—program context. Based on further marketing research combined with the judgment of experts in the driver education field, an alternate defensive driving course was formulated that included three new content items and fuel economy training. Subsequent experimental administration and testing of the alternate and conventional programs revealed that the alternate program was responsible for male drivers exhibiting a significant improvement on two of the three intermediate measures of effectiveness, i.e., fuel consumption and behind-the-wheel tests, and for female drivers exhibiting an improvement on the fuel consumption test. Following the laboratory experiment to measure program effectiveness, the programs were subjected to a field adoption experiment in a suburban community setting. Comparison of the resulting course registrations revealed a significantly higher rate of adoption for the alternate program.

Social marketing has been defined as "the design, implementation, and control of programs calculated to influence the acceptability of social ideas and involving consideration of product planning, pricing, communication, distribution, and marketing research" (1). Thus, social marketing is an implicit part of the broadened marketing concept in which marketing is not limited to commercial organizations but is crucial to nonprofit and social organizations as well. However, since that concept is similar to that of marketing traditional commercial products, the social marketer must design and package his or her social idea in such a manner that the target audience will find the idea attractive and worthy of purchase.

For many social products, which include the driver improvement program explored here, strategic decisions regarding which of the several potential product designs to employ can be aided through the use of experimental studies that rely on measuring program adoption and effectiveness. The overall success of a social product may be expressed as follows:

Overall success = (adoption rate) x (effectiveness on adopters)

In addition to the separate contributions of adoption and effectiveness to the overall success of a social product, these measures can interact with each other in a number of important ways:

1. Despite the potential effectiveness of a social program it will not be effective unless it is adopted by individuals.
2. The overall success of an ineffective program will be null regardless of the number of adopters.
3. If a program is effective or if variant designs of the program are especially effective on various market segments, adoption can be enhanced by directing it to the members of the segments involved and by increasing the attractiveness to third parties or intermediaries who are influential and have an interest in seeing that the program is adopted by certain individuals. This statement is especially true for the social program considered in this study.

Similar to marketing commercial products, laboratory and field testing can contribute to the decision regarding the design of the social product as it relates to the adoption and effectiveness components for the overall success of the program. In the case of some social products such as charitable contributions or blood donations, measures of both adoption and effectiveness are readily available. For others such as an antilitter campaign, measures of the overall success—for example, the observation of the weekly amount of litter collected along a designated section of highway—are available, even though adoption and effectiveness components may defy meaningful definition and measurement.

In the case of some social products, field measures of effectiveness (MOEs) may be made over an extended time span during which exposure to unwanted outside forces is extended and strategic product design decisions are unnecessarily delayed. The defensive driving cource (DDC) and other driver improvement programs are examples of this type of social product. The ultimate field MOEs of these programs are not only confounded by numerous extraneous variables, but are also observable only over an extended period of time. Under such circumstances, a well-conceived intermediate laboratory MOE can not only lend convergent validity to field study results, but the laboratory MOE can also contribute to the timely development of program designs that are best suited for various segments of the target market.

The systems concept that provides for the overall success of a social product by using a combination of adoption rate and effectiveness is central to this study. This approach for improving the DDC first involves the generation of an attractive alternate design. This design is then evaluated and compared with the conventional design on the bases of appropriate adoption rate and effectiveness measures. This study has three principal components as follows:

1. Analysis of the conventional DDC design and the application of marketing research techniques toward formulating an alternate design,
2. Experimental measurement of the safety and fuel economy effectiveness of the conventional design versus the alternate design, and
3. A field adoption experiment to measure the relative attractiveness of the conventional design versus the alternate design by drawing students from the general driving population.

MARKETING RESEARCH AND FORMULATION OF ALTERNATE DDC PROGRAM DESIGN

Exploratory Phase

A variety of viewpoints regarding the DDC and its design were examined by using group interviews and questionnaires. These methods were used to obtain information from judgment samples that consisted of (a) 9 DDC graduates employed by a major Pittsburgh corporation, (b) 10 potential DDC students who decided not to enroll in the program when it was made available to them at the same corporation, and (c) 5 DDC instructors who were responsible for teaching the DDC through the assistance of another Pittsburgh-based firm in cooperation with the Western Pennsylvania Safety Council. In addition, the potential-student questionnaire was administered to a judgment sample of 77 drivers, and the DDC-graduate questionnaire was administered to 26 individuals who had taken the DDC either at their places of employment or through other means.

Results

Non-DDC Responses

The results of both the questionnaire responses and group interviews reflected some of the widely held beliefs regarding the DDC. Many respondents expressed the feeling that the DDC is a corrective program for those who either do not know how to drive or have had excessive violations or accidents. These respondents also expressed the view that the course was a boring repetition of facts they already knew or that the course was unnecessary. The negative connotation of the word defensive in the course title was an item frequently mentioned in both the group interviews and questionnaires. In the DDC instructor group interview, the point was made that those who take the course to become better drivers suffer because of guilt by association with those who are forced to attend the course for corrective reasons such as violation point reduction.

One questionnaire response revealed one image of the DDC. In projecting the stick figure's nonparticipation response in one question, the respondent simply filled in the words, "No, I gave at the office." This response was not intended to be comical; it represented the respondent's feeling that the DDC resembles a charitable undertaking in which one gives but does not receive. Such attitudes are unwittingly encouraged by the National Safety Council itself. For example, after the program is completed, the DDC graduate is awarded a certificate of appreciation to thank the student for his or her personal effort toward helping reduce the severity of our nation's traffic accident problem. For both DDC graduates and potential students, the zero or minimal monetary cost of the course may serve to reinforce this impression of DDC attendance as a charitable effort.

DDC Graduates

DDC graduates generally expressed the desire to have some form of individualized or behind-the-wheel instruction included in the current, strictly classroom program. DDC graduates tended to agree with potential students that the name of the course was a negative selling point, and, for them, not fully descriptive of the benefits they obtained from the DDC experience.

DDC Instructors

The majority of the DDC instructors in the group interview felt that the course was too long. Most instructors believed that the subject matter could be adequately covered in 6 h rather than the current 8 h of instruction. However, besides representing a classroom variable, the time length of the course was also relevant to the instructor's ability to sell department managers on providing employee person-hours for class attendance during company time. Currently, the instructor's main argument to reluctant managers' concerns is the promise of money saved by reducing accidents that involve company cars and trucks. The managers were especially attentive during a late-interview discussion concerning the possibility that the DDC, in conventional or alternate design, might be taken to improve driver fuel economy as well as safety.

Conclusions and Implications

It had been expected that program content would be a dimension of major interest to both past and potential DDC students. This expectation was fulfilled because many written responses, both structured and unstructured, were oriented toward the content of the course. The group interviews also revealed a number of course content items that past and potential students deemed desirable for inclusion into the program. In addition, the exploratory marketing research supported the potential attractiveness of four new topics that were felt to be of possible interest. At this point, it was decided to limit the scope of the investigation to course content, and an alternate program was designed and experimentally evaluated. Inherent in this decision was the recognition that limited resources constrained the level of experimentation to one that was capable of incorporating and measuring the effect of major program revisions within one dimension of the program.

PROGRAM CONTENT RESEARCH PHASE

During the research phase, additional marketing research was undertaken to measure the degree of the potential students' intensity toward a broader selection of DDC topics. The expanded list contained 10 new course content items and was based on the results of the questionnaires and group interviews of the exploratory research phase. The telephone interview and telephone precontact plus mail-questionnaire techniques were then used to collect further course content preference information. A systematic sample of 116 persons from the Indiana, Pennsylvania, telephone directory was used.

Survey results indicate that there were four topics that consistently possessed the highest level of preferred emphasis. The acceptability of these items was further analyzed by using the following coding scale to numerically represent survey responses.

Degree of emphasis you would prefer:

NONE			MODERATE			HEAVY
☐	☐	☐	☐	☐	☐	☐
0	1	2	3	4	5	6

The leading content items and the percentage of mail-questionnaire respondents selecting each on a level corresponding to numbers 5 or 6 were as follows:

Content Item	Percent
Driving techniques for winter, wet, and other adverse conditions	90
Driving techniques to get the most kilometers per liter from your car	63
Review of traffic laws and enforcement policies in your state	62
Behind-the-wheel driving instruction	60

Based on the consistently high and widely held ratings that were accorded these leading topics and the apparent feasibility of their incorporation into what the exploratory research had indicated would be an attractive alternate DDC program, the marketing research was culminated, and the findings were subjected to the judgment of experts in the safety field.

A convenience sample of safety educators and DDC instructors were consulted, and these individuals were asked to assess the practicality of including the four leading content items in an alternate DDC program. With the exception of behind-the-wheel instruction, which was held to be unworkable in a course of relatively short duration attended by 20 to 30 drivers and taught by a single instructor, the three other topics were felt to be feasible for inclusion into such a program.

Alteration of the conventional course to allow time to treat the three remaining new content items was carried out by (a) reducing the attention afforded the numerous case examples in the course, (b) reducing the amount of class discussion encouraged by the instructor, and (c) proceeding directly whenever possible to the presentation of the major points of a topic instead of relying on introductory instructor questions that are intended to encourage student participation. Further reduction in program duration was achieved by omitting DDC session 7, which deals with drugs, drinking, and driving. Although this session is an important safety topic, it is less oriented toward driving techniques and was judged to be dispensable for purposes of the effectiveness experiment.

EXPERIMENTAL MEASUREMENT OF EFFECTIVENESS OF CONVENTIONAL AND ALTERNATE DDC DESIGNS

The effectivness of the conventional and and alternate DDC designs was measured by a laboratory experiment that involved the administration of each course accompanied by three performance measures: driving simulator, test-drive fuel consumption, and safety checklist, which was recorded by an on-board observer.

The main body of subjects were randomly assigned into three groups as described below:

R	Group 1	0	X_1	0
R	Group 2	0	X_2	0
R	Group 3	0		0

where

R = random assignment to groups,
O = before and after performance measurements,
X_1 = administration of the conventional DDC, and
X_2 = administration of the alternate DDC.

The driving simulator used in the experiment was located at the Greater Latrobe High School in Pennsylvania. The fuel economy MOE involved a test drive over a 6.87-km (4.27-mile) route in the vicinity of the Greater Latrobe High School and included four-lane, two-lane, and urban conditions. The test vehicle, a 1975 Ford Torino, was equipped with automatic transmission and power steering and brakes. Special instrumentation included a fuel consumption meter that registered each 0.04 L (0.01 gal) of fuel entering the carburetor and a trip recorder that measured each 0.02 km (0.01 mile) traveled.

A behind-the-wheel test was developed to measure and compare student performance before and after the instructional programs. The test items were developed in cooperation with the program instructors and were judged to relate to the safety instructional content of the programs and to be logically related to accident-free driving. The test contained 18 yes or no performance items that contributed to a simple additive score for each test drive. The items, unique in order and combination to the 6.87-km (4.27-mile) route, were pretested during preexperimental test drives to ascertain the observer's ability for adequately rating the student's performance on each item.

Subjects

Similar to the marketing research phase, the broad potential applicability of the social product under investigation and the desire for maximum external validity of the study results led to the decision for procuring experimental subjects from the general driving population. The Greater Latrobe Chamber of Commerce identified officers from a variety of civic, social, and fraternal organizations in the area. These organizations were contacted with the proposal that monetary compensation would be provided for each licensed driver who was referred by the organization to the experiment. The participant would have the option of either personally accepting the payment or choosing to contribute it to the organization. A balanced sample of subjects was obtained by stratification according to age and sex. These criteria were used to guide the organizational contacts for accenting subjects into the experiment.

As a result of these efforts, six organizations provided a total of 66 subjects who fit the age-sex stratification that had been determined for the sample. This total was then randomly divided into three groups of 22 each, which, within the limits of divisibility, approximated the age-sex distribution of the U.S. driving population. The subjects were telephoned to confirm their participation and to arrange times for scheduling the pretests and posttests. Additional incentive for individuals who signed up to complete the experiment was provided by informing the subjects that payment for their participation would be forthcoming during the measurement session that followed the instructional program.

Program Administration

The program was conducted from May 15 through May 23, 1976, and used the following schedule:

Day	Time	Activity
Saturday or Sunday	–	Driving simulator pretest and test drive in specially instrumented vehicle
Monday	6 to 8:15 p.m.	Class
Wednesday	6 to 8:15 p.m.	Class
Friday	6 to 8:15 p.m.	Class
Saturday or Sunday	–	Driving simulator posttest and test drive in specially instrumented vehicle

During the first weekend, each student made a single appearance and was pretested on both the driving simulator and on the test drive in the instrumented vehicle. Each student also received an information sheet that contained the research coordinator's telephone number and a reminder of the student's scheduled day and time for the postprogram testing. In addition, members in the experimental groups received written confirmation about their assigned classrooms for the three class sessions. The possible effects of daily traffic density and personal response patterns were compensated for by scheduling students for the same day and time for the pretest and posttest.

The conventional DDC class generally received DDC training as outlined in the fourth edition of the instructor's manual of the National Safety Council. However, the slightly less than 7-h class length was compensated for by omitting DDC session 7, which is largely oriented toward the dangers of drinking, drugs, and driving. It had been judged earlier that, although this subject matter was important, it had little relevance to the conditions involved in the experiment and that its omission would help reduce the time required of the students. The alternate DDC class received its DDC-based training during the first two evenings. The topics were recommended by earlier marketing research that was covered during the Friday evening session. The illustrated DDC student workbooks (seventh edition) were supplied by the National Safety Council and used by members of both classes.

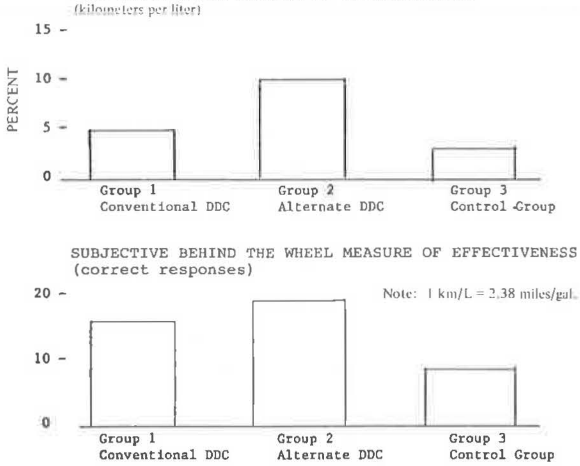
Data Collection

Collection of simulator and driving performance data took place on the weekends that immediately preceded and followed the instructional programs. The students' time involvement was minimized by taking the measurements during a single visit to the high school simulator facility and training course. The students were scheduled to drive the test vehicle at 15-min intervals throughout the day, and the driving simulator was run for 17 min once every hour. Efficient use of the students' time thus necessitated a less efficient operating mode for the simulator installation (one-half of its eight-person capacity). The first MOE was the student's test drive, during which the fuel consumption and on-board observer safety-checklist data were obtained. Because of the need for one observer to occupy the front seat to reset and monitor the fuel consumption meter and trip recorder, it was necessary for the safety observer to sit in the rear seat. However, this vantage point proved satisfactory for the observer, an experienced driver-education instructor, since it afforded him or her an improved view of the driver's eye movements via the rear-view mirror. During the 6.87-km (4.27-mile) test drive, the safety observer noted correct and incorrect responses on the safety-checklist data sheet. Before the test drive, the student was directed to simply drive around the route as safely as possible. This instruction was repeated for each student during the posttest. Depending on the student's degree of familiarity with the route, various levels of on-course instruction were required and provided well in advance of all decision points.

During the same test drive, fuel consumption and trip time data were collected by means of a digital flowmeter and a stopwatch. The fuel flowmeter registered hundredths of a gallon of fuel as they entered the carburetor of the test vehicle. Given the distance and the typical fuel consumption of approximately 12 to 14 m/gal (74.23 to 85.76 km/L), each hundredths of a gallon registered meant a difference of nearly 0.5 mile/gal (3.07 km/L). Therefore, the accuracy of the fuel-consumed data was increased by resetting the 0.01 mile trip recorder to zero at each fuel meter movement during the final approach toward the starting point. This resetting allowed the eventual recording of the number of hundredths of a gallon of consumed fuel plus the number of hundredths of a mile the car had traveled since registering this amount of consumed fuel. Extrapolation of these data, based on the observed fuel consumption of the vehicle during the final approach to the starting point, resulted in the recording of fuel consumption to the nearest 0.1 digit on the flowmeter.

The students' next MOE was the driving simulator, which required a 17-min test drive. Preceding each simulated run, the operator spent a short time helping the subjects acclimate themselves to their simulator units and controls and directed them to drive to the best of their ability in response to the traffic events depicted on the screen. The operator also used the monitoring capability of the installation to identify and correct any drivers who may have neglected to start or restart their vehicles before and during the test trip. Possible contamination of the simulator results was avoided by asking the students who arrived a few minutes early for their test drive on the highway, to remain outside the simulator facility while the film was being shown.

Figure 1. Percentage improvement from pretest to posttest.



Results

A summary of each group's performance on the various measures of program effectiveness is shown in Figure 1. Based on the percentage improvement for each measure, all groups improved from pretest to posttest. The percentage improvement was greater for the driving simulator measure than for the other measures because, as expected, the students were generally unfamiliar with the existence and the operation of such a device when the experiment began. Table 1 gives a summary of the mean improvements for each group on the measures of program effectiveness. Although the group mean improvements do not differ significantly on the driving simulator measure, the improvements are significantly different for the fuel consumption (0.001 level) and checklist (0.072 level) for behind-the-wheel tests. As expected, the greatest improvement on the fuel consumption MOE was shown by the group exposed to the alternate DDC, which contained a segment devoted to economical driving techniques.

Table 2 gives the statistical levels of significance between the mean improvements of pairs of groups and among all three groups on the three measures of program effectiveness. For male students, the alternate DDC resulted in significantly greater fuel economy performance ($p < 0.001$) along with an increased mean number of correct responses in the behind-the-wheel test ($p < 0.026$). Although directional improvements were observed for each measure of program effectiveness, the conventional DDC group did not differ significantly from the control group on any of the three improvement measures. Female students did not improve as much as male students did from the instructional program exposure, although directional improvements that were compared to the control group suggest that there was some degree of effectiveness from both programs. Female students who had taken the alternate DDC showed significant improvement (0.<0.024) on the fuel consumption MOE.

The results of the effectiveness experiment indicate that both the conventional and alternate versions of the DDC are capable of improving the performance of adult drivers in a laboratory setting. In 11 of the 12 possible comparisons between the instructed group and the control group, the instructed group showed greater improvement on the performance measure used. A summary of the statistically significant mean improvement differences between instructed and control groups by sex and effectiveness measure appears below:

	Effectiveness Measure		
Sex	Driving Simulator	Fuel Consumption	Behind-the-Wheel Test
Male	–	Alternate DDC	Alternate DDC
Female	–	Alternate DDC	–

The possibility of female students not benefiting from either instructional program to the same degree as male students do is worthy of further study. It appears conceivable that female students, for some reason,

Table 1. Summary of data for measures of program effectiveness.

Effectiveness Measure	Improvement						ANOVA		
	DDC		Alternate DDC		Control				
	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	d.f.	f	p
Driving simulator, increase in correct responses	14.68	9.85	14.77	10.57	13.32	7.88	2, 63	0.162	<0.851
Fuel consumption, increase in kilometers per liter	0.57	0.55	1.20	0.48	0.30	0.42	2, 63	19.970	<0.001
Subjective behind-the-wheel test, increase in correct responses	2.14	1.94	2.36	1.92	1.18	1.44	2, 63	2.740	<0.072

Table 2. Program effectiveness hypothesis tests.

Effectiveness Measure	Hypothesis	ANOVA			
		Male		Female	
		f	p	f	p
Driving simulator	$\mu_1 = \mu_2$	0.286	<0.598	0.632	<0.438
	$\mu_1 = \mu_3$	0.224	<0.641	0.076	<0.785
	$\mu_2 = \mu_3$	0.017	<0.896	0.765	<0.395
	$\mu_1 = \mu_2 = \mu_3$	0.194	<0.824	0.569	<0.573
Fuel consumption	$\mu_1 = \mu_2$	14.871	<0.001	2.811	<0.112
	$\mu_1 = \mu_3$	1.004	<0.327	2.276	<0.150
	$\mu_2 = \mu_3$	36.699	<0.001	10.820	<0.005
	$\mu_1 = \mu_2 = \mu_3$	16.249	<0.001	4.986	<0.015
Behind-the-wheel test	$\mu_1 = \mu_2$	2.567	<0.123	0.632	<0.438
	$\mu_1 = \mu_3$	0.485	<0.493	3.140	<0.094
	$\mu_2 = \mu_3$	4.753	<0.039	1.196	<0.290
	$\mu_1 = \mu_2 = \mu_3$	2.889	<0.069	1.656	<0.211

Note: Group 1 = conventional DDC, group 2 = alternate DDC, and group 3 = control.

may have simply acquired a lesser degree of additional driving knowledge than the male students who had taken the same course. However, the results of a DDC study by Crowe and Loft (2) include the finding that neither age nor sex was related to the degree of knowledge that students gained from exposure to the program. Although it may be that the female students were more affected by anxiety during the test drives and therefore did not fully exhibit their improved knowledge, this explanation is not supported by Planek's (3) finding that female DDC graduates improved less than male graduates with regard to the number of accidents experienced in the year following the course. A rewarding subsequent effort to the research reported here would be a similarly designed study that was entirely aimed at female drivers. Such a study could lead to an alternate design of the same content taught by a female instructor and incorporate the same MOEs used here.

Because the students in this experiment generally seemed to be on their best behavior during both the pretest and posttest drives, it might be informative to conduct a similar experiment that uses unobtrusive measures of performance, which correspond to those discussed by Webb (4) that are used in various social sciences. One such possibility would involve each subject taking the test drive without the presence of on-board observers. The difficulty of setting up and adequately controlling such a solo test drive might be handled by assigning the subject to complete a portion of the testing session at one location. Then the subject would be directed to drive to a second location where the testing requirements would presumably be completed. Along the actual test route between the two locations, observers would be stationed at strategic points to record each subject's reactions to traffic conditions. This recording would be similar to that of the on-board safety checklist used in this experiment. In addition, the test could introduce a special traffic condition such as a slow vehicle in which the driver would be assigned to pull in front of each driver to allow the subject an opportunity to exhibit the courteous and safe responses that the instructional program encourages. Although the use of such an unobtrusive measure of safety performance would add additional staff and expenses and necessitate the use of a citizen's band radio or other suitable communications equipment, it would allow the experimenter to measure subjects' performance in a way that would have externally valid advantages over the current procedure.

FIELD ADOPTION EXPERIMENT

Methodology

The experiment was cross sectional and involved the cooperation of the Monroeville Pennsylvania Department of Recreation and Parks, an agency that offers a variety of evening instructional programs for community residents. The design of the experiment is as follows:

R Group A X_1 0

R Group B X_2 0

where

- R = random assignment of a sample of community residents to each experimental group;
- X_1 = mailing of course announcement that includes title and brief description of content and orientation (this treatment consists of the alternate product design that includes state law and enforcement policy review, driving under adverse weather conditions, driving techniques to obtain increased fuel economy, and the conventional safety topics of the DDC);
- X_2 = mailing similar to X_1 in all respects except for substituting the conventional DDC design and describing the alternate design in X_1; and
- O = proportion of sample adopting the course that is evidenced by completion and return of course registration form attached to announcement.

The course announcements were sent to a systematic sample of 1980 residents listed in the Monroeville telephone directory. Each addressee also received a single program announcement. The alternate design, treatment X_1, was divided into two treatments: one course description that mentioned the 10 percent fuel economy improvement observed in the effectiveness experiment and one that did not mention the fuel economy improvement. It was felt that a sponsoring agency, by offering a program that had as one of its content items the improvement of students' fuel economy performance, would wish to use actual research results that supported the likelihood of such an improvement on the part of the potential student. On the other hand, such a numerical promise of course value could constitute an unfair advantage as well as a deviation from the alternate program that had resulted from the earlier marketing research. In that research a specific percentage improvement was not mentioned in presenting the potential content item that dealt with driving techniques for improved fuel economy. Therefore, it was decided to divide the alternate program treatment into two treatments. Each treatment was administered to one-fourth of the addressees along with the administration of the conventional treatment to the remaining one-half.

Because the alternate program design, with its fuel economy and other new content items, could not properly be designated as the DDC and because the lack of such designation might provide the course with a disadvantage compared to the conventional program that is identified as such, it was decided to use course titles judged to be innocuous, yet descriptive of the content of the two programs. A pretest of the two course titles involved the interviewing of a small convenience sample of adult drivers and resulted in the consensus that Driving Defensively was comparable to Defensive Driving Course and that Driving for Economy and Self-Defense was an appropriate title for a program that included techniques for driving economically as well as safely.

Descriptions of both programs were based on a DDC information sheet that was prepared by the National Safety Council. An extra paragraph of length comparable to that describing the new content items of the alternate course was inserted into the corresponding segment of the conventional program description to compensate for what would have been a slightly longer description for the more inclusive alternate design.

Findings and Implications

Examination of the registration rates for the treatment groups revealed the following: (a) the alternate program without quantitative mention of fuel economy improvement had three registrations (1.1 percent return), (b) the alternate program with quantitative mention of fuel economy improvement had four registrations (1.5 percent return), and (c) the conventional program had two registrations for the alternate program compared to two for the conventional, which yielded proportions of 1.3 and 0.4 percent respectively. Analysis of the difference between these two proportions revealed a significant difference at the 0.046 level of significance for a one-sided test.

As anticipated from the size of this mailing and the registration rate experience reported in previous DDC direct-mail efforts (5), the levels of enrollment for both programs were low on an absolute basis. However, the relative enrollments observed for the alternate and conventional programs do suggest that the alternate program, in addition to demonstrating certain effectiveness advantages over the conventional program, possesses a marketability advantage as well.

CONCLUSIONS AND IMPLICATIONS

As a general conclusion, the research results were judged to support the initial perception of the potential benefits to be gained from the application of marketing research and experimental procedures to a social product such as the DDC.

A number of research results indicate the desirability of the National Safety Council's investigating the adoption of a strategy of differentiated marketing in which the heterogeneity of the market would be recognized and met with more than a single driver improvement program. One finding of the group interviews was that some respondents tended to perceive taking the DDC as a penalty for having received a traffic citation rather than as a positive experience of self-improvement and personal benefit. This observation would tend to support the supplementation, instead of replacement of the conventional DDC program with one or more courses that did not suffer from the stigma of association with a form of punishment. The alternate program formulated in this study, with its revised content and promise of fuel economy improvement, could be such a course.

Since only the alternate program yielded significant improvements in comparison with the control group, there is directional support for the possibility that both the conventional and alternate DDC tested here may help to improve the fuel economy performance as well as the safety performance of DDC graduates. The promise of fuel economy improvement on the part of the alternate DDC would appear to be especially helpful in marketing the program to big business and other potential students. Group interviews with DDC instructors suggested the difficulty faced in obtaining employees on company time for a program that could be justified on only a single economic basis, i.e., reduction of the company's accident costs. With an alternate DDC that is capable of bringing about significant reductions in fuel consumption through its graduates, the marketability of a company-sponsored training plan would be enhanced by energy savings and accompanying favorable publicity of the company's involvement in the national effort to extend scarce energy resources.

The results indicated here should be noted by public policy makers as an example of the potential effectiveness of a voluntary program that could contribute to the solution of national problems such as energy and safety. However, it is not improbable that the National Highway Traffic Safety Administration will someday successfully encourage the conformity of the various states to a national requirement for the completion of an approved driver training program before the issuance of an operator's license. If such a mandatory program is instituted, it should, based on this research, include instruction of the techniques of driving economically as well as safely. Hence this instruction would contribute simultaneously to the reduction of two national problems.

In a larger perspective, the present study could assist a variety of social marketers to better recognize the marketing nature of their respective social causes and ideas and lead to the enhancement of their social marketing proficiency by providing an example of the application of marketing research and experimental techniques to the generation and evaluation of improved social product designs.

REFERENCES

1. P. Kotler and G. Zaltman. Social Marketing: An Approach to Planned Social Change. Journal of Marketing, July 1971.
2. B. I. Loft and J. W. Crowe. An Evaluation of the National Safety Council Defensive Driving Program at Ft. Wayne, Indiana. National Safety Council, 1969.
3. T. W. Planek, S. A. Schupack, and R. C. Fowler. An Evaluation of the National Safety Council's Defensive Driving Course in Selected States. Accident Analysis and Prevention, Pergamon, Great Britain, 1974.
4. M. R. Stiff. Reforms as Products: A Marketing Management System Model for an Adult Education Course in Driving Improvement. Northwestern Univ., PhD dissertation, 1971.
5. E. J. Webb, D. T. Campbell, K. D. Schwartz, and L. Sechrist. Unobtrusive Measures: Nonreactive Research in the Social Sciences. Rand McNally, New York, 1966.

Publication of this paper sponsored by Committee on Driver Education.

Measuring the Outcomes of Driver Training: University of Southern California Driver Performance Test

Margaret Hubbard Jones, Traffic Safety Center, University of Southern California

A new test for evaluating driver performance is described. The objective was to develop a test that is reliable, valid, and feasible for routine administration in the high schools. This test requires 30 min and is scored by a trained coder. The scoring is simplified to permit the coder to focus on observing and judging driver behavior. Standards for performance are learned by the coders during a 40-h training program. The test requires driver interaction with moderately heavy traffic and is intended to test the limits of driver performance. Intercoder agreement was about 80 percent, even though there were different seating positions. Some changes in scoring assignments and training are expected to improve the reliability of the test. This pilot study was carried out with 197 students at the end of their driver training course. A number of part scores and subtotals were used so that faults could be diagnosed. In general, these novice drivers did poorly in visual scanning. However, there was a wide range in driver proficiency. A hypothesis, the validation of which needs a large-sample study, is proposed to test the reason for the poor scanning.

The effectiveness of driver training courses has suffered because these courses lack a reliable, valid, and standardized measure of student performance in the normal traffic environment. Without such a measuring device, neither alternative programs nor individual students can be evaluated. Hence, curricular decisions continue to be made on the basis of personal preference, and course effectiveness is not achieved. Not only is there a pressing need for a reliable and valid test for beginning students, but there is also a need for evaluating experienced drivers because of an increasing concern for promoting driver training programs for the elderly, minorities, and the handicapped.

There have been many performance tests devised in the past, and these include (a) the McGlade test (6), which has a strong instructor bias that makes it unreliable; (b) the Michigan State BETSS test (2, 3), which is too costly to be practical for routine testing and does not have route criteria; (c) the Rockwell test (9), which does not evaluate traffic interaction; (d) the Quenault test (8), which is only in the pilot-test stage and would be much too expensive for routine use; (e) the German behavioral survey (1), which is too time-consuming and not validated; and (f) the California Department of Motor Vehicles test, which is a cost-effective experimental road test in which the route criteria are available but the scoring is not reliably controlled. Thus, there is still no test that can be used satisfactorily by a school district or a research team to evaluate large numbers of drivers. Because there is no acceptable criterion of real-world performance other than accidents, large numbers of students must be tested to validate a program. A valid intermediate criterion would make the task of developing effective curricula simpler, quicker, and less costly. However, such an intermediate criterion must be validated by using a large-sample study.

The objective of this study was to develop a test that is feasible, reliable, and valid for use in a school program. If the test is to be feasible, it must be as short as possible, which makes it consonant with the other goals. Therefore, the upper limit of time was set at 30 min. If a test is to be reliable, psychometric rules must be followed, the most critical of which is the requirement for a large number of independent observations. If a test is to be valid, a minimal requirement is that the items tap the most important aspects of safe driving behavior rather than those that have been the most convenient to test in the past. There are two further requirements: (a) The test must be simple to score, so that the coder can devote more attention to observing the driver's behavior than to scoring the results, and (b) the test must be safe for the public and the driver-education automobile. The last requirement is difficult to meet because high levels of skills, rather than minimal competencies, must be tested in moderately heavy traffic to assess driver capabilities. Thus, driver interactions with traffic are required so that the skills necessary for safety can be assessed.

DRIVER PERFORMANCE TEST

The University of Southern California (USC) driver performance test was devised to meet the previously mentioned needs; thus it is different from previous tests. The content of the USC test is based on the Safe Performance Curriculum (4), and those elements that are the last in a skill series and require on-road testing in traffic were emphasized. Because of the time limit, a selection of elements was required. (Because the testing is based on sampling the individual's skills or behaviors, a representative sample should be chosen.) Automobile control skills were not tested because these skills cannot be safely tested on a public street. These skills should be tested on a range that provides for a thorough, demanding, and safe test at a reasonable cost. Freeway and rural driving tests were eliminated for four reasons: (a) These tests require an inordinate amount of time, for even a brief excursion, and yield only one or two measures, which does not yield a reliable index; (b) the traffic volume on freeways varies according to time of day, and thus it is impossible to provide for comparable conditions for all cases; (c) freeway merges could be used in the absence of significant traffic, but they do not challenge the driver; and (d) it is unsafe to take novice drivers on crowded freeways. The final list of items includes those necessary for safe driver interaction with normal traffic, and these are based on the content of the Safe Performance Curriculum and the literature on accident causation. For example, a test for properly observing while backing up was included because backing up accounts for a significant number of pedestrian fatalities. As it must be, that test is highly standardized and leaves little room for variation from one location to another or individual foibles in scoring.

The USC test begins on a route that is constructed according to rigid specifications, which are contained in the route construction manual. These requirements include a certain number of specified kinds of intersections, streets, and traffic densities, which are based on counts. These requirements are shown in Figure 1, and the required maneuvers are shown in Figure 2. Once the route is determined, it is marked on a route map (Figure 3). This map is also the score sheet. There are three advantages to this method: (a) By following the route, the coder knows precisely where to mark the score, hence he or she can attend to the driver's behavior; (b) the coder is then set to attend to the next behavior; and (c) the scoring process is very simple.

Because the driving instructor is normally responsible for the safety of the vehicle, he or she cannot be the coder. The coder is a trained person who sits in the middle rear seat with a clipboard on his or her lap and attends to nothing but the driver's performance. However, the instructor is now assigned two important scoring duties, which are marked on his or her route map: (a) All hazards that are encountered are recorded and circled or crossed out, depending on whether the student handled the hazard properly; (b) every instance in which the instructor must take control, either physically or verbally, is also recorded. These instructor duties have only recently been assigned because they are part of the instructor's normal task. However, in the results reported here, these duties were assigned to the coders.

The coders are teacher's aides who are selected because they have certain minimal skills, but, in California, they are untrained. This type of person is selected after considering trainability, availability for a peculiar schedule, reliability of attendance, and cost. One requirement was that the coders have no special training in driving or driving instruction. This requirement promotes the aim of training the coders to produce identical judgments, which can best be accomplished if there is no diversity of entrenched opinions.

Figure 1. Sample of a route layout form.

School Marina High School — Route: Inbound Outbound Circular

City Huntington Beach, CA.

TRAFFIC DENSITY	CHARACTERISTICS	MANEUVER	MINIMUM NUMBER	CHECK
High	Signalized	Left Turn	2	111
High or Medium	Signalized	Left Turn	2	1
Low	Uncontrolled	Left Turn	2	1111
High	Signalized	Right Turn	2	111
High or Medium	Signalized	Right Turn	2	11
Low	Uncontrolled	Right Turn	2	11
High or Medium	Signalized	Through	2	1111
Low	(Blind) Un-controlled	Through	2	11
MIDBLOCK ENTERING AND LEAVING TRAFFIC				
High/Medium	Uncontrolled for High/Ned, to Low	Left Turn H/M to L	1	1
High/Medium	Uncontrolled for High/Med. to Low	Right Turn H/M to L	2	111
Medium	Uncontrolled or controlled by stop sign for Low to Medium	Left Turn L to M	2	1111
High/Medium	Uncontrolled or controlled by stop sign for Low to High/Med.	Right Turn L to H/M	1	1
MIDBLOCK LANE CHANGE AND TURNABOUT				
High		Lane Change	4	11X1
High or Medium		Lane Change	4	11X1 1
Low		Three-point Turnabout	2	11

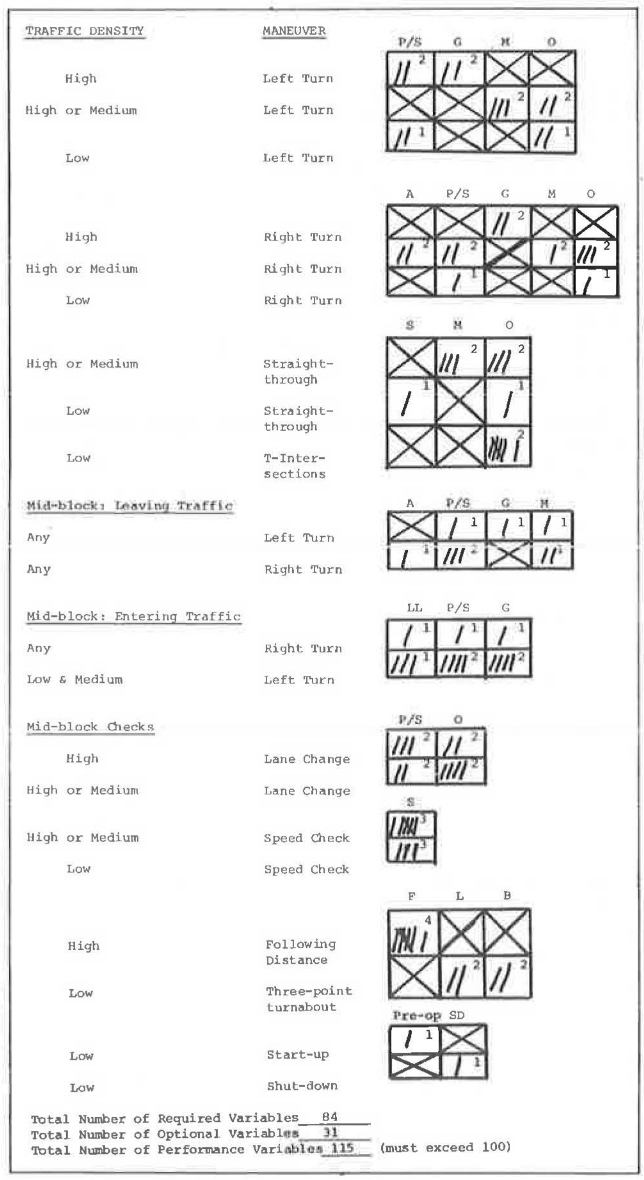
Driving time (experienced driver): 20½ minutes — Date: 16 December 1975
Length of route 7.1 miles
Amount of time to lay out route 16 hours
Name of route constructor J. Wood

However, the coders must be intelligent, alert, and observant.

The training of the coders is guided by the training manual and materials, which include videotapes for practice scoring. The training requires 2 weeks; a little less than half of the time is spent in the classroom, and the remainder is spent in the automobile. The training in the automobile includes comparisons among coders scoring the same driver and also a comparison of each coder with the course instructor. Coders are not accepted if they fail to achieve the required intercoder reliability. The standard performance for each maneuver is described, and the coders are required to learn the criteria thoroughly.

The driver behavior to be rated at any one time is but a part of the total driving maneuver. This is done to enable the coder to attend closely to accurate performance, to compare it with the standard, and to mark the score sheet. Individual judgment is minimized as far as possible to maximize standardization among the coders. Thus, the coder may be directed to observe either eye movements (seen in the rear-view

Figure 2. Sample of a performance variables check sheet.



mirror) or path and speed, but never both; or the coder may be required to watch speed through one uncontrolled intersection and for the next intersection watch only eye movements. Only in this way can necessary singleness of attention be achieved. In the course of the test route there are more than 100 observations; therefore, each aspect of the driving behavior is rated a number of times. The aim is to randomly sample the critical skills over the entire duration of the drive. For example, it is not necessary to sample all the part behaviors involved in a left turn at the same instant; in fact, it is preferable to sample these behaviors independently. Thus, any sizable unbiased sample will be representative of the driver's usual behavior. The aim here is to obtain a large number of independent measures.

The test is a criterion-referenced test, which is in line with modern educational theory. The purpose is not selection of applicants, but an assessment of the success of the program in bringing all students to a standard performance criterion for safe driving in normal traffic. For this reason, the standards of performance are standards for all drivers. An attempt to devise a standard that takes into account experience and that measures on a sliding scale what is good for a student driver against what is good for a driver with 2 years of experience would be unreliable and defeat the purpose of the test. Because the standard of performance is absolute, experienced drivers can be tested as readily as novices; thus, the differences in performance between the two experience groups can be stated in behavioral terms. The further advantage of this test permits diagnosis of deficiencies in individual training and particular curricula.

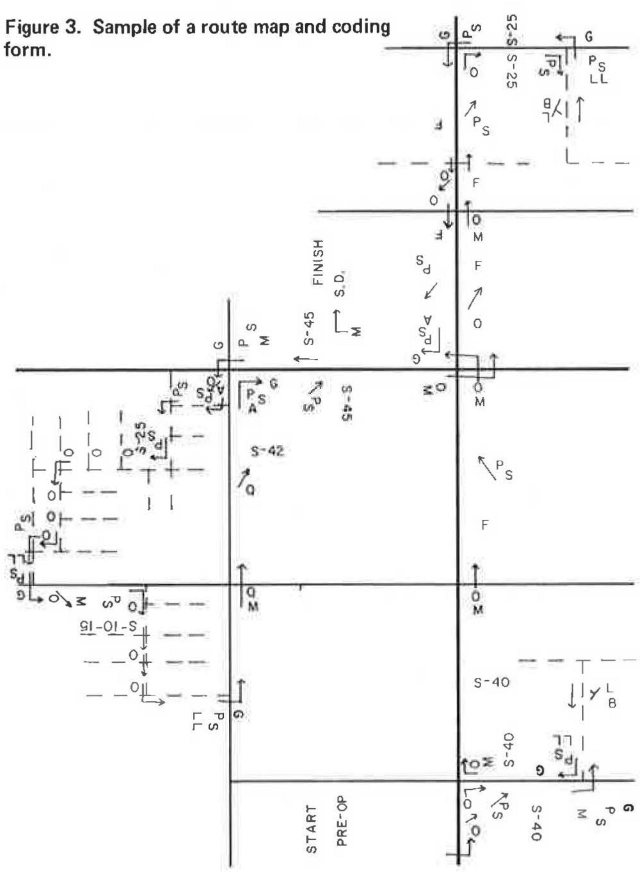


Figure 3. Sample of a route map and coding form.

CODER AGREEMENT

The crucial question is how well the coders agree in their judgments. Table 1 gives the intercoder agreement for all pairs. The overall mean agreement varies considerably by category, which is dependent on the complexity of the judgment, the precision of the critieria given the coders, and the coders' levels of skill. The more critical categories of speed and observation are in respectable agreement: 78 and 93 percent for speed and 84 percent for observation. The judgment of hazards by the coders was poor. The probable reasons are inadequate intuition about what a hazard is and, since these are unexpected events, concentration of attention on other things. This problem has subsequently been solved by assigning this coding function to the driving instructor because he or she attends to hazards and knows what constitutes a hazard. The category of instructor control has also been assigned to the driving instructor because the instructor knows when he or she has taken control. The other category with less than desired agreement is gap and following in which the major problem was where to code following distance. (Following distance is a problem because neither it nor gap acceptance can be scheduled as the other events are scheduled.) Extra training has since been added for this point. Overall, the mean percentage agreement was approximately 80, which is satisfactory under the comparison circumstances. The agreement would be higher if the coders could sit in the same position; of the two different seating positions, one is noticeably worse for observing eye movements and better for observing path and limit line. The positions are also quite different in terms of seeing the hazards, a difficulty that is no longer present. The transfer of the ratings of hazard and instructor control to the instructor and the improvement in following and gap training should improve the agreement still further.

An analysis of rating performance by coders 1 and 2 is as follows:

Performance	Coder 1	Coder 2	Total
Correct	547	565	1112
Wrong	326	308	634
Missed	104	108	212
Total	977	981	1958

Table 1. Mean percentage agreement by coder pairs after training.

Variable	5 and 1	5 and 2	3 and 1	3 and 2	1 and 2	Mean
Approach path and limit line	77	79	83	82	84	81
Speed for turns and lane change	75	75	76	86	80	78
Gap and following	80	60	66	60	67	67
Speed through	{90	88	95	95	95	93
mirror	{77	81	88	86	90	84
Location, backing-up, preoperation, and shutdown	88	87	84	74	94	85
Hazard	64	36	42	33	37	42
Instructor control	89	73	75	70	62	74
All variables	78	76	80	78	82	79

Table 2. Analysis of codings missed by coders 1 and 2.

Coder 1	Coder 2	Total	Following	Gap	Other
Missed	Correct	27	11	13	3
Missed	Wrong	5	0	0	5
	Subtotal	32	11	13	8
Correct	Missed	27	1	9	17
Wrong	Missed	9	1	0	8
	Subtotal	36	2	9	25
Missed	Missed	72	25	23	24
Total		140	38	45	57

Table 3. Means and standard deviations for USC driver performance test scores.

Variable	Original Test (N = 194) Mean	S.D.
Test duration, minutes	27.0	3.6
Observing score, percentage correct	51.6	16.3
Gap score	83.2	18.8
Mirror score	36.2	23.9
Observing subtotal	53.7	14.1
Path score	80.3	12.1
Speed for turns and lane change	67.5	21.1
Speed for through intersections	74.7	21.7
Control subtotal	73.1	13.4
Limit-line score	76.0	26.4
Approach score	52.6	30.9
Following score	93.0	18.1
Judgment subtotal	74.2	16.4
Y-turn location	45.9	27.1
Y-turn backing-up	44.1	41.7
Preoperation	42.8	49.3
Shutdown	92.6	26.0
Miscellaneous subtotal	52.5	19.4
Total score for all variables	65.0	9.8
Hazard score	69.8	31.5
Instructor control, N	2.7	2.4

There is no significant difference between the coders in the assignment of right, wrong, or missed, as indicated by the ϕ coefficient (0.0212). There is also no significant effect of coder, as indicated by χ^2 (0.8024). Analysis of the codes missed is given in Table 2, and in one-half of the cases, the coders agreed. In many of these cases (two-thirds), the called-for behavior did not occur (no traffic to provide for gap or following distance). The coding instructions required that the symbol be underlined to indicate the observations that were missed under these circumstances. In the other third of the cases, there was a difference in judgment regarding whether the traffic was close enough for the called-for situation. Further, in a task requiring vigilance over a long period of time, it is inevitable that some blocking of attention will occur. The coders were instructed to use the code missing under such circumstances. In addition, for these comparison runs, one coder sat in the right rear seat, which was poor for observing some maneuvers. For short coders, it was difficult to observe speed. The short coder missed 16 of the speed codings that the other coder was able to code. However, there were no codings missed in the opposite direction. This situation only applies to the comparison coding and not to the data for students. The analysis of variance on student performance data is significant for the coder $p < 0.02$). The coders themselves do not differ significantly by direct comparison, which may mean that a coder might have been assigned to better students or that the coder had a tendency toward giving the student the benefit of the doubt. For the latter to be evident, a large sample of judgments should be used.

TEST RELIABILITY

A small sample of students (N = 67) was retested approximately 2 weeks after the original test. The correlations were not impressive (0.30 to 0.40). The technical problems with the test-retest technique as a measure of reliability in this particular situation are as follows:

1. The route test might have become familiar to some students, especially those who have better spatial memories.
2. The test itself represents a large proportion of the student's total driving time (20 percent), and this additional driving time could promote a substantial learning. It is well known that different abilities come into play at different stages in any learning process and that people learn at different rates. Hence, the extra training will change rankings significantly.
3. The complexity of the driving task implies that many individual and environmental factors will vary from day to day. Thus, the test may be theoretically reliable, but the driver-vehicle-environment interaction may differ from day to day. This difference reflects the current concept of varying individual risk. The use of an odd-even technique is also not suitable, because the test is not intended to be homogeneous and there are not enough measures of a single type of behavior to permit splitting the test into two minitests.

Another attempt to measure the reliability of the test will be made by using experienced drivers, who are unlikely to gather more knowledge by taking a course such as this. Since reliability sets the limit for validity, validity coefficients may shed some light on the problem.

RESULTS

The pilot-test data, reported here, were obtained from 194 driver education students in a moderately large California school district. The students were tested immediately after completing their on-road training. All students who completed the program in midsemester were tested. Table 3 gives the means and standard deviations for the USC driver performance test scores. The test duration was 27.0 min (the maximum duration was set at 30 min). The scores (which are given as percentage correct) are far from perfect: They vary between 36 and 93 percent. Thus, it is apparent that the diverse skills are unevenly learned at this point. Of even greater interest are the sizable standard deviations that indicate the diversity of skills among students who are the same age and have approximately the same amount of training and experience (5). Thus, driver education programs should have individually tailored instruction to be the most cost-effective.

The intercorrelations among the subcategories are typically low, indicating that there are different complexes of abilities. However, the two speed measures were significantly related ($r = 0.43$, $p < 0.001$). The following were also found

1. Students scan intersections only about half the time and check their mirrors even less; they are flying blind a good deal of the time and tend to stare straight ahead with unmoving eyes.
2. For three-point turnabouts, students will frequently choose an unsafe location.
3. Students generally do not look back while they are backing up in a turnabout situation.

The last two items can be easily learned within the limits of the present driver education programs, if they are given more emphasis.

A number of these students were retested 2 weeks later. Most behaviors showed improvement, particularly those for speed when turning. Originally the speed was too slow for most students coming out of a turn, but occasionally the speed was too fast going into a turn. The limit-line observance deteriorated, but moved toward the norm for the few experienced drivers tested.

An analysis of variance was made for route, estimated traffic density (which varied somewhat with the time of day but was controlled within limits), and coder for each subtotal score. The routes are not significantly different, and the small variation in traffic does not matter, given the constraints of the original route construction. Although instructors do not differ, coder differences were statistically significant, as mentioned above.

DISCUSSION OF RESULTS

The USC driver performance test appears to have met the objectives of the study in terms of time limit, code reliability, safety, and ease of scoring. In addition, it permits a breakdown into part scores that represent the various facets of this complex psychomotor and judgmental task. The validation of the test must await a long and costly study of a large sample of students and their first-year accident records, which is currently under way in Georgia. Further work with experienced drivers is also planned.

The objective description now available of typical performance patterns of new driver education graduates leads to the proposal of an important hypothesis that is currently testable on a small sample. The failure of students to scan adequately or often requires consideration. It is well known that the driver is often overloaded with information, which engenders considerable stress. Probably the most useful model of driving is as a two-function task that requires divided attention between automobile control and visual scanning. However, if automobile control is uncertain, then it receives priority because without control scanning will be useless. This concept is attested to by Mourant's and Rockwell's description of the eye movements of novice drivers (7). The hypothesis proposed here is that these students cannot adequately scan because they have not yet developed sufficiently sure and automatic responses to automobile control. Until they achieve this control, they cannot be taught to scan properly. If proper scanning were taught under those conditions, it would overload the system to the point where driving behavior would break down. This hypothesis could be tested immediately by training student drivers to scan using a control group design. This research can be done on a relatively small scale with several groups who would receive training in various amounts. It may prove to be that adequate scanning behavior will be the true test that determines when a person can drive safely alone.

ACKNOWLEDGMENTS

This research was performed under a contract with the National Highway Traffic Safety Administration. The opinions expressed are mine and do not necessarily reflect those of the National Highway Traffic Safety Administration.

REFERENCES

1. B. Biehl, G. H. Fischer, H. Häcker, D. Klebelsberg, and U. Seydel. A Comparison of the Factor Loading Matrices of Two Driver Behavior Investigations. Accident Analysis and Prevention, Vol. 7, 1975, pp. 161-178.
2. T. W. Forbes, R. V. Nolan, F. L. Schmidt, F. E. Vanosdall, D. L. Smith, G. S. Burnett, J. W. Counts, W. H. Greenwood, F. J. Graber, R. H. Johnson, J. W. Lounsburg, J. E. Schlick, and F. W. Reuter. Driver Performance Measurement Research. Department of Psychology and Highway Traffic Safety Center, Michigan State Univ.; Final Rept., National Highway Traffic Safety Administration, 1973.
3. T. W. Forbes, R. O. Nolan, F. L. Schmidt, and F. E. Vanosdall. Driver Performance Measurement Based on Dynamic Driver Behavior Patterns in Rural, Urban, Suburban, and Freeway Traffic. Accident Analysis and Prevention, Vol. 7, 1975, pp. 257-280.
4. Safe Performance Curriculum. Human Resources Research Organization, Alexandria, Va., 2 Vols., Final Rev., no date.
5. M. H. Jones. The California Driver Training Evaluation Study. School of Engineering and Applied Science, Univ. of California, Los Angeles, 1973.
6. F. McGlade. Test Driving Performance: Developmental and Validation Techniques. Highway Research News, No. 5, 1963, pp. 13-22.
7. R. R. Mourant and T. H. Rockwell. Strategies of Visual Search by Novice and Experienced Drivers. Human Factors, Vol. 14, 1972, pp. 325-335.
8. S. W. Quenault and C. F. Harvey. Convicted and Nonconvicted Drivers: Values of Drive Indices. Road Research Laboratory, Crowthorne, England, Rept. LR395, 1971.
9. The Development and Validation of Attitude, Knowledge, and Performance Tests for Evaluating Driver Education Curricula. Ohio Department of Education, Columbus, 1973.

Publication of this paper sponsored by Committee on Driver Education.

Skill Training for Collision Avoidance

G. Richard Hatterick,* GRH Consulting, Fairfax, Virginia
Richard F. Pain,* BioTechnology, Inc., Falls Church, Virginia

The purpose of this two-phased study was to determine the feasibility of training drivers to acquire the skills needed to avoid critical-conflict, motor-vehicle accidents and to develop the procedures and materials necessary for such training. Basic data were derived from in-depth accident investigations and task analyses of driver behavior. A specification was prepared for curriculum development and performance measurement. A prototype bimodal simulator was developed as a training tool for acquisition of key perceptual and decision-making skills, and a concept was defined for behind-the-wheel training on an advanced driving range that included surrogate vehicles to create critical traffic conflicts. Results of the study indicate that such training is theoretically feasible and, if implemented on a large scale, could result in a substantial reduction of multivehicle accidents.

The study reported here resulted from a decision by a panel of driver-training specialists (1) that none of the advanced driver-training programs appears effective in reducing the large number of critical-conflict accidents. A critical conflict is defined as (a) a conflict between two road users that will result in a collision unless one of the two parties responds correctly, (b) a possibility that a collision can be avoided or ameliorated if one party makes a correct response, and (c) a compressed time interval that precludes recourse to normal driving skills.

The basic purpose of the resulting program was to investigate the feasibility of training drivers to avoid imminent automobile accidents (phase 1) and to develop the methods and materials necessary to accomplish such training (phase 2). This project used a tripartite team: The Institute for Research in Public Safety (IRPS) of Indiana University conducted an in-depth analysis of accident situations (2, 5, 6), the National Public Services Research Institute (NPSRI) of Central Missouri State University (CMSU) conducted task and behavioral analyses of a set of potential accident situations (3), and the URS/Matrix Company directed and synthesized the results of phase 1 (12) and conducted the phase 2 investigations.

DATA

Phase 1 of the study focused on determining the nature and frequency of traffic-conflict accidents, whether conflict-avoidance techniques were available, and whether sufficient accident reduction was possible to warrant the definition and development of a training program. Parallel analyses were conducted by IRPS and CMSU.

Accident Situation Definition

The accident data base used by IRPS was 372 accidents that involved 613 vehicles in Monroe County, Indiana. Four major accident situation categories were defined, and the number of vehicles involved are listed as follows:

1. Group 1.0—degraded vehicular performance (21),
2. Group 2.0—environment or driver-induced emergency (102),
3. Group 3.0—multivehicle collision (488), and
4. Group 4.0—other (2).

Among the 372 accidents studied, there were 115 (31 percent) nonconflict or single-vehicle accidents (groups 1.0, 2.0, 4.0), and the remaining 257 (69 percent) were conflict accidents (group 3.0). Further analysis of the 257 accidents in group 3.0 (488 drivers) revealed 17 major accident situations that were then subclassified into a total of 40 types of conflict situations.

Another situation taxonomy was developed to parallel the in-depth accident analyses and was based on previous driver-task analyses (9) and previously published accident data, i.e., multidisciplinary accident investigations (MDAI) case summaries. After all possible conflict situations in the task analyses were identified, the situations were diagrammed and analyzed to identify additional conflict possibilities and were then categorized and classified. The five basic situations that resulted are as follows:

Vehicle Situation	Definition
Lead	Rapid closure with a vehicle or obstacle ahead
Following	Rapid overtaking by a following vehicle
Intersecting	Approach of two vehicles on an intersecting course, i.e., right angle
Converging	Convergence of two adjacent vehicles
Oncoming	Approach of two vehicles on a (head-on) collision course

The two sets of situation taxonomies, i.e., one analytic and one empirical, were then synthesized, and the relative importance of each was established. Figure 1 shows that, of the nine resulting basic situations, intersection conflicts occur more than twice as often as any other situation.

Conflict Nullification Potential

During the in-depth analysis of the accidents comprising the situation groups, investigators attempted to determine whether the drivers perceived the danger in time to attempt evasive actions as well as whether evasive actions were attempted. In group 3.0, 223 drivers (44.7 percent) did not perceive the danger in time. For all 613 drivers, 259 (42.25 percent) did not perceive the danger until it was too late. This finding supports the original report (5), which concluded that inattention is a major causal factor in accidents, and has interesting implications for driver education, licensing, and performance research.

By applying the definition of conflict developed for this study, we further classified conflict accidents in terms of avoidance probabilities. The result was that 47 percent of conflict accidents were determined to have certain (≥0.9) or probable (≥0.7) potential for avoidance by a driver-induced maneuver. Another 9 percent of the accidents were possible candidates for evasive actions (0.5 to 0.69). Thus, the total pool of accidents subject to analysis (and potential amelioration) in this project is 47 to 56 percent of all conflict accidents (32 to 38 percent of all accidents).

Maneuvering Potential

Both analysis techniques were directed at identifying a maneuver taxonomy. As expected, some form of directional or velocity change can be used to avoid any of the conflict situations. There were 31 usable maneuvers empirically derived (Figure 2), and one additional variation came from the task analysis. All the maneuvers are variations of magnitude, timing, and sequence of steering, braking, or accelerating. In current training programs, neither accelerating nor turning 90° is offered as an avoidance maneuver that is a viable option.

The probability of success (PS) for each maneuver in each situation was estimated by using a rating technique (2). Several findings are of note. A straight-ahead stop was rarely the preferred maneuver in a critical-conflict situation. It is interesting to note the lack of preference for this maneuver. First, any situation in which straight braking will avoid the collision is not considered to be a critical conflict, since straight braking is a normal driving skill, as previously defined. Of course, if there is no place to move, the driver must attempt to brake as effectively as possible. Second, in a conflict, especially converging or intersecting, vehicles may be so

Figure 1. Synthesis of two situation taxonomies.

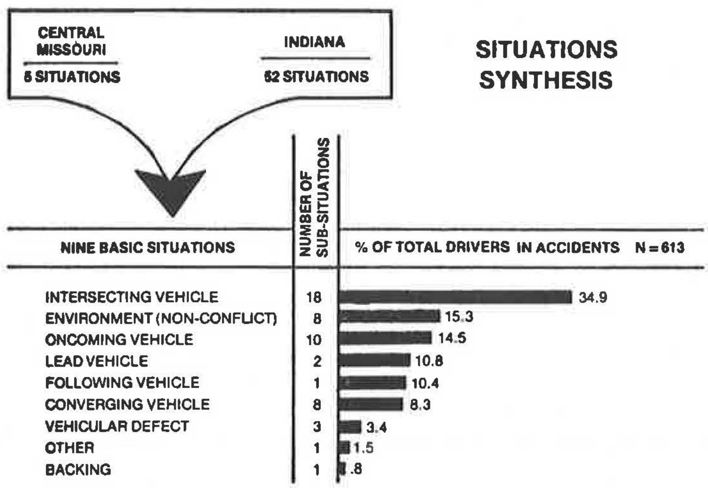
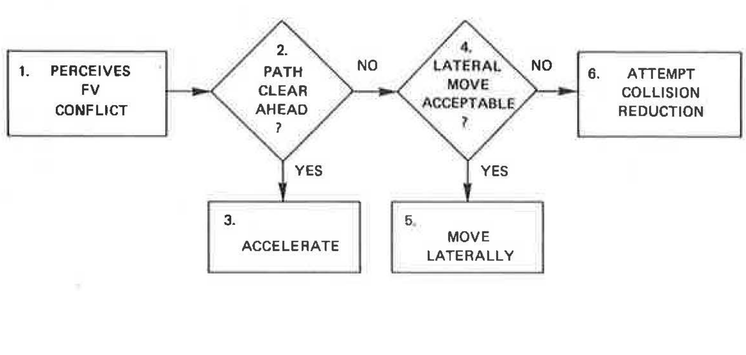


Figure 2. Maneuver taxonomy.

DIRECTION: \ SPEED	0 = Constant	1 = Braking	2 = Decelerating	3 = Combined braking and decelerating	4 = Accelerating	5 = Decelerating then accelerating	INTENT:
0 = Steer straight only	●				●		To continue past object
1 = Steer straight only		●		●			To stop before object
2 = Steer straight then right		●	●	●		●	To continue past object
3 = Steer straight then right		●		●			To stop before object
4 = Steer straight then left		●	●	●		●	To continue past object
5 = Steer straight then left		●		●			To stop before object
6 = Steer right then straight	●	●	●	●	●		To continue past object
7 = Steer right then straight		●		●			To stop before object
8 = Steer left then straight	●	●	●	●	●		To continue past object
9 = Steer left then straight		●		●			To stop before object
10 = Steer straight only					●		To reverse direction

Combinations of direction and speed are expressed as a decimal. Direction is to the left of the decimal, and speed is to the right, e.g., 6.4 indicates to steer right then straight, use acceleration, and continue past object.

Figure 3. Driver behavior in following-vehicle conflicts.



close that braking guarantees a collision. The highest PS of avoidance in such situations may be acceleration. An unresolved dilemma is that, if both drivers respond with this avoidance behavior, the potential benefits will be cancelled. However, with more than 42 percent of the drivers unable to perceive the danger in time to attempt an avoidance maneuver, the likelihood that only one driver would respond by accelerating is very high. Third, this finding does not imply that braking is not crucial to avoidance, but rather that braking must usually be performed in conjunction with some lateral movement. The skill of braking while maintaining steering control is particularly important in light of the finding (2) that 45 percent of the drivers in conflict situations locked up their wheels sometime during their avoidance attempt. Fourth, the empirical analysis included only those attempts that failed, i.e., those attempts that resulted in an accident. There are probably many more near-miss situations in which effective braking did avoid an accident.

These qualifications indicate that the brake-only maneuver will continue to be important in driving, but in many conflict situations it is not the best accident-avoidance technique. Future training must consider the type and emphasis of braking technique to be included, particularly since 38 percent of the accident-involved drivers in conflict situations who do have the time to attempt an evasive maneuver will attempt such a maneuver (steer straight only and brake with intent to stop before object). Another finding of interest was the apparent value of acceleration as an avoidance maneuver. Among the 18 substitutions composing the intersecting situation, there are three situations that can be avoided by straight-ahead acceleration and two by lateral movement combined with acceleration. In the following-vehicle situation, the maneuvers most likely to avoid an accident are accelerating straight ahead or ahead and turning to the left or right.

As anticipated, many of the situations have several maneuvers that are close in their PS ratings. A driver's decision to go right versus left, stop before, or continue by a conflicting vehicle is strongly influenced by the characteristics of the impending collision. Since this variance in constraints is highly specific, it could not be considered in the situation taxonomies. Instead, an environmental constraint or hindrance rating was applied concurrent with the PS maneuver estimate, which resulted in a proportion index for each maneuver in each of the situation categories. A new set of PS maneuvers was calculated to include environmental hindrance. In general, an environmental hindrance to the maneuvers (averaged across situations) is present from 7 to 26 percent of the time. It is not surprising that steering maneuvers, particularly to the left, had the highest hindrance proportions. The implication of this factor is that training will have to produce a more flexible, adaptive capability in drivers if the drivers are to select the best responses in terms of traffic and environmental situations, rather than simple, stimulus-response chains.

Behavioral Requirements

Task analysis and experimental observations were used to derive the behavioral requirements of accident avoidance. Each of the five major situations previously mentioned was analyzed from a behavioral viewpoint, and a flow of behaviors was charted along a time line. Behaviors that were either marginally useful in a compressed time conflict or redundant were eliminated. The result was a catalog of the minimum behavioral and information-processing sequences necessary for avoidance in any of the five situations (Figure 3 shows the behavioral process for one conflict situation). When all situations had been analyzed, behaviors were cataloged and prioritized. While frequency of occurrence is often of interest, location in the behavioral flow and dependence of subsequent behavior on output information from preceding behaviors are more indicative of behavioral significance in successful accident avoidance. Over two-thirds of accident-avoidance behaviors entail information processing that must always occur before any motor response is initiated, and this response is further delineated into perceptual and then response-selection behaviors.

Current accident-avoidance training programs place a heavy emphasis on training driver motor skills; however, these programs offer little or no training in the other areas. Perceptual and response-selection behaviors should receive an increased proportion of the training emphasis; motor-skill training should be performed in a high-fidelity setting that demands use of perceptual cues so that appropriate responses can be selected. Each of the skill types may initially be trained separately; however, at some point, all components will have to be incorporated into the training program so that realistic sequencing, timing, and interacting can be developed. Beyond that, a question still unanswered is what amount of practice, in any of the behavioral areas, is required for an effective and lasting transfer of training to real-world driving. The answer appears to involve achieving valid performance criteria, rather than determining the needed amounts of training time.

Perceptual Skills

Four perceptual skills were found to be involved in each behavioral area. In terms of frequency of use and criticalness of accuracy, judging the intervehicle closure is of paramount importance and is an element in all five conflict situations. Second is judging the clearance between the driver's vehicle and another vehicle or object. Third is determining the direction of vehicle motion. (This seems rather obvious, but in certain situations it may be difficult to determine.) Fourth is perceiving the surface condition.

Response Selection and Motor Responses

Six basic response selections were identified and are given below:

1. Braking versus moving laterally,
2. Moving right versus moving left,
3. Accelerating versus braking,
4. Choosing a braking technique,
5. Moving from or toward a conflicting vehicle, and
6. Choosing among types of collisions.

It was found that all of the six choices did not have to be considered in every conflict situation. The accident data also suggest that drivers will first pick their path and then change their velocity. The task analysis indicates that the sequence of choices should vary, depending on the situation, but the strategy to be used in making a response selection is not yet known.

The motor skills (responses) are similar to those already well known in accident avoidance training. The basic responses for car control are evasive steering, rapid braking, rapid accleration, skid recovery, and impact recovery. The ancillary responses are vehicle oriented—observation and signals—and body position—front, rear, and side impact. However, evasive steering includes the potential use of a 90° turn, which requires a somewhat different use of controls.

Learning Perceptual and Response Selection

The ability of drivers to acquire the motor skills for accident avoidance has been demonstrated; however, such a demonstration for relevant skills for perceptual and response selection is not available. Therefore, by using a limited capability-fidelity simulator and motion pictures of two conflict situations, a small number of subjects were pretested, trained, and then posttested. The skills that indicated an evidence of learning include

1. Perception—In intersecting-vehicle conflicts, the subjects learned to distinguish between an accelerating and a braking situation by using cues of position, distance, and change in viewing angle.
2. Response selection—In lead-vehicle conflicts, the subjects learned to select a braking or steering response that is based on a complex response-selection process.
3. Motor response—In lead-vehicle conflicts, the subjects learned to carry out quickly the observational responses that are needed to detect the presence or absence of a vehicle or vehicles that follow closely or are in adjacent lanes.

The skills that did not appear to be learned through use of the simulation process include

1. Perception—In lead-vehicle conflicts, the subjects could not judge closure with the lead vehicle, which was primarily due to the lack of speed cues.
2. Motor response—In lead-vehicle and intersecting-vehicle conflicts, the subjects were unable to properly perform evasive steering and modulated-braking responses when these responses had to be carried out concurrently with perception, response selection, and observational responses.

Potential Benefits

A benefit analysis was made by calculating the potential reduction in accidents that would have been realized if one of the drivers involved in each traffic-conflict accident had correctly implemented an avoidance maneuver that had a high PS for that conflict situation. The average PS of avoidance was calculated for each accident situation category by identifying the two maneuvers for each contributing situation that had the highest PS and by averaging them for the accident situation. The resulting PS was then multiplied by the number of instances within the accident situation category where at least one of the involved drivers perceived the danger in time to attempt an evasive maneuver. This determined the potential number of accidents within that accident situation category that could have been avoided. The reductions were then summed for the composite accident category (Table 1).

Since it is not realistic to assume that training would always enable a driver to correctly choose and apply the highest PS maneuver, levels of 25 and 50 percent training effectiveness were selected for analysis purposes. Table 1 gives the percentage contribution of each accident category to potential accident reduction. It is unlikely that training effectiveness will ever be greater than 50 percent; therefore, the maximum program effectiveness would be 10.4 percent reduction in all accidents. This situation does not consider the environmental hindrance variable that ranged from 6 to 26 percent, or the unknown amount of benefit to be gained among single-car accidents. Considering all these factors, a realistic estimate of accident reduction potential that results from accident-avoidance training appears to be 5 to 10 percent of all accidents. In 1974, that would have meant avoiding between 780 000 and 1 560 000 accidents. Based on the 1973 and 1974 accident data, the following is the accident-reduction potential for 50 and 25 percent levels of training effectiveness.

	Accident Reduction		
Description	Number Avoided	Percent Reduced	Cost Reduced ($)
1973			
50 percent level	1 726 400	10.4	2 100 800
	1 600 000	10.0	2 020 000
25 percent level	863 200	5.2	1 050 400
	830 000	5.0	1 010 000
1974			
50 percent level	1 622 400	10.4	2 007 200
	1 560 000	10.0	1 930 000
25 percent level	811 200	5.2	1 003 600
	780 000	5.0	965 000

Greater accident severity was slightly overrepresented in the Indiana University data because of the MDAI system constraints and the nature of the data collection process. However, there appears to be no reason to suspect that only less severe accidents will be avoided as a result of training. For comparison purposes, as given above, a uniform cost per accident was assumed based on data from the National Safety Council (10, 11). Based on the analytic, empirical, and benefit analyses presented above, there was adequate justification and promise to continue the program into phase 2.

DEFINITION AND DEVELOPMENT OF TRAINING PROGRAM

Phase 2 of the accident-avoidance, skill-training project (AAST) included defining the course objectives, preparing the curriculum and performance measurement specification, and developing some critical components of the envisioned training programs.

Definition of Training and Testing Requirements

In this task, a specification was developed to enable accident-related task analysis material to be transformed into a driver-training curriculum. The topics addressed by specification are as follows:

1. Instructional objectives
   a. Knowledge
   b. Skill
   c. Effective
2. Material requirements
   a. Student aids
   b. Teacher aids
3. Training support requirements
   a. Personnel
   b. Standard training equipment
   c. Special devices, e.g., driving simulators
   d. Facility and resource needs and essential exercise areas

4. Prerequisite trainee capabilities quantitatively specified for

    a. Training program
    b. Training event or maneuver within the program

5. Measurement devices and instruments

    a. Skill
    b. Knowledge

6. Administration of training and testing

    a. Guidelines
    b. Manuals
    c. Instructional and testing conditions

Since each conflict situation required the driver to implement a slightly different arsenal of avoidance skills (perception, response selection, motor response) to achieve conflict nullification, the instructional approach selected was based on conflict characteristics, rather than skills per se.

The training program concentrated on accident situations that contributed significantly to accident experiences by deleting the converging-vehicle situation from consideration. Of the five basic conflicts, those that involved converging vehicles occurred least frequently. In addition, the characteristics of the situation differed primarily in terms of path angles from the intersecting, lead, and following-vehicle conflicts. The final selection of conflict situations to be treated included a decision to split the intersecting-vehicle situation into two discrete topics characterized by the threat versus obstacle nature of the conflict. (Note that the other three conflicts are either a threat to the driver or an obstacle to the progress of the driver's vehicle.)

Integrating the five conflict situations with the skills to be trained and the training techniques to be employed (Figure 4) required use of a modal-submodal format in which each of the five conflict situations composed a module of the training program. The skill factors and training modes were integrated at the submodal level.

To the five conflict-situation modules were added two others modules: (a) one to orient the student to the course and to develop advanced vehicle-handling skills, and (b) another to administer a comprehensive performance test. Figure 5 shows the structure of the training program, together with the factors that lead to this format. Figure 6 shows how the modal format was extended to the submodal level, based on the mode of instruction. One of the attributes of this format is flexibility of administering the program. Figure 7 shows how the nominal training program can be modified, in terms of sequence and length of instruction, to accommodate local resources and requirements. The specification (4, 7) that resulted from these efforts must still be considered preliminary because it has not yet been validated through conduct of a training program.

Requirements are set forth in the specification that are expected to assure that the training course will aid student drivers, who face conflict situations in executing ing workable accident-avoidance strategies. Avoidance strategies to be taught and learned are, or are adaptations of, those recommended by Indiana University (2) for the conflict situations defined. Actually teaching the execution of successful strategies will be accomplished by classroom instruction, simulation practice, and driving range practice. Classroom instruction will be used solely to impart knowledge and establish in the student the proper subconscious set considered requisite to the subsequent acquisition of vital perceptual, decision-making, and operational skills. Both simulation and driving range practice will be used to extend and internalize the knowledge gained in the classroom to develop the three vital skills.

Perceptual skills have sensory and cognitive components. Hence, both components must be developed if the driver being trained is to be able to detect and recognize the presence of conflict. Thus, driving simulation and two independent levels of driving range practice sessions were used to accomplish this objective.

During the beginning practice on the driving range, the driver develops an ability to modulate vehicle control inputs during extreme maneuvers. These maneuvers will allow the driver to maintain or regain a safe car orientation and provide a first interaction with perceptual realism. Descriptively, these maneuvers include practice of advanced vehicle-handling maneuvers, e.g., skid recovery, slalom exercises, and lane switching. The perceptual skills learned will contribute to the driver's ability to track vehicle orientation in a full-scale static environment.

For multi-vehicle-conflict situations, the student is subjected to equipment familiarization sessions and conflict-nullification training in the simulator. The visual feel of entering various conflict situations is experienced by the student in a film presentation of various traffic conflicts. The student drives the simulated car by using the vehicle controls provided to negate any conflict encountered. Although the simulation lacks one-to-one perceptual realism, student drivers should learn to

1. Recognize some of the significant perceptual antecedents to conflict situations,
2. Perceive and extrapolate the relative locations of other objects, and
3. Select and execute appropriate evasive maneuvers based on acquired visual data.

During the more realistic advanced sessions on the driving range, the rudimentary skills gained during the simulation practice should be forged into operational skills that are more useful in an actual driving environment. When the student executes accident-avoidance strategies on the range, he or she will learn to integrate the simple operational skills already learned into effective, complex control scenarios that will be appropriate to the dynamic threats the student is facing.

As the student is developing perceptual and operational skills through simulation and range practice, he or she will also be developing decision-making skills. The simulation and advanced practice sessions on the driving range will be beneficial for this purpose. Both of these training techniques place the student in multi-moving-body conflicts in which a complex array of perceptual data are sampled and integrated. The driver must extrapolate the positions of all moving bodies with respect to the fixed environment, recall car-maneuvering capability, and decide on the appropriate control inputs. This task must be done repeatedly, until the faced conflict is nullified.

Simulator Definition and Development

A key element of the proposed curriculum for AAST was the availability of a suitable simulation system. The need for a driving simulator that could be used for training students to acquire collision-avoidance skills was established and is based on the postulated economic

Table 1. Accident reduction potential by accident category.

Accident					Percentage of Reduction at Effectiveness Level					
					50 Percent			25 Percent		
Category	Conflict Situation Number	Number	Number Perceived in Time[a]	Potential Number Avoided	Accident Category	Total Multivehicle Conflicts	All Accidents	Accident Category	Total Multivehicle Conflicts	All Accidents
Head-on	3.6; 3.7	39	34	18.10	23.2	3.7	2.4	11.6	1.8	1.2
Rear-end	3.8; 3.9	60	48	25.43	21.2	5.2	3.4	10.6	2.6	1.7
Intersecting vehicle	3.1; 3.2; 3.3; 3.4; 3.5	113	91	24.28	10.8	5.0	3.2	5.4	2.5	1.6
Adjacent vehicle	3.10; 3.11; 3.12; 3.13	27	17	7.44	13.8	1.5	1.0	6.9	0.8	0.5
Other multivehicle	3.14; 3.15; 3.16	7	7	2.31	16.5	0.4	0.3	8.2	0.2	0.2
Total multivehicle conflicts[b]		246	197	77.56		15.8	10.3		7.9	5.2

[a] Number of accidents in which one driver perceives the danger in time to attempt an evasive maneuver.

[b] Excludes some multivehicle accidents that involved other contributing factors.

Figure 4. Factors to be integrated into accident-avoidance training and testing curriculum specification.

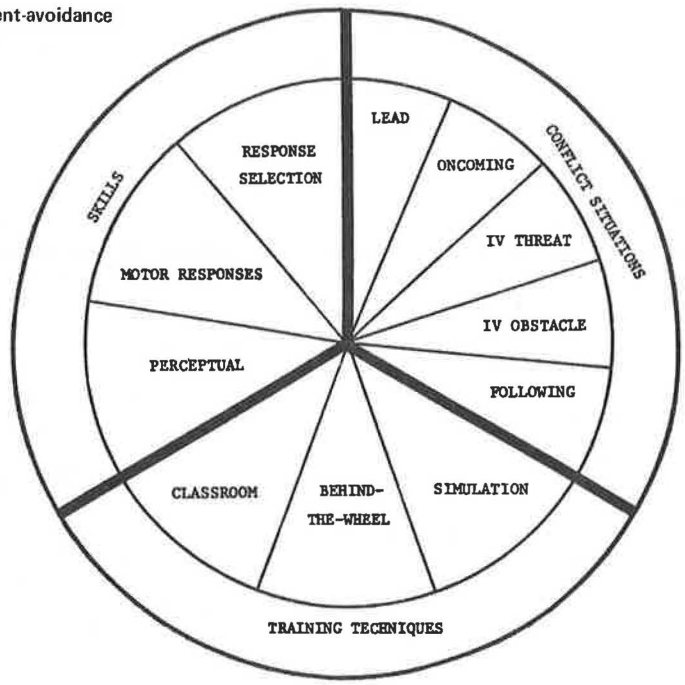


Figure 5. Modal organization of training program.

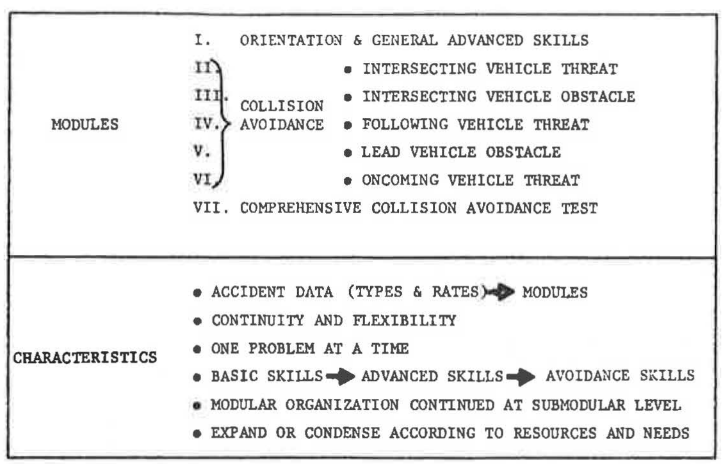


Figure 6. Submodal organization of training program.

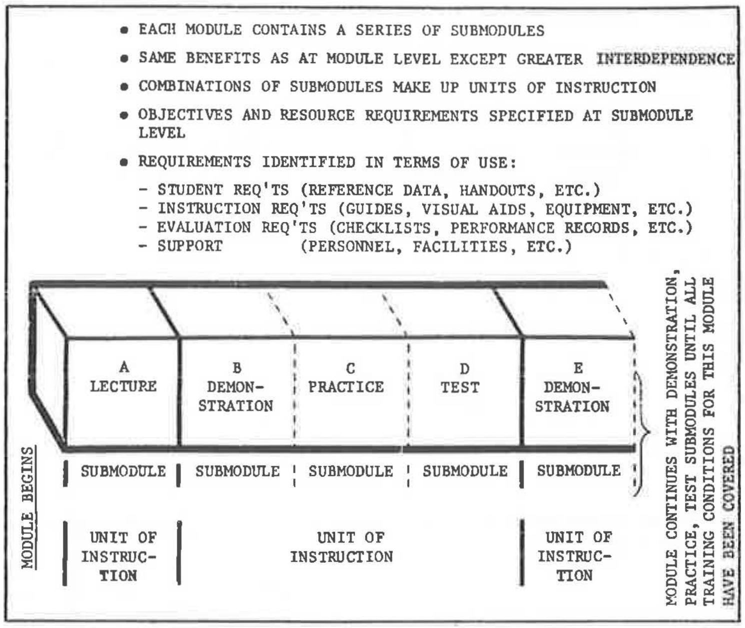
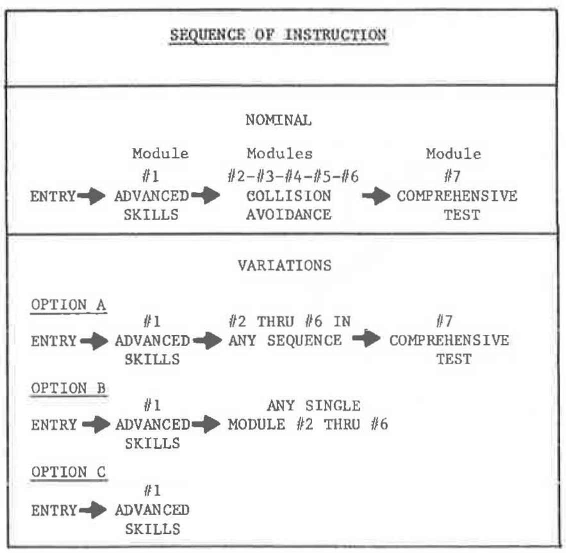


Figure 7. Flexibility of instruction sequence and length.



requirements of an operational AAST program. With such a program, large numbers of students would be involved in many repetitions of many different situation-learning trials. It was judged impractical to attempt such an operational program by using only behind-the-wheel training, if a suitable simulation method were available as a supplement or a substitute.

It was postulated that, to be effective, any approach selected would have to equip the student drivers to

1. Predict the specific point of impact of two vehicles,
2. Determine viable roadway and roadside vehicle-placement alternatives,
3. Select an appropriate conflict-nullification strategy, and
4. Execute the strategy selected.

Many of the simulation and driving range practice techniques reported in the literature are extremely realistic, in some respects. Unfortunately, none provided the needed combination of interactiveness and one-to-one perceptual fidelity at a reasonable cost. A training technique had to be defined that would provide these two qualities. Since real-world driving provided these two qualities, the question to be answered was, How can we safely replicate traffic conflicts between an automobile under the control of a (student) driver and some other automobile (not under student control)?

It was hypothesized that there might be a primary, trainable key skill required to nullify multivehicle conflicts that was not being addressed in existing training programs and that would not be dependent on those characteristics of existing methods of film simulation, which were found to be unsatisfactory. Further evaluation of the accident, task, and behavioral analyses revealed that, for the training of conflict-nullification skills to be feasible, students would have to learn to recognize the existence and the nature of an impending collision. In turn, this recognition would require the ability to extrapolate the velocities of the involved automobiles and predict the point of impact. Identification of a way to develop driver skills for extrapolation of velocity became the principal requirement for simulator definition. By changing the training emphasis to develop specific but limited skills, the need for realistic perceptual cues was diminished. The basic design requirement was for a display that accurately communicated to the student the velocity of two automobiles. One of the automobiles on that display would have to be under the student's direct control. The other automobile would be controlled by the instructor. Most film presentations and the other two-dimensional, perspective-view generators were unacceptable because of inherent velocity distortion characteristics. These factors resulted in the identification of the need for a two-dimensional, plan-view, iterative trainer. By using such a training device, the velocity components were able to be communicated to the students.

The simulator that was developed is bimodal because of the two distinctly different types of presentations that are used for driver training. First, through-the-windshield movies of the roadway scene and the events were projected on a display immediately in front of the driver. This portion of the simulation is only used

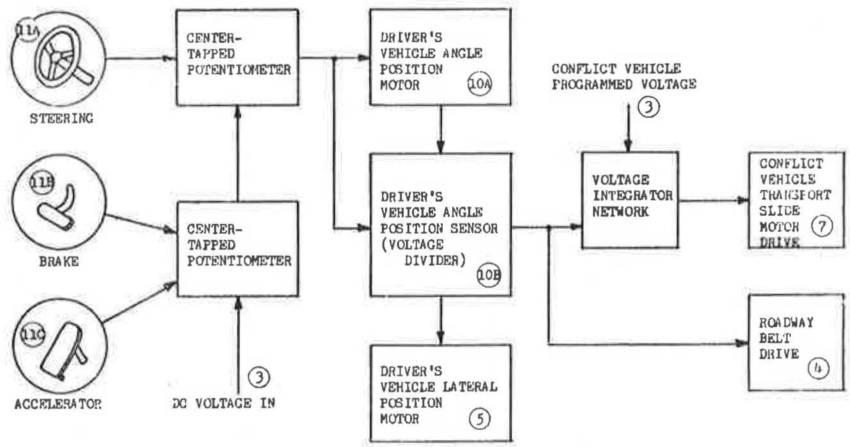


Figure 8. Operational layout of bimodal simulator.

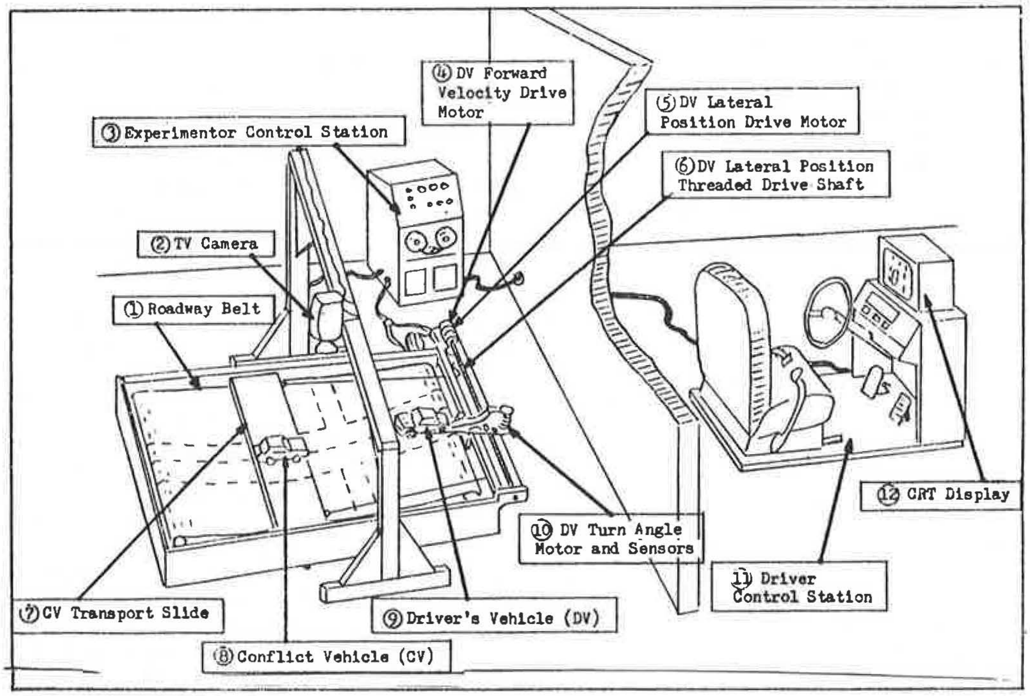


Figure 9. Functional flow of plan-view generator.

during the early training trials. The movie presentation is used to impart a feeling for the perceptual antecedents of collisions, and to stage the setting for the impending interactive session. No subject control over the unfolding events being viewed could be exercised. At the point in the simulation where subject control is desired, the first (movie) presentation is terminated and the second is activated. This second mode consisted of a plan view of the two vehicles engaged in conflict. At this point, the simulator is partially under the student's control, and interactive feedback is provided for the student. Both the perspective view of the roadway scene and the plan view of the unfolding conflict situation are displayed on a television screen that is installed before the subject is in the remote driver's station.

The bimodal-simulator configuration, shown in Figure 8, has four major subsystems:

1. A plan-view generator for simulating the traffic conflicts,
2. A driver-control station,
3. An instructor-control station, and
4. A video system.

The plan-view generator portion of the system can use either computer-generated graphics or, as was done for purposes of prototype demonstration, can be electromechanical. The principal components of the electromechanical plan-view generator are scale-model vehicles, a moving roadway belt, a transport slide mechanism for the conflict vehicle, and the motors and sensors needed to position and move the other components. The instructor can exercise control over all components from the experimentor control station and can permit the student to control the driver-vehicle parameters.

Figure 9 shows the functional flow of driver-control inputs to the plan-view generator components. The brake pedal and the accelerator pedal operate a single center-tapped potentiometer to ensure that, when those two controls are in the null position, the plan-view generator automatically effects a driver-vehicle velocity of of 56 km/h (35 scale mph). This control assures that the scheduled conflict results in a precisely defined accident, barring any subject control input.

If the subject imparts any steering control to the vehicle, an associated voltage is sent to the driver-vehicle angle-position motor, which begins to change the angle of the vehicle in respect to the longtitudinal axis of the roadway belt. This change is at a rate proportional to the angle of the steering wheel as well as to the position of the accelerator and brake pedals. As the vehicle changes its angular orientation, the angle-position sensor (mechanically coupled to the vehicle-position shaft) drives the accelerator or brake pot output voltage, according to the sine and cosine of the vehicle's angle.

The electromechanical, plan-view, conflict generator used is capable of moving the vehicle along subject-ordered paths at subject-chosen rates of speed. Further, by internal mechanisms, the generator is capable of incorporating the movements of a conflict vehicle. Details of the configuration and operating characteristics are given elsewhere (7). The video portion of the system has the following primary components: a closed-circuit television camera, a video tape recorder, and a 22.8-cm (9-in) television screen. Video tapes having prerecorded sequences of the filmed perspective-view conflicts are used in both the interactive and noninteractive portions of the training session. The sequence begins with the prerecorded segments by having the training instructor depress the play switch on the video tape recorder. When the subject's interactive participation is to being, the instructor depresses the record controls on the recorder and activates the plan-view generator. Thus, not only is the plan view of a particular developing conflict presented to the student by the television camera, the recorder, and the closed-circuit television camera, but the vehicle-movement activity that takes place on the generator during each learning trial is also recorded for future reference, analysis, and student feedback.

Advanced Driving Range

The concept of an advanced driving range stems from the need for collision-avoidance training to be as real as possible to develop the perceptual, cognitive, and operational skills needed for efficient accident-avoidance behavior. The following alternatives that appeared to be available to satisfy this need.

1. Conduct training in real vehicles in real traffic conflict situations—This approach was rejected for obvious reasons of student, instructor, and bystander safety; astronomically high property damage costs; and an inability to control the frequency or characteristics of the traffic conflict.
2. Conduct training in real vehicles on a closed driving range—While this approach does allow control of the training situation, the safety and cost factors would not be sufficiently ameliorated to be practical, leading to its rejection.
3. Conduct training in a high-fidelity simulator (6d.f.) in which all real-world parameters are faithfully reproduced—Such simulators can be built, as we know from the experiences of the National Aeronautics and Space Administration and the U.S. Air Force, at great expense. Even with the financial resources that have supported the development of such simulators, these are still subject to severe criticism regarding inadequacies in simulating real situations (8). However, assuming, that simulators could be built that satisfied all perceptual and motor requirements, the costs of manufacturing in sufficient quantities—and with the associated facility and computer support requirements—to make them available for training the general driving population nationwide resulted in the dismissal of this alternative as impractical.
4. Conduct training in some other way that faithfully reproduces the significant psychomotor parameters, reduces the hazards to an acceptable level, is amenable to training staff control, and can be accomplished at a reasonable cost—This alternative was selected and defined as the advanced driving range concept.

The characteristics of the training concept for the advanced driving range were defined as follows: Collision-avoidance training would be conducted on an automobile driving range where pedestrian and other motor-vehicle traffic can be eliminated and where there are few, if any, surface obstructions. Such facilities already exist in many parts of the country, and where they do not, the major acquisition cost is for open land. Even this cost can be reduced by locating suitable, existing roadways and closing them off to traffic while training is in progress. In this concept, the student driver will operate a standard automobile, either compact or midsize. Automobiles currently in use for driver education would be entirely suitable. The final requirement of a controlled, safe, real-collision situation can be satisfied by providing a low-mass, remotely controlled, surrogate vehicle in a real-vehicle size. This surrogate vehicle is the key to the advanced driving range concept and fills the role of the conflict vehicle discussed in the section on the bimodal simulator.

The surrogate vehicle should approximate the size, shape, and appearance of a typical subcompact car, but it must present little in the way of hazard to student drivers and must be damage-resistant to impact by a full-size automobile. Finally, it must be able to execute a preestablished series of maneuvers at the distretion of the training instructor. For practical purposes, this solution safely provides all the training advantages of the real-world conflict, i.e., such a vehicle could be used to engage the student in those conflicts identified during phase 1. Moreover, the experience of those conflicts would be interactively and perceptually real. The student driver could actually crash into the other car without sustaining injury or inflicting property damage, if he did not successfully nullify the presented conflict. In fact, except for not eliciting the same degree of subject-perceived risk and a debilitating startle response, the experience on an advanced driving range would be precisely real. Thus, from a face validity standpoint, a training program such as that would provide the means for answering the important research question: Is it feasible to develop an effective accident-avoidance training program for critical conflict situations? Because this is the case, the driving range practice exercises that should be employed have already been defined in the curriculum specification, even though the feasibility of the surrogate vehicle has not yet been demonstrated. The majority of any future work in this area should be directed toward preparing instructional materials, supplying appropriate program support equipment, and providing operational surrogate vehicles.

CONCLUSIONS AND RECOMMENDATIONS

The principal products of phase 2 are as follows:

1. The accident conflict and maneuver taxonomies developed during phase 1 should be verified so that the basis of a collision-avoidance, skill-training program can be formulated;
2. A comprehensive curriculum and performance measurement specification that is both sufficiently detailed and flexible should be developed before the training

program development and adaptation to local needs and resources are compiled;

3. The bimodal simulator that is to be used for training drivers in key collision-avoidance skills should be defined, developed, and preliminarily tested;

4. The method for in-vehicle training in collision-avoidance techniques that satisfies requirements for safety, reality, low cost, and training staff situation control (the advanced driving range concept) should be defined; and

5. The research problems that must be addressed before an addident-avoidance, skill-training program can become a reality should be identified and, if possible, resolved.

The principal conclusion reached during this program is that accident-avoidance skill training is necessary, is feasible, and can be accomplished at a reasonable cost. The products of this study, in both phases 1 and 2, are believed to provide the basis for continuation of this development program area under the continuing sponsorship of the National Highway Traffic Safety Administration.

ACKNOWLEDGMENTS

This project was supported by the National Highway Traffic Safety Administration. All conclusions and recommendations are our responsibility.

Special appreciation must be expressed for the guidance and patience of Herbert R. Miller, who was the contract technical manager for this study and without whom the results achieved would not have been possible.

We also wish to acknowledge the contributions of James R. Bathurst, who conceived and developed the bimodal simulator and the advanced driving range training concepts; A. James McKnight, who directed the portion of the study accomplished by Central Missouri State University; and Ronald W. Drahos and John R. Treat, who directed the accident data analysis performed by the Institute for Research in Public Safety of Indiana University.

REFERENCES

1. Workshop on Advanced Driver Education Techniques. Proc., Office of Driver Performance Research, National Highway Traffic Safety Administration, Jan. 21, 1972.
2. An Analysis of Emergency Situations, Maneuvers, and Driver Behaviors in Accident Avoidance. Institute for Research in Public Safety, Indiana Univ., Final Rept., Feb. 14, 1975.
3. Collision Avoidance Training: Analysis of Requirements Imposed Upon Drivers by Collision Avoidance Situations. National Public Services Research Institute, Central Missouri State Univ., Final Rept., Feb. 1975.
4. G. R. Hatterick. Preliminary Curriculum and Performance Measurement Specification for Accident Avoidance Skill Training and Performance Testing. URS/Matrix Co., Falls Church, Va., Rept. PR-0530-19, Sept. 12, 1975.
5. Tri-level Study of the Causes of Traffic Accidents. Institute for Research in Public Safety, Indiana Univ.; National Highway Traffic Safety Administration, Repts. DOT-HS-801-334 and DOT-HS-801-335, Vols. 1 and 2, Aug. 1973.
6. Tri-level Study of the Causes of Traffic Accidents. Institute for Research in Public Safety, Indiana Univ.; National Highway Traffic Safety Administration, Interim Rept. 2, Vols. 1, 2, and 3, June 1975.
7. G. R. Hatterick and J. R. Bathurst. Accident Avoidance Skill Training and Performance Testing. URS/Matrix Co., Falls Church, Va., Final Rept; National Highway Traffic Safety Administration, Rept. DOT-HS-801-852, March 1976.
8. C. O. Hopkins. How Much Should You Pay for That Box? Human Factors, Vol. 17, No. 6, Dec. 1975.
9. A. J. McKnight and others. Driver Education Task Analysis. Human Resources Research Organization, Alexandria, Va., Vols. 1, 2, 3, and 4, 1970.
10. Accident Facts. National Safety Council, 1975.
11. Accident Facts. National Safety Council, 1974.
12. R. F. Pain. Accident Avoidance Skill Training and Performance Testing. URS/Matrix Co., Falls Church, Va., Rept. PR-0530-09, April 1975; National Highway Traffic Safety Administration.

Publication of this paper sponsored by Committee on Driver Education.

**Messrs. Hatterick and Pain were with URS/Matrix Company, Falls Church, Virginia, when this research was performed.*

System-Safety Techniques Useful for Transportation Safety

Michael Horodniceanu, Edmund J. Cantilli, Martin L. Shooman, and Louis J. Pignataro, Department of Transportation Planning and Engineering, Polytechnic Institute of New York

This paper reviews existing system-safety techniques in terms of their applicability to the current transportation structure, status, and available data; their ease of comprehension; and their usefulness in reducing accidents and fatalities. The two techniques of failure mode effects and criticality analysis and fault-tree analysis are reviewed, explained, and modified for use in transportation safety studies. When applied at each level or activity cycle of a transportation system, these two techniques provide safety specialists with tools that lead to concern for safety at every stage of a project from conception through facility operation. The cohesive approach that is suggested by the concept of system safety is well-suited to the needs of transportation safety. As a methodology, system safety must be adopted and its technical and managerial analyses applied at the modal facility level.

Currently, transportation safety is a field of activity in disparate parts, many of which are not necessarily interrelated, interdependent, or mutually helpful for cohesively tying transportation safety efforts. The integration of all safety-related activities is facilitated by using the systematic, technical-managerial approach to safety that is known as system safety. This approach was initially developed by the military (1, 2) and National Aeronautics and Space Administration (NASA) (3), and is currently being proposed for adoption by the transportation industry.

The system-safety approach is intended to regularize and order safety considerations from the earliest stages of concept formulation through design, testing and evaluation, construction, training, certification, and operation and maintenance. System safety is derived from system-analysis techniques that have been devised and used over the years to maximize system design and operating objectives. The intended use of these techniques has been to enable decision makers to reach correct conclusions by using an orderly process of data collection, modeling, analysis management, and evaluation.

System-safety procedures require a logical examination of all elements of a system, i.e., identifying all possible sources of accidents. The analysis does not end with the identification of system failures; it estimates the probability of accident occurrence and points out the options available for eliminating these occurrences. In addition to safety analysis, system safety includes a set of managerial, contractual, manufacturing, testing, and operational procedures that help improve the decision-making process regarding the elimination of failures. Thus, the need to identify, at the earliest stages of design, all possible elements of combinations of causes that might contribute to a failure of the system led to the development of a set of formalized procedures (system safety) for safety analysis. Terms like safety systems and combinations thereof are frequently used out of context or are referred to from different points of view. For uniformity, these terms are clarified and defined as follows:

1. Safety is freedom from those conditions that can cause injury or death to personnel, or damage to or loss of equipment or property;
2. A system is a composite of controlling contingencies at any level of complexity of operational and support equipment, personnel, hardware and software, and procedures that, used as an entity, are capable of performing or supporting an operational role;
3. A system-safety methodology is a repertoire of tools and techniques that are used to obtain an optimum degree of safety within the constraints of operational effectiveness, time, and cost; and
4. The state of the system is attained through specific application of system-safety management and engineering principles throughout all phases of system-activity cycles (Figure 1).

TRANSPORTATION PROGRAM FOR SYSTEM SAFETY

A transportation program for system safety should follow the phases of the transportation-activity cycle (TAC). First, there is a concept formulation stage, which is the planning period for determining the location of a transportation facility, its characteristics and mode, and its capacity and purpose. This stage is followed by a preliminary design in which alignments may be set and some details of the design and capability are set. The engineering design is the stage in which all details are set down. Production or construction may involve the guideway or the vehicles of a given system, and, finally, operation, and maintenance represent the ongoing phase of a transportation facility.

In the military and NASA, disposal of an entire system is a distinct phase in the life cycle of a weapons system or a space program; but, in public or private transportation, it is rare that an entire system is disposed of. Generally, the systems are phased and and replaced. At any rate, feedback from each phase, and especially from the operating phase, to the planning or conceptual phase is essential to improving the existing and future systems.

The primary function of such a program is to assist management in their attempt to achieve the basic safety goals and objectives of the system. The preparation of a transportation system-safety program plan (TSSPP) is the backbone of a systematic approach to the problem. The development of such a plan is usually divided into two basic phases: (a) preparation of a preliminary TSSPP and (b) preparation of a final TSSPP.

The preliminary phase is primarily a managerial tool for setting forth the safety-planning procedures. The following are some of the basic points to be developed under such a management plan:

1. Define the system;
2. Set safety goals and objectives;
3. Determine organizational structure and responsibilities;
4. Identify, in preliminary fashion, the hazards and how to control them;
5. Define and describe scheduling and review procedures (establish milestones);
6. Describe methods for evaluating and monitoring performance; and
7. Define data base and documentation requirements and procedures.

The system definition should not be limited only to central elements, but should also include an identification and definition of subsystems and internal and external elements that might have an effect on the system.

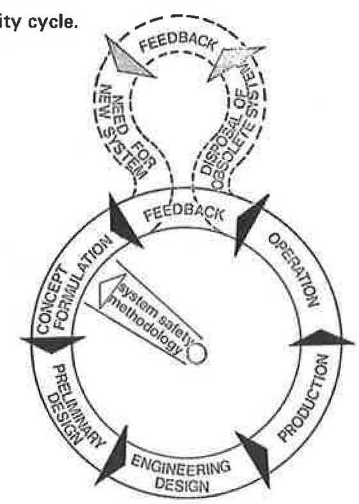
Specific safety goals and objectives should be established to give a safety program a definite direction. These objectives should cover both short- and long-range goals. Some questions that must be posed and answered at this level are as follows: What level of safety is acceptable, and what level of safety is achievable within the given constraints?

Since safety is sometimes overlooked or treated only as an afterthought, sufficient managerial visibility on the topic is a must. This visibility will ensure that the next step is to determine the optimum location of the safety group within the organizational structure and to select and designate qualified personnel by assigning responsibilities respectively.

In addition to having knowledge about the system, the analyst should enter into a preliminary hazard analysis. The purpose of such an analysis is to help develop design requirements that are used in the conceptual phases of system development. Data and experience acquired from older, analogous systems should also be employed in determining preliminary hazards. Milestones should also be established to ensure effective and timely review and modification of the system-safety objectives. Milestones are formally designated points in a program that are chosen because of their prominent significance. Usually, milestones are identified as crucial points in a program where progress is assessed and decisions are made.

A description of methods to be used for the purposes of evaluating and monitoring the effectiveness and per-

Figure 1. Transportation-activity cycle.



formance of the program should follow. A data base should be established, and procedures for data collection and analysis should be defined. A preliminary system-safety program plan also uses elements of program management to ensure the accomplishment of the systems safety tasks. These tasks include identification of the system-safety requirements and planning and organization of the efforts directed toward the safety objectives.

Thus, the final version of the TSSPP is a document with a technical and engineering content that is more developed than in the preliminary TSSPP. A checklist of requirements for a system-safety program, as used in the military and industry (4, 5), is as follows:

1. Purpose and scope
2. Applicable documents (only documents cited in the plan text)
3. Safety organization

   a. Relation to total organization
   b. Organizational array
   c. Responsibilities
   d. Interfaces

4. Safety tasks to be completed

   a. Criteria development
   b. Analyses
   c. Design (program review participation)
   d. Contractor (subcontractor requirements)
   e. Reporting
   f. Documentation
   g. Planning
   h. Evaluations

5. Methods for accomplishing safety tasks

   a. Criteria development, documentation, and monitoring
   b. Analysis technique
   c. Other program activities

6. Schedule for task completion (keyed to major program milestones)

The evaluation of the safety program should be performed to assure compatibility with stated goals and objectives. Sometimes such assessments may lead to realignment of the program or redefinition of the goals.

Once the boundaries of the system have been defined, possible hazards identified, and objectives established, analytical techniques are employed to analyze the system and data regarding failure roles, repair roles, and probabilities and environmental conditions collected for the analysis. There are many analytical techniques available for hazard and risk evaluation and some of these include failure mode effects and criticality analysis (FMECA), fault-tree analysis (FTA), reliability analysis, risk analysis, procedure analysis, human factors analysis, and task analysis.

ANALYTICAL SAFETY TECHNIQUES

The analytical techniques described below should be used in the early stages of the system-development process (even if they are based on scant information) and updated at key milestones when further details and data become available. Although several techniques were previously mentioned, the purpose of this paper is to illustrate and analyze the merits and demerits of two analytical techniques that lend themselves to the analysis of safety-related problems: FMECA and FTA (6, 7).

Failure Mode Effects and Criticality Analysis

Failures can be classified in many ways, depending on the specific object of the analysis. In some instances, failures are classified according to repairability or repair time; in other instances, they are classified according to the severity of effect on safety in a system (e.g., whether the result is a fatality or an injury). Different failure modes arise through different failure mechanisms that exhibit different characteristics; consequently, different types of corrective actions are required to minimize the probability and severity of an accident. Thus, it is implied that a component may exhibit several different failure modes in that each mode is characterized by its own failure rate and set of failure mechanisms; therefore, each failure should be considered individually, and all consequences of the given failure should be analyzed accordingly.

At an early stage in system development, when only the broad concepts of system operation are known, the concept of failure modes allows for the performance of a safety analysis, which provides a basis for later studies.

FMECA is initially constructed and periodically updated to reflect changes and improvement in design and application. These steps are necessary for evaluating the various alternatives during the early design stages. FMECA should be performed or updated at the following major milestones:

1. Concepts formulated and alternatives selected,
2. Preliminary design and planning of system completed,
3. Detailed subsystem designs completed, and
4. Design improvements introduced.

The basic questions to be answered in FMECA are as follows:

1. How can each component conceivably fail?
2. What mechanisms might produce these modes of failure?
3. If a failure does occur, what could be the effects?
4. What is the severity (criticality) associated with a given failure?

Once the analysis is completed, it will shed light on two important aspects: (a) the manner in which the failures can be detected, and (b) the existence of inherent provisions in the system to compensate for the effects of a failure.

Before an actual FMECA is performed, the following preparatory steps are required.

1. Define the system, its boundaries, and its mission(s);
2. Describe the operation of the system;
3. Identify failure categories; and
4. Describe the environmental conditions.

The degree to which the preparatory steps are performed depends on the complexity of the system that is being studied and the experience that one has with similar systems. The more complex the system, the greater the need to carefully define it. The original FMECA was extended to suit various applications, and the modifications are reflected in the titles. However, the fundamental technique remains unchanged. The following information is required for performing FMECA:

1. Functional diagrams, schematics, and drawings of each subsystem for facilitating the determination of interrelations;
2. A complete list of components in each subsystem and the specific function of each component;
3. The establishment and review of operational and environmental stresses that affect the system for determining the effects on the system or the components; and
4. The identification of significant failure mechanisms that could occur by using historical data on types of failures for different systems and subsystems.

Although this method is simple and direct in its approach to safety-related problems, it also has limitations. The most obvious and serious problem in this method is that the analyst is unable to find possible system failures caused by a combination of failures of individual components because none would have been considered hazardous by itself. Since this method was previously developed for hardware analysis, the combined effect of a component failure factor, which is not hazardous by itself, and the factors of adverse environmental conditions and human errors, which may lead to the creation of a serious system failure, may also be omitted in the consideration. Therefore, FMECA was improved and made acceptable for broader use by introducing a human error factor. Thus, the accident cause-consequence analysis (ACCA) is used. This method provides a step-by-step procedure for listing all hardware failures, human errors, adverse environmental conditions, and procedural incompatibilities that may lead to an unsafe state in the system.

The proposed column headings with subheadings for an ACCA form are as follows:

1. Specific operation or work task
2. Source of hazard
3. Basic causes
    a. Mechanical failure
    b. Human error
    c. Procedural incompatibility
    d. Adverse environmental condition
4. Possible consequences
    a. Direct
    b. Indirect
    c. Ultimate to the system
5. Severity
6. Probability of occurrence
7. Suggested preventive and control action
    a. Hardware
    b. Human error
    c. Procedural incompatibility
    d. Adverse environment condition
8. Estimated rate of return

A carefully conducted ACCA is useful because it forces the identification of possible failures, which provides invaluable inputs to FTA.

Fault-Tree Analysis

Fault-tree analysis is a technique that uses logic diagrams to represent and record a deductive reasoning process (9). Although relatively new, the technique lends itself to application in various fields and can successfully be used at all levels of complexity. Similar to other techniques, FTA uses certain symbols and notations (Figure 2).

The foundation of a fault tree is the notion of logic gates, which was borrowed from the field of electrical engineering. The gates indicate whether a single event or a combination of events is required to produce the next level of events. Only two types of gates are necessary, AND gate and OR gate, to perform a fault-tree analysis.

1. The AND gate is defined as a logical operation that produces an output event requiring the coexistence of all the input events. In set theory, this gate is referred to as an intersection.
2. The OR gate is defined as a logical operation that produces an output event if one or more of the input events exist. In set theory, this gate is referred to as a union. It should also be noted that there can be no fewer than two inputs to this gate.

Any other logic gates are only special combinations or modifications of the fundamental gates, and these would be created for purposes of convenience. A fault tree can be constructed by using only the fundamental gates. The concept of negation or NOT (called complement inset theory) is also needed. For example, if the brakes on a car working is denoted by BGood, then the event in which the brakes are not working is denoted by NBGood.

In the process of constructing a fault tree, the analyst should distinguish between two basic types of events.

1. Desired events are those events that take place in a normal and planned change of state, and
2. Undesired events are those events that take place in an abnormal and unwanted change of state.

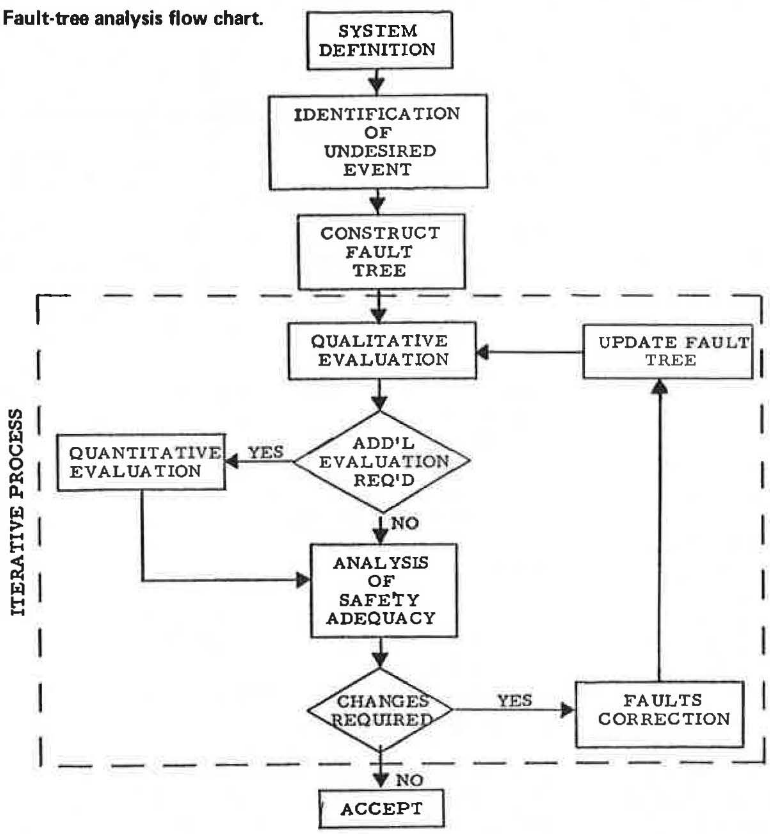
Undesired events can further be divided into independent and dependent events as follows:

1. An independent event can be defined as an event that does not depend on other components in the system for its occurrence. It is a single element in a dynamic change of state from an unfailed state. Frequently, an independent event will also be defined as a basic fault event.
2. A dependent event is the resultant output event of a logic gate. It is dependent on the type of logic gate

Figure 2. Description of fault-tree symbols.

Logic Gate and Mathematical Symbols	Terminology	Relation Between Input and Output	Truth Table 1 ≡ occurrence of the event 0 ≡ absence of the event
output z x y Inputs $Z = X \cap Y$	'AND' Gate Intersection	z = (x) and (y)	Inputs: x y → Outputs: z 0 0 → 0 1 0 → 0 0 1 → 0 1 1 → 1
output z x y Inputs $Z = X \cup Y$	'OR' Gate Union	z = (x) or (y)	Inputs: x y → Outputs: z 0 0 → 0 1 0 → 1 0 1 → 1 1 1 → 1
output z x y Inputs $Z = (X \cap \bar{Y}) \cup (\bar{X} \cap Y)$	'Exclusive or' Gate	z = {(x) and (not y)} or {(not x) and (y)}	Inputs: x y → Outputs: z 0 0 → 0 1 0 → 1 0 1 → 1 1 1 → 0
(rectangle)	'Intermediate Dependent Event'	----------	-------------
(circle)	'Independent (Basic) Event' Sometimes Called a ' Basic Fault'	----------	--------------

Figure 3. Fault-tree analysis flow chart.



employed and the input events to the logic gate. Dependent events are also called gate fault events. During fault-tree development, the gate fault events on one level may become input events to gate fault events on higher levels.

Thus, FTA as used in a system-safety program involves several basic steps (Figure 3).

The analysis is started by first defining the system under investigation. For the conclusions to be meaningful, a system reference line should also be included. This is also the stage in which the researcher will define the constraints (limits) to be placed in terms of time, cost, results desired, and such. The next step is to determine the top undesired event. The definition of this event is dependent on the needs, requirements, and objectives of the program under consideration. After defining the event to be analyzed, the building of the fault tree begins. The deductive process starts with the development of cause and effect relations of faults and normal events throughout the system. This process involves determining the type of gates and inputs to these gates at each level of the fault tree. The adequacy of the construction is dependent on the amount and quality of information and the data and knowledge acquired about the system.

Following the definition of the system and the identification of the top undesired event, other potential accidents and hazardous conditions related to the system are also identified and structured into a top event or tree-top event. The top event is used to identify those areas that need to be developed or expanded by further analysis. An important step in the construction of fault trees is dividing the tree events into phases that correspond to the system-operating phases. This second level of fault-tree development is done by examining the system elements from a functional point of view. Fault-tree development continues with the identification of normal and fault events in the system, until all events are definable in terms of basic events for which failure rates or estimates become available.

Once the fault-tree structure is complete, an evaluation is performed. The purpose of the evaluation is to determine what risks are associated with the top undesired event and which ones are unacceptable and require elimination.

The evaluation may be done on two levels.

1. The qualitative evaluation is an inspection or an engineering judgment; the fault tree is mainly used as a visual aid to clarify relations.
2. The quantitative evaluation is one in which known failure rates of the system elements are used and combined to yield a numerical evaluation of the undesired event.

The information acquired through the qualitative and quantitative analyses is then used to analyze the safety of the given system. If the problem areas are identified and found unacceptable, corrective action is taken and the fault-tree structure or failure rules are changed to correspond to the modified system. The process is reiterated until the system is safe for acceptance.

The qualitative analysis of a fault tree implies that the analyst will have a thorough familiarity with the system under investigation. This analysis will generally proceed from top to bottom. Occasionally, it is convenient to check or construct some paths by working from bottom to top. At each OR gate, the analyst will have to decide, on the basis of his or her knowledge and experience, which paths to follow, thus indicating the most likely path to lead to the event above the OR gate. The process is repeated for every branch until each path terminates in basic fault events. The analyst will then determine the most likely path of events leading to the top undesired event. The outcomes of such a qualitative evaluation are not as manageable as the quantitative ones, but sometimes the qualitative evaluation includes practical considerations that are not easily quantifiable.

If more information is required, a quantitative evaluation of a fault tree is started. The following four basic steps are involved in the quantitative evaluation:

1. Convert logic diagram into a mathematical expression,
2. Eliminate all redundancies,
3. Compute probabilities of top undesired events, and
4. Determine criticality of input events.

The logic diagram is converted into algebraic form by using elements of set theory and Boolean algebra. Figure 4 shows the different relations by using the mathematical laws applicable to Boolean algebra and set theory. The quantitative evaluation of a fault tree is possible only when data for the occurrence probabilities of the basic failure events are available. Four basic results are obtained from a numerical evaluation of the fault-tree equations:

1. The probability of occurrence of the undesired event,
2. The importance of the undesired event,
3. The importance of the various paths leading to the undesired event, and
4. The establishment of a reference level of safety to be used in determining effectiveness of changes.

In preparing a fault-tree diagram, only those elements that contribute to the occurrence of an undesired event should be considered. Therefore, the effort is directed toward the study and control of safety-related problem areas. The importance of an undesired event is a function of the effect it has on overall system safety and its frequency of occurrence. The undesired event that results in a fatality may be considered most critical, while the undesired event that causes minor injury may be considered the least critical. These factors must also be taken into consideration in safety analysis. The utility of the fault-tree analysis technique is found in the orderly and concise manner by which it identifies potential problem areas and reveals their impact on the system.

The use of both ACCA and FTA is illustrated by investigating a situation in which there is need for an emergency deceleration. The automobile used in the example is a 1969 Ford. The testing automobile does not have power or antiskid brakes, a parking brake, or dashboard warning lights.

An example of ACCA for an emergency deceleration is as follows. The specific operation or task is to decelerate a vehicle and come to a full stop. The sources of hazard are

1. Vehicle operator fails to stop automobile;
2. Adverse weather conditions such as skidding and poor visibility;
3. Heavy traffic conditions in which vehicles are tailing each other; and
4. Brake failures in (a) one-half of the system (4.1), (b) total system (4.2), (c) master cylinder for one-half of the system (4.3), (d) master cylinder for total system (4.4), (e) self-adjusting mechanism in the drum brakes (4.5), (f) tubing brackets and con-

Figure 4. Conversion of logic diagrams into algebraic forms.

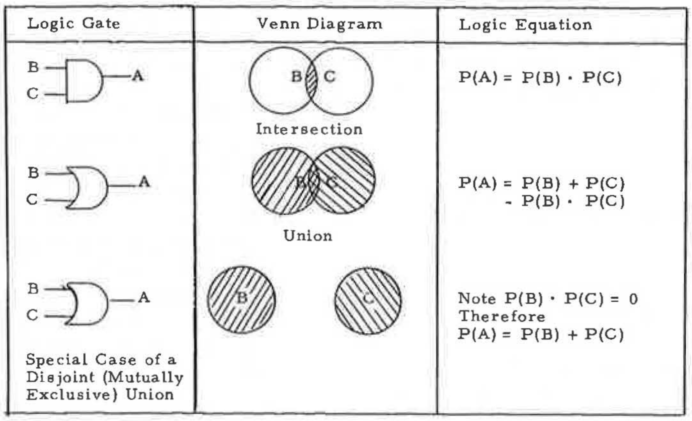
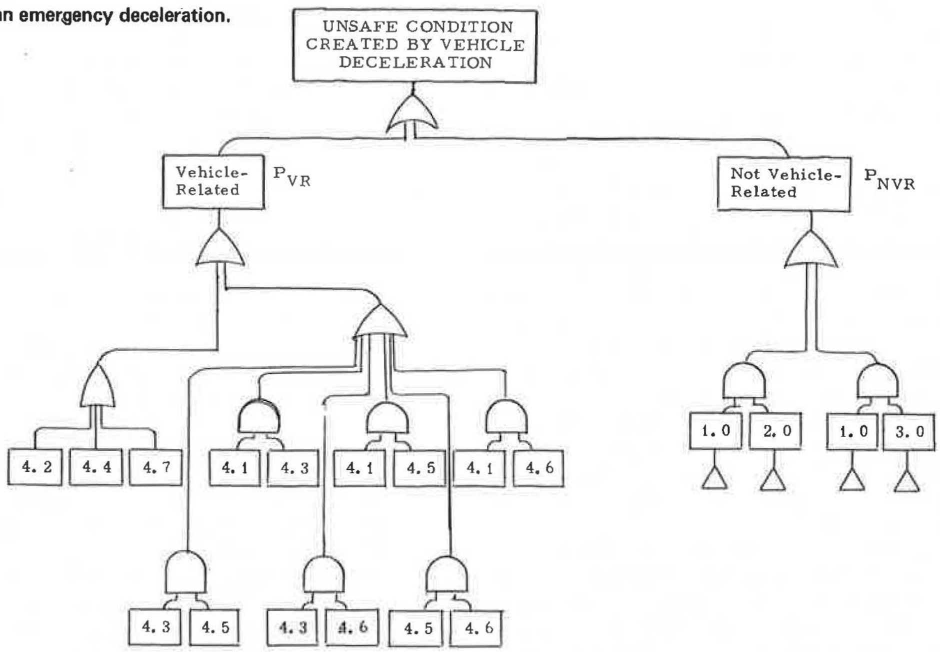


Figure 5. Fault tree for an emergency deceleration.



nectors (4.6), and (g) pedal and linkage (4.7).

In this case, human error, procedural incompatibility, and adverse environmental conditions are not applicable (basic causes and suggested preventive and control action). However, mechanical failures apply to brakes and include the following for the above mentioned areas: (a) leakage or blockage (4.1, 4.3, 4.6), (b) leakage affecting both front and back systems (4.2, 4.4), (c) leakage or blockage to one wheel only (4.5), and (d) broken or jammed mechanism (4.7).

The direct possible consequences include a reduction in the braking efficiency (4.1, 4.3, 4.6), a loss in the braking system (4.2, 4.4, 4.7), and an imbalance in the brakes that cause the vehicle to behave erratically. The indirect probable causes are that an automobile collides with a moving or standing vehicle(s) or an automobile hits a moving or standing pedestrian. The ultimate possible consequence to the system is damage to the automobile, operator, and occupants; other automobiles and their occupants; and property. The severity is rated moderate (4.1, 4.3, 4.5, 4.6) and high (4.2, 4.4, 4.7). The probability is determined accordingly. For the suggested preventive and control actions, hardware can be adjusted by better maintenance or by better brakes with an estimated rate of return that is moderate and high respectively.

Thus, it can be seen that a multitude of causes can lead to the creation of a hazardous situation. The analysis is facilitated by using only a simplified braking system. It was determined from inspection that hazards 4.2, 4.4, and 4.7 should be looked at in detail during design review to assure that the probability of a hazard occurring is minimized. The next step in the analysis is to construct a fault tree (Figure 5). The assumptions made were that an unsafe condition occurs if

1. Modes 4.2, 4.4, or 4.7 occur individually;
2. Modes 4.1, 4.3, 4.5, and 4.6 occur in pairs (actually the paired modes must affect both front and rear systems to constitute a failure; therefore, for simplicity, an approximation was made);
3. Modes 1.0 and 2.0 occur in pairs; and
4. Modes 1.0 and 3.0 occur in pairs.

For illustrative purposes only, the probability for the vehicle-related failures (P_{VR}) is computed as follows:

$$P_{VR} = P[(x_{4.2} + x_{4.4} + x_{4.7}) + (x_{4.1} \cdot x_{4.3} + x_{4.1} \cdot x_{4.5} + x_{4.1} \cdot x_{4.6} + x_{4.3} \cdot x_{4.5} + x_{4.3} \cdot x_{4.6} + x_{4.5} \cdot x_{4.6})] \quad (1)$$

Each failure mode has a different probability of occurrence. The analysis is continued by using the failure data on modes 4.1 through 4.7. For example, if the failure rate for 4.7 were λ failure per kilometer (mile), then

$$P = e^{-\lambda M} \quad (2)$$

if mode 4.7 does not occur in M kilometers and

$$P = 1 - e^{-\lambda M} \quad (3)$$

if mode 4.7 does occur in M kilometers.

For completion of the analysis, the failure rate λ_1 is substituted in the equation for P_{VR}, and this substitution will eventually lead to the computation of the probability of the unsafe situation created by the deceleration. Thus, even for a problem this size, the equations will become long and cluttered with many terms. Therefore, computer analysis programs are used to perform the computations in these complex problems.

Some of the difficulties of and solutions to performing fault-tree analysis are listed as follows:

1. The analysis of a large-scale system is complex; therefore, the analyst must be concerned with including all possible (important) events. The analysis can be cross-checked by comparing it with the ACCA and holding design reviews to discuss and check the model.
2. The exact evaluation of the probabilistic equations for any complex problem can tax a digital computer (the number of computations increases roughly as 2^n for n events). Therefore, the solution is to use analytical approximations to simplify the computations.
3. The basic event probabilities are often difficult to obtain but they are needed for computing the safety index. In many cases, these values can be obtained by averaging the opinions of experts (if no data exist) or by making a parametric study.
4. When a fault tree is used to model systems, some of the probabilities become dependent. Therefore, three special cases are indicated. First, if any two events (A and B) are mutually exclusive (they cannot logically occur at the same time), then any OR expression that involves these events must be evaluated [$P(A \cdot B) = 0$ and not $P(A) + P(B)$]. Often, the exclusive OR gate, as described on the checklist of requirements, is used in the fault tree instead of the regular OR gate when this situation occurs. Thus, the exclusive OR gate reminds the analyst (or signals the computer program) to perform this special evaluation. Second, if any two events (A and B) must occur in sequence (e.g., A before B), then the fault-tree diagram must be modified accordingly. One way to modify the diagram is to use a symbol known as the priority gate, which is a special type of AND gate. This symbol reminds the analyst or signals the computer program that a special condition exists. Another way to handle this case is to define a new event such as priority of A before B (PAB) and use a three-input regular AND gate into which A, B, and PAB events can be fed. Third are the cases in which failure of one component weakens other components, and, thus, the probability of failure is increased. In such a case conditional probabilities must be used to evaluate the resulting expressions.

After the probability of occurrence of the top undesired event is established, the criticality of the input events is evaluated, and the events are ranked so that corrective action can be undertaken. The method is flexible and can be used during any phase of system life, i.e., from conception through operation. Similar to other tools, fault trees are a function of the knowledge and imagination of the analyst; they are only as reliable and useful as the information that is fed into them. The fault-tree method is clearly a systematic way of tracing the vulnerable parts of a system. It is a method that has the ability to provide a simple and visible way of supporting managers and engineers in the decision-making process, particularly in regard to risk acceptability and preventive action.

CONCLUSION

Through the use of a systematic approach to safety, potential hazards can be identified before they are activated. The thrust of a system-safety approach is oriented toward action rather than reaction. This orientation is one of the main differences between the conservative approach to system safety and the dynamic approach to system safety discussed above. Accidents can be prevented if the necessary and adequate actions are taken to eliminate and control hazards. A system-safety approach does not imply that that system must be free of risk, but rather that the risks are controlled and made known to management. Thus, the resources needed to design or redesign a transportation system to meet specified risks can be estimated at the outset and refined as the work progresses. Development of data to support managerial decisions may be seen as the real role of system safety.

REFERENCES

1. System Safety Program for Systems and Associated Subsystems and Equipment. Military Standards, No. 882, 1969.
2. System Safety. Air Force Systems Command, U.S. Air Force, Design Handbook, No. 1-6, 4th Ed., 1974.
3. System Safety. National Aeronautics and Space Administration Safety Manual, Vol. 3, 1970.
4. System Safety Engineering. Space and Missiles Organization, U.S. Air Force Systems Command, Manual, 1973.
5. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. U.S. Atomic Energy Commission, Vols. 1-13, Aug. 1974.
6. W. Hammer. Handbook of System and Product Safety. Prentice-Hall, Englewood Cliffs, N.J., 1972.
7. A. Goldsmith. Guide to System Safety Analysis in the Gas Industry. International Telephone and Telegraph Research Institute.
8. C. A. Erickson. System Safety Analytical Technology: Fault-Tree Analysis. The Boeing Co., 1970.
9. H. A. Watson. Minuteman Launch Control System. Bell Telephone Laboratories, 1962.

Publication of this paper sponsored by Group 3 Council.