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Contents

Foreword

This Record is a compendium of papers broadly related by their focus on transportation safety. Within this group five more specific safety areas are addressed.

Gordon and Robertson assessed the magnitude and nature of the problem of driver noncompliance with traffic signals. Both a survey of states and observations at intersections were used in this study. A survey of commuters in the Los Angeles area by Shirazi et al. found that drivers wanted more specific and higher-quality traffic information.

Zwahlen used eye scanning and car control behavior as measures of the effectiveness of STOP AHEAD signs preceding an unexpected, partially concealed intersection.

Davis et al. developed a sampling method and expansion models to allow more efficient determination of pedestrian volumes. The model was validated for one city. To find out if the distribution of pedestrian volumes during the day can be generalized like vehicle flow distribution, Hocherman et al. took hourly day counts in 86 urban locations. The standard deviation of the hourly rate and the coefficient of variation from the average hourly volume were calculated. To evaluate pedestrian activity spaces, time-space analysis was recently developed. Fruin et al. validated this method for determining pedestrian levels of service in corners and crosswalks. Finally, in this group of papers, Witkowski studied pedestrian accident typing and related it to land use data.

Smith and Walsh compared experience with accidents for bicycle lanes placed on the right and left sides of the street. Lagerwey and Puncochar determined the effect of an 8-year-old bicycle and pedestrian trail on property values and crime. The adequacy of bicycle accident data sources was studied by Stutts et al. They recommended that additional work was necessary to reduce the frequency and severity of bicycle-related injuries. Hooson summarized a study of the key elements of urban bicycle-on-train programs in North America. Pendakur then discussed the use of nonmotorized transport modes in India. The importance of incorporating nonmotorized trips as an integral part of analysis and planning by urban planners was stressed.

Using an interview technique with Canadian motorcycle riders in combination with all 1984 British Columbia motorcycle accident reports, Cooper and Rothe found amount and type of exposure to be the most important determinants of accident frequency. They also described the difficulties of mandating protective gear.

In addition, Sivanandan et al. present a study of computer use in planning heuristic shortest-path routes for emergency vehicles following a disaster such as the 1985 Mexico City earthquake.

A Study of Driver Noncompliance with Traffic Signals

STEWART R. GORDON AND H. DOUGLAS ROBERTSON

There is a perception among traffic engineers that driver noncompliance with traffic control devices is a significant problem. Summarized in this paper are the results of a study of driver noncompliance at 12 signalized intersections in the Washington, D.C., metropolitan area to determine whether driver noncompliance is a problem and to define its relationship to intersection operational characteristics and roadway features. The results indicated that driver noncompliance is a problem that requires attention. It was found that higher violation rates occurred at intersections with low annual average daily traffic volume levels. These high violation rates were predominant on one-lane approaches during the off-peak hours. A correlation analysis indicated moderately high associations between high traffic signal violation rates and low traffic volumes. This research study recommends that drivers, local police, and local traffic engineers be informed that driver noncompliance with traffic signals is a problem with potential safety consequences and should be addressed through education, increased enforcement, and the application of sound engineering principles.

Traffic engineers have expressed a growing concern over the lack of driver compliance with traffic control devices in recent years. Driver noncompliance with traffic control devices, especially regulatory control devices, has been increasing significantly over the years. Drivers' apparent disregard for and perhaps lack of confidence in traffic control devices has been recognized by the American Association of State Highway and Transportation Officials' (AASHTO) Highway Subcommittee on Traffic Engineering. The AASHTO Standing Committee on Highways conducted a nationwide survey in October 1985 to determine if a driver noncompliance problem exists and, if so, what can be done to correct it. Surveys were sent to each state and the District of Columbia traffic engineer. They were asked to comment on motorist noncompliance with traffic control devices. To the question "Is traffic control device noncompliance a significant problem?" 34 of the 46 respondents said "yes" while 12 states answered "no" (*1*).

Other research studies in recent years have indicated that specific traffic control devices are being violated more than others. For example, studies have found that the violation rate with stop signs has been increasing linearly since 1935 (*2*). In another study it was found that the violation rate (i.e., not stopping when required) increased from 0.1 percent to 0.6 percent when the signal configuration changed from regular operation to flashing red (*3*). In another instance, the violation rate increased by a factor of five when sign configurations (a symbol only, instead of a symbol and message) were changed (*4*).

The traffic control device violations may result from the combined effects of human behavior characteristics and related traffic operational characteristics. Such human factors might include the driver age, vision, and perceived travel time. Highway geometrics and such traffic operation characteristics as volume, type of regulatory control, and speed may also affect driver noncompliance.

In order to develop solutions, however, the problem of driver noncompliance must be defined in terms of where, when, how, how much, how serious, and why. The objective of this study was to determine the magnitude of driver noncompliance with traffic signals at intersections as it related to roadway features and traffic operational characteristics.

Driver noncompliance with traffic signals was studied at 12 intersections in Virginia, Maryland, and the District of Columbia during June and July of 1986. Drivers were observed under various operational conditions at signalized intersections during the peak and off-peak day and nighttime hours. Violation frequencies, operational characteristics, and roadway features were recorded and analyzed. The results of this study, which was sponsored by the Federal Highway Administration's Graduate Research Fellowship Grant program, are documented fully elsewhere (*5*).

METHODOLOGY

The experimental plan for determining the magnitude of driver noncompliance with traffic signals was made up of five parts:

1. Measures of effectiveness (MOEs),
2. Sample size,
3. Site selection criteria,
4. Data collection procedures, and
5. An analysis plan.

Measures of Effectiveness

The principal MOEs were the four driver violation types defined as follows. Each type was expressed in terms of hourly frequency and rate—violations per 100 vehicles.

- Running the red signal (RUNRED)—the number of through and left-turning vehicles entering the intersection past the near curb line after the onset of the red signal indication.
- Right-turn-on-red (NOSTOP)—the number of right turning vehicles not coming to a complete stop during the red signal indication.

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- No right turn on red (NRTOR)—the number of vehicles making a right turn on red when there is a "No Turn on Red" sign.
- Total violations (TOTVIOL)—the total number of vehicles that violate the red signal indication (i.e., the sum of the three previous MOEs).

Violation rates were calculated per 100 vehicles for each MOE—RUNRED, NOSTOP, NRTOR, and TOTVIOL—based on its corresponding traffic volume—through left turn (THLTVOL), right turn (RTVOL), right turn (RTVOL), and total volume (TOTVOL), respectively.

Sample Size

Twelve signalized intersections were selected from a population of 30 intersections. The sample intersection population was limited because of the available information provided by each transportation agency, a short data collection time period of 2 months, and the manual data collection effort by only one observer.

The minimum sample of observations (380) for each intersection was found using a standard statistical estimating procedure that determined the minimum number of observations needed to meet a desired level of confidence and permitted error (*6*).

Site Selection Criteria

The intersection location and characteristics used as criteria in the selection of sites included the number of approaches (four only), number of approach lanes (one or two lanes), average annual daily traffic (AADT) (high, medium, and low), right turn on red (permitted or prohibited), approach speed limits (25 to 30 mi/hr), and jurisdiction in which the intersection was located.

The results of applying the site selection criteria are given in Table 1. The primary site selection criterion, AADT volume level, was used to stratify the intersection approaches into low, medium, and high AADT. Low was fewer than 7,500 entering vehicles per day, medium was 7,500 to 15,000, and high was greater than 15,000. These AADT volume levels were selected based on the volume ranges in the intersection population. Ranges of AADT volume levels were used to determine if violation rates or frequencies varied according to volume levels. Although AADT cannot indicate volume variations throughout the day, it was recognized that most of the travel occurred during the 7:00 a.m. to 11:00 p.m. study time period.

A balanced number of approach lanes was sought, with the selected sites consisting of 21 one-lane approaches and 27 two-lane approaches, for a total of 48 approaches.

The other regulatory control of interest was the "No Turn On Red" sign posted at a signalized intersection. Posted speed limits were controlled to reduce the variation of vehicle approach speeds that might influence driver noncompliance. All intersections had approach speed limits posted at 25 mi/hr, except for one intersection with a 30 mi/hr limit.

With respect to jurisdiction, Arlington and Fairfax counties in Virginia; Montgomery County, Maryland; and Washington, D.C., were represented by three, three, two, and four intersections, respectively.

Data Collection Procedures

Intersection inventory data were obtained by calling and visiting the transportation agencies in each jurisdiction and by visiting the sites. Operational data were collected for 2-hr periods during each of the morning peak, midday off peak, afternoon peak, and evening off-peak time frames, a total of 8 hr per intersection approach. Data collection for the 12 intersections was performed between June 23 and July 25, 1986. Dry pavement conditions existed throughout each observation time period except for one 2-hr off-peak period at one intersection.

Traffic volumes were counted on a rotation of 5-min (or nearest multiple signal cycle length) time intervals per approach for 2 hr. This provided a 15-min sample count per hour per approach. While counting traffic, all approaches were monitored for traffic violations. Thus, recorded violations represented total counts, while hourly volumes were obtained by expanding the 15 min of sample counts for each approach. Data collection quality was maintained by having only one observer collect all data.

Analysis Plan

To quantify driver noncompliance with traffic signals, the number of violations and violation rates for each MOE were

TABLE 1 CHARACTERISTICS OF SAMPLED INTERSECTIONS

Intersection No.	No. of Approach Lanes/AADT	Jurisdiction	Signal Location	Land Use
1	1/low AADT; 2/low AADT	Washington, D.C.	Post corner	Office
2	2/medium AADT and high AADT	Washington, D.C.	Post corner	Commercial
3	1/low AADT; 2/low AADT	Washington, D.C.	Post corner	Commercial
4	2/medium AADT and high AADT	Washington, D.C.	Post corner	Commercial
5	2/medium AADT	Arlington Co., Va.	Overhead	Commercial
6	1/low AADT and medium AADT	Arlington Co., Va.	Overhead	Residential
7	1/low AADT; 2/low AADT	Arlington Co., Va.	Cantilever arm	CBD[a]
8	1/low AADT and medium AADT	Fairfax Co., Va.	Overhead	Office
9	1/low AADT; 2/high AADT	Fairfax Co., Va.	Cantilever arm	Commercial
10	1/low AADT; 2/high AADT	Fairfax Co., Va.	Overhead	Commercial
11	2/medium AADT	Montgomery Co., Md.	Cantilever arm	CBD
12	1/low AADT; 2/low AADT	Montgomery Co., Md.	Post corner	Residential

[a]CBD = central business district.

examined to assess the overall noncompliance problem. Intersection characteristics such as the number of approach lanes, grades, stop bar distance to the near curb, signal location (i.e., post corner, overhead), land use, cycle lengths, curb parking, and traffic volume levels were examined in conjunction with violation occurrence. The resulting relationships indicated which independent variables (i.e., time, volumes, number of lanes, etc.) were related to the dependent variables (MOEs). These relationships were examined for each signalized intersection and for all 12 intersections combined. Pearson's correlation coefficients were also calculated to determine if the MOEs were associated with traffic volumes. These analyses established where, when, and how, as well as the magnitude of driver noncompliance with traffic signals.

FINDINGS

The MOEs will be discussed first with respect to violation frequency and rate and then by examining the intersection characteristics at intersections with similar violation rates. Characteristics of the sample of intersections used in the analysis included AADT volume levels, number of approach lanes, intersection jurisdiction, traffic signal location, and primary land use and are summarized by intersection in Table 1. The distribution of these characteristics by number of approaches and number of intersections is shown in Table 2.

TABLE 2 DISTRIBUTION OF INTERSECTION CHARACTERISTICS

	No. of Approaches	No. of Intersections
AADT volume levels		
Low	24	
Medium	16	
High	8	
No. of lanes		
One	21	
Two	27	
Jurisdiction		
Montgomery Co.		2
Arlington Co.		3
Fairfax Co.		3
District of Columbia		4
Signal location		
Post corner		5
Overhead spanwire		4
Cantilever arm		3
Primary land use		
CBD		2
Commercial		6
Residential		2
Office		2

Frequency Violation and Rate

Presented in Table 3 for each MOE are the total violations for all observation hours, the range of violations per hour, the percentage of time that at least one violation per hour was observed, and the average number of hourly violations per intersection approach. The number of violations per hour per approach was the greatest for NOSTOP, while NRTOR was the lowest. This result implies that drivers obeyed the "No Turn On Red" sign more often than drivers who properly executed RTOR by coming to a complete stop before turning right.

TABLE 3 OVERALL VIOLATIONS

	Measures of Effectiveness			
	NOSTOP	NRTOR	RUNRED	TOTVIOL
Violation sum	767	64	469	1,300
Range of violations per hour	0 to 23	0 to 8	0 to 11	0 to 23
Percent of at least one violation per total observed hours	74	48.7	54.3	85.9
No. of violations per intersection approach per hour	2.56	0.84	1.25	3.46

The violation rates by MOE for each intersection are given in Table 4. As expected, NOSTOP violation rates were significantly higher at all sites than the other MOEs. The propensity for many drivers to not come to a full stop before turning right on red has been recognized since the implementation of RTOR. The most hazardous violation, RUNRED, was observed for about one of every 200 through vehicles entering the intersection. Overall 1.25 violations occurred for every 100 vehicles entering the intersection.

TABLE 4 TRAFFIC VIOLATION RATES BY MEASURES OF EFFECTIVENESS AND INTERSECTION

Intersection	Overall Rate			
	NOSTOP	NRTOR	RUNRED	TOTVIOL
1	12.20	2.28	0.36	0.64
2	3.14	–	0.23	0.44
3	7.13	0.99	0.61	1.18
4	4.46	1.75	0.32	0.95
5	5.68	–	0.59	1.64
6	3.91	–	1.09	1.40
7	9.25	–	0.88	2.64
8	17.22	–	0.65	4.06
9	11.22	–	0.27	1.16
10	7.00	–	0.42	0.74
11	–	2.56	0.95	1.22
12	17.87	–	0.93	3.07
Mean rate	7.59	2.02	0.52	1.25

NOTES: All rates per 100 vehicles. Dashes indicate not applicable.

Intersections with similar violation rates were grouped and their characteristics examined. Intersections were considered to have similar violation rates if their rates were within plus or minus 1.5 of one another. This range was chosen arbitrarily based on the researchers' judgment.

The intersection groupings by overall violation rate for each MOE are displayed in Table 5. As an example, for the NOSTOP MOE, 9 of the 12 intersections were combined into

TABLE 5 INTERSECTION GROUPINGS BY OVERALL VIOLATION RATE FOR EACH MEASURE OF EFFECTIVENESS

Measure of Effectiveness	Group			
	I	II	III	IV
NOSTOP	1, 9	2, 4, 6	3, 10	8, 12
NRTOR	1, 11			
RUNRED	1, 4, 10	11, 12	3, 5, 8	2, 9
TOTVIOL	1, 10	3, 9, 11	5, 6	8, 12

four groups, with each group having NOSTOP violation rates within ±1.5 of one another. As is readily apparent, not all intersections were included in the groupings. This was particularly the case with the NRTOR MOE. A comparison of the information in Tables 1, 4, and 5 yields the following observations:

- Of the four groups of the NOSTOP MOE overall rates, three groups (I, III, IV) had low AADT volume levels in common with higher violation rates (rates greater than or equal to 7.00), and all groups within themselves had a similar number of approach lanes. Only one group, Group II, had medium and high AADT volume levels associated with lower violation rates. These results suggest that low AADTs and the number of approach lanes could be correlated with high NOSTOP violations.
- Although similar NRTOR violation rates occurred for Intersections 1 (2.28) and 11 (2.56), these intersections did not have similar characteristics.
- Intersections with similar RUNRED violation rates were combined into four groups; however, there were no intersection characteristics that dominated every group. It should be noted that Group IV had the lowest RUNRED violation rate with high AADTs on two-lane approaches for each intersection. These results suggest that no single characteristic with all approaches combined for an 8-hr period have an effect on RUNRED violations.
- Looking at all four groups for the TOTVIOL violation rate, the nine intersections were characterized by low, medium, and high AADT volume levels, one- and two-lane approaches, all three signal locations, all land use types, and all jurisdictions. No patterns were evident except that Group I had the lowest violation rates with low AADTs in common, while Group IV had the highest violation rates with mostly medium AADTs. These results suggest that low violation rates are associated with low AADTs, while higher violation rates are associated with medium AADT volume levels.

Number of Approach Lanes

The violation rates by the number of approach lanes were calculated for an 8-hr period per intersection and are shown in Table 6. Some intersections had four approaches with two lanes, four approaches with one lane, or a combination of one- and two-lane approaches.

The mean rate for all MOEs indicated that one-lane approaches had twice as many violations as two-lane approaches, except for the NRTOR violation rate. This trend was not consistent, however, for intersections individually. A further examination of the NOSTOP rates revealed that one extreme value skewed the results, and when it was removed, the mean rate for one-lane approaches became 9.84 compared to the previous value of 5.89 for two-lane approaches.

The RUNRED mean violation rate indicated twice as many violations for one-lane versus two-lane approaches. Upon further examination of each intersection individually, this trend was not consistent.

Looking at the overall TOTVIOL violation rates for one- and two-lane intersection approaches, the one-lane approaches had a higher violation rate with the exception of two intersections. One had an approach with a downhill grade of 7 percent. Thus, vehicles tended not to stop completely before they turned right (NOSTOP violation). This approach also had low AADT volume levels. The other intersection also had low AADT volume levels, good sight distance, and the majority of its violations were NOSTOP. Thus, both intersections had geometric conditions conducive to high NOSTOP violations and low AADT volume levels, thus less chance for conflicts.

Intersection Jurisdiction

The violation rates calculated by intersection jurisdiction included all four approaches for an 8-hr period. The results

TABLE 6 VIOLATION RATES BY NUMBER OF APPROACH LANES

Intersection	One Lane				Two Lanes			
	NOSTOP	NRTOR	RUNRED	TOTVIOL	NOSTOP	NRTOR	RUNRED	TOTVIOL
1	10.45	1.91	0.38	0.68	16.51	2.86	0.34	0.56
2	–	–	–	–	3.14	–	0.23	0.44
3	87.42	–	1.66	4.49	0.49	0.99	0.31	0.36
4	–	–	–	–	4.46	1.75	0.32	0.95
5	–	–	–	–	5.68	–	0.59	1.64
6	3.91	–	1.09	1.40	–	–	–	–
7	6.11	–	0.83	1.78	19.69	–	1.61	10.94
8	17.22	–	0.65	4.06	–	–	–	–
9	11.95	–	0.24	2.12	11.12	–	0.27	1.08
10	9.96	–	0.00	2.67	4.44	–	0.45	0.56
11	–	–	–	–	–	2.56	0.95	1.22
12	19.31	–	1.01	2.66	16.68	–	0.77	3.73
Mean rate	11.56	1.91	0.86	2.21	5.89	2.03	0.41	0.95

NOTES: All rates per 100 vehicles. Dashes indicate not applicable.

TABLE 7 JURISDICTION VIOLATION RATES

	Mean Violation Rates			
Jurisdiction	1[a]	2[b]	3[c]	4[d]
Fairfax Co.	11.94	–	0.38	1.33
Montgomery Co.	17.87	2.56	0.94	1.78
D.C.	4.96	1.72	0.36	0.79
Arlington Co.	6.06	–	0.82	1.74

NOTES: All rates per 100 vehicles. Dashes indicate not applicable.
[a]NOSTOP.
[b]NRTOR.
[c]RUNRED.
[d]TOTVIOL.

showed that Montgomery County, Maryland, had the highest NOSTOP, NRTOR, RUNRED, and TOTVIOL mean violation rates, whereas the District of Columbia had the lowest rates (Table 7). Fairfax County had the second highest NOSTOP mean violation rate, and Arlington County had the second highest mean violation rates for RUNRED and TOTVIOL. Each jurisdiction has a different law concerning the violation of a red signal indication as summarized below:

- *Maryland*—Drivers are required to exercise "caution" when entering an intersection when the traffic signal is yellow. However, they are not legally bound to stop.
- *Virginia*—Motorists are required to stop at an intersection if the signal has turned yellow and if they have what police call ample time to halt.
- *District of Columbia*—Drivers are legally in violation and subject to a $50 fine if they enter the intersection when the signal is yellow and if they had ample time to stop. The fine for running a red signal is $75, the stiffest penalty in the region.

Traffic officials of all three jurisdictions indicated that the yellow interval is generally the same (4 sec) in all jurisdictions (7).

The jurisdictions' different laws may have affected the violation rates. The District of Columbia had the lowest violation rates and also the stiffest penalties in the region. On the other hand, Montgomery County had the highest violation rates with a lesser red signal violation penalty (i.e., to only exercise "caution" when entering an intersection when the traffic signal is yellow). Arlington County and Fairfax County, Virginia, had greater violation rates than D.C., but lower than those of Montgomery County. This could be a result of Virginia's lesser violation penalty compared with D.C's. The collection of enforcement data was not within the scope of this study, thus no conclusions can be drawn concerning the role of existing enforcement levels.

Traffic Signal Location

Of the three traffic signal locations, the cantilever arm signals had the highest mean violation rates for the NOSTOP and NRTOR (Table 8). The overhead spanwire signal location had the highest RUNRED and TOTVIOL mean violation rates. The post corner signal intersections had the lowest mean violation rates for all MOEs. When overhead spanwire and cantilever arm intersections were combined, they had mean violation rates of 8.29, 2.56, 0.60, and 1.47 for the NOSTOP, NRTOR, RUNRED, and TOTVIOL violation rates, respectively. These rates were all greater than the post corner signal locations. This could be due to the overhead spanwire locations having better visibility than post corner locations, thus giving drivers a better view of the signal and an ability to react to conflicting traffic appropriately.

TABLE 8 SIGNAL LOCATION VIOLATION RATES

	Mean Violation Rates			
Signal Location	1[a]	2[b]	3[c]	4[d]
Post corner	4.83	1.72	0.51	0.94
Overhead spanwire	7.44	–	0.63	1.50
Cantilever arm	10.34	2.56	0.55	1.43

NOTES: All rates per 100 vehicles. Dashes indicate not applicable.
[a]NOSTOP.
[b]NRTOR.
[c]RUNRED.
[d]TOTVIOL.

Time-of-Day Comparisons

The NOSTOP mean violation rate was highest during the nighttime hours, second highest during the off-peak hours, and third and fourth highest during the morning and evening peak hours, respectively (Table 9). These mean violation rates indicate that the NOSTOP violations occurred more often during the off-peak hours. The NRTOR mean violation rate was also highest during the nighttime hours, with the off-peak hours second, evening peak hours third, and morning peak hours fourth. The RUNRED mean violation rate indicated that the evening peak hours had the highest violations. The morning peak hours were second, with off-peak and nighttime hours third and fourth, respectively.

With all the violations combined (TOTVIOL), the nighttime hours produced the highest overall mean violation rate. The off peak was second, with evening and morning peak hours fairly even. To examine these results further, each individual intersection MOE violation rate was compared to the different 2-hr time periods.

At 7 of 11 intersections, both the nighttime and off-peak hours had the greatest NOSTOP violation rates compared to the peak hours. The other four intersections had the second highest NOSTOP violation rates during the peak hours.

Only four intersections prohibited turning on red at any time during the day. Two intersections had the greatest violation rate during the nighttime hours, while the other two intersections were greatest during the peak periods. Overall (all four intersections combined), the highest violation rates occurred at nighttime. However, no time period dominated the NRTOR violation rates.

An examination of each intersection RUNRED violation rate indicated that seven intersections had the highest violation rates during at least one peak period (morning or evening). Three intersections had both peak periods with higher rates than the off-peak periods. These results strongly suggest that most of the intersections had the highest RUNRED violation rates during the peak periods.

The TOTVIOL mean violation rates suggested that all violations combined occurred more often in the nighttime and off-peak hours. Eight out of the eleven intersections with nighttime

TABLE 9 TIME-OF-DAY VIOLATION RATES

Inter-section	NOSTOP				NRTOR			
	Morning[a]	Evening[b]	Off Peak[c]	Night[d]	Morning[a]	Evening[b]	Off Peak[c]	Night[d]
1	–	–	–	12.54	1.97	2.46	2.21	–
2	2.75	2.75	1.78	5.48	–	–	–	–
3	3.35	3.17	17.55	9.43	1.92	0.00	0.89	–
4	4.08	2.99	4.60	14.09	0.56	1.05	2.09	7.23
5	1.65	4.11	5.79	18.01	–	–	–	–
6	3.49	3.50	2.83	–	–	–	–	–
7	8.98	8.58	10.12	–	–	–	–	–
8	15.42	14.38	15.61	39.71	–	–	–	–
9	18.92	6.30	10.18	20.39	–	–	–	–
10	6.80	4.00	11.03	7.45	–	–	–	–
11	–	–	–	–	2.84	2.12	1.72	4.79
12	26.25	10.28	21.95	16.47	–	–	–	–
Mean rate	6.51	5.43	8.54	13.14	1.34	1.61	1.79	5.89

NOTES: All rates per 100 vehicles. Dashes indicate not applicable.
[a]Morning 2-hr peak.
[b]Evening 2-hr peak.
[c]Off peak 2 hr.
[d]Nighttime 2 hr.

observations had the highest violation rates. One intersection was not monitored at night, but it had the highest violation rate during the off-peak hours.

Similarities Among Intersection Characteristics

As previously discussed, intersections were grouped according to similar violation rates. Once these groups were established, other intersection characteristics such as number of approach lanes, land use, signal locations, and AADT volume levels were examined to determine if any relationships existed. The only similar intersection characteristic that emerged was the intersection approach AADT volume level.

The results presented here are based on intersections grouped by their similar overall violation rates (rates calculated for an 8-hr period with all four approaches). It should be noted that these violation rates are not directly related to AADT volume levels (i.e., the violation rates were calculated from the expanded traffic volume counts, not AADT volume levels).

Illustrated in Table 10 is the relationship between each MOE's overall violation rates (high or low) and the AADT volume levels. The NOSTOP MOE resulted in 9 out of 11 intersections extracted into four groups. Six of the nine intersections had high violation rates (greater than or equal to 7.00) while three intersections had violation rates less than 7.00. The combined six intersections with high violation rates had 75 percent of the approaches with low AADT volume levels. The three intersections with low violation rates had 83 percent of the approaches with medium or high AADT volume levels. Thus, the high NOSTOP violation rates were associated with low AADTs and low violation rates with medium and high AADT volume levels.

The NRTOR MOE resulted in one group with two of four intersections. These two intersections did not have similar AADT volume levels. Therefore, no association existed between NRTOR and AADT volume levels.

The RUNRED MOE resulted in four groups. There were 10 of 12 intersections within these four groups. Five intersections had low rates (rates less than 0.50), while five intersections had higher rates (rates greater than 0.50). The low violation rate intersections had mostly medium and high AADT volume levels (60 percent of the approaches), whereas the high violation rate intersections had mostly low AADT volume levels. Thus, these results imply that low AADTs can be associated with higher violation rates, and medium and high AADT's can be associated with low violation rates.

TABLE 10 OVERALL VIOLATION RATES RELATED TO AADT VOLUME LEVELS FOR EACH MEASURE OF EFFECTIVENESS

Measure of Effectiveness	AADT Volume Level Categories		
	Low	Medium	High
NOSTOP	High rate	Low rate	Low rate
NRTOR	[a]	[a]	[a]
RUNRED	High rate	Low rate	Low rate
TOTVIOL	High rate	Low rate	Low rate

[a]No association noticed.

The TOTVIOL MOE resulted in nine intersections with similar violation rates that were placed into four groups. Seven of the intersections had violation rates greater than 1.00 (high rate), and two intersections had violation rates less than 1.00 (low rate). The seven intersections with high violation rates had 50 percent of the approaches with low AADTs. The two low-rate intersections had 75 percent of the approaches with low AADTs. Since the majority of intersections have high rates with low AADTs, this suggests that high rates are more often associated with low AADTs.

Violations Versus Volume Correlations

A useful technique for studying the volume versus violation rate relationship is to establish a correlation between these variables. Descriptive statistics were calculated for the violation rate and volume distributions and included means, standard deviations, and a measure of skewness. The data were aggregated from hourly observations to an 8-hr count by approach. Thus, there were 48 observations or cases. This was done because of the small amount of variance using hourly observations. Based on standard deviation values and skewness, the 48 observations were not normally distributed. For nonnormal data, either a nonparametric test, which is distribution free, may be used or the data may be transformed so that parametric tests may be applied. The use of parametric tests is generally more desirable because they are more powerful than nonparametric tests. Consequently, the data were transformed.

The transformation of data raised a contentious issue. On one hand, some statisticians argue that transforming data is nothing more than "fudging" the data to fit the model and that the implications of transforming data are not fully understood. On the other hand, other statisticians argue that all measurement systems are arbitrary; hence transformed data are just as valid as untransformed data. This latter group has no reservation in using a transformation to normalize data if normally distributed data are required (*8*). Thus, since statisticians have used transformation processes to normalize their data, and a normal distribution is required for parametric testing, it was applied here.

For a transformation to be applied, the skewness measure must be examined. If the data are positively skewed, a transformation is needed that will reduce values in the upper tail by a greater amount than those located in the lower tail. This is accomplished by taking either the square root (fairly moderate transformation) or the logarithm (more radical transformation) for each observation. Both of these transformation processes were applied for the 48 hr observations. The logarithm transformation process gave the better result.

Given in Table 11 are the logarithmic transformations for an 8-hr period by approach. These results indicate low standard deviations versus the mean values for most variables, and the skewness test for normality resulted in all variables falling within the Beta 1 critical limits with 98 percent confidence limits. The NRTOR MOE did not have B1 critical limits, but as the sample size decreases, the B1 critical limits increase. Therefore, the NRTOR skewness value of 0.08 fell within the B1 critical limit. Since logarithmic transformations produced normal data, Pearson's correlations were calculated.

Correlation Analysis Results

The correlation coefficients are presented in Table 12. They ranged from −0.0800 for NRTOR versus RTVOL to −0.6941 for TOTVIOL versus TOTVOL for all 48 observations. These correlations indicate that as traffic volumes increased, the violation rate decreased. A *t*-test tested the null hypothesis. Using the *t*-test, all correlated variables' null hypotheses (i.e., that the population correlation coefficient is zero) were rejected at the 90 percent or greater confidence level, except that of NRTOR versus RTVOL.

If the correlation coefficient is squared, inferences can be made about the total variation explained. For example, right turn volume explained 10.4 percent of the variation in NOSTOP. The THLTVOL explained 30.8 percent of the variation in RUNRED, and TOTVOL explained 48.2 percent of the variation in TOTVIOL. These coefficients of determination indicated that volume is not significant in explaining the amount of variation in the violation rate for NOSTOP but are fairly significant for RUNRED and TOTVIOL.

Additional correlations for violation rates versus volume were calculated by the number of approach lanes (see Table 12). The NOSTOP versus RTVOL had a 5.2 percent decrease in the amount of variance explained by one-lane approaches versus the one- and two-lane approaches combined coefficient of determination (10.4 percent). However, there was an increase of 6.3 percent variance explained between one-lane and two-lane approaches. The correlation coefficient on two-lane approaches is fairly high with a 90 percent confidence level, indicating a stronger association between NOSTOP versus RTVOL on two-lane approaches, as opposed to one-lane approaches.

There was no correlation coefficient for NRTOR versus RTVOL on one-lane approaches since there were only two observations. On two-lane approaches, the correlation coefficient was −0.2313. This correlation was not significant.

The RUNRED versus THLTVOL correlation was the least for one-lane approaches and was not significant. The two-lane approach correlation (−0.6068) was much higher than that for the one-lane approach. The difference in the amount of variance explained between one- and two-lane approaches was 33.8 percent. The two-lane approaches had higher correlations than with both one- and two-lane approaches combined and explained 6.0 percent more variation.

The total violation versus total volume correlations indicated that two-lane approaches had a higher value compared with those of one-lane approaches. These values were −0.6898 and −0.4242, respectively. The one-lane approach correlations were significant at the 95 percent confidence limit while the two-lane approaches were significant at 99.5 percent. It can be concluded that two-lane approaches had a greater degree of association between TOTVIOL and TOTVOL than one-lane approaches, but not with both one- and two-lane approaches combined.

TABLE 11 LOGARITHM TRANSFORMATION FOR AN 8-HR COUNT BY APPROACH

Variable	8-Hr Observations	Mean	Standard Deviation	Skewness	B1 (2%)
NOSTOP	43	0.838	0.361	−0.118	0.71
NRTOR	10	0.280	0.258	0.121	–
RUNRED	46	−0.266	0.340	−0.137	0.64
TOTVIOL	48	0.128	0.389	0.006	0.64
RTVOL	48	0.325	0.333	−0.058	0.64
THLTVOL	48	1.128	0.381	−0.078	0.64
TOTVOL	48	1.214	0.344	−0.062	0.64

NOTE: Dash indicates no table value.

CONCLUSIONS

The violation frequencies and rates in the preceding sections described quantitatively the magnitude of driver noncompliance with traffic signals at signalized intersections as it related to traffic operational characteristics and roadway features.

Considering each MOE separately, the NOSTOP violation rate was greatest on low AADT volume intersection approaches. This was also supported by its rates being highest

TABLE 12 PEARSON'S CORRELATION TABLE FOR VIOLATIONS VERSUS VOLUMES

	48 Observations				One-Lane Approach				Two-Lane Approach			
Correlated Variables	NOSTOP RTVOL	NRTOR RTVOL	RUNRED THLTVOL	TOTVIOL TOTVOL	NOSTOP RTVOL	NRTOR RTVOL	RUNRED THLTVOL	TOTVIOL TOTVOL	NOSTOP RTVOL	NRTOR RTVOL	RUNRED THLTVOL	TOTVIOL TOTVOL
No. of observations	43	10	46	48	21	2	19	21	22	8	27	27
Pearson's correlations	−0.3222	−0.0800	−0.5551	−0.6941	−0.2279	–	−0.1731	−0.4242	−0.3391	−0.2313	−0.6068	−0.6898
R**2	0.1038	0.0064	0.3081	0.4818	0.0519	–	0.0300	0.1800	0.1150	0.0535	0.3682	0.4758
t-test	Reject	N.reject	Reject	Reject	N.reject	–	N.reject	Reject	*Reject	N.reject	Reject	Reject

NOTES: R**2 = coefficient of determination. Reject = rejected at 5%, 2.5%, and 0.5% levels. N.reject = not rejected. *Reject = rejected at 10% level. Dashes indicate sample size too small.

during nighttime and off-peak hours (low volumes during these time periods). When correlated with right turn volumes, the NOSTOP violation rate had significant correlations for all approaches combined and for two-lane approaches. These results may be attributed to a lesser risk of conflict events (low traffic volume levels), better sight distances on two-lane approaches, and possibly lower enforcement levels at off-peak and nighttime hours.

The NRTOR violation rate constituted a relatively small sample size, and therefore, no associations were found between it and right-turn volumes. This MOE was found to occur most often at nighttime.

The RUNRED violation rate was highest during the evening peak hours. It was also found that these high rates occurred for mostly low AADT approaches. Relatively high negative correlations indicated that as the traffic volumes increased, the RUNRED violation rate decreased. These results are expected since more conflict opportunities exist during high levels of traffic volumes.

With all violations combined, TOTVIOL resulted in the highest significant correlations, most violations occurred at nighttime, and the highest rates occurred on low-AADT-volume intersection approaches.

These results suggest that driver noncompliance with traffic signals exists at low-volume intersections during off-peak and nighttime hours on one-lane approaches. Does this suggest that driver noncompliance with traffic signals is a significant problem? With all violations combined, the answer is yes. An overall TOTVIOL violation rate of 1.25 vehicles per 100 vehicles is fairly significant with the highest MOE violation rate being NOSTOP. Does this violation type pose potential safety hazards? What can be done to correct it? The answers are the 3 Es, Education, Enforcement, and Engineering.

Efforts should be made to inform the driver, local police, and local traffic engineers that driver noncompliance is a problem and should be addressed. Improvements such as higher enforcement levels at low traffic volume intersections, stiffer violation penalties, and educating the public of what constitutes a traffic signal violation should be considered. Engineering improvements might include removing unnecessary informational, or regulatory control, devices adjacent to intersection approaches, better signal timing and network progression, lighted intersections, and intersection geometric improvements. Not all of these improvements are applicable for every signalized intersection; therefore, the traffic engineer must use professional judgment. It is also recommended that signalized intersections be monitored periodically for driver noncompliance levels. As traffic volume conditions change, further intersection improvements may be justified.

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Commuters' Attitudes Toward Traffic Information Systems and Route Diversion

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This report describes the findings of the Los Angeles County Transportation Commission (LACTC) commuter information survey conducted by Commuter Transportation Services, Inc., in February 1987. Commuters in the Los Angeles area were surveyed by telephone to identify how various forms of traffic information are currently used and to assess their attitudes toward diverting from the freeway with improved traffic reporting. The survey collected information on commute characteristics, factors affecting route change, and commuters' attitudes toward improved traffic information. The survey evaluated three types of traffic information. These included continuous radio reporting, electronic freeway message signing, and a traffic information telephone number. The results of this study will assist LACTC before testing the "smart street network" concept along the Santa Monica freeway. Under this demonstration project, commuters will have access to direct real-time traffic information. The results of this study show that commuters in Los Angeles County want improved traffic information. Nearly four-fifths of the commuters surveyed throughout the county said that the current information was inadequate. Nearly 70 percent said that they would alter their commute if accurate traffic information were available. The survey also indicates that improved traffic information alternatives such as continuous radio traffic reporting and a traffic information telephone number could assist commuters in both route selection and route diversion.

In Los Angeles, growth in freeway use has resulted in excessive levels of traffic congestion. The development of improved traffic information systems can provide commuters with reliable traffic reporting on the status of traffic conditions and alternative routes to relieve congestion.

Traffic information systems allow the commuter to be aware of traffic conditions and thus enables them to plan their commute accordingly. One example of such a system is the use of freeway message signs, which have been found to be an effective means of informing commuters and rerouting them around congested areas (*1*). Another example is that of commercial radio reporting on traffic conditions, or real-time radio reporting (*2*).

The Los Angeles County Transportation Commission (LACTC), in conjunction with California Highway Patrol, City of Los Angeles Department of Transportation, the Los Angeles Police Department, and the California Department of Transportation, are jointly developing a "smart street network" in Los Angeles. These agencies are envisioning a traffic management and information system that links ramp meters, detectors, and changeable message signs on freeways with centralized automated surveillance and signal control on major parallel streets. The centralized traffic information can be used to coordinate signal timing and to manage traffic congestion. Additionally, up-to-the-minute traffic information can be communicated directly to the commuter at home, via the personal computer or telephone, and on the road via an in-vehicle navigation system, commercial radio, roadside radio, and changeable message signs. To test this "smart street network" concept the participating agencies have developed a demonstration project on a selected portion along the Santa Monica freeway (I-10) west of downtown Los Angeles.

This study provides some insight into conditions under which drivers will divert from the freeway and the type of information that may motivate drivers to change from their normal travel route (such as real-time information, electronic message signs, and traffic information numbers). Previous studies have documented some of the effects of improved information systems on reducing commuter stress, traffic congestion, and improving the overall commute (*3–6*).

METHODOLOGY

The commuter information survey collected information on the following three topics:

- *Commute Characteristics.* Questions in this section assessed commuting time to and from work, commuting delay as a result of congestion, stopover delay, travel conditions, travel route, and route change.
- *Factors Affecting Route Change.* This section identified factors affecting route change, such as electronic freeway message signs and radio traffic reports.
- *Improved Traffic Information.* The final set of questions determined the effect of improved traffic information through media such as continuous traffic reporting and a telephone information number.

This survey includes 7 screener questions and 25 survey questions. The screener questions eliminated all but those commuters who were 18 years of age and older, and who traveled to and from work by freeways during peak hours. All survey questions were pretested and revised.

Commuter Transportation Services, Inc., 3550 Wilshire Boulevard, Suite 300, Los Angeles, Calif. 90010.

Approximately 10 interviewers contacted 400 commuters in Los Angeles County on weeknights and weekend days at their homes by telephone. The interviewers were trained to clarify questions but to avoid leading a response. In addition the interviewers were provided with a list of answers to questions about the study to use if asked by a potential respondent (i.e., "What is the purpose of this study?") The interviewers made up to three attempts at each number per night and "no answers" were followed up for 2 days. Most of the commuters responded to all the questions and offered additional information on the traffic situation in Los Angeles County.

Further areas for analysis could include duration of travel time, commute distance, demographics of respondents, and commuting mode. Additionally, it would have been useful to see if the portion of trip traveled on freeways affected the way respondents answered the questions and if commuters of specific freeways responded differently. This study was performed under contract to LACTC and had a limited budget.

Sampling

The sample for this study was drawn from a random list of computer-generated telephone numbers for the 213, 818, 714, and 805 area codes in Los Angeles County. To select a sample of Los Angeles County residents, Los Angeles County phone prefixes were used as a selection probability. A basic program generated random prefixes, which were then screened against valid Los Angeles prefixes. Random suffixes were then generated. A total of 2,000 telephone numbers were developed. A sample size of 400 was selected to permit a worst-case sampling error of ± 5 percent with 95 percent confidence. (Unless otherwise noted, all percentages given in this report are based on the total 400 sample size.)

Demographics

The survey requested information about the respondent's age and gender. This information was used to compare age and gender with factors relevant to the respondent's commute and his or her attitudes toward improved traffic information. The survey results show that the majority (67 percent) of the respondents are in the 21 to 40 yr age group. Only 5 percent of the respondents are in the 18 to 20 yr age group and the remaining 28 percent are above 40 years of age. The interviewers were required to indicate the gender of the respondents. Based on the responses, it was determined that 58 percent are male and 42 percent are female.

COMMUTE CHARACTERISTICS

The respondents' commute characteristics are discussed in the following sections.

Commuting Time

Commuters were asked to estimate their average travel time to and from work and the average delay they experience as a result of congestion. Interviewers were told to use the word "usually" (if asked) to describe the respondent's average commute time during the 5-day work period. Commuters travel an average of 37.3 min to work and 41.9 min home from work. In comparison, a study conducted by Commuter Transportation Services, Inc., Carpool Evaluation 1987, found that Los Angeles County commuters (freeway and nonfreeway users) travel on the average 33.7 min to work and 39.6 min from work and have an average trip length of 16.8 mi. This survey, however, did not ask for trip length. The average reported delay due to congestion is 18 min. These results are given in Table 1.

TABLE 1 TRAVEL TIME AND DELAY

How much time does it usually take you to get to work?
How long does it take you to get home from work?
How much delay as a result of congestion do you experience?

Travel Time (min)	To Work (count)	To Work (%)	From Work (count)	From Work (%)	Average One-Way Delay (min)
Under 15	16	4	17	4	6.6
15–29	99	25	86	22	10.1
30–44	138	34	117	29	15.7
45–59	66	17	73	18	23.6
60–89	54	14	66	17	30.7
90+	12	3	26	7	47.5
Invalid response	15	3	15	3	
	400	100	400	100	
Average	37.3		41.9		18

Respondents were also asked whether they regularly make any stops on their way to or from work and if so, what they usually are. The results show that approximately 9 percent of the commuters make regular stops on their way to work, and 7 percent make stops on their way home. The most frequent regular stop made by commuters is for coffee or food on the way to work and stopping for groceries or other personal errands on the way home (3 percent and 4 percent, respectively). Commuters (both on their way to and from work) rank picking up or dropping off a carpooler or a friend as the second most frequent type of regular stopover (3 percent and 2 percent, respectively). All other reasons cited total only 4 percent, and these include dropping off and picking up children and performing work-related errands. Interviewers did not ask the respondents whether their stopover time was included in their estimate of travel times. If the survey is repeated, it will be necessary to ask respondents to account for stopover time in total trip time.

Travel Conditions

The respondents were asked to describe the traffic conditions they experience on the way to work. Three categories of responses were provided: flow freely, flow with some slowdowns, and always stop and go. Interviewers told respondents, in making a choice between these categories of traffic conditions, to consider more than a 50 percent portion of their trip. Three-quarters of the commuters experience some slowdown due to congestion during their commute. The responses are indicated in Table 2.

TABLE 2 TRAFFIC CONDITIONS

Please tell me which of the following best describes normal traffic conditions on your way to work. Does traffic

	Count	Percent
Flow freely?	83	21
Flow with some slowdowns?	191	48
Always stop and go?	113	28
Invalid response	13	3
Total	400	100

Commuting Route and Route Change

The survey participants were asked if they ever change to another route while on their way to work. Forty percent of the commuters say that they change to another freeway or street, and 31 percent said they do not (Table 3).

TABLE 3 ROUTE CHANGE

Do you ever change routes to another freeway or street while you are on your way to work?

	Count	Percent
Yes	161	40
No	124	31
Invalid response	115	29
Total	400	100

The respondents who alternate routes were asked how often they change to another route while on their way to work. Fourteen percent of the respondents change to an alternate route on the way to work very often or often. Approximately 25 percent change rarely or sometimes. The purpose of these questions was to provide LACTC with information on the existing propensity of commuters to change travel routes. The responses are given in Table 4.

TABLE 4 FREQUENCY OF ROUTE CHANGE

How often do you change to another route while you are on your way to work?

	Count	Percent
Very often	17	4
Often	39	10
Sometimes	62	15
Rarely	43	11
Never	0	0
Do not change route	124	31
Invalid response	115	29
Total	400	100

The responses in each category were then compared to the traffic conditions that the respondents experience on their way to work (refer to Table 2). Commuters who report stop and go traffic conditions are more likely than expected (chi-squared analysis) to report that they change to another route very often or often. Commuters who report freely flowing traffic conditions are less likely than expected to change routes (a lower than expected actual number in "very often" and "often" categories and a higher than expected actual number in "rarely" or "never" categories).

Frequency of route change was compared to age, gender, travel time, and delay. The results show that variables of age, gender, travel time, and delay have no significant relationship to the frequency of route change.

FACTORS AFFECTING ROUTE CHANGE

Knowledge of Alternate Routes

The survey participants were asked if they know of any routes they could take to work other than the usual route traveled. Of the 400 participants, 71 percent said that they know of other routes they could take to work. The remaining 27 percent said that they know of no alternative route (Table 5). Therefore, 31 percent of the total respondents who know of an alternate route do not change their travel routes (refer to Table 3).

TABLE 5 KNOWLEDGE OF ALTERNATE ROUTES

Do you know about any routes you could take to work, other than the one you usually take?

	Count	Percent
Yes	284	71.0
No	106	26.5
Invalid response	10	2.5
Total	400	100.0

The respondents who know of an alternate route were analyzed by the categories of age, gender, travel time, and delay. The results indicate no significant relationship between knowledge of alternate routes and categories of age, gender, and delay. However, the results show a relationship between knowledge of alternate routes and travel time. People commuting for shorter periods of time (less than 45 min) were more likely to know of alternate routes to work than those with longer travel times (greater than 45 min). This relationship may be explained by the fact that shorter distance commuters often have more choices available to them in route selection than longer distance commuters who use freeways for their commute. These results are indicated in Table 6 by percentages.

Survey results indicate that of the 284 commuters who know of an alternate route to work, men are more likely to change travel routes than women. A total of 62 percent of all men who know of alternate routes change routes on the way to work and 38 percent of all women who know of alternate routes change routes.

Traffic Conditions and Route Changes

Survey participants were asked to identify traffic conditions that motivate them to change their normal travel route. The majority of commuters who change travel routes on occasion say they would alter their route if traffic was stopping often or was completely stop and go. The purpose of this question was

TABLE 6 ALTERNATE ROUTE AND TRAVEL TIME

Knowledge of Alternate Route	Travel Time to Work: Under 15 (count)	(%)	15–30 (count)	(%)	31–45 (count)	(%)	46–60 (count)	(%)	61–90 (count)	(%)	Over 90 (count)	(%)	Invalid Response (count)	(%)	Total (count)	(%)
Yes	14	3	81	20	95	24	48	12	34	9	3	1	9	2	284	71
No	2	1	15	4	42	10	18	5	19	5	9	2	1	–	106	27
Invalid response	0	–	3	1	1	1	0	–	1	–	0	–	5	1	10	2
Total	16	4	99	25	138	34	66	17	54	14	12	3	15	3	400	100

to provide LACTC with information on traffic conditions that may cause route diversion. Responses are indicated in Table 7.

Additional Factors Affecting Route Change

The 176 respondents who do change to another freeway or street on their way to work were read a list of factors affecting route change. As indicated in Table 8, the most frequently cited factor affecting route change is radio traffic reports, followed by personal experience, and having to arrive on time.

Each of the factors affecting route change was compared to age, gender, travel time, and delay. The results show no significant relationship between any of the variables.

TABLE 7 MOTIVATION FOR ROUTE CHANGE

Earlier, you described traffic conditions on your way to work. Would you change the route you usually take to work if you found out that traffic on your usual route that day was

	Count	Percent
Completely stop and go?	58	14
Stopping often?	30	8
Slowing down often and stopping sometimes?	45	12
Slowing down often?	11	2
Slowing down sometimes?	11	2
Do not change routes	224	56
Do not change because of delay	5	1
Invalid response	16	5
Total	400	100

TABLE 8 FACTORS AFFECTING ROUTE CHANGE

Do any of the following usually help you decide to change routes while you are on your way to work?

	Count	Percent of Responses
Radio traffic reports	129	30
Personal experience	89	20
Need to arrive on time	73	17
Mood	56	13
Conditions of the drive	44	10
Electronic freeway signs	36	8
Other		
Heavy traffic	6	1
Bad exhaust	1	–
Other	6	1
Total	440	100

NOTE: Participants were permitted to indicate more than one factor.

Radio Traffic Reports

Radio traffic reports are the most frequently cited factor affecting route change. All respondents were asked how often they listen to radio traffic reports. The majority of the participants report that they listen to radio traffic reports often or very often. Only 9 percent said that they never listen at all. These responses are presented in Table 9.

TABLE 9 RADIO TRAFFIC REPORTS

How often do you listen to the traffic reports on the radio?

	Count	Percent
Very often	176	44
Often	84	21
Sometimes	62	16
Rarely	40	10
Nevery	37	9
Invalid response	1	–
Total	400	100

Of the 77 respondents (19 percent) who rarely or never listen to radio traffic reports, 58 (14 percent) offer the reasons, given in Table 10, for not listening.

A further analysis reveals that there is no relationship between how often commuters listen to radio traffic reports and delay. In addition, no significant relationship is identified with respect to age, gender, and travel time.

TABLE 10 REASONS FOR NOT LISTENING TO REPORTS

Why don't you listen to radio traffic reports?

	Count	Percent
No radio or dislike radio in general	17	4
Listen only to music	13	3
Not interested in traffic reporting	28	7
Total	58	14

Electronic Freeway Message Signs

Commuters were then asked to state how often they notice a message on the electronic freeway message signs (Table 11). A quarter of the commuters (26 percent) say that they sometimes, often, or very often notice a message on the electronic freeway message signs, and three-quarters (75 percent) say that they rarely or never notice a message. Even though 26 percent may notice the signs, only 8 percent ever use the signs in their decision to change routes (refer to Table 8).

TABLE 11 ELECTRONIC FREEWAY MESSAGE SIGNS

How often do you notice a message on the electronic freeway message signs?

	Count	Percent
Very often	24	6
Often	21	5
Sometimes	60	15
Rarely	106	26
Never	187	47
Invalid response	2	1
Total	400	100

A further analysis reveals no significant relationship between how often respondents notice a message on the freeway signs and age, gender, travel time, and delay.

A follow-up survey on electronic message signs may include questions on whether commuters see message signs on their travel route and if they ever notice messages displayed on the signs.

IMPROVED TRAFFIC INFORMATION

Potential for Improved Information

Survey participants were asked whether they would leave the freeway if more accurate information about their commute were available and if they knew that surface streets offered shorter travel time to or from their work that day (Table 12). The vast majority of commuters (94 percent) responding to this question said that they would maybe, probably, or definitely leave the freeway if more accurate information about the commute were available and if they knew that surface streets offered a shorter travel time to or from their work that day. Only 5 percent said that they would probably not or definitely not leave the freeway. Interviewers were told to give respondents a list of methods through which the traffic information would become available to commuters (if asked).

The responses in each category were then compared to the traffic conditions that the respondents experience on their way to work (Refer to Table 2). Commuters who reported stop and go traffic conditions are more likely then expected (chi- square analysis) to report that they would definitely or probably leave the freeway. Additionally, those commuters that reported normal traffic conditions as flowing freely are less likely to leave the freeway (probably not or definitely not). This analysis illustrates consistent responses by commuters among questions in the survey.

TABLE 12 POTENTIAL FOR IMPROVED INFORMATION

If more accurate information about your commute were available and you knew that surface streets offered shorter travel time to or from your work that day, would you use this information to leave the freeway?

	Count	Percent
Definitely	274	69
Probably	76	19
Maybe	25	6
Probably not	9	2
Definitely not	10	3
Don't know	4	1
Invalid response	2	–
Total	400	100

Commuters' propensity to leave the freeway was compared to age, gender, travel time, and delay. The results show that no relationship exists between leaving the freeway and travel time, and no significant correlation is identified with age, gender, and delay within this confidence range (95 percent).

The 375 participants (94 percent) who said that they would (maybe, probably, or definitely) leave the freeway were then asked whether they would use the accurate information to leave the freeway and use another freeway or street or make no changes. Approximately half of the respondents (45 percent) said that they would leave the freeway and use streets, an eighth would use another freeway, and approximately a third (32 percent) would make the choice based on circumstances at the time. Respondents' answers to this question may have been affected by choices influencing the existing commute; for example, not all commuters may have the choice of using another freeway. The responses are given in Table 13.

A further analysis showed no significant relationship between reasons for leaving the freeway and age, gender, travel time, and delay. Nineteen of the commuters who said that they would not leave the freeway and would make no changes offered the following explanations:

TABLE 13 DIRECTION AFTER ROUTE CHANGE

Would you use the accurate information to leave the freeway and

	Count	Percent
Use another freeway?	51	13
Use surface streets?	178	45
Make no changes?	9	2
Depends	126	32
Don't know	6	1
Invalid response	30	7
Total	400	100

- Did not want to change habit (mentioned 12 times).
- Streets were too slow (mentioned 4 times).
- Everyone else would have also changed to the same route (mentioned 3 times).

The participants were asked for ways in which traffic information could be improved. Eighty percent (319 people) of all commuters surveyed responded to this question (Table 14). Respondents were permitted multiple responses. Only 17 percent (mentioned 57 times) of those responding think that information is already good enough, and 19 percent (mentioned 64 times) do not know how it can be improved. The remaining respondents (64 percent) made suggestions. The most frequent suggestion for traffic information improvements was having more timely and accurate information. This was followed by

TABLE 14 IMPROVED TRAFFIC INFORMATION

How could traffic information be improved to make it more useful to you?

	Count	Percent
More timely and accurate	89	27
Don't know	64	19
Already good enough	57	17
More frequent reporting	50	15
More or better use of electronic freeway message signs	28	8
Suggest alternative routes	17	5
Localized reports	16	5
Other	12	4
Total	333	100

more frequent reporting and more and better use of electronic freeway message signs.

Continuous Traffic Reports

Participants were asked how often they would listen to a radio station that only gives highway traffic reports. The majority of respondents favor continuous traffic reporting, saying that they would listen to it sometimes or often. Respondents in each category were then compared to the traffic conditions that they experience on their way to work (refer to Table 2). Commuters who reported stop-and-go traffic conditions are more likely than expected (chi-square analysis) to listen to radio stations that give highway traffic reports often or sometimes. Commuters who reported free-flowing traffic conditions were less likely than expected to listen (never). The responses are given in Table 15. A further analysis reveals no major correlations by age, gender, and travel time.

TABLE 15 CONTINUOUS RADIO TRAFFIC REPORTS

How often would you listen to a radio station that only gives highway traffic reports?

	Count	Percent
Often	125	31
Sometimes	150	37
Never	114	29
Don't know	3	1
Invalid reponse	8	2
Total	400	100

Traffic Information Telephone Number

The survey participants were asked whether they would use a traffic information telephone number to compare traffic conditions on their normal route with those on alternative routes. Fifty-three percent of the commuters surveyed say that they would probably or definitely use the traffic information telephone number, 28 percent said that they would not or probably would not, and 18 percent say that maybe they would or they didn't know whether they would use it. Overall these results showed that commuters would use a direct access real-time telephone number. The responses are presented in Table 16.

TABLE 16 TRAFFIC INFORMATION TELEPHONE NUMBER

If you could make a telephone call to compare current traffic conditions on your usual route with alternative routes, would you use this number?

	Count	Percent
Definitely	122	30
Probably	92	23
Maybe or don't know	70	18
Probably not	76	19
Definitely not	38	9
Invalid response	2	1
Total	400	100

The 284 respondents (71 percent) who say that they would (maybe, probably, or definitely) use the traffic information number were asked how many times a week they think that they would use this number if it were available. Their responses are given in Table 17.

TABLE 17 USE OF TRAFFIC INFORMATION NUMBER

How many times a week do you think you would use such a traffic information number?

	Count	Percent
Less than 1 call per week	31	8
1 call per week	45	11
2 calls per week	64	16
3 calls per week	47	12
4 calls per week	16	4
5 calls or more per week	68	17
Probably not or definitely not	114	28
Don't know or invalid response	15	4
Total	400	100

A further analysis reveals no major trends between use of the traffic information number and age, gender, travel time, and delay.

The respondents who said that they would not use the number (28 percent) gave the reasons indicated in Table 18 for their responses. The most frequent reason cited by respondents for not wanting to use the traffic information number is that it is not useful to them and that it takes too much time and is inconvenient.

TABLE 18 REASONS FOR NOT USING INFORMATION NUMBER

Why would you not be interested in using a traffic information number?

	Count	Percent
Service not useful to them	40	10
Too much time or inconvenient	39	10
Radio reports are good enough	9	2
Wouldn't trust reports	6	1
Other	10	3
Don't know or invalid response	25	6
Would use information number	271	68
Total	400	100

CONCLUSIONS

The conductors of this study mainly collected information on three areas of commuter characteristics, factors leading to route change, and attitudes toward improved information systems. According to survey results, on the average, freeway commuters travel 37.3 min to work and 41.9 min from work. The average one-way delay for commuters was 18 min. The statistics show that commuters (freeway) in Los Angeles County are facing long commutes, great portions of which are accounted for by delays.

Survey results also showed that 71 percent of the surveyed commuters knew of alternate routes to work, which indicates that the idea of taking alternative routes may not be that uncommon to Los Angeles commuters. Survey results also showed that commuters with stop-and-go traffic were more likely than other commuters to change routes. In fact, only 12 percent of all commuters experienced free-flow traffic to work. The most frequently cited factor that made commuters change routes was radio traffic reports (30 percent), followed by personal experience (20 percent), and having to arrive on time (17 percent).

One of the valuable findings of the survey was that nearly 70 percent of commuters would definitely leave the freeway if more accurate information regarding their commute were available and if they knew that surface streets offered a shorter route to work. This piece of information can be useful to LACTC because it shows that if given more accurate information, commuters perceive that they will divert from congested freeways.

Overall, commuters want timely and accurate information (27 percent), more frequent reporting (15 percent), and better uses of electronic freeway message signs (8 percent). Only 17 percent of the commuters said that current traffic information was adequate. These figures show that Los Angeles County commuters want better information on traffic, and their responses were favorable toward both continuous radio traffic reporting (68 percent) and a traffic information number (53 percent).

The results of this survey could be useful in considering and implementing the "smart street network" project, however further research could place a greater emphasis on commuter demographic characteristics such as occupation and income, and commute characteristics such as commuting mode and commuting distance. Commuter attitudes as they correlate to origin and destination of commute and freeway of travel may prove useful in tailoring frequency and volume of traffic information that will be generated. Further research could also help identify the optimum sources for the dissemination of traffic information, such as personal computers, car phones, downtown parking lots, and so on.

This study and other related research can demonstrate the potential for traffic information systems and their effect on route diversion in metropolitan areas.

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STOP AHEAD and STOP Signs and Their Effect on Driver Eye Scanning and Driving Performance

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The objective of this study was to determine the effectiveness of the STOP AHEAD sign in warning drivers of an upcoming, unexpected, partially concealed STOP sign and intersection during daytime and nighttime driving conditions. The driving performance and eye-scanning behavior of 39 subjects was studied as they approached an intersection (from the north and southbound directions) of two two-lane rural roads where they were required to stop. Each test driver was subjected to only one condition, which was the same for both intersection approaches (day or night, with or without the STOP AHEAD sign) and belonged to a group of three to six experienced or inexperienced drivers. The results show few statistically significant differences in driver eye-scanning and control behavior (velocity, longitudinal deceleration, gas pedal deflection, lateral lane position, and brake activation) between Run 1 and Run 2 and between inexperienced and experienced drivers. However, the test drivers approached the STOP sign with lower average velocities and lower average longitudinal decelerations near the STOP sign at night when the STOP AHEAD sign was present than when it was not present. Despite this fact, 10 of the test drivers were unable to come to a complete stop at the intersection (eight of the improper stops occurred when the STOP AHEAD sign was present). Although the STOP AHEAD sign seemingly influenced the test drivers' behavior at night, it is concluded that STOP AHEAD signs with STOP AHEAD written on their face do not give drivers adequate visual stimulus to prepare them to stop when approaching an unexpected, partially concealed intersection.

According to Allington (*1*), it is imperative that a stop indicator be visible for a distance equal to the stopping sight distance to allow drivers to complete all perception and decision-making functions and then comfortably decelerate their vehicles to a stop before reaching the stop indicator. Allington recommends stopping sight distances of 450 ft for an approach speed of 50 mph and 625 ft for an approach speed of 60 mph. However, because of physical obstructions or the geometric configuration of the roadway, it is often impossible to place STOP signs so that they can be seen this far in advance. According to section 2C-3 of the *Manual of Uniform Traffic Control Devices* (*2*), in rural areas warning signs (including the STOP AHEAD sign) should be placed approximately 750 ft in advance of a hazardous condition. Section 2C-15 further states that STOP AHEAD signs (either *W*3-1 with STOP AHEAD written on its face or *W*3-1*a* with the red octagonal symbol) should be used on an approach to a STOP sign that is not visible for a sufficient distance to allow a motorist to bring a vehicle to a stop at the STOP sign. Also, according to this section, the STOP AHEAD sign may be used for emphasis when there is poor observance of the STOP sign.

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The effectiveness of the STOP AHEAD sign has been questioned and previous studies have explored the effectiveness of various devices, most notably flashing yellow beacons, which would improve the effectiveness of the STOP AHEAD sign. One such study by Lyles (*3*) evaluated signs for hazardous rural intersections. His results showed that regulatory speed zone configurations and lighted warning signs were more effective than traditional unlighted warning signs in reducing motorists' speeds in the vicinity of the intersections. Goldblatt (*4*), in a study on the operational effects of various types of continuously flashing and vehicle-actuated flashing traffic control devices, found that the use of continuously flashing intersection beacons along stopped approaches encourages speeds that are lower than speeds achieved by STOP signs or vehicle-actuated warning devices. Goldblatt also found that when vehicle-activated flashing beacons were placed on top of a STOP AHEAD sign, which was placed in advance of a simple STOP sign, drivers began braking sooner and had a lower speed variance than they did when a beacon was not present. However, when a beacon was installed at the downstream intersection these results became less significant.

Although the literature review revealed studies on improvements to STOP AHEAD signs, no study was found that focused strictly on the determination of the effectiveness of the STOP AHEAD sign. Therefore, it was the objective of this study to determine the effectiveness of the 36 × 36-in. diamond-shaped yellow STOP AHEAD sign with the words STOP AHEAD written on its face in 7-in.-high black letters in warning drivers of a STOP sign at an unexpected, partially concealed intersection. The effectiveness of the STOP AHEAD sign was to be measured in terms of a test driver's control actions and eye-scanning behavior. This study was to account for numerous variables that might affect the results, including the driving experience of the test drivers, short-term familiarity with the roadway, as well as daytime and nighttime driving conditions.

METHOD

Test Drivers

A total of 39 test drivers took part in the experiment and were divided into one of two groups based on their driving experience (either experienced or inexperienced drivers). The 21 experienced, licensed drivers (12 male, 9 female) had an average age of 22 yr and had driven an average of 44,000 mi during an average of 6 yr. The 18 inexperienced licensed drivers (10 male, 8 female) had an average age of 17 yr and had driven an average of 4,000 mi during an average of 2 yr. All test drivers were initially interviewed and required to fill out a biographical and driving questionnaire. Each subject was tested in the laboratory for (a) foveal vision (Bausch and Lomb vision tester) and peripheral vision (Landolt rings, 10 degrees horizontal, presented left or right), and (b) for simple (1 choice, 0 bits) and choice (8 choices, all equally likely, 3 bits) reaction times using a CR-200 Information Response Instrument (response uncertainty mode). The test drivers also underwent a limited health evaluation. The results of these tests indicated that all test drivers had normal visual acuity and reaction times and were in good health. None of the test drivers were familiar with the road or the experimental vehicle. All test drivers were paid and told only that the study involved driving on two-lane rural roads without being informed of the actual aim of the experiment.

Apparatus

An instrumented 1973 Volkswagen 412 with an automatic transmission and type 4000 low beams was used as the experimental vehicle. This vehicle contains better than 30 instruments and mechanisms that are combined into a system that allows the experimenter to monitor and record a driver's eye movements, as well as time, distance, speed, lateral lane position, steering wheel position, gas pedal deflection, brake activation, and the vertical, longitudinal, and lateral accelerations of the car (sampling rate of 60 hertz). Further description of the experimental car and equipment, including the in-car corneal reflection technique television eye-scanning system, has been published earlier by Zwahlen (*5*).

Experimental Test Sites

In order to make the results of this study widely applicable it was necessary for the chosen site to meet the following criteria:

1. The intersection was to have fairly low average daily traffic (ADT),
2. The intersection was to have 55 mph approaches,
3. The intersection was to be equipped with STOP signs without previously existing STOP AHEAD signs,
4. No raised reflective pavement markers or post delineators were to be installed at the intersection,
5. The approaches to the intersections were to be fairly straight for a few miles (no curves), and
6. The intersections themselves were to be unexpected, partially concealed, and not visible at distances much greater than 1,000 ft.

The intersection of Ohio State Route 188 and Ohio State Route 674 located northeast of Circleville, Ohio, fulfilled all of these criteria and was chosen as the experimental site. Experimental runs were made on both the northbound and southbound approaches to this intersection while traveling on State Route 674, which divides rolling farmland. The northbound approach to this intersection is a straight approach. However, a small hill, over which the road crosses, obscures the intersection completely until the vehicle is within 1,000 ft of the intersection (visible for 965 ft when traffic is present in the intersection and visible for 919 ft when there is no traffic in the intersection). The southbound approach to this intersection is straight with no obstructions and so the intersection can be seen for a relatively long distance (visible for 1,962 ft when traffic is present in the intersection and visible for 1,761 ft when there is no traffic in the intersection). Both the north- and southbound approaches are on slight downgrades (4 percent northbound and 2.5 percent southbound). The ADT on State Route 674 on the north side of the intersection was 1,086 in both directions. No accidents occurred at this intersection during a recent 6-yr period.

The specific intensity was measured at a –4 degree entrance angle and a 0.2 degree observation angle for each of the 36-in. high, octagonal red STOP signs and the new 36 × 36 in. diamond-shaped yellow STOP AHEAD signs. The red background on the high-intensity sheeting STOP sign on the northbound approach had an average specific intensity of 44.0 $cd/ft^2/fc$ and the silver letters on this sign had an average specific intensity of 337.5 $cd/ft^2/fc$. The red background on the high-intensity sheeting STOP sign on the southbound approach had an average specific intensity of 23.4 $cd/ft^2/fc$ and the silver letters on this sign had an average specific intensity of 303.8 $cd/ft^2/fc$. The engineering grade yellow STOP AHEAD signs had a measured average specific intensity of 61.0 $cd/ft^2/fc$ (northbound) and 67.2 $cd/ft^2/fc$ (southbound).

According to Table S-1 of the Ohio *Manual of Uniform Traffic Control Devices* (*6*), the STOP AHEAD sign was to be placed 750 ft before the intersection, assuming that the drivers approach at 55 mph and come to a complete stop at the intersection. Therefore, the STOP AHEAD sign on the southbound approach was placed at 757 ft before the intersection. However, the STOP AHEAD sign on the northbound approach was placed 832 ft before the intersection to avoid obstructions that would have diminished the sign's visibility had it been placed 750 ft in advance of the intersection.

Experimental Procedure and Design

Before the test driver study began, a local familiar driver study was completed that involved the inconspicuous videotaping of 215 vehicles traveling northbound on State Route 674, and 263 vehicles traveling southbound on State Route 674 as they approached the intersection of State Routes 674 and 188 during both daytime and nighttime conditions. All vehicles that were videotaped were used in the analysis. Because State Route 674 is not a major through road and is not normally used by drivers from other areas of the state, it was assumed that a very high percentage of the videotaped vehicles were driven by local drivers who were familiar with the intersection. During this study there were no STOP AHEAD signs along either of the intersection approaches. Time and distance data and the points of brake light activation were recorded. Calculations were then made to determine velocities, decelerations, and points of first-brake application at various distances from the STOP sign. The local familiar driver data was collected to provide base-line data that could be compared with the test-driver data.

The test-driver study involved the continuous recording of the test drivers' eye-scanning behavior and vehicle measures as they drove northbound and then southbound along a typical stretch of a rural two-lane highway, which included the 674-188 intersection. The subjects were randomly assigned to one of eight groups so that each group had either experienced or inexperienced test drivers and as near a half male and a half female representation as was possible. Although it was originally planned for a group of six to be tested under each condition, some nighttime conditions were tested with fewer test drivers because of the frequent existence of ground fog at the test locations. Each of the eight groups were then subjected to a different experimental condition; that is, they would be either "experienced" or "inexperienced" drivers, drive during the daytime or nighttime (using low beams), and drive through the intersection when it was equipped with both the STOP signs and the STOP AHEAD signs, or when it was equipped with only the STOP signs. Each test driver drove the experimental car along Ohio State Route 674 for about 30 to 45 min during which eye scanning behavior, as well as speed, longitudinal deceleration, gas pedal deflection, brake activation, and lateral lane position of the car were recorded continuously so that the experimental purpose (to study the 674-188 intersection) was not apparent. All test drivers were asked to follow the test route twice to allow the experimenters to evaluate the effects of short-term familiarity on driver performance.

This procedure then enabled the experimenters to evaluate the effects of the following independent variables:

- Time of day (level of illumination, day versus night),
- Driver experience (inexperienced versus experienced),
- Presence or absence of the STOP AHEAD sign, and
- Familiarity (Run 1 versus Run 2, or completely unfamiliar versus somewhat familiar).

The effects of the independent variables were measured using the following dependent variables:

- Speed (mph),
- Gas pedal position (0–7 idle, 69–73 fully deflected),
- Brake pedal activation (on or off),
- Longitudinal acceleration (ft/sec/sec),
- Lateral lane position (ft), and
- Eye movement measures (foveal and near foveal or slightly peripheral eye fixations on STOP AHEAD signs and STOP signs).

The design variables that might influence performance measures and were beyond the control of the experimenter included:

1. Traffic (ahead in opposite or in the same direction),
2. Background luminance during the nighttime,
3. Road surface condition (debris, pot holes, etc.),
4. Condition of edge lines and center lines,
5. Visibility (haze, dust, and light fog),
6. Environment (foliage, height of crops, and grass along the highway),
7. Temperature and humidity, and
8. Position of the sun, level of daytime illumination, glare, and cloud cover.

RESULTS

Vehicle Measures

Detailed eye scanning and vehicle measure results for individual test drivers and groups are given by Zwahlen (5). In order to obtain compact results from the vehicle measures data, it was necessary to choose a few points along the intersection approach that would indicate a driver's behavior at the approach to the intersection. For this reason the velocity, gas pedal deflection, and lateral position of the experimental vehicle were analyzed at 1,300, 298, and 50 ft before the intersection on the northbound approach and at 1,360, 359, and 100 ft before the STOP sign on the southbound approach. These distances represent the position of the experimental vehicle just as it entered the approach to the intersection, about midway between the STOP AHEAD sign and the intersection and just before the intersection. However, the longitudinal deceleration was analyzed at 175, 63, and 38 ft before the STOP sign on the northbound approach and 175, 88, and 63 ft before the intersection on the southbound approach. Because classical t and F tests indicated very few statistically significant differences in comparisons of experienced and inexperienced drivers as well as in comparisons of Runs 1 and 2, these conditions were combined to achieve larger sample sizes.

Shown in Table 1 are data on speed at selected distances from the STOP sign combined with data on experienced and inexperienced test drivers and Runs 1 and 2. It can be seen from this table that during the day there seemed to be relatively little, if any, difference in the speed of the experimental vehicle as the test drivers approached the intersection, regardless of whether or not it was equipped with the STOP AHEAD sign. However, at night (when a driver's sight distance is presumably lower because of less favorable illumination) the drivers approached the intersection 2.4 to 9.1 mph slower when the STOP AHEAD sign was present than when it was not (statistically significant for the two points closest to the intersection on both the north and southbound approaches).

It should be noted that on the northbound approach at the 1,300-ft mark the test driver's average speed was 2.4 mph slower when the STOP AHEAD sign was present, and at the 1,360-ft mark on the northbound approach the test driver's average speed was 3.7 mph slower when the STOP AHEAD sign was present (statistically significant at the 0.05 level). This speed difference occurred even though most of the test drivers would not have been able to read clearly individual letters displayed on the STOP AHEAD signs at these distances because the visual angle for the 7-in.-high black letters on the STOP AHEAD sign was 4.3 min of visual arc on the northbound approach and 3.7 min of visual arc on the southbound approach. It might be noted that, because of the position of the STOP AHEAD signs, the 1,300-ft distance from the STOP sign to the experimental car for the northbound approach and the 1,360-ft distance from the STOP sign to the experimental car for the southbound approach are equal to distances from the experimental car to the STOP AHEAD sign of 468 and 543 ft respectively. Therefore, these speed differences suggest that the subjects were responding to the presence of the warning signs along the side of the road or to the pattern of the two words and were most likely unaware of or guessing at the exact message displayed on the sign.

TABLE 1 SPEED AT SELECTED DISTANCES FROM STOP SIGN

	Velocity (mph) by Distance from Sign											
	1,300 ft		298 ft		50 ft		1,360 ft		356 ft		100 ft	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Northbound												
With STOP AHEAD												
Day (*N*=22)	53.9	2.1	39.6	3.4	18.6	4.3	–	–	–	–	–	–
Night (*N*=14)	49.8	2.8	37.1	4.2	13.0	5.0	–	–	–	–	–	–
Without STOP AHEAD												
Day (*N*=23)	53.7	2.3	41.0	4.1	18.7	5.2	–	–	–	–	–	–
Night (*N*=11)	52.1	3.4	44.5	4.0	22.1	6.6	–	–	–	–	–	–
Southbound												
With STOP AHEAD												
Day (*N*=23)	–	–	–	–	–	–	50.2	3.2	39.7	3.2	25.2	3.6
Night (*N*=16)	–	–	–	–	–	–	44.7	2.6	35.4	4.0	19.7	3.7
Without STOP AHEAD												
Day (*N*=24)	–	–	–	–	–	–	49.1	2.7	38.3	3.0	22.8	3.6
Night (*N*=12)	–	–	–	–	–	–	48.3	3.1	39.4	4.5	23.2	4.1

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2. Dashes indicate data not applicable.

Again referring to Table 1, it can be seen that while the STOP AHEAD sign was present the test drivers maintained higher average speeds during the daytime than they did during the nighttime when the STOP AHEAD sign was present (statistically significant at the 0.05 level at five of the six positions along the intersection approaches). However, when the STOP AHEAD sign as absent this relationship did not exist. In fact, the only statistically significant difference at the 0.05 level occurred at the 298 ft distance point for the northbound approach, where it was found that the average nighttime speed was statistically higher than the average daytime speed.

Furthermore, Table 1 shows that all average nighttime speeds after the STOP AHEAD sign were higher than the average daytime speeds. This might be expected because at 359 ft before the STOP sign the visual angle subtended by the eye was 28.7 min of visual arc for the 36-in. high STOP sign and at 298 ft before the STOP sign the visual angle subtended by the eye was 34.6 min of visual arc. Therefore, under favorable lighting conditions, the test drivers should have been able to locate and identify the unique octagonal red STOP sign and therefore reduce their speed regardless of whether the STOP AHEAD sign was present. At night, however, when lighting conditions were not as favorable and no STOP AHEAD sign was present, the STOP sign and the intersection may not have been easily distinguishable at this distance. The test drivers would therefore have been unaware that they were approaching a STOP sign and an intersection and would have had no reason to begin reducing their speed in order to stop.

It can be seen from Table 2, which shows the average distance and standard deviations of first brake activation, merging data of experienced and inexperienced test drivers and Runs 1 and 2, that on the average the subjects first applied their brakes when they were within 509 to 702 ft from the STOP sign. No statistically significant differences or trends exist that would indicate that the test drivers began braking sooner when the STOP AHEAD sign was present than when it was not.

Shown in Table 3 are the gas pedal position averages and standard deviations at selected distances from the STOP sign, merging data of experienced and inexperienced test drivers and Runs 1 and 2. This shows that the average gas pedal deflections were between 14.6 and 26.4 as the drivers began to approach the intersection (1,300 ft before the STOP sign for the northbound approach and 1,360 ft before the STOP sign for the southbound approach). By the time the test drivers reached the point about midway between the position of the STOP AHEAD sign and the intersection (359 ft before the STOP sign in the southbound approach and 298 ft before the STOP sign for the northbound approach) the average gas pedal deflections ranged from 5.2 to 7.3, regardless of whether the STOP AHEAD sign was present. This indicates that the gas pedal was being deflected very slightly, if at all, by the time the test drivers were within 298 ft of the STOP sign on the northbound approach and 359 ft of the STOP sign on the southbound approach, because values for the gas pedal deflection from 0 to 7 indicate no pressure and deflection.

TABLE 2 DISTANCE FROM STOP SIGN AT FIRST BRAKE ACTIVATION

	Distance (ft)	
	Avg	SD
Northbound		
With STOP AHEAD		
Day (*N*=22)	583	114
Night (*N*=14)	509	107
Without STOP AHEAD		
Day (*N*=23)	619	198
Night (*N*=11)	436	97
Southbound		
With STOP AHEAD		
Day (*N*=23)	639	118
Night (*N*=16)	571	127
Without STOP AHEAD		
Day (*N*=24)	675	154
Night (*N*=12)	702	266

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2.

Presented in Table 4 are the longitudinal deceleration averages and standard deviations at selected distances from the STOP sign, merging data of experienced and inexperienced test drivers and Runs 1 and 2 for both the north- and southbound approaches. From this it can be seen that, on the average, when the STOP AHEAD sign was present, the test drivers accepted

TABLE 3 GAS PEDAL POSITION AT SELECTED DISTANCES FROM STOP SIGN

	Gas Pedal Deflection[a] by Distance from Sign											
	1,300 ft		298 ft		50 ft		1,360 ft		359 ft		100 ft	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Northbound												
With STOP AHEAD												
Day (N=21)	21.7	8.4	6.2	0.6	6.0	0.6	–	–	–	–	–	–
Night (N=14)	14.6	8.2	5.8	1.2	5.2	0.9	–	–	–	–	–	–
Without STOP AHEAD												
Day (N=23)	25.7	8.3	6.0	0.7	5.7	0.6	–	–	–	–	–	–
Night (N=11)	22.9	10.8	5.4	1.6	4.6	1.9	–	–	–	–	–	–
Southbound												
With STOP AHEAD												
Day (N=23)	–	–	–	–	–	–	20.4	14.6	6.2	0.6	6.1	0.6
Night (N=16)	–	–	–	–	–	–	21.0	9.8	7.3	6.1	5.6	0.8
Without STOP AHEAD												
Day (N=24)	–	–	–	–	–	–	15.2	9.7	6.1	0.7	5.9	0.7
Night (N=12)	–	–	–	–	–	–	26.4	15.1	5.2	2.2	4.8	1.9

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2. Dashes indicate data not applicable.

[a]Gas pedal deflection: idle, 0–7; at kickdown, 61–62.

TABLE 4 LONGITUDINAL DECELERATION AT SELECTED DISTANCES FROM STOP SIGN

	Longitudinal Deceleration (ft/sec^2 by Distance from Sign							
	175 ft		63 ft		38 ft		88 ft	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Northbound								
With STOP AHEAD								
Day (N=21)	5.5	1.7	8.3	4.2	7.8	3.5	–	–
Night (N=14)	5.4	2.9	7.0	1.9	6.5	3.3	–	–
Without STOP AHEAD								
Day (N=23)	5.4	2.1	7.7	3.4	8.0	2.7	–	–
Night (N=11)	5.5	2.3	10.2	4.9	11.4	4.7	–	–
Southbound								
With STOP AHEAD								
Day (N=23)	4.2	1.7	7.1	2.8	–	–	6.8	3.3
Night (N=16)	4.2	1.4	6.2	2.5	–	–	4.5	3.0
Without STOP AHEAD								
Day (N=24)	4.2	1.5	7.5	3.1	–	–	6.7	4.9
Night (N=12)	4.3	1.8	7.0	3.5	–	–	7.2	2.8

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2. Dashes indicate data not applicable.

higher longitudinal decelerations at the first two distance points when the STOP AHEAD sign was present than they did when the STOP AHEAD sign was not (statistically significant at the 0.05 level for the 88-ft distance point on the southbound approach only).

It can also be seen from Table 4 that when the STOP AHEAD sign was present the test drivers were able to use lower longitudinal decelerations at the final distance point (statistically significant at the 0.05 level for the 38-ft distance point on the northbound approach). Therefore it would seem that when a STOP AHEAD sign was present the test drivers produced higher longitudinal decelerations farther from the intersection so that they did not have to decelerate as quickly closer to the intersection as they did when a STOP AHEAD sign was not present. It is also shown in this table that at nighttime when the STOP AHEAD sign was not present the test drivers found it necessary to accept higher average longitudinal decelerations than they did when the STOP AHEAD sign was present (statistically significant at the 0.05 level in 3 of the 6 cases tested) in order to stop at the intersection.

Throughout the experiment the test drivers were able to maintain good lateral control over the experimental vehicle. This can be seen from Table 5, which shows the distance measured from the inside of the right edge line to the center of the experimental vehicle. Values from this table indicate that on the average the vehicle was roughly in the center of the approximately 10-ft-wide lane. It can also be seen that the values for the standard deviation were all reasonably small (between 0.4 and 1.1 ft), which would indicate that all of the drivers were driving at about the same place in the lane.

In 11 of the 156 intersection approaches completed in this study, the test drivers failed to bring the vehicle to a complete and proper stop before entering the intersection (one subject came to an improper stop on both the north- and southbound approaches to the intersection). Nine of the improper stops were made by test drivers who were driving when the STOP

TABLE 5 LANE TRACKER POSITION AT SELECTED DISTANCES FROM STOP SIGN

	Lane Tracker Position (ft) by Distance from Sign											
	1,300 ft		298 ft		50 ft		1,360 ft		359 ft		100 ft	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Northbound												
With STOP AHEAD												
Day (*N*=21)	4.9	0.4	5.2	0.6	5.1	0.6	–	–	–	–	–	–
Night (*N*=14)	5.1	0.9	5.5	0.6	5.4	0.8	–	–	–	–	–	–
Without STOP AHEAD												
Day (*N*=23)	5.0	0.4	5.1	0.6	4.8	0.4	–	–	–	–	–	–
Night (*N*=11)	5.2	0.5	5.8	0.5	5.8	0.7	–	–	–	–	–	–
Southbound												
With STOP AHEAD												
Day (*N*=23)	–	–	–	–	–	–	5.0	0.4	5.3	0.5	4.6	0.5
Night (*N*=16)	–	–	–	–	–	–	4.5	0.4	5.6	0.5	4.8	1.0
Without STOP AHEAD												
Day (*N*=24)	–	–	–	–	–	–	5.0	0.7	5.1	0.6	4.2	0.4
Night (*N*=12)	–	–	–	–	–	–	4.5	0.5	5.9	0.4	4.9	1.1

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2. Dashes indicate data not applicable.

AHEAD sign was present and only two of the improper stops were made when the STOP AHEAD was not present. Four of the improper stops were made during the day and seven improper stops were made at night. All 11 of the improper stops were made during the first experimental loop (Run 1) with 8 of the improper stops occurring on the northbound approach to the intersection. It should be noted that although test drivers were chosen who were completely unfamiliar with this stretch of highway, the northbound approach of Run 1 would have been the first time they had encountered this unexpected, partially concealed intersection. During the "local familiar" driver study only one vehicle failed to stop at the intersection. This occurred at night. The alarming incidence of improper stops made by the test drivers might be partially attributable to the small light beam that was projected into the subject's right eye as part of the eye-monitoring system. This small light caused a slight visual obstruction and this obstruction may have made it difficult for the drivers to see the signs clearly through the right eye, especially at large distances.

The speed maintained by the test drivers is compared in Figures 1 and 2 with the speed maintained by the local familiar drivers as each of the groups approached the intersection equipped with a STOP sign without a STOP AHEAD sign. Figure 1, which shows the test drivers' and the local familiar drivers' average velocities on the southbound intersection approach during the day, is representative of the velocities of the two groups of drivers for both day and night conditions on the southbound approaches as well as the day condition on the northbound approach. From this figure it can be seen that the test drivers displayed a tendency to drive about 2 to 4 mph slower than the local familiar drivers as they approached the STOP sign during daytime driving conditions on the south-

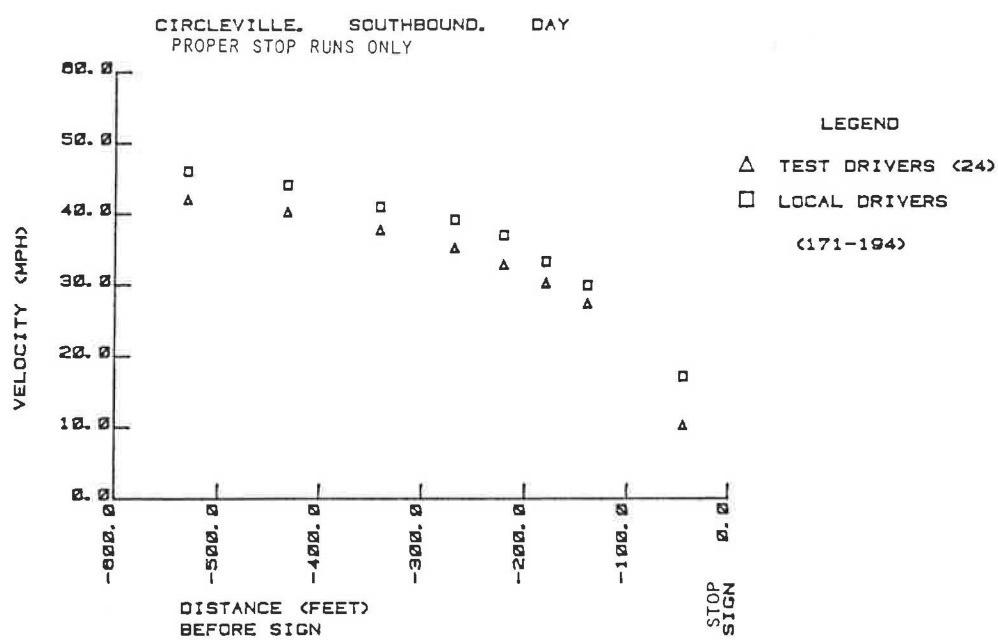

FIGURE 1 Comparison between test and local familiar drivers for northbound approach to intersection during day.

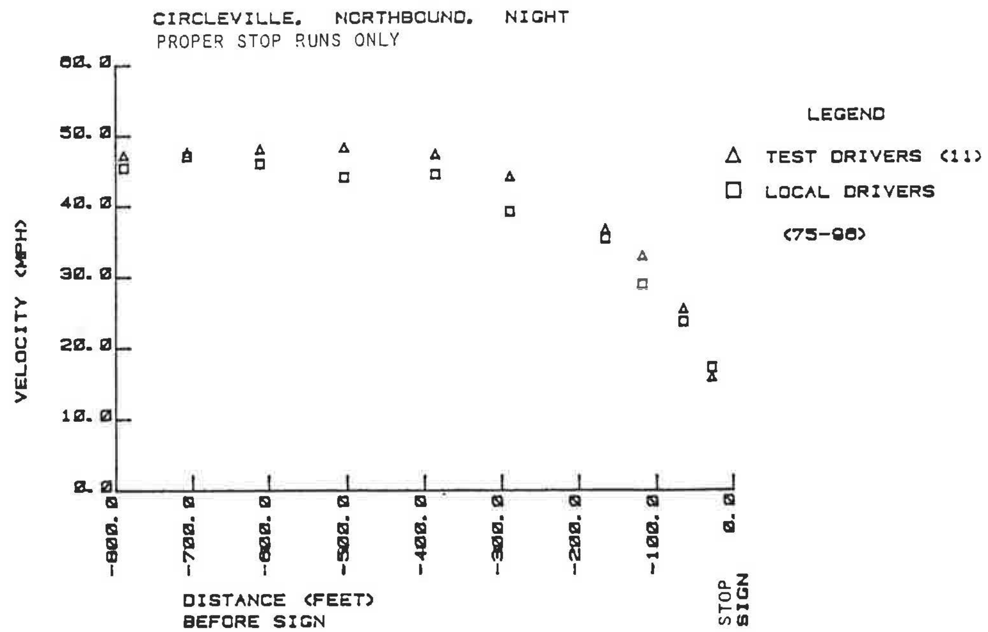

FIGURE 2 Comparison between test and local familiar drivers for southbound approach to intersection at night.

bound approach. This was also true for the southbound approach at night and the northbound approach during the day. *T*-tests at the 0.05 level showed that in 17 of the 20 intersection approaches tested for these three conditions, the test drivers drove slower than the local familiar drivers. This may indicate that the test drivers maintained lower than normal speeds because of their wariness of the unfamiliar roadway, their uneasiness at being observed by the experimenter, or restrictions imposed by the monitoring system. However, looking at Figure 2, which compares the velocities of the two groups of drivers as they approached the intersection in the northbound direction at night, it can be seen that the test drivers approached the STOP sign with a speed of up to 5 mph faster than the average approach speed of the local familiar drivers (statistically significant at 5 of the 10 positions along the intersection approach). In fact, the test drivers' average speed was higher than the speed of the local familiar drivers at all distance points except 28 ft before the intersection, where the test drivers' average speed was about 1 to 2 mph slower than the local familiar drivers' average speed.

EYE SCANNING

During the data-reduction process, the test drivers' eye-scanning behavior was analyzed in terms of when and where the test drivers were looking at the STOP AHEAD sign and the STOP sign from 1,600 ft before each sign to the sign of interest. Shown in Table 6 are the eye-scanning results for the STOP AHEAD sign, merging data of experienced and inexperienced test drivers and Run 1 and Run 2 on both the north- and southbound approaches to the intersection and for both daytime and nighttime conditions. This table indicates that the test drivers looked at this sign an average of 1.45 to 2.77 times, with an average duration of between 0.65 and 0.82 sec.

The first- and last-look distances shown in Table 6 appear to be highly variable within any condition, as shown by the values for the standard deviation, which range from 16 to 763 ft. It can be seen that when the drivers first looked at the STOP AHEAD sign the visual angle for the 36 × 36-in. sign was between 12.7 and 35.1 min of visual arc. Given these values, the driver should have been able to distinguish the presence and the shape of the sign. However, the visual angle for the 7-in.-high letters ranged from only 2.5 to 6.8 min of visual arc. With these small visual angles it is not likely that the drivers were able to read the individual letters displayed on the STOP AHEAD sign at

TABLE 6 EYE-SCANNING SUMMARY RESULTS FOR STOP AHEAD SIGN

	Day		Night	
	North	South	North	South
No. of runs	24	24	18	18
Total no. of looks	66	51	26	50
Looks per subject				
Avg	2.73	2.13	1.45	2.77
SD	1.86	1.53	0.71	1.82
Look duration (sec)				
Avg	0.70	0.65	0.66	0.82
SD	0.58	0.67	0.39	0.61
First-look distance (ft)				
Avg	813	680	294	743
SD	493	244	16	715
Average first-look (sec)	10.9	9.3	4.8	9.5
First-look visual angle (min of arc)				
7-in. letter	2.5	2.9	6.8	2.7
36-in. sign	12.7	15.2	35.1	13.9
Last-look distance (ft)				
Avg	291	330	205	431
SD	192	189	52	763
Average last-look time (sec)	4.1	4.6	3.3	4.8
Last-look visual angle (min of arc)				
7-in. letter	6.9	6.1	9.8	4.7
36-in. sign	35.4	31.3	50.3	23.9

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2.

these first-look distances. However, most drivers could probably see the pattern of the two words and were probably able to guess the message on the diamond-shaped warning sign.

The last-look distances in Table 6 show that the test drivers looked away from the STOP AHEAD sign for the last time at an average distance of between 205 and 432 ft. Given these last-look distances, the visual angles for the 7-in.-tall letters on the STOP AHEAD sign were between 4.6 and 9.8 min of visual arc. These rather small visual angles indicate that it would have been somewhat difficult for the subjects to have read the individual letters in the words "STOP AHEAD," which were written on this sign when they looked away from it for the last time. However, the subjects were probably able to interpret the meaning of the sign based on the pattern of the words. In order to obtain a visual angle of 20 min of visual arc for 7 individual letters, which would allow a driver with 20/20 vision to comfortably read each letter in the two words displayed on the STOP AHEAD sign, a driver would have to be about 100 ft in front of the sign.

The average last-look times in Table 6 show that the test drivers look away from the STOP AHEAD sign for the last time an average of 3.3 to 4.8 sec before they reach the STOP AHEAD sign. From these results it would seem that the test drivers thought they had acquired the information that was displayed on the sign or that other stimuli in the driving environment were more important.

Shown in Tables 7 and 8 are the eye-scanning summary results for the STOP signs on the north- and southbound approaches to the intersection, merging data of experienced and inexperienced test drivers and Run 1 and Run 2. The results displayed in these tables are rather similar to those shown in Table 6, with the exception that the number of looks per test driver is much higher for the STOP sign than for the STOP AHEAD sign (3.65 to 6.40 looks per test driver for STOP signs as opposed to only 1.45 to 2.77 for STOP AHEAD signs). It is likely that the test drivers looked at the STOP sign more often than they did at the STOP AHEAD sign because the STOP sign is an important and unique sign that may serve as a convenient stationary visual target that allows the test drivers to monitor their position, speed, and deceleration as they bring their vehicles to a stop. It can also be seen that the visual angles for the last-look distances were larger for the STOP sign than for the STOP AHEAD sign. This is because the size of the letters on the STOP sign are 5 in. taller than the letters on the STOP AHEAD sign, as well as shorter last-look distances for the STOP sign.

TABLE 7 EYE-SCANNING SUMMARY RESULTS FOR STOP SIGN ON NORTHBOUND APPROACH

	With STOP AHEAD		Without STOP AHEAD	
	Day	Night	Day	Night
No. of subjects	24	18	24	12
Total no. of looks	108	101	154	44
Looks per subject				
Avg	4.50	5.60	6.40	3.65
SD	3.36	3.14	3.07	2.39
Look duration (sec)				
Avg	0.62	0.75	0.55	0.63
SD	0.50	1.02	0.59	0.50
First-look distance (ft)				
Avg	686	676	780	696
SD	230	218	142	193
Average first-look (sec)	13.6	14.9	15.1	12.0
First-look visual angle (min of arc)				
12-in. letter	5.0	5.1	4.4	4.9
Sign	15.0	15.3	13.2	14.8
Last-look distance (ft)				
Avg	153	158	198	232
SD	125	123	151	180
Average last-look time (sec)	4.4	5.4	5.3	5.0
Last-look visual angle (min of arc)				
12-in. letter	22.5	21.8	17.4	14.8

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2.

TABLE 8 EYE-SCANNING SUMMARY RESULTS FOR STOP SIGN ON SOUTHBOUND APPROACH

	With STOP AHEAD		Without STOP AHEAD	
	Day	Night	Day	Night
No. of subjects	24	18	24	12
Total no. of looks	102	83	141	48
Looks per subject				
Avg	4.28	4.60	5.88	4.00
SD	2.68	2.64	2.50	2.99
Look duration (sec)				
Avg	0.55	0.70	0.66	0.37
SD	0.45	0.83	1.35	0.45
First-look distance (ft)				
Avg	881	593	1,026	640
SD	339	208	381	263
Average first-look time (sec)	16.9	15.7	19.7	16.2
First-look visual angle (min of arc)				
12-in. letter	3.9	5.8	3.4	5.4
Sign	11.7	17.4	10.1	16.1
Last-look distance (ft)				
Avg	211	162	209	156
SD	154	100	113	68
Average last-look time (sec)	5.9	6.4	6.1	7.3
Last-look visual angle (min of arc)				
10-in. letter	16.3	21.2	16.4	22.0

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2.

Comparing the results shown in Tables 7 and 8 in each of the four cases shown, the first-look distances for the STOP sign were shorter when the STOP AHEAD sign was present than when the STOP AHEAD sign was not (not statistically significant). In fact, the first-look distances that were recorded during the day without the presence of the STOP AHEAD sign actually indicate that the drivers looked at the STOP sign before they reached the STOP AHEAD sign had it been present. The first-look distances also seem to have been slightly shorter (although statistically not significant) during the day than at night.

CONCLUSIONS

Based on the results of this study, diamond-shaped STOP AHEAD signs with the words "STOP AHEAD" written in 7-in.-high letters across the face do not provide a strong and reliable enough stimulus to prepare a driver to stop at an intersection if this intersection requires a full stop and is unexpected and partially concealed. However the STOP AHEAD sign appears to elicit some limited changes in driving behavior, including lower approach velocities at night and lower longitudinal decelerations near the STOP sign. Further research should be conducted to find more effective methods of warning drivers of intersections requiring a full stop that are unexpected and partially concealed.

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Predicting Pedestrian Crosswalk Volumes

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The measurement of pedestrian volumes for use in determining signal warrants or calculating accident exposure has traditionally been accomplished by manual counting. Some efforts have been directed to the development of mechanical devices and analytical modeling. None of these developments have yet enjoyed widespread success and acceptance. In an effort to reduce the costs and resources to produce manual pedestrian counts, a sampling technique was developed using expansion models to predict hourly pedestrian volumes, thus reducing manpower requirements and data collection costs. The procedure was developed from data collected in Washington, D.C., that included over 18,000 5-min pedestrian count intervals. The resulting expansion models were validated with data not used to develop the models. The models and the procedures for applying them were deemed valid. There was strong intuitive evidence that this method may be applicable in other cities even though this aspect has not yet been tested.

The measurement of pedestrian volumes is considerably more difficult than the measurement of vehicle volumes. When compared to vehicles, pedestrians are less confined to marked traffic lanes; frequently tend to form groups; object to being controlled, observed, or measured; and display a great curiosity for unfamiliar objects and situations. In part, because of this variability and unpredictability of pedestrian movements, most pedestrian studies have used manual counts at specific sites for limited periods of 1 to 10 hr to obtain pedestrian volume data. Although this technique is labor intensive and expensive, past studies have not generally concerned themselves with developing more efficient data collection techniques.

The purpose of this study was to develop an optimum pedestrian sampling scheme using small count intervals to predict hourly and multihourly pedestrian volumes. With such a technique developed, savings in time and resources would be obtained to be applied with the two primary uses of these data: (a) evaluation of traffic signal warrants and (b) exposure data to be used in conjunction with accident or conflict data to produce accident rates or hazard indices.

PEDESTRIAN VOLUME MEASURING TECHNIQUES

Although manual counting is the most prevalent method of collecting pedestrian volume data, mechanical counting devices and analytical models have been developed for measuring pedestrian volumes. Cameron (*1–3*) describes an automatic pedestrian counter that was developed and refined during 1971 and 1972 in Seattle, Washington. The automatic pedestrian counter was used to record pedestrian volumes for a downtown employee population, a downtown shopper population, and a mixed population of employees, shoppers, visitors, and residents. Cameron concluded that the automatic pedestrian counter could be used to provide a reliable, economic data base for planning and designing pedestrian movement systems.

Mudaly (*4, 5*) describes a computer-based infrared pedestrian data acquisition system. The combined hardware-software instrumentation system enables pedestrian flow conditions at any point in a pedestrian traffic stream to be sampled, event by event, stored on magnetic cassette tape, and analyzed remotely by a digital computer. A photocell detector senses infrared reflections off the human body and clothing from a linear lamp. The effectiveness of the technique was evaluated by observation and by manually and automatically recording count comparisons. The error between observed number of pedestrians and automated count number was found to be approximately 5 percent.

Although automatic pedestrian counters have been developed, they have not been widely accepted and used. The mechanical counter developed and used in Seattle, Washington, has not been reported as being used outside that city and has not been used there on a regular basis. The computer-based infrared system first reported in 1979 and then again in 1980 has not been found in the literature since that time. It appears that this is not an area of active interest or current research and development.

Mathematical models for predicting pedestrian volumes have been developed, but they suffer from various deficiencies and limitations (*6–9*). Most models are site specific (i.e., they are limited to the area for which they have been developed and no record has been found of any attempt to generalize models from one city to another). The accuracy of the models depends on the amount and type of input data. Data collection costs increase rapidly as the amount and complexity of data increase. Finally, the reported models have not been tested over an extended period of time and temporal effects could have a significant influence on their accuracy.

Manual counting procedures using direct observation is the method most commonly used by cities to gather pedestrian volume data for routine use. Continuous counting procedures and sampling procedures are generally employed in this method. Pedestrian counts are generally conducted in accordance with procedures that are widely recognized and accepted but which may vary from city to city. Several research studies have also used manual counting procedures. However, these pedestrian volume counts were usually included as part of a larger study and were not the main focus of the research. Several studies have used some form of sampling for pedestrian volume data collection. Manual pedestrian counting procedures currently in use are both costly and labor intensive.

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METHODOLOGY

Short-term vehicle counts of 5, 6, 10, or 15 min are routinely used to estimate hourly and daily vehicle volumes. In most cases the accuracy of the expanded counts is adequate for their intended use such as analysis of maximum flow rates, flow variations within peak hours, capacity limitations, and peak hour volume characteristics. One of the major uses for pedestrian volume data is to determine whether or not revised Warrant 3, the minimum pedestrian volume warrant for the installation of traffic signals, as specified in the *Manual on Uniform Traffic Control Devices* (MUTCD) is satisfied. To make this determination, a knowledge of hourly pedestrian volumes for the highest volume hour (at least 190 pedestrians) or 4 hr (at least 100 pedestrians per hour) during the day is required. In view of this requirement and considering the variable nature of pedestrian activities, pedestrian counts are usually made continuously for a 10- to 12-hr period. This technique provides great accuracy, but is labor intensive and therefore expensive.

The expansion model developed in this study uses a sampling technique to predict hourly pedestrian volumes, thus reducing manpower requirements and data collection costs. For this method, a short-term count is taken within each hour (or multihour) of the study period and expanded, based on the length of the count period, to predict the total count for the hour(s). In this way hourly volume counts may be determined for the entire study period. The accuracy of the expanded counts is determined by the length of the count period and the position of the count period within the hour(s). For example, a 5-min count may be selected for a given crossing site. It could be specified that this count be made for the first 5 min of each hour, the last 5 min of each hour, some 5-min period within the hour, or for a randomly chosen 5-min period within each hour. This study investigated sampling schemes with sampling periods of varying length, occurring at differing positions within the hour, in order to determine an optimum procedure.

DATA COLLECTION

The data for this study were the number of pedestrians observed crossing at either an intersection or midblock crossing during 5-min intervals. Data were collected in Washington, D.C., during July 1986 at eight intersections and six mid-block locations. The principal criterion for site selection was land use, because this is usually the dominant factor in the generation of pedestrian trips. The sites by name, primary land use, and type of crossing are given in Table 1. A mixture of signalized and unsignalized locations was obtained. Care was taken to select locations with significant pedestrian volumes so that an adequate amount of data could be collected within the resources of the study.

All pedestrian crossings were counted at each site during each 12-hr data collection period. These 12-hr samples consisted of continuous counts that were made at each site by one or two data collectors (depending on the level of pedestrian activity). The counts were made on weekdays for the 12-hr period from 7 a.m. to 7 p.m. Pedestrian volumes were recorded in each crosswalk at 5-min intervals. Three days of data were recorded at each site.

TABLE 1 SITES SELECTED

Site	Land Use	Type of Crossing
Connecticut Ave. at National Zoo, N.W.	R	M
14th & E Sts., N.W.	O	I
14th & U Sts., N.W.	Rs	I
23rd & H Sts., N.W.	S	I
Jefferson Dr. & 7th St., S.W.	C	I
12th & Monroe Sts., N.E.	Rs	I
15th St. & Constitution Ave., N.W.	R	I
1st St. & Independence Ave., S.E.	C	I
Connecticut Ave. & DeSales St., N.W.	O	M
Howard University on Georgia Ave., N.W.	S	M
Connecticut Ave. & Woodley Road, N.W.	Rs	I
17th St., N.W. between Constitution & Independence Aves.	C	M
4200 block Massachusetts Ave., N.W.	Rs	M
7th St. south of D St., S.W.	O	M

NOTE: C = cultural/entertainment, I = intersection, M = midblock, O = office/retail, R = recreation/parks/zoo, Rs = residential (multifamily), and S = schools/institutions.

DATA ANALYSIS

A data base of 18,432 5-min intervals of pedestrian counts was produced that in turn permitted a complete and thorough analysis of any combination of variables. For model development, 10 sites were randomly selected from the 14-site data base. The remaining four sites were used to validate the models. Only the first data set (one 12-hr day of data per site approach) was used for both modeling and validation. Thus, 408 hr of observations were used in the expansion modeling and 120 hr in the validation.

The sampling interval times investigated were 5, 10, 15, and 30 min. All of these sampling intervals were analyzed for the first, middle, last, and random positions in the time frame being predicted.

In reviewing the data distributions for use in the 1-hr prediction models, all variables showed positive skewness. (Normality of data is a requirement in regression.) The skewness values associated with each interval and position variable are shown in Table 2. For a sample size greater than 250, the critical skewness value ($B1$) at a 98 percent confidence level is 0.13. The original data for all variables had skewness values greater than 3.

To adjust these data in order to produce a normal distribution, the logarithms were calculated for all observations for all variables. Table 2 also shows the skewness values for the logarithmic transformation. All variables except for last 10-min, first 15-min, and last 15-min events are less than the critical value of 0.13; thus, at the 98 percent confidence level, these variables constitute a normal distribution. As for the three exceptions, they are slightly skewed to the negative side of the normal distribution. However, regression was performed on all variables while recognizing that these three exceptions were not normally distributed.

From the regression analysis of 1-hr modeling, Table 3 was constructed to evaluate the count intervals and the position of the events within the interval. For all count intervals, the middle event produced the better model because it exhibited the highest coefficient of determination (R^2) and the lowest standard error about the mean (SE_y). Also, it was apparent that

TABLE 2 SKEWNESS VALUES FOR 1-HR MODEL VARIABLES

Time Interval and Position Within Hr	Original Data		Transformed Data	
	Sample Size	Value	Sample Size	Value
Total hr	408	3.80	408	−0.06
First 5 min	402	4.07	358	0.02
Middle 5 min	404	3.88	366	−0.02
Last 5 min	404	3.81	374	−0.04
Random 5 min	404	4.09	370	0.03
First 10 min	408	4.00	394	−0.08
Middle 10 min	404	3.78	396	−0.08
Last 10 min	404	3.84	393	−0.19[a]
Random 10 min	404	5.07	394	−0.07
First 15 min	408	3.90	402	−0.16[a]
Middle 15 min	404	3.86	399	0.02
Last 15 min	404	3.68	400	−0.21[a]
Random 15 min	404	3.45	401	−0.10
First 30 min	408	4.01	408	−0.08
Middle 30 min	404	3.88	404	−0.01
Last 30 min	404	3.71	403	−0.04
Random 30 min	404	3.86	403	−0.00

NOTE: Not all samples will have 408 observations because of missing data or logarithms of observations with counts of zero.

[a]Exceeded critical skewness value of 0.13.

as the count interval increased from 5 to 10 to 15 to 30 min, the prediction models became better. This was expected since the variation among count intervals decreased as the count interval increased. Therefore, based on the R^2 and SE_y values, the middle event count intervals were selected as the best predictors of 1-hr counts.

TABLE 3 COEFFICIENTS OF DETERMINATION AND STANDARD ERROR OF ESTIMATES FOR 1-HR MODELS

Variables Correlated with Total Hr	R^2	SE_y
First 5 min	0.72	0.26
Middle 5 min	0.77	0.22
Last 5 min	0.75	0.24
Random 5 min	0.73	0.25
First 10 min	0.80	0.22
Middle 10 min	0.86	0.18
Last 10 min	0.82	0.20
Random 10 min	0.70	0.27
First 15 min	0.85	0.19
Middle 15 min	0.91	0.15
Last 15 min	0.88	0.17
Random 15 min	0.90	0.15
First 30 min	0.94	0.12
Middle 30 min	0.96	0.09
Last 30 min	0.94	0.12
Random 30 min	0.95	0.11

NOTE: All F- and t-statistics were significant at $p = 0.0001$.

The expansion models developed for the middle event of the four count intervals follow:

$$5 \text{ min: } V1 = 19.91\ I5^{0.7862} \quad (1)$$

where $V1$ is 1-hr prediction and $I5$ is the middle 5-min count.

$$10 \text{ min: } V1 = 9.82\ I10^{0.8465} \quad (2)$$

where $I10$ is the middle 10-min count.

$$15 \text{ min: } V1 = 5.75\ I15^{0.8996} \quad (3)$$

where $I15$ is the middle 15-min count.

$$30 \text{ min: } V1 = 2.37\ I30^{0.9625} \quad (4)$$

where $I30$ is the middle 30-min count.

As stated earlier, the larger the count interval for the middle event became, the better the volume prediction became. However, all models are presented in order to give the user the option of choosing the desired degree of accuracy. The user may need only a rough 1-hr estimation, thus using a middle 5-min count is adequate. If a more accurate 1-hr estimation is desired, a middle 30-min count may be required.

Models were also developed for 2-, 3-, and 4-hr volume counts using the same procedures discussed previously. Thus, only a brief description of each of these models will follow. Because the random sampling scheme produced the poorest results for the 1-hour modeling, this scheme was not used for the modeling of 2-, 3-, and 4-hr volumes. Also, the "middle event" was defined as the middle period of the time interval being modeled.

Skewness values were determined for the observations of the first, middle, and last count interval variables. Again, all variables had positive skewed distributions, and the logarithm was taken to correct this skewness. A few variables still exhibited skewness; however, as before, regression was used on all sampling schemes.

Using R^2 and SE_y, the sampling scheme models were evaluated to find the optimum counting event. The values of R^2 and SE_y for each set of multihour models are presented in Table 4. Reviewing this table showed the middle event of all counting intervals to produce the better models. Also, as the count interval increased, the expansion models' predictability improved. Based on these results, the middle event produced the best predictor of multihour volumes, which corresponded to the findings with the 1-hr models. The equations for the three multihour expansion models based on the middle event follow:

$$5 \text{ min: } V2 = 43.04\ I5^{0.7686} \quad (5)$$

$$10 \text{ min: } V2 = 20.89\ I10^{0.8226} \quad (6)$$

$$15 \text{ min: } V2 = 14.65\ I15^{0.8241} \quad (7)$$

$$30 \text{ min: } V2 = 6.14\ I30^{0.8918} \quad (8)$$

where $V2$ is the 2-hr volume prediction.

$$5 \text{ min: } V3 = 60.19\ I5^{0.7851} \quad (9)$$

$$10 \text{ min: } V3 = 32.15\ I10^{0.8184} \quad (10)$$

$$15 \text{ min: } V3 = 17.38\ I15^{0.8842} \quad (11)$$

$$30 \text{ min: } V3 = 9.44\ I30^{0.8901} \quad (12)$$

where $V3$ is the 3-hr volume prediction.

TABLE 4 COEFFICIENTS OF DETERMINATION AND STANDARD ERROR OF ESTIMATES FOR 2-, 3-, AND 4-HR MODELS

Variables Correlated with 2-, 3-, and 4-Hr Counts	2-Hr		3-Hr		4-Hr	
	R^2	SE_y	R^2	SE_y	R^2	SE_y
First 5 min	0.67	0.27	0.61	0.29	0.58	0.30
Middle 5 min	0.74	0.24	0.75	0.23	0.85	0.17
Last 5 min	0.70	0.25	0.68	0.26	0.51	0.31
First 10 min	0.70	0.26	0.43	0.33	0.59	0.30
Middle 10 min	0.84	0.19	0.81	0.20	0.86	0.17
Last 10 min	0.78	0.22	0.75	0.23	0.67	0.27
First 15 min	0.73	0.25	0.68	0.27	0.63	0.28
Middle 15 min	0.86	0.18	0.85	0.18	0.91	0.14
Last 15 min	0.80	0.22	0.78	0.23	0.72	0.26
First 30 min	0.83	0.20	0.75	0.24	0.72	0.25
Middle 30 min	0.92	0.14	0.90	0.15	0.90	0.15
Last 30 min	0.86	0.18	0.84	0.20	0.76	0.23

NOTE: All F- and t-statistics were significant at $p = 0.0001$.

$$5\text{ min: } V4 = 62.43\ I5^{0.8113} \quad (13)$$

$$10\text{ min: } V4 = 44.89\ I10^{0.7618} \quad (14)$$

$$15\text{ min: } V4 = 27.13\ I15^{0.8087} \quad (15)$$

$$30\text{ min: } V4 = 15.57\ I30^{0.8134} \quad (16)$$

where $V4$ is the 4-hr volume prediction.

In summary, this analysis effort produced good expansion models based on the evaluation of the parameters R^2 and SE_y. Additionally, four observations were made:

- The middle event for any counting interval of any hour or multihour expansion model was determined to be the best sampling scheme with respect to position. This phenomenon indicated that the position of a count during any time period was important in order to produce an accurate expanded count.
- As the counting interval increased, the volume prediction became more accurate. Because small count intervals have more variation from one interval to the next, the potential for extracting a nonrepresentative count for the time period being predicted is high. Thus, a larger count interval will reduce this variation and produce a better representation of the time period.
- As the sampling period increased (from 1 to 2 to 3 to 4 hr), the prediction became less accurate based on the four sample count intervals (5, 10, 15, and 30 min) used in this study. This result was due to the variation that exists with small sample intervals.
- The different volume distributions of the 10 sites used in this analysis did not affect the outcome of the position of the counting interval. This observation was based on the high values of R^2 for the middle event. Thus, these expansion models were reliable in predicting volumes regardless of the volume distribution patterns.

VALIDATION

As stated earlier, four sites were excluded from the modeling effort for use in validating the models developed. These sites produced 120 observations for the 1-hr models, 60 observations for the 2-hr models, 40 observations for the 3-hr models, and 30 observations for the 4-hr models. All four counting intervals were studied for each model.

The purpose of the validation study was to investigate the accuracy of the models using data that were not included in the development of the models. Even though these four sites were from the same city from which the models were developed, their volume distribution patterns were all different. As was observed in the development of the models, the middle counting interval produced the best models regardless of the volume distributions. The 14 sites produced six 12-hr distribution patterns. These patterns are shown in Figure 1. Therefore, the hourly or multihourly observations contained in these four sites are intuitively representative of any observation that could have been taken from any site in any city.

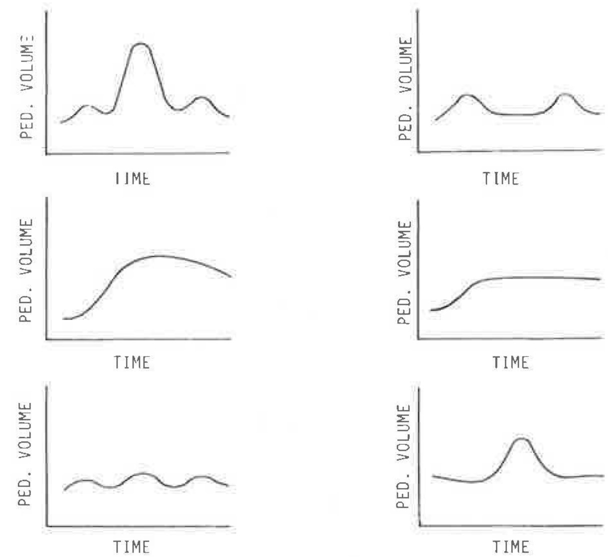

FIGURE 1 12-hr distribution patterns.

The average percent differences between predicted and actual counts were calculated for each count interval expansion model and are presented in Table 5. The table clearly shows that the percent error (average percent difference) decreased as the count interval increased. As found earlier, the models also became more accurate as the count interval increased.

TABLE 5 PERCENT ERROR BASED ON THE FOUR VALIDATION SITES FOR 1-, 2-, 3-, AND 4-HR EXPANSION MODELS

Predicted Volume (hr)	Count Interval (min)			
	5	10	15	30
1	31.2	27.1	18.9	11.9
2	34.5	28.7	23.6	20.6
3	33.2	31.0	28.0	23.6
4	33.6	28.4	27.4	23.5

NOTE: All percentages are in ± values.

In terms of accuracy of the models developed, the following example compares the percent error (Table 5) to the SE_y of the 1-hr model for a 5-min count of 10 pedestrians. By use of the

1-hr, 5-min model (Equation 1), the hour volume predicted was 122 pedestrians. The SE_y for this equation (0.22) produced a volume range of 202 to 73 pedestrians. For the percent error factor (31.2 percent), the volume range was 160 to 84 pedestrians. Therefore, based on the validation data set, predictions made by the model were within the parameters set forth by the regression modeling analysis.

APPLICATION OF PEDESTRIAN COUNTING PROCEDURE

The application procedure contains four steps. Each step is described and its implementation is illustrated with an example.

Step 1: Select Type of Application

To evaluate signal warrants, there must be hourly counts by crosswalk. However, because the pedestrian volume warrant is based on the number of pedestrians crossing the highest volume crosswalk exceeding a stated minimum for each of 4 hr or 1 peak hr in a given day, it is only necessary to determine which crosswalk has the highest volume and count that one. Therefore, the user must make a sample count during each of at least 4 hr or 1 hr on a given day.

For exposure data applications, a daily total pedestrian volume count for the crossing or entire intersection is usually required. Therefore, samples may be taken every hour, every 2 hr, every 3 hr, or every 4 hr depending on the level of accuracy desired.

Step 2: Select Count Interval

The sample count interval (5, 10, 15, or 30 min) is established by the user's selected application, desired level of accuracy, and the use of the percent error (prediction range factors) developed in the previous section. For the signal warrant application, only 1-hr predictions are used. For exposure data, 1-hr or multihour predictions may be used.

The values in Table 5 are percentages that indicate the expected degree of accuracy of an expanded sample crosswalk count. For example, a 5-min sample count of an hourly volume is less accurate than a 30-min count because the percent errors are 631.2 percent and ±11.9 percent, respectively.

Step 3: Collect Data

Through careful scheduling, greater economies in time and resources may be achieved. Not only will time be saved at a specific site by sampling, but also that time saved may be used to sample additional sites. As discussed in the previous section, the selected count interval (5, 10, 15, or 30 min) must be positioned in the middle of the period to be sampled (i.e., 1 hr, 2 hr, 3 hr, or 4 hr). For example, a 10-min sample for the period 8 to 9 a.m. would be from 8:25 to 8:35 a.m.

In order to schedule a data collector to cover more than one site, the period from which the sample is drawn is simply redefined for each site. For example, given three sites within 10-min travel time of one another, a 10-min count interval is selected, sampling 1-hr periods. The schedule for the first hour might be as follows:

Site	*Period (a.m.)*	*Sample Count (a.m.)*
1	7:40–8:40	8:05–8:15
2	8:00–9:00	8:25–8:35
3	8:20–9:20	8:45–8:55

If for some reason the hourly volume counts for one site are to be compared with the hourly volume counts at other sites, the periods and sample count times must be the same and more than one data collector would be required.

Step 4: Compute Estimated Volumes

Select from Equations 1–16 the expansion model that corresponds to the period (1, 2, 3, or 4 hr) and count interval (5, 10, 15, or 30 min). For example, the model for a 3-hr period and a 15-min count interval would be:

$$V3 = 17.38\ I15^{0.8842}$$

Substitute the sample count, I, in the model selected and perform the calculation to obtain the expanded period count. For example, a sample count of 20 would predict an expanded 3-hr volume of 246.

$$V3 = 17.38\ (20)^{0.8842} = 246$$

Note that the predicted volumes correspond to the period selected in accordance with the application selected in Step 1 (i.e., the 1-hr models produce 1-hr volumes, the 2-hr models produce 2-hr volumes, and so on).

CONCLUSIONS AND RECOMMENDATIONS

The modeling effort resulted in good pedestrian volume prediction models based on R^2 and SE_y. In all cases, the middle interval position event produced the best model regardless of the size of the count interval. However, it was apparent that the larger the count interval, the better the volume prediction.

Additional findings were as follows. As the multihour volume period increased, the multihour prediction became less accurate. This was a result of the increase in variation of the counting intervals as the 1-hr volumes increased to 4-hr volumes. Also, the models for the middle counting intervals were not affected by the different volume distributions that existed for the hour or multihour volume counts. This was evident by the constant result of the middle event being the best predictor of pedestrian volumes.

A validation study was conducted using the middle count models. The purpose of this study was to determine the prediction error of the expansion models. Findings of this validation reflected the earlier findings in the modeling effort. As the count interval increased, the percent error decreased; thus, the better the volume prediction. Also, as the prediction of hourly volumes increased to multihour volumes, the percent error became larger and was reflected in the modeling effort by the decrease of R^2 and increase of SE_y.

Regardless of the findings of the modeling approach, one question will arise for studies constrained by using data in only one city: Are these models valid in other cities that have different characteristics? The answer, at present, is unknown. However, the hourly models were derived with approximately 400 hourly observations and validated with 120 observations. This means that there were possibly 400 different 1-hr volume distributions in the modeling derivations and 120 different distributions in the modeling validations. Thus, the potential of encompassing many of the typical 1-hr distributions is good.

As for the multihour models, the sample sizes were less than for the 1-hr models. Confidence in the reliability and validity of these models was not as great as it was in the 1-hr models. Therefore, additional research would improve these multihour models.

Additional research on these models could take two approaches. To test the validity of the models developed in this study, data should be collected at several sites for several cities throughout the country. These data then would be input into these models. The validity would be tested by comparing the percent errors calculated in this study with the percent errors calculated for the additional data. If these percent errors are found to be statistically the same, then the models developed here would be valid.

The second approach would test the models' reliability. In testing model reliability, models would have to be developed for various cities and then compared with the models of this study. The models developed in this study would be reliable for use in other cities if the models developed for other cities had the following characteristics: positively skewed data (corrected by logarithmic transformation), optimum counting intervals occurring at the middle event, and regression equations and parameters similar to those of this study.

In conclusion, promise has been shown for the use of expansion models in predicting pedestrian volumes. As presented in the application section of this report, the ease and cost reduction in the use of these models is clear. With the additional research conducted in other cities, these models could prove to be beneficial in the prediction of pedestrian volumes for use in signal warrants and exposure data applications.

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Estimating the Daily Volume of Crossing Pedestrians from Short-Counts

I. HOCHERMAN, A. S. HAKKERT, AND J. BAR-ZIV

The main issue of this paper is whether the distribution of pedestrian volumes during the day can be generalized in a way similar to vehicular flow distribution, so that the daily average can be deduced from short counts. Hourly whole day counts in 86 urban locations were used to determine the typical daily distributions of crossing pedestrians in residential and central business district streets in Israel. For each hour, the standard deviation and coefficient of variation were calculated, as measures of variation among locations, to determine the best time of day for performing short counts. The standard deviation of the hourly rate was generally 1 to 3.5 percent of the total daily volume. The coefficient of variation was generally 20 to 50 percent of the average hourly volume. Hours during nonpeak periods and afternoon peak were identified with relatively low dispersion. These hours should be preferred whenever short counts are performed for the purpose of risk estimates. The average daily estimates can be improved by using counts of 2 or more hours. In addition, 135 daily counts in 15-min intervals were used to examine the adequacy of such short counts for estimating hourly flows in residential locations. The four 15-min counts in each full hour were regarded as four independent samples from the same distribution. Coefficients of variation (CVs) among the 15-min counts were calculated for each hour and averaged over locations. The CVs varied across hours but in each case were greater than 30 percent. It was concluded that 15-min counts should not be used for the estimation of hourly pedestrian flows in residential areas.

Data collection is the backbone of experimental research. Even the most sophisticated research tools can lead researchers astray when the data being analyzed are insufficient, biased, or inaccurate. The current study deals with the proper gathering of one type of data used in the field of road safety, namely pedestrian counts (PedC). PedC are used both in research and for design purposes. PedC are used to determine warrants for pedestrian facilities such as pavements, crossings, pedestrian signals, and underpasses and overpasses. In safety research, PedC are used together with vehicle counts to determine exposure and assess risk. The findings are used to identify pedestrian blackspots, to determine the efficacy of pedestrian facilities, or to evaluate the effect of measures aimed at pedestrian safety in before and after studies.

Most vehicular traffic counts are automated, and thus relatively simple and inexpensive. Pedestrian counting, however, does not lend itself to simple mechanical counting for several reasons:

- Unlike vehicles, pedestrian movements are not limited to a linear track;
- Pedestrians can change direction, halt, or retrace at any point; and
- Pedestrians may move in groups, sometimes very close together.

When dealing with safety, the relevant pedestrian activity is usually road crossing. This activity may cause an encounter between the pedestrian and a vehicle, thus exposing the pedestrian to the risk of an accident. The observation area may be a marked crossing, its surroundings, a midblock section, or an intersection.

Because manual counts by observers are expensive, the estimation of pedestrian flows is often based on short counts of 5 to 20 min duration. For warrants, these short counts are performed during peak hour and then expanded to represent the whole hour count. In safety evaluation studies, short counts may be used to represent exposure during a period of several years.

Most pedestrian counting procedures date back to the 1950s. In England, Russell (*1*) divided urban streets into sections of 30 to 100 m. Each section was counted twice for a period of 5 min as the counting team moved along the street. Counts were performed during the hours of 1030 to 1245 and 1400 to 1630. Older (*2*) increased the count period to 6 min. Neither investigator justified the duration of the counts. Regarding the counting hours, Older explained that he avoided peak hour conditions, which may exist in some sections and not in others.

Russell used short counts to define a measure of risk to pedestrians. Risk was defined as the number of accidents in 2 years divided by the pedestrian volume in 10 min. This measure is based on the hidden assumption that pedestrian exposure during the 2-yr period can be adequately estimated from short counts.

Mackie and Older (*3*) and Jacobs and Wilson (*4*) found that the distribution of pedestrians by place of crossing along the street for the short count was similar to that of the whole day. However, the adequacy of short counts as a measure of exposure for a period of several years was not dealt with.

Studies in other European countries [see Jorgensen and Rabany (*5*)] used two 6-min counts, quoting the aforementioned English studies. In the United States, the *Highway Capacity Manual* recommends counts of 15 min during peak hour, for the purpose of warranting sidewalks and crossings (*6*).

The question of how well short counts represent exposure for a whole year or more is complex. Generally, the average annual daily pedestrian volume (AADPV) is assumed to be a proxy measure of exposure. The validity of this assumption presents an interesting problem that is outside the scope of this paper.

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Accepting this assumption, the next question is how accurate is an estimate of AADPV that is based on a short count. To answer this question, it is necessary to first consider the calculation of such an estimate. First, a short count is usually taken to represent the flow of a whole hour. An estimate of the hourly flow is achieved by multiplying the short count by a factor. Next, the hourly estimate is expanded to represent a whole day's flow. To determine the expansion factor it is necessary to know the daily distribution of crossing pedestrians. Finally, this daily flow is taken to represent a typical day during the study period. If seasonal variations exist, correction should be made for them. In summary

$$aadpv = C_{ij} \times K \times D_i \times S_j \qquad (1)$$

where

$aadpv$ = an estimate of AADPV,
C_{ij} = short-count value in hour i and season j,
K = hourly multiplier: 60/minutes of short count,
D_i = daily expansion factor for hour i, and
S_j = seasonal correction factor for season j.

Given that the three sources of variation in $aadpv$, C_{ij}, D_i and S_j are independent, the variance of $aadpv$, var($aadpv$), can be expressed as

$$\text{var}(aadpv) = K^2 \times f[\text{var}(C_{ij}), \text{var}(D_i), \text{var}(S_j)] \qquad (2)$$

Var(C_{ij}) measures the day-to-day variation in pedestrian flow counted during the same period of day. It is a function of the count duration, as well as of site-specific idiosyncrasies. Var(D_i) represents the deviation of the expected daily distribution at a specific location, from the mean distribution used to calculate the daily expansion factor, for the specific hour. Thus, var(D_i) is a function of the homogeneity of the locations used to calculate the daily distribution. Var(S_j) is a measure of the variation of the seasonality factor within the season and among locations.

There is little seasonality in traffic flow in Israel (7) and this seems to be true for pedestrian flows as well. Flow distributions do change during school vacation periods and of course on weekend days (Friday and Saturday), but these changes are better dealt with by calculating special distributions for these periods when necessary than by using seasonality correction factors. Thus, two major sources of variation remain—random fluctuations within location [affecting var(C_i)], and variations in daily distribution among locations [affecting var(D_i)]. Because these two sources of variation are independent, the variance of $aadpv$ can be expressed as follows (8):

$$\text{var}(aadpv) = K^2 \times [c^2 \times \text{var}(D) + d^2 \times \text{var}(C) + \text{var}(D) \times \text{var}(C)] \qquad (3)$$

where $c = E(C)$ and $d \times E(D)$. (The subscripts were dropped for the sake of clarity.)

Equation 3 may be obtained by expanding $Y = C \times D$ in a Taylor series about its expected value, $c \times d$. It is an exact evaluation of var($aadpv$), as second derivatives are zero, and var($aadpv$) can be conveniently expressed in terms of the coefficients of variation (CV). (CV is defined as the standard deviation divided by the expected value.) If V is defined as CV^2, so that $V(X) = \text{var}(X)/E^2(X)$, then Equation 3 takes the form

$$\text{var}(aadpv) = K^2 \times c^2 \times d^2 \times [V(C) + V(D) + V(C) \times V(D)] \qquad (4)$$

In situations where seasonality exists, Equation 4 can be readily generalized as follows:

$$\text{var}(aadpv) = K^2 \times c^2 \times d^2 \times s^2 \times [V(C) + V(D) + V(S) + V(C) \times V(D) + V(C) \times V(S) + V(D) \times V(S) + V(C) \times V(D) \times V(S)] \qquad (5)$$

If the variances of C, D and S are small relative to their expected value, var($aadpv$) can be approximated by

$$\text{var}(aadpv) = K^2 \times c^2 \times d^2 \times s^2 \times [V(C) + V(D) + V(S)] \qquad (6)$$

Both sources of variation in Equations 3 and 4 (C and D) are addressed in the present paper. However, because of lack of repeated counts for the same periods and locations on different days, random fluctuations are discussed only in the context of estimating hourly flows from 15 min counts. The use of such short counts for hourly estimates in residential locations is examined.

The main issue dealt with in this paper is whether the distribution of pedestrian volumes during the day can be characterized in a way similar to vehicular flow distribution, so that the daily average can be deduced from short counts. Hourly whole-day counts are used to determine the typical daily distributions of pedestrians in residential and central business district (CBD) streets in Israel and to determine the best time of day for performing short counts.

METHODS

Existing data from studies carried out at the Road Safety Center during the period 1970 to 1972 were used in this study. The data consisted of full day counts by hours, performed on weekdays, at 86 locations on urban streets. Fourteen locations were in CBDs and 72 on collector and arterial streets in residential neighborhoods. Most of the counts were performed during the hours 0700 to 2200; a few were 24-hr counts. Some of the counts were conducted at pedestrian crossings, some near crossings, and others at midblock sections. According to Jacobs and Wilson (4), the daily distribution of pedestrians is not seriously affected by the place of crossing. Thus, data for all sites were combined and analyzed together.

The hourly pedestrian volumes at each site were converted to percentage of total daily volumes. Thus, for each site a daily distribution of crossing pedestrians was calculated. The use of percentage distributions, rather then absolute numbers, was needed because of the wide range of hourly volumes in our data. For example, pedestrian volumes in non-CBD locations during peak hours ranged from 17 to 959 and in CBD locations from 233 to 4,671. This wide range reflects not only differences among streets but also differences in the width of the sections that were counted.

The average distributions for CBD sites and for residential sites were calculated, along with the hourly standard deviations (SD) and coefficients of variation (CV: defined as the SD divided by the mean). These measure the stability of the hourly share of total daily volume among sites for each hour. Thus the SD and CV serve as measures of stability of the different daily expansion factors, which are based on hourly counts. Periods with relatively small coefficients produce better estimates of the daily expansion factor, yielding better estimates of the daily volumes.

For many of the sites, the hourly volumes consisted of four 15-min intervals. Some of these sites were counted again after a few months. Counts of less than a full day were also used. In all, there were 135 daily counts by 15-min intervals. These 15-min counts were used to assess the adequacy of short counts to represent hourly volumes. Most sites were in residential neighborhoods. Counts were carried out during the main hours of pedestrian activity, between 0700 and 2200. The average of pedestrian volumes was relatively low: 8 to 10 pedestrians per 15 min.

The four 15-min counts in each full hour were regarded as four independent samples from the same distribution. The assumption of independence seems reasonable (*9*). The assumption of identical distribution implies no trend within the hour. This may not always be correct, especially during morning peak hour. During other parts of the day volumes are fairly constant. When trends do exist, the assumption of common distribution results in an overestimate of the variation.

SDs were calculated for each hour to measure the dispersion among the four 15-min counts and, thus, the reliability of an hourly flow estimate based on a 15-min count. To compare among different sites, the SD was standardized by dividing by the average of the four counts (m) to produce the CV.

RESULTS

Daily Volume Distributions in Residential Neighborhoods

Presented in Figure 1 are the average daily (24-hr) volume distributions in four residential neighborhoods in the city of Haifa. The distributions are fairly similar and display three peak periods: a morning peak between 0700 and 0800, a noon peak between 1200 and 1300, and an afternoon peak between 1600 and 1900.

The average daily distributions in two cities, Haifa and Givatayim, are compared in Figure 2. As counts in Givatayim were performed during day and evening hours only, both distributions are displayed and compared for this period. Again, a high degree of similarity can be observed between the two distributions. Therefore, all 72 residential sites were combined

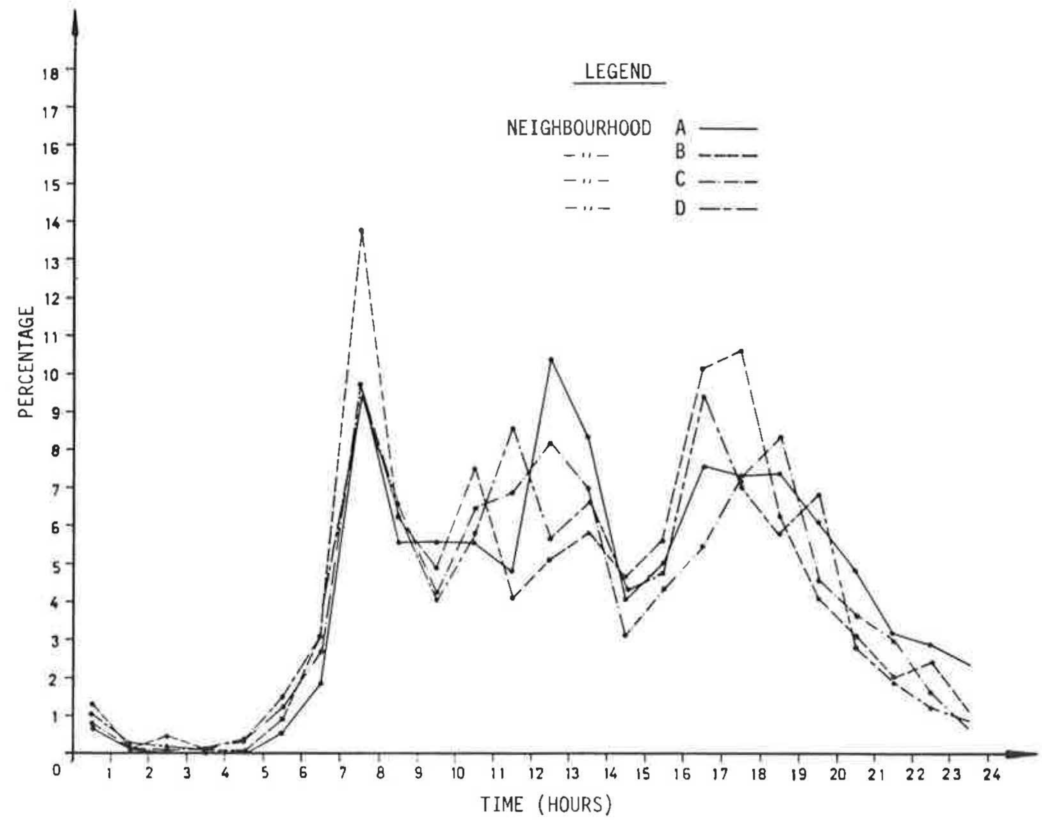

FIGURE 1 Daily distribution of crossing pedestrian volumes (percentages) in four residential neighborhoods in Haifa.

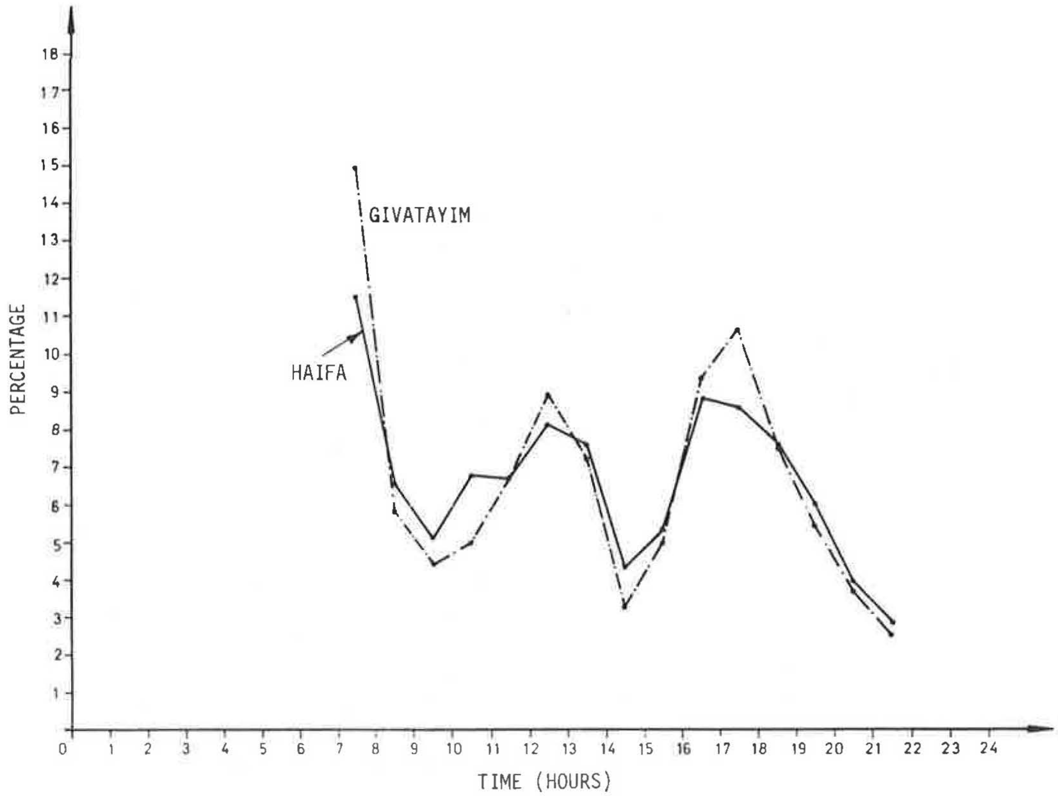

FIGURE 2 Comparison of daily distribution of crossing pedestrian volumes (percentages) in Haifa and Givatayim.

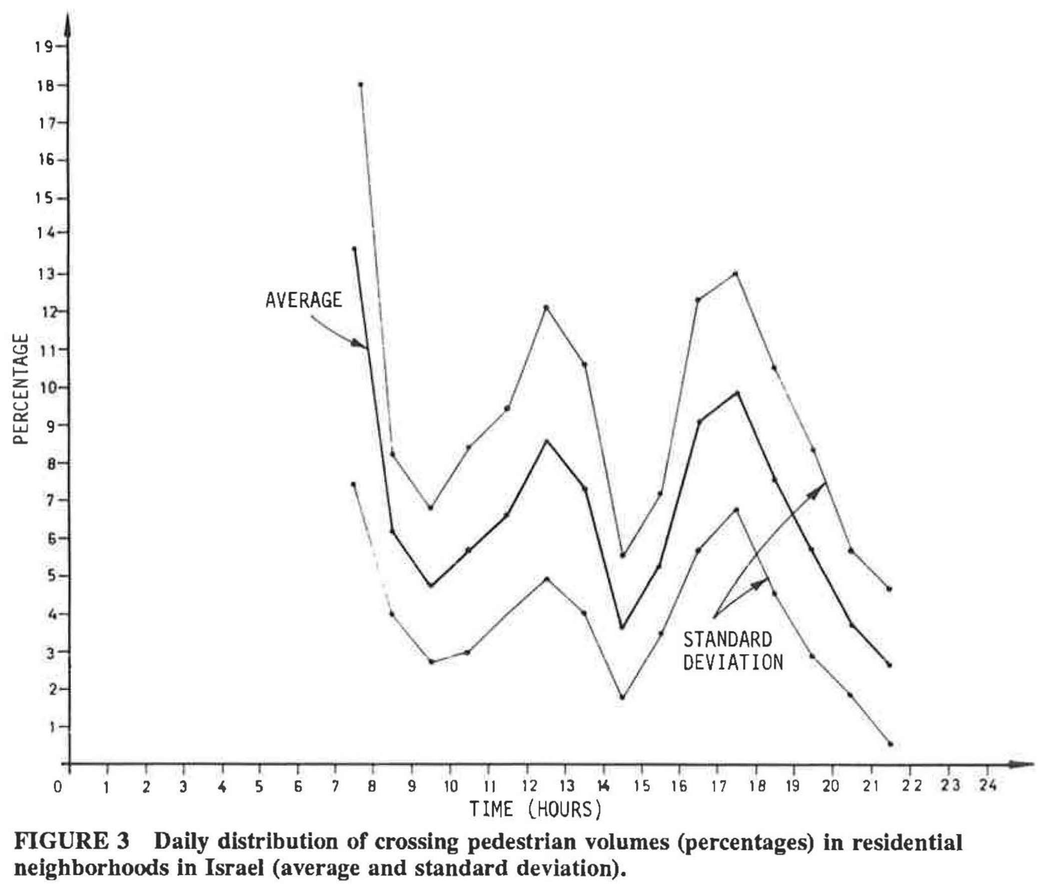

FIGURE 3 Daily distribution of crossing pedestrian volumes (percentages) in residential neighborhoods in Israel (average and standard deviation).

to calculate an average, or typical, distribution of pedestrian volumes in urban residential areas. This average distribution and the standard deviation of hourly pedestrian volumes are displayed in Figure 3. The same data are presented in Table 1, together with the hourly CVs.

The main results for residential areas are summarized as follows:

• Pedestrian volume during night hours, 2200 to 0700, constitutes only 3 percent of the total daily volume. Counts that do not include these hours are therefore almost complete. This result is based on the 24-hr counts performed in residential locations in Haifa.

• The daily distribution of crossing pedestrians has three peaks: a steep morning peak between 0700 and 0800, which carries 14 percent of the daily volume; an afternoon peak between 1600 and 1900, with an hourly flow of 8 to 10 percent of the total daily volume; and a midday peak between 1200 and 1300, containing 9 percent of the daily volume.

• The standard deviation of the hourly rate is 2 to 3.5 percent of the total daily volume, except for the morning peak, which has an SD of 6.1 percent. The lowest variation occurs during the nonpeak periods: 0800 to 1000 and 1400 to 1600, when the SD is about 2 percent.

• The CV is generally 30 percent to 50 percent of the average hourly volume (except for the hour 2100 to 2200, when pedestrian traffic is already very low). The lowest CVs occur again in the off-peak periods from 0800 to 0900 and from 1500 to 1600, when variance is low, but also during the afternoon peak from 1600 to 1900, when the variation in pedestrian volumes and the average flow are relatively high, so that their ratio remains relatively low.

TABLE 1 DAILY DISTRIBUTION OF HOURLY PEDESTRIAN CROSSING VOLUMES IN RESIDENTIAL AREAS

Hour	Mean (%)	SD (%)	CV (%)
7–8	13.6	6.1	0.45
8–9	6.2	2.1	0.34
9–10	4.7	2.1	0.44
10–11	5.7	2.6	0.46
11–12	6.6	2.7	0.40
12–13	8.6	3.7	0.42
13–14	7.4	3.4	0.46
14–15	3.7	1.9	0.52
15–16	5.3	1.9	0.35
16–17	9.1	3.2	0.35
17–18	9.9	3.2	0.32
18–19	7.6	3.1	0.40
19–20	5.6	2.8	0.49
20–21	3.7	2.0	0.53
21–22	2.6	2.2	0.82

NOTE: Sample size = 72 sites.

Daily Volume Distributions in CBD Areas

The average daily distribution of pedestrian crossing volumes in 14 CBD locations for the period of activity, from 0700 to 2200, is shown in Figure 4. The same information is presented together with the hourly SDs and CVs in Table 2. In addition,

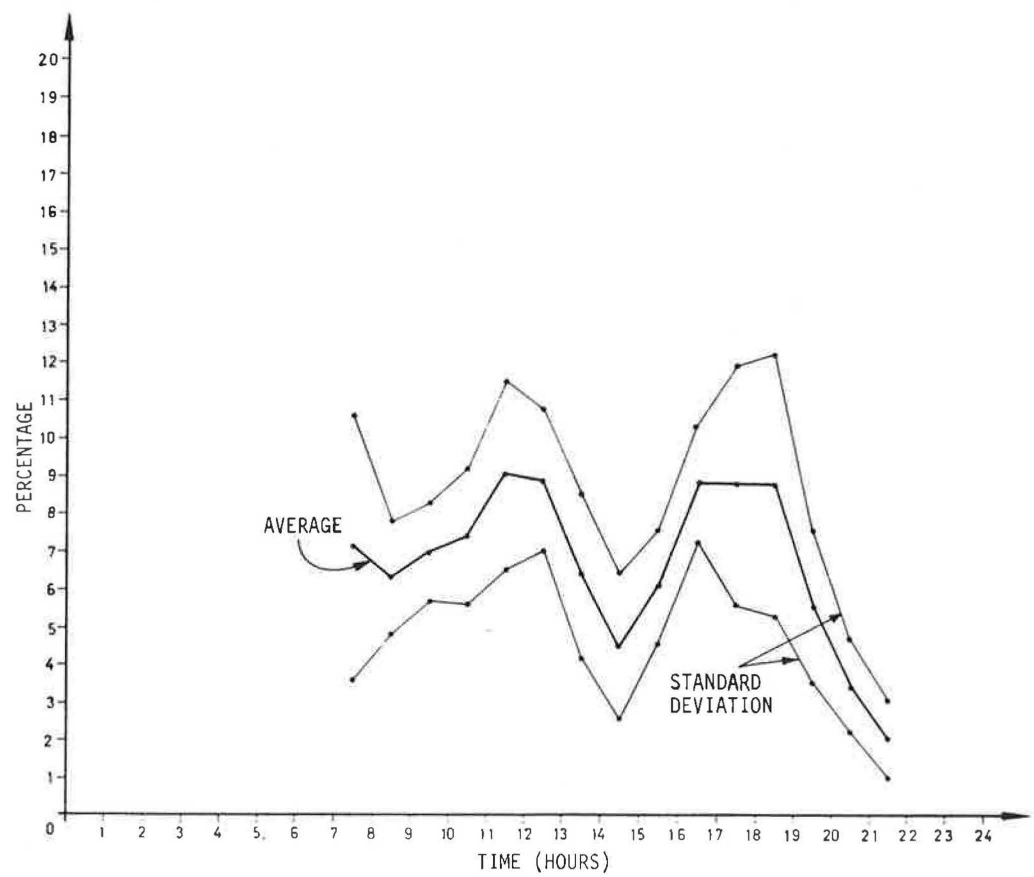

FIGURE 4 Daily distribution of crossing pedestrian volumes in the CBD (percentages).

TABLE 2 DAILY DISTRIBUTION OF HOURLY PEDESTRIAN CROSSING VOLUMES IN THE CBD

Hour	Mean (%)	SD (%)	CV (%)
7–8	7.1	3.5	0.49
8–9	6.3	1.5	0.23
9–10	6.9	1.4	0.19
10–11	7.4	1.8	0.24
11–12	9.1	2.5	0.28
12–13	8.8	1.9	0.22
13–14	6.5	2.2	0.34
14–15	4.5	1.9	0.42
15–16	6.1	1.6	0.25
16–17	8.8	1.5	0.17
17–18	8.8	3.1	0.35
18–19	8.8	3.5	0.39
19–20	5.6	2.1	0.37
20–21	3.6	1.3	0.37
21–22	2.1	1.0	0.47

NOTE: Sample size = 14 sites.

TABLE 3 ACCURACY OF SHORT 15-MIN COUNTS AS AN ESTIMATE OF THE HOURLY VOLUME

Hour of Counting	CV	No. of Sites	Ranking of Estimate Accuracy
7–8	51.8	40	9
8–9	66.9	57	13
9–10	67.7	62	14
10–11	37.5	31	2
11–12	48.0	63	8
12–13	55.2	70	12
13–14	53.1	64	10
14–15	45.7	18	6
15–16	32.7	28	1
16–17	41.2	67	4
17–18	45.3	64	5
18–19	46.0	57	7
19–20	40.1	41	3
20–21	53.8	45	11
21–22	69.1	46	15

data on pedestrian activity in the CBD during night hours were also available, but are not displayed here, to facilitate comparison with the daily distribution in residential areas.

The main findings for CBD areas are summarized as follows:

- Pedestrian volume during night hours, 2200 to 0700, constitutes only 7 percent of total the daily volume. Counts that do not include these hours are therefore almost complete.
- The daily pedestrian distribution in CBD locations is similar to that in residential locations and also contains three peak periods: morning (0700 to 0800), noon (1100 to 1300), and afternoon (1600 to 1900). The main difference between the two distributions is that the morning peak in the CBD is not as steep and contains only 7 percent of the daily volume. This difference reflects the fact that there are no schools in CBD areas (schools in Israel start between 0700 and 0800), whereas shops open only at 0900.
- The hourly variation is generally lower in CBD locations than in residential areas and amounts to 1 to 3.5 percent of the daily pedestrian volume. The variation is higher at peak hours than at off-peak periods, in accordance with the findings for residential sites.
- The CVs vary between 20 and 50 percent of the average hourly volume. CVs do not exceed 30 percent for the periods from 0800 to 1300 and 1500 to 1700, and they are lowest (<20 percent) for the hours from 0900 to 1000 and 1600 to 1700.

Short Counts

CVs for 15-min counts for each hour are presented in Table 3. The CVs are averaged over locations and range between 33 and 69 percent. The largest variations stem from trends within the hour, but even for hours with constant flows of pedestrians, the variation among short counts within the same hour is 33 to 50 percent. These findings are in accordance with those of Haynes (*9*), who recommends full hour counts when pedestrian flows are less than 10 pedestrians per minute.

SUMMARY AND DISCUSSION

Analysis of the daily distribution of pedestrian crossing volumes leads to a number of conclusions with practical implications for improved pedestrian counting. These can be used in the design of crossing facilities and for the study of pedestrian risk and safety.

- Typical daily distribution of pedestrian crossing volumes were developed for both residential and CBD locations in urban areas in Israel. These distributions can be used to estimate daily pedestrian volumes during the main hours of activity, 0700 to 2200. Total 24-hourly volumes can be estimated from 15-hourly volumes by multiplying by 1.03 for residential sites and by 1.07 in the CBD.
- The daily distribution for Israel was compared with similar distributions obtained for Germany and Australia. Neumann (*10*) conducted detailed counts at 111 sites in various German cities. Cameron (*11*) counted pedestrian volumes at 29 sites in Melbourne, Australia. The respective daily distributions are plotted in Figure 5. It can be seen that the three distributions have similar shapes, with differences reflecting differing lifestyles (e.g., school, work, and shopping hours).
- The standard deviation of the hourly rate in residential areas is generally 2 to 3.5 percent of the total daily volume. The hourly variation is generally lower in CBD locations and ranges between 1 and 3.5 percent of the daily pedestrian volumes. The lowest SDs occur during nonpeak periods. The coefficient of variation in residential areas is generally 30 to 50 percent of the average hourly volume. CVs smaller than 35 percent occur during the hours between 0800 and 0900 and 1500 and 1800. In CBD areas the CVs vary between 20 and 50 percent of the average hourly volume. CVs do not exceed 30 percent for the periods 0800 to 1300 and 1500 to 1700. These hours should be preferred whenever short counts are performed for the purpose of risk estimates. Counts during peak hours are still needed if facility design is the major aim. The average daily estimates can be improved by using counts of 2 or more hours. Tables 1 and 2 can be used to calculate the resulting SDs and CVs of such counts in Israel.

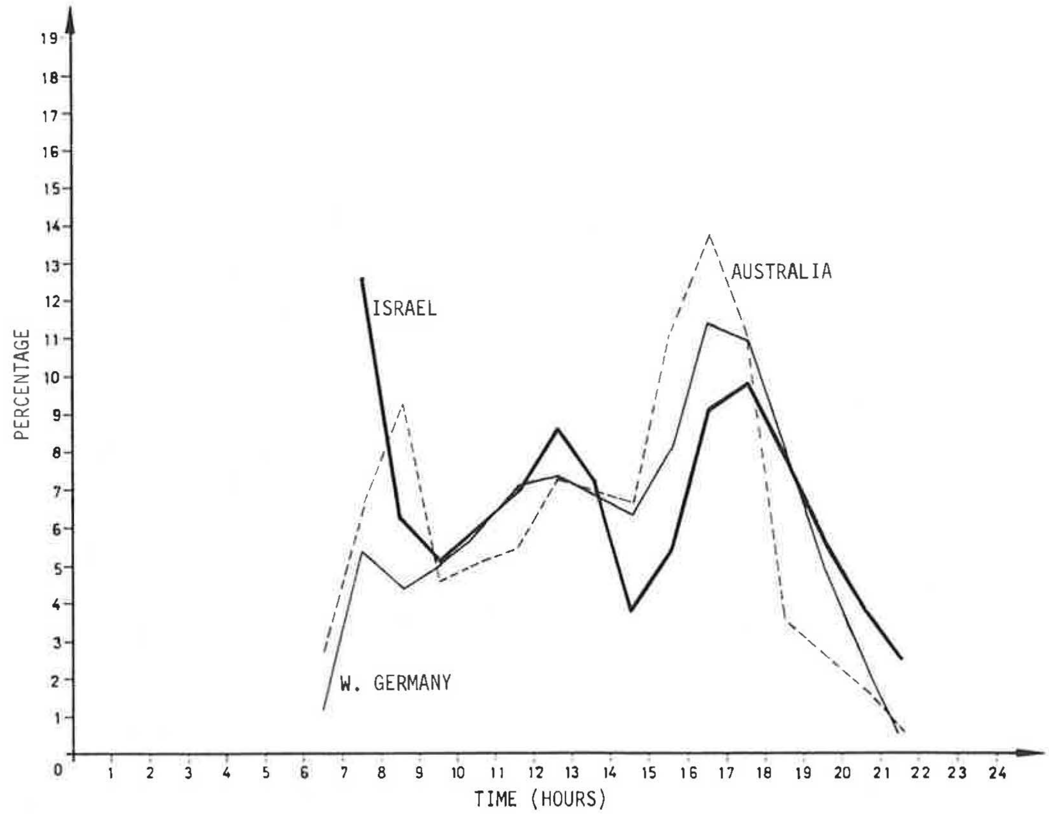

FIGURE 5 Comparison of daily distribution of crossing pedestrian volumes (percentages) in Israel, Germany, and Australia.

• Haynes (*9*) studied the accuracy of short pedestrian counts. Pedestrians were counted at 11 crossing sites in Norwich, England, with varied levels of activity. Counts were made during 1-min intervals for 2 hr. The data were then cleared of trends. Trend-cleared counts at 1-min intervals were found to be nearly normally distributed and independent of each other. The variance was found to be proportionate to the mean, which indicates that the accuracy of estimates based on these counts increases as pedestrian volumes increase. Assuming normality, Haynes developed a series of curves for various levels of activity. The relationship between maximum expected sampling error and length of count is shown for various levels of pedestrian activity in Figure 6. This figure can aid in choosing count duration to comply with a desired level of accuracy. It can be seen that for volumes of 30 pedestrians or more per minute, an error of less than 10 percent can be achieved with

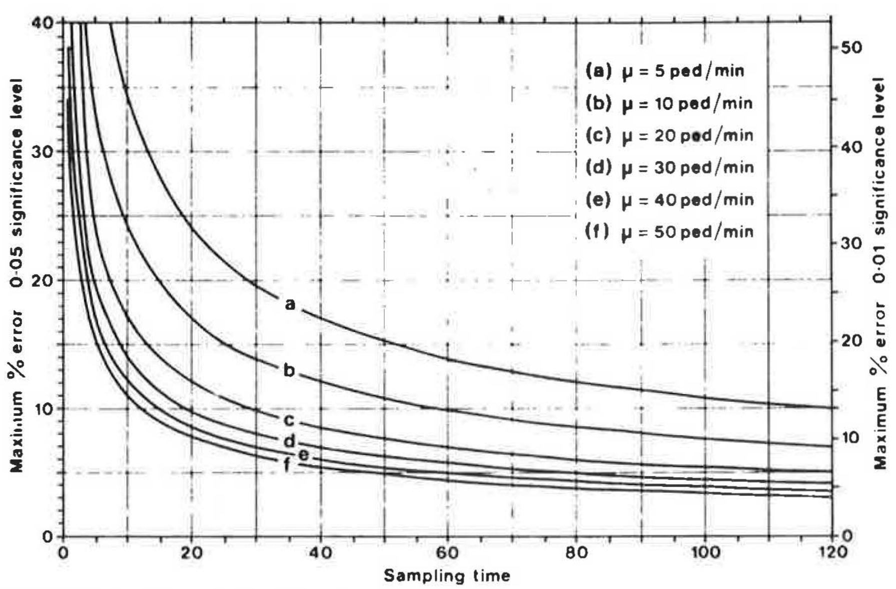

FIGURE 6 The relationships between maximum expected sampling error and sampling time for various levels of pedestrian activity (*9*).

12- to 15-min counts. For levels of 10 pedestrians per minute, full-hour counts are needed.

- Similar analysis on 15-min data at residential sites with relatively low pedestrian volumes was conducted in this study. The CV was found to change with the hours but in each case was greater than 30 percent. It is concluded that 15-min counts should not be used for the estimation of hourly flows in residential areas. When used to estimate daily flows, the short-count error is compounded to the error in the hourly expansion factor.

Pedestrian counts of varying durations are used to estimate AADPV, which serves as a measure of exposure. Further research on the day-to-day variation in hourly or daily counts is needed to fully address the issue of accuracy of these estimates. This will enable the estimation of var(*aadpv*) according to Equation 3.

Although the data used in the study date back to the early 1970s, it is not expected that pedestrian distributions have changed because basic life-styles in Israel have not changed during this period. However, this assumption should be checked periodically and the distributions updated if necessary.

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Validation of the Time-Space Corner and Crosswalk Analysis Method

JOHN J. FRUIN, BRIAN T. KETCHAM, AND PETER HECHT

Time-space analysis is a new method for evaluating pedestrian activity spaces. This technique has been used in the *Highway Capacity Manual* to determine pedestrian levels of service in corners and crosswalks. Although the new method follows established pedestrian traffic relationships, it had not been validated as a measure of actual street conditions. Evaluation of the pedestrian traffic impacts through the use of the *Highway Capacity Manual* is a part of New York City's environmental review process for new developments, motivating the City Planning Commission, with U.S. Department of Transportation support, to sponsor a time-lapse photography study to validate the *Highway Capacity Manual* pedestrian analysis method. Based on the analysis of time-lapse photography of pedestrian traffic activity at four Manhattan central business district intersections, the *Highway Capacity Manual* time-space analysis model was found to be a valid procedure for determining pedestrian levels of service in corners and crosswalks. However, the photographic observations of pedestrian activity, combined with a computer sensitivity analysis of *Highway Capacity Manual* model input parameters, indicated the following changes would improve the accuracy of the method: (a) standing area in corners for those waiting to cross increased from the *Highway Capacity Manual* value of 5 sq ft/person to 7 sq ft/person; (b) occupancy time in corners for those moving through the corner changed from a uniform 4 sec to a value determined by a linear regression equation based on sidewalk width; (c) start-up time or delay of 3 sec for pedestrians to begin crossing in the *Highway Capacity Manual* model eliminated to simplify the analysis model; and (d) walking speeds of pedestrians in crosswalks reduced from 4.5 ft/sec to 3.3 ft/sec as more representative of observed crosswalk platoon flow. An additional observation of the study was that although pedestrian levels of service show relatively little degradation because of turning vehicles, heavy pedestrian traffic noticeably reduced intersection capacity, potentially warranting turn restrictions where there are high crossing-volumes to increase intersection capacity, with secondary benefits of improved pedestrian safety and convenience.

A new method for analyzing pedestrian activity spaces (time-space corner and crosswalk analysis method) was introduced at the annual Transportation Research Board Meeting in January of 1984 (*1*). After technical review the analysis procedure was incorporated in the *Highway Capacity Manual* (HCM) (2). Although the new method followed established pedestrian traffic relationships, it had not been validated as a measure of actual street conditions.

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New York City's environmental impact analysis process requires the evaluation of both the pedestrian and vehicle impacts of new developments that are based on HCM procedures. Because of the need to ensure the validity of the new HCM method for the formal impact analysis process, the Planning Commission of the City of New York, with the financial support of the Urban Mass Transportation Administration, U.S. Department of Transportation, sponsored the study described in this paper (*3*).

Corners and crosswalks are important because pedestrian activity is concentrated at these locations, and they provide the only valid measure of pedestrian network convenience. Experience has repeatedly shown that although two intersecting sidewalks may be operating at high midblock levels of service (LOS), the corners and crosswalks may be saturated and inadequate. Additionally, in crosswalks pedestrians must compete with turning vehicles for the available green signal cycle time.

STUDY OBJECTIVES AND METHODOLOGY

The purpose of the study was to test, evaluate, validate, and modify if indicated, the 1985 HCM procedure for measuring and analyzing pedestrian movement and LOS in corners and crosswalks for New York City conditions. The primary study method used was time-lapse photography of actual pedestrian traffic activity on street corners and crosswalks for four busy Manhattan intersections and the comparison of these measurements with the HCM procedure for determining LOS for the same pedestrian traffic volumes, intersection configurations, and signal timing.

Major elements of the study included

- Computer sensitivity analysis of HCM procedure input parameters to establish their relative significance in determining corner and crosswalk LOS;
- Surveys to identify sites that would provide a range of pedestrian activity and suitable photographic conditions;
- Time-lapse photography and traffic counting of the four intersections;
- Data takeoff from the time-lapse films and data summary and analysis; and
- Comparison of results with HCM method and recommendations for changes to improve accuracy.

In addition, interview surveys were conducted at two sites to determine if pedestrian perceptions of crowding and convenience were consistent with LOS measures.

CORNER AND CROSSWALK ANALYSIS PROBLEM

Street corners are difficult to analyze because of

- The convergence of intersecting flows from adjoining sidewalks and crosswalks;
- Multiple changes in pedestrian movement directions within the corner;
- Pulsating volumes of pedestrians moving through the corner in sequence with changing signals;
- Buildup of queues of waiting pedestrians on opposite sides of the corner frontage alternating with the signal cycle; and
- Unusable space in the corner because of signal posts or other permanent or transient obstructions.

Because of these factors, corners bear little resemblance to the typical corridor where flow is relatively uniform, primarily bidirectional, and controlled by abutting walls. Thus, LOS traffic-flow analysis techniques developed for corridors cannot be directly applied to corners. However, the freedom of movement of pedestrians is related to the average available space per person, and therefore the personal area criteria used in LOS standards remain as a valid measure of levels of pedestrian convenience.

The crosswalk more closely resembles a corridor in terms of the uniformity and directionality of pedestrian movement. However, unlike a corridor, there are no walls to contain pedestrians, and they may move outside of the marked crosswalk if it is perceived to be too crowded. Additionally, pedestrians in crosswalks must compete with turning vehicles, and conventional corridor analysis cannot account for vehicle effects on pedestrian movement.

Two stages of movement occur in crosswalks during the normal green cycle. The first is the initial surge or maximum occupancy of the crosswalk that occurs in the period shortly after the green signal releases the "red platoons" (*2*), or pedestrians accumulated during the red interval, and the second, the average flow during the total green interval time. The surge condition determines the ability of the crosswalk to contain crosswalk volumes within the striped area, the average flow during the cycle, and the ability of the crosswalk to also accommodate turning vehicles.

HCM METHOD

The time-space (TS) method for analyzing corners and crosswalks compares the supply of space available to pedestrians during an analysis interval (the total signal time) with the demand for space by pedestrians using the corner or crosswalk during the interval. For corners the supply of available TS is the product of the usable area of the corner in square feet and the total length of the signal cycle in seconds. For crosswalks, the supply of available TS is the product of the area of the crosswalk in square feet and the length of the green interval available for pedestrians to cross the street.

For corners, the TS demand is based on the average of two conditions: (a) the minor-street-crossing phase during which moving pedestrians cross the minor street and others stand and wait to cross the major street and (b) the major-street-crossing phase where movement is to that crosswalk and waiting is at the minor curb. The two conditions are illustrated in Figures 1 and 2, respectively.

In order to estimate the average circulation area available for moving pedestrians, the HCM method deducts the average area occupied by standing pedestrians during the minor and major street crossings from the TS supply, based on an assumed standing area of 5 sq ft/person, an average area occupancy typically observed in many competitive queueing situations. The demand for the remaining circulation TS is determined by the product of the total number of persons moving through the corner during the signal cycle, and an assumed corner occupancy time during this movement of 4 sec. The corner LOS is

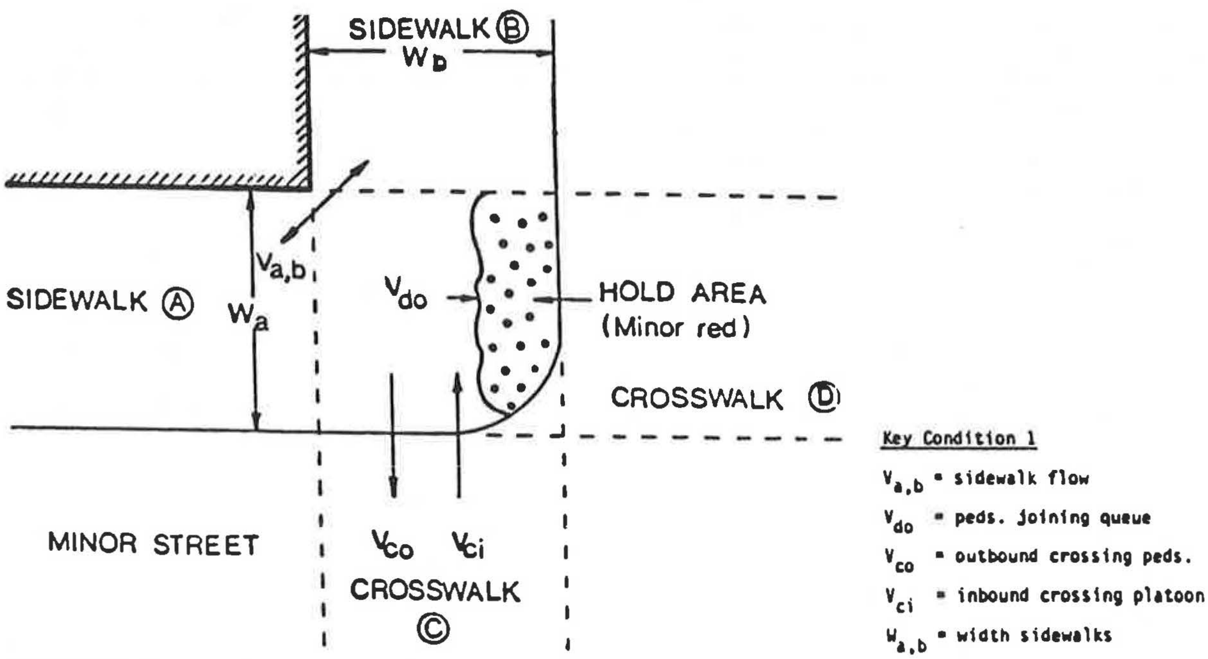

FIGURE 1 Intersection corner condition: minor street crossing (*2*).

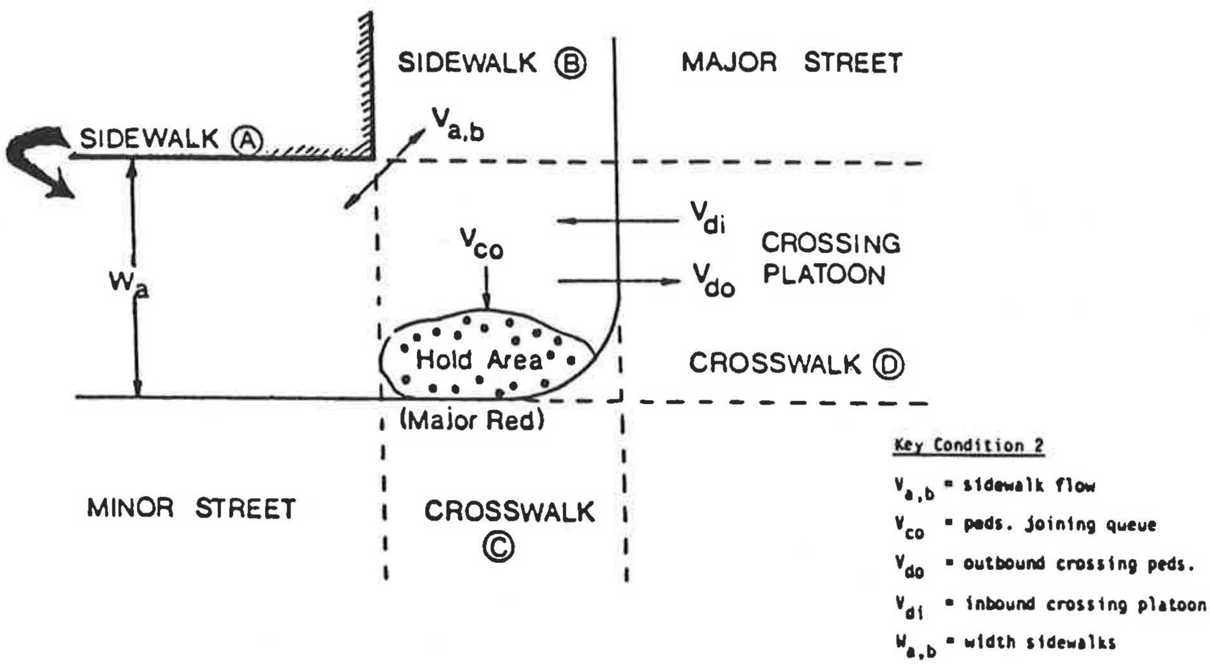

FIGURE 2 Intersection corner condition: major street crossing (*2*).

determined by dividing the circulation demand in pedestrian seconds into the remaining circulation TS in square feet seconds to obtain the average area occupancy in square feet per pedestrian during the cycle. This average pedestrian area is compared with LOS area standards to determine the corner LOS.

Both the assumption of a standing area of 5 sq ft/person, and a moving occupancy time of 4 sec were considered to be reasonable estimates of these parameters but had not been validated by observations of actual corners. The 4-sec occupancy time was considered to be conservative because many pedestrians short cut corner edges, occupying the corner for only a few seconds.

For crosswalks, the HCM method examines two conditions: the initial surge when pedestrians waiting during the red interval cross as a platoon, and the average flow during the green interval. For the surge, a "start-up" delay of 3 sec is assumed during which others arrive at the crosswalk, and a crossing speed of 4.5 ft/sec is assumed for the leader of each of the red platoons to reach the opposite curb. The maximum occupancy of the crosswalk is the total number of persons waiting during the red interval time plus the start-up time, plus those entering the crosswalk during the time taken for the red platoon leaders to reach the opposite curbs. The maximum number of pedestrians occupying the crosswalk in the surge is divided into the area of the crosswalk to determine the average area per pedestrian and the surge LOS.

The average square feet of circulation area per pedestrian and LOS during the green interval is determined by dividing the product of the total crossing volume during the interval and average pedestrian crossing time (based on 4.5 ft/sec walking speed) into the crosswalk TS supply in area seconds.

Because turning vehicles can be expressed in time-space units, the HCM method provides a means of estimating the effect of turning vehicles on crosswalk pedestrian LOS, and of potentially greater importance, the possible limits on turning movements where there are heavy pedestrian crossing volumes. At such crossings, "spill-back" due to vehicle turn delays can reduce intersection capacity and throughput.

HCM ASSUMPTIONS TO BE VALIDATED

In addition to the primary task of determining if the HCM TS method provides a valid model for predicting corner and crosswalk pedestrian densities and LOS, the following parameters assumed in the HCM analysis procedure were measured for comparison purposes:

- Average standing area for waiting pedestrians;
- Average occupancy time of pedestrians moving through the corner;
- Pedestrian speeds in crossing platoons;
- Platoon start-up times; and
- Turning vehicle time related to pedestrian crossing volumes, for a limited sample.

COMPUTER SENSITIVITY ANALYSIS

A computer program was developed, based on the LOTUS 1-2-3 spreadsheet for the IBM-PC, of the HCM corner and crosswalk analysis procedure for processing data collected in the study and comparing it with HCM assumptions. The program provided a means of determining the relative sensitivity of changes in each of the HCM model input parameters used to estimate pedestrian LOS. By varying the input parameters over an expected range of values, the sensitivity analysis indicated the following:

- *Waiting area per pedestrian*: Limited sensitivity for low and moderate volumes, but would affect predicted corner LOS for high volumes;
- *Average corner circulation time*: Significant nonlinear impact for changes from the HCM value of 4 sec, important factor in predicting accurate corner LOS;

- *Platoon start-up time*: Relatively insensitive to change and predicting crosswalk LOS;
- *Crossing speed*: Significant impact in predicting crosswalk LOS based on variations from the HCM assumption of 4.5 ft/sec; and
- *Vehicle turning time*: Turning time and vehicle volume shown as relatively insensitive in affecting the predicted crosswalk LOS for average crosswalk conditions (did not consider possible vehicle delay or high pedestrian volumes).

STUDY SITES AND PROCEDURES

Four Manhattan intersections were selected for study: (a) 5th Avenue and 34th Street, (b) 5th Avenue and 49th Street, (c) Broadway and Maiden Lane, and (d) 8th Avenue and 40th Street. Each of the sites was selected on the basis of providing a full range of pedestrian activity, as well as having differing intersection and corner geometry. A significant study constraint was the finding of cooperative building owners who would allow the positioning of time-lapse cameras at the approximate six-story height required for the camera field of view of the intersection. Some owners required extensive liability coverage that precluded use of their buildings.

Three time-lapse cameras set at a frame interval of 1/2 sec were used to obtain a full view of the corner and intersecting crosswalks. At the initial pilot study site the New York City Traffic Department installed a special light on top of the signal head to indicate signal changes in the camera field of view, but at subsequent sites it was necessary to accomplish this with hand signals that would appear on the film. The geometrics of each corner and crosswalk were measured and signal splits timed.

Complete pedestrian counts on a cycle-by-cycle basis were made of all pedestrians moving through the corner via the two crosswalks and adjoining sidewalks. Spot speed studies of persons moving through the corner and crossing the street were also made for later comparison with film data take-off values. A limited sample of vehicle turning times was also collected.

Data takeoff from time-lapse films was accomplished by using an analyst projector with a single-frame stop action capability and frame-counting feature, which helped to locate specific signal cycle sequences on the film roll. The selection of signal cycles for analysis was based on reference to the field count volumes for that cycle and previewing of the film to ensure that no unusual conditions occurred, for example, the temporary blocking of the crossing by a parked truck.

Standing areas for pedestrians waiting to cross at corners were determined by drawing an "envelope" around standing groups, measuring the area within the envelope using a grid designed to correct for parallax, and dividing the area by the number of standees. Circulation times for persons moving through corners to join queues, cross the street, or reach the intersecting sidewalk were determined by sampling typical pathways and counting the number of photo frames at 1/2 sec each to move between corner boundaries. Street crossing times and speeds and platoon start-up times were also obtained by similar frame-counting procedures.

STUDY RESULTS

The results of the film data takeoff for the HCM model input parameters indicated the following:

- Standing area for pedestrians waiting to cross was found to vary from 5.1 to 12.3 sq ft/person, with a median of 7.6, as compared with the HCM assumption of 5 sq ft;
- Corner occupancy time, or the time moving through the corner, was found to be dependent on corner dimensions and was not equal to the HCM constant of 4 sec except for corners with narrower intersecting sidewalks;
- Platoon start-up times were found to vary from 0 to 8.5 sec, with a median of 2.5 sec, compared with the HCM constant of 3 sec;
- Crossing speeds were found to vary from 2.1 to 5.5 ft/sec, with a mean of 3.4 and a median of 3.3 ft/sec, as compared with the HCM speed of 4.5 ft/sec;
- Vehicle turning times for a limited sample varied from 2 to 30 sec compared with the HCM value of 5 sec, indicative that heavy pedestrian volumes could limit the number of turns in a signal cycle, and reduce intersection capacity.

TYPICAL PATTERNS OF CORNER AND CROSSWALK USE

Typical patterns of corner activity are shown in Figure 3. Red queues alternately build up during the signal cycle and are subsequently released at the green, as others enter the corner crossing from the other side of the street. The total traffic volume passing through this 189-sq-ft corner during the cycle shown was 196 persons. Five distinct peaks of 24 to 27 persons using the corner at various points during the cycle are shown, as well as a minimum occupancy of only 5 persons. This indicates that although corner conditions were generally LOS *E*, they were as high as LOS *C* for one brief interval. Predicted LOS for the corner based on the HCM method was LOS *E*.

From Figure 4, illustrating crosswalk activity patterns, it can be seen that the crosswalk only experiences one peak, compared with the multiple peaks for the corner, occurring as the two platoons released from opposite curbs merge. A total of 131 pedestrians crossed during the cycle illustrated, and the maximum observed occupancy of the 996.8-sq-ft crosswalk was 75 persons at 13.3 sq ft/person, LOS *E*. The surge predicted by the HCM model was 62 persons occupancy at 17.6 sq ft/person, LOS *D*. Average observed crosswalk occupancy during the cycle was 37.6 pedestrians or 25.6 sq ft/person, LOS *C*, and as predicted by the HCM model 38.4 sq ft, also LOS *C*.

RECOMMENDED CHANGES TO HCM METHOD

Based on study results the following changes were recommended to the HCM method to more accurately predict corner and crosswalk LOS for observed New York City traffic conditions:

- *Standing area*: Constant of 7 sq ft/person, based on observations combined with computer sensitivity results indicating a value more critical for high volumes when pedestrians would tend to stand closer together (this is the borderline between queueing LOS *C* and *D*);
- *Corner circulation time*: From a constant of 4 sec to the following formula based on corner dimensions:

$$To = 0.12\ (Wa + Wb) + 1.4$$

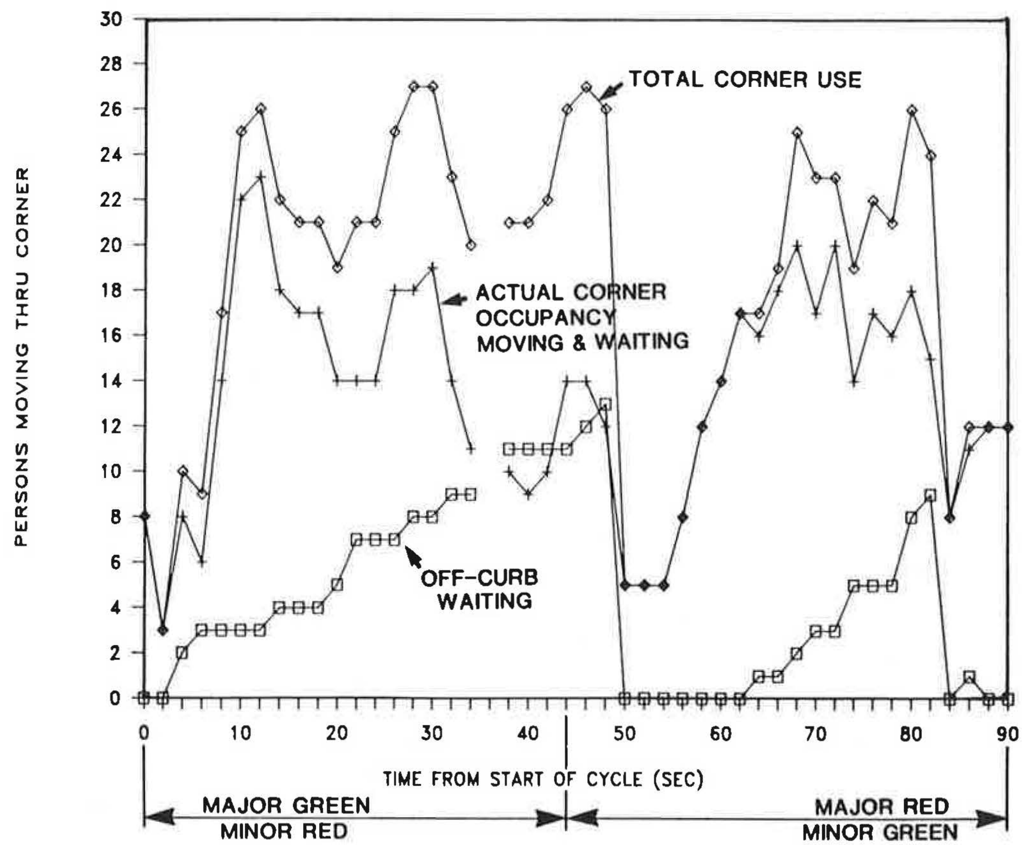

FIGURE 3 Pedestrian corner dynamics.

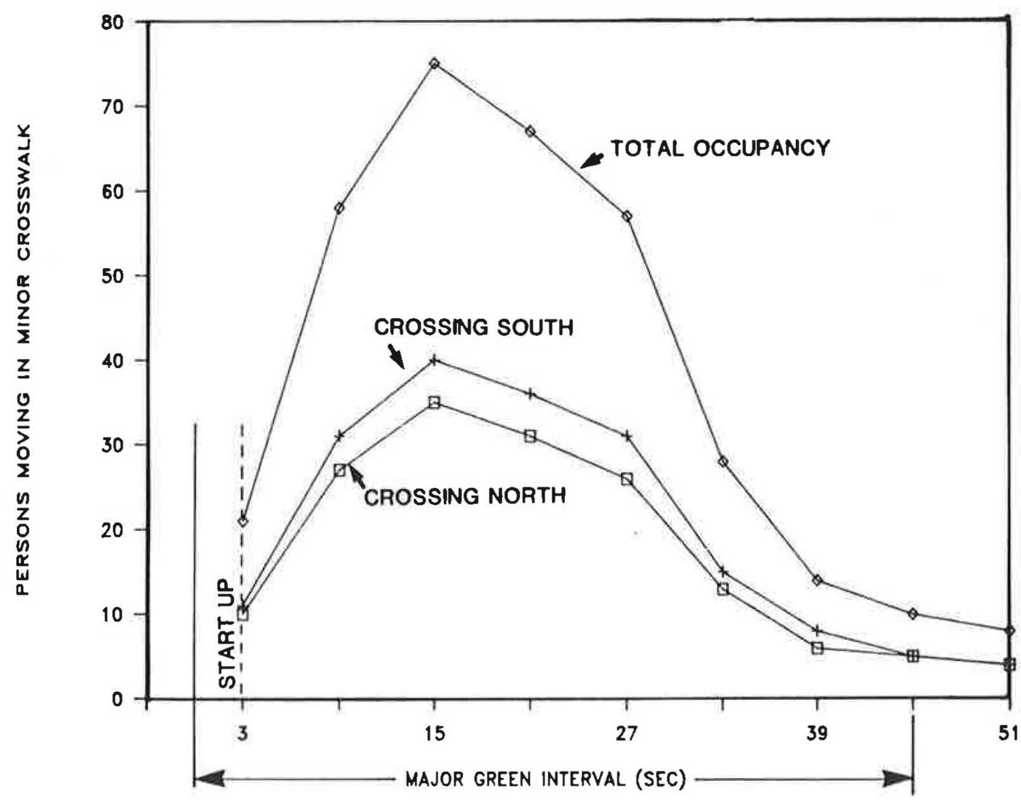

FIGURE 4 Pedestrian crosswalk dynamics.

where *To* is circulation time (sec) and *Wa* and *Wb* are intersecting sidewalk (widths in ft).

- *Platoon start-up time*: Eliminated because of minimal effect noted from sensitivity analysis and to simplify equations;
- *Crossing speeds*: Changed to 3.3 ft/sec from 4.5 ft/sec to agree with observed platoon flow, rather than free-flow pedestrian walk speeds; and
- *Vehicle turning times*: No recommendation, pending further studies relating turning times to pedestrian crossing volumes and intersection throughput.

EVALUATION OF CHANGES

Comparisons were made with the pedestrian traffic conditions observed in time-lapse film and the HCM method modified by the changes recommended in this study. In order to ensure compatibility of the observed data with the HCM method, it was necessary to adjust observed corner and crosswalk values for nonconforming pedestrian behavior, those persons waiting off the curb, bypassing the corner by moving through adjoining crosswalks, and those walking outside marked crosswalk lines.

Criteria for a good predictive model are that the average pedestrian LOS be equal to, or slightly lower than, that observed in photographs because an LOS lower than the average will be experienced one or more times during the typical signal cycle and the standard for design and evaluation should be one that tends to provide more convenience for pedestrians, rather than less. LOS area standards are originally based on corridor flow, but the movement in corners and crosswalks is more complex.

The modified HCM model, using the changes recommended in this study, predicted the same corner LOS (or per person area) as observed in photographs for 11 out of 24 cycles examined, a lower LOS in 7 cycles, and a higher one in 4 cycles. The modified crosswalk analysis model for 22 cycles predicted the observed average LOS for 11 cases and a lower LOS for 11 cases, and for the surge, the observed LOS for 22 out of 31 cycles, a lower LOS for 8, and higher for 1. In general the modified HCM model was shown to be a good predictor of observed average corner and crosswalk conditions, based on the street-crossing count data typically collected in traffic engineering studies, and more accurate than the HCM model for observed New York City conditions.

BEHAVIORAL STUDIES

The interview surveys conducted at two sites, although not providing conclusive data on the possible readjustment of LOS convenience criteria for corners and crosswalks, did show significant differences in male and female perceptions of crowding and a measurable difference in the perceptions of two different intersections established as operating at different LOS. The study results indicated that more controlled studies could potentially establish a more definitive behavioral base for LOS standards.

RECOMMENDATIONS FOR FURTHER RESEARCH

As a result of this study the following areas are recommended for further research:

- Replication of the study in smaller and medium-sized cities for comparison with New York City's high-density traffic conditions;
- Possible reevaluation of pedestrian density LOS standards, originally developed for pedestrian flow in corridors, for applicability to corners and crosswalks; and
- Study of the effects of pedestrian crossing flow on vehicle turning movements and intersection capacity, for the purpose of determining pedestrian and turning volume thresholds that would warrant turning restrictions to increase intersection capacity and additionally improve pedestrian convenience and safety.

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Abridgment

Accident Type Designations and Land Use Data in Pedestrian Accident Analysis

JAMES M. WITKOWSKI

An improved perception of the characteristics of pedestrian accidents is demonstrated through the application of accident type designations. Four accident types accounted for over 75 percent of the accident history: midblock cross, intersection cross, midblock dartout, and intersection dash. The young (ages 1 through 9) were overrepresented in the midblock dartout history, and the elderly (60 and over) were overrepresented in the intersection cross history. Specific accident types were also found to occur more often adjacent to residential and commercial-or-financial land uses. Two thousand pedestrian accidents would be required to generate statistical reliability for the more obscure accident types. The application of accident type analysis at specific sites appears limited to locations with either a large number of accidents or accidents confined to only a few types.

Studies sponsored by the Federal Highway Administration (FHWA) have concluded that pedestrian accident evaluation and the identification of appropriate countermeasures could be significantly improved through the use of accident type designations (*1*, *2*). The use of accident type designations for pedestrian accidents can improve the analyst's perception of events beyond that available using traditional accident data. The use of accident type designations is recommended as the primary resource for the identification of pedestrian accident causes and countermeasures in the FHWA-sponsored guidelines presented in the *Model Pedestrian Safety Program—User's Guide* (*3*).

STUDY OBJECTIVES AND METHODOLOGY

The primary objectives of this study were to demonstrate the application of the accident type designations presented in the Model Pedestrian Safety Program (MPSP) for urban areas. This research also incorporated land-use data into the analysis. The evaluation of accident data in terms of land use adjacent to accident sites has been shown to improve the identification of potential accident risk of various locations (*4*).

The study methodology was an analysis of pedestrian accident records for 556 accidents that occurred within the incorporated city limits of Tucson, Arizona, for the 3-yr period from 1982 through 1984. Information on accident type was extracted from copies of the individual accident reports from the accident diagram and narrative description supplied by the reporting police officer.

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Eighteen accident types were used.The accident type definitions used were those presented in an FHWA report on pedestrian trip-making characteristics and exposure measures by Tobey et al. (*4*). These are virtually the same as the definitions presented in the MPSP User's Guide (*3*) except for the distinction made in the user's guide between midblock dartout and midblock dash accidents. This distinction was virtually impossible to use based on the information in the accident reports. The combination of these accident types into the single midblock dartout, as described in the Tobey study (*4*), was deemed more appropriate for application in this demonstration.

The distinction between the vehicle turn-merge and turning vehicle accident types was also difficult to make for the data collectors. This was resolved through the evaluation of the right-of-way conflict for the turning vehicle. In general, if a vehicle was turning into cross traffic that had the right of way, the accident was considered a vehicle turn-merge type. A turning vehicle accident type was assumed if the vehicle was considered to have the right-of-way over cross traffic and was either turning right or left through gaps in opposing traffic.

Land-use data were collected for each accident location through field visits. Seven major land-use categories were employed and each was initially disaggregated into several subcategories. The data were collected based on the land use immediately adjacent to the accident location on both sides of the roadway. The data were collected for the land use the pedestrian was crossing away from (near side) and toward (far side) based on the travel direction indicated in the police report.

RESULTS

Statistical significance in this presentation is based on either the chi-square test or the *z*-test of proportions at a 95th percentile level of confidence.

Accident Type

The results of the accident type analysis are shown in Table 1. All but 17 (3.1 percent) of the accidents were capable of being classified by the accident types indicated. Intersection cross,

TABLE 1 NUMBER OF ACCIDENTS BY ACCIDENT TYPE

Accident Type	Number	Percent	Percent From Other Cities[a]	Significantly Different
Midblock cross	102	18.3	9.4	Yes
Intersection cross	151	27.2	12.1	Yes
Midblock dartout	123	22.1	33.0	Yes
Intersection dash	42	7.6	11.1	Yes
Right turn on red	16	2.9	1.4	Yes
Vehicle turn-merge	10	1.8	4.9	Yes
Multiple threat	22	4.0	2.3	No
Bus-stop related	2	0.4	1.9	Yes
Exit or enter parked vehicle	8	1.4	3.2	No
Trapped by changing light	6	1.1	0.6	No
Disabled vhicle	4	0.7	1.7	No
School-bus related	0	0.0	0.2	No
Hitchhiking	2	0.4	0.1	No
Walk along roadway	21	3.8	8.9	Yes
Playing in roadway	3	0.5	3.7	Yes
Vendor or ice cream truck	7	1.3	1.7	No
Vehicle or vehicle collision	13	2.3	NA	
On sidewalk	7	1.3	3.3	Yes
Other	17	3.1	0.4	
Total	556	100.0	99.9	
Intersection cross + dash	191	34.8	23.2	Yes
Midblock cross + dartout	224	40.4	42.4	No

NOTE: NA = Not available.
[a](*4*, p. 85)

intersection dash, midblock cross, and midblock dartout represent the four most common accident types. These four types accounted for over 75 percent of the accidents.

Several accident types were indicated to have a significantly different proportion of the accident history than that in an earlier study of five metropolitan areas (*4*). However, except for the four major accident types, the frequency of accidents for any type was too small in the Tucson sample for the results to be considered reliable. This indicates that 3 yr of accident data are insufficient for the evaluation of most accident types for a city with approximately 200 pedestrian accidents per year.

A comparison of a surrogate pedestrian population distribution presented by Tobey (*4*) to the accident study population distribution by age group revealed that pedestrians 9 yr of age and younger and those aged 60 and older were significantly overrepresented in the accident history. The data in Table 2 indicate accident problems associated with these age groups and identify some potential problem areas for age groups that were not overrepresented in the general accident history. The results for the vendor or ice cream truck accidents are unreliable due to the small sample size.

Land Use

In the Tobey (*4*) study, land use adjacent to a roadway was defined on the basis of the proportion of the land given over to specific land uses. However, this type of land-use data is not typically available in a format conducive to application with accident records.

A direct association between pedestrian activity and land use adjacent to the roadway cannot be determined from accident record data. It was extremely rare (less than 1 percent) that an accident report contained information indicating that a pedestrian was crossing to or from a specific land use. Accident locations were typically well defined in terms of the land use on either side of the roadway.

Land-use types were grouped into 7 categories for the aggregate analysis, and 39 categories for the disaggregate analysis. The disaggregate analysis did not yield particularly meaningful results because of the limited data. The number of accidents by aggregate land-use category near side and far side is given in Table 3. Over 88 percent of all accidents had either a commercial-or-financial or a residential land use on at least one side of the roadway. Twenty-nine percent and 19.4 percent of the accidents occurred with commercial-or-financial and residential land use on both sides of the roadway, respectively. Both land use categories have been associated with a high level of pedestrian activity (*4*).

Vacant land was found to be on at least one side of the roadway at over 23 percent of the accident locations. Open or undeveloped land has been associated with a high level of hazard for pedestrian activities at intersection locations (*4*).

Accidents adjacent to residential land uses were concentrated in areas with single-family dwellings. Single-family dwelling was the land-use type on the near side of the roadway for over 75 percent of the accidents where residential land existed on the near side. It was also the land use on the far side for over 78 percent of the accidents where residential landexisted on the far side. Nearly 15 percent (83 cases) of all

TABLE 2 NUMBER OF ACCIDENTS BY ACCIDENT TYPE AND AGE OF PEDESTRIAN

	Age Group							
Accident Type	1–4	5–9	10–14	15–19	20–29	30–59	60+	Total
Midblock cross	1	7	4	12	21	28	15	88
Intersection cross	0	5	12	12	28	40	41[a]	138
Midblock dartout	10[a]	32[a]	7	16	18	22	7	112
Intersection dash	2	2	10[a]	6	7	10	2	39
Walk along roadway	0	0	1	2	10[a]	1	5	19
Vendor or ice cream truck	3[a]	2	0	0	0	0	0	5
All others	2	4	11	6	23	31	20	97
Total	18	52	45	54	107	132	90	498

[a]Value that is significantly higher than expected based on z-test of proportions at the 95th percentile level of confidence in comparison to the total accident-type distribution.

TABLE 3 NUMBER OF ACCIDENTS BY AGGREGATE LAND-USE NEAR SIDE VERSUS LAND-USE FAR SIDE

Near Side	Commercial or Financial	Manufacturing	Residential	Education or Religious	Medical	Recreational	Vacant Land
Commercial or financial	161	0	32	6	5	1	28
Manufacturing	0	1	2	0	0	0	2
Residential	23	1	108	16	4	7	9
Educational or religious	11	0	13	5	0	0	16
Medical	4	0	4	1	2	0	0
Recreational	3	0	15	0	0	1	1
Vacant land	29	0	12	12	4	0	17
Total	231	2	186	40	15	9	73

TABLE 4 FREQUENCY OF ACCIDENTS BY ACCIDENT TYPE WHERE COMMERCIAL-OR-FINANCIAL OR RESIDENTIAL LAND USE EXISTED ON BOTH SIDES OF THE ROADWAY

	Commercial or Finance		Residential			Commercial or Financial
Accident Type	Number	Percent	Number	Percent	Total	Significantly Different
Midblock cross	26	16.1	17	15.7	43	
Intersection cross	49	30.4	19	17.6	68	Higher
Midblock dart	30	18.6	33	30.6	63	Lower
Intersection dash	18	11.2	2	1.9	20	Higher
Right turn-on-red	9	5.6	1	0.9	10	
Vehicle turn-merge	4	2.5	0	0.0	4	
Multiple threat	8	5.0	2	1.9	10	
Bus stop–related	0	0.0	0	0.0	0	
Exit or enter parked vehicle	0	0.0	3	2.8	3	Lower
Trapped by changing light	4	2.5	0	0.0	4	
Disabled vehicle	0	0.0	2	1.9	2	
School bus–related	0	0.0	0	0.0	0	
Hitchhiking	1	0.6	1	0.9	2	
Walk along roadway	2	1.2	10	9.3	12	Lower
Play in roadway	1	0.6	2	1.9	3	
Vendor or ice cream truck	0	0.0	6	5.6	6	Lower
Vehicle or vehicle collision	4	2.5	4	3.7	8	
On sidewalk	3	1.9	3	2.8	6	
Other	2	1.2	3	2.8	5	
Total	161	99.9	108	100.0	269	

accidents occurred with single family residential land adjacent to both sides of the roadway.

Land Use and Accident Type

The data in the cross tabulation of aggregate land-use type versus accident type were too sparse for meaningful statistical analysis across the entire matrix. The majority of accidents were concentrated in the four major accident types and the two dominant land-use categories.

The accident-type distribution was significantly different for those accidents where commercial-or-financial or residential land use existed on both sides of the roadway as shown in Table 4. Accident types that were significantly higher in areas of commercial or financial land use included both intersection cross and intersection dash. Accident types that had a significantly higher incidence in residential areas included midblock dartout, exit or enter parked vehicle, walk along roadway, and vendor or ice cream truck. The results for exit or enter parked vehicle, walk along roadway, and vendor or ice cream truck are not considered reliable because of the low frequency of these accident types.

SUMMARY AND CONCLUSIONS

The use of accident type designations, as prescribed in the MPSP user's guide (*3*), does supply enhanced perceptive capability to the evaluation of pedestrian accidents. Accident type application to pedestrian accidents can be accomplished with relative ease using the narrative description and diagram typically supplied on accident reports. Care must be taken when interpreting and applying certain accident type definitions.

The major drawback to the use of accident type analysis is that it requires several years of data beyond the 3 yr typically used in accident studies to maintain statistical credibility. This is due primarily to the rarity of events. Approximately 1,000 to 2,000 events would appear necessary in order to generate sufficient frequency of occurrence to effectively evaluate the less frequent accident types.

The inclusion of aggregate land-use data supplies limited useful information in pedestrian accident analysis. The land use immediately adjacent to accident locations can be used to gain some general knowledge on the relationship with accident type, and these data can be collected relatively easily. However, a direct cause-and-effect relationship between land use and accident type is difficult to justify.

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Safety Impacts of Bicycle Lanes

ROBERT L. SMITH, JR., AND THOMAS WALSH

In September 1977 bicycle lanes were implemented on a 1.3 mi section of a one-way arterial pair in the central part of Madison, Wisconsin. On Johnson Street the bicycle lane was placed on the left side whereas on Gorham the lane was in the conventional location on the right side. Bicycle accident data and estimates of bicycle use in Madison for the 4 years before and after the introduction of the bicycle lanes were used to evaluate the safety impacts of the bicycle lanes. A statistically significant increase in bicycle accidents between the before and after periods was found, but the increase was traced to two specific types of accidents on Johnson Street that occurred primarily in the first year of the after period. In subsequent years the increase was not statistically significant in contrast to a significant increase in total bicycle accidents in the city. Recommendations for countermeasures to reduce the initial accident problems associated with the left-side bicycle lane are made.

As part of the overall development of transportation facilities in the City of Madison, Wisconsin, the Madison Department of Transportation (MDOT) published its *Bicycle Facilities Plan* in 1974 (*1*). The plan provides for an extensive network of both on- and off-street bicycle facilities. Bicycle routes on local streets were signed to provide access to major generators such as the University of Wisconsin and the State Capitol area. Heavy bicycle traffic through and within the university campus was provided for by combined bus-bicycle reserved lanes on University Avenue.

A significant concentration of student housing is situated east of the Capitol (Figure 1). Because of the high concentration of private and governmental offices in the Capitol area and the limited land area, no local streets are available to provide a continuous through bicycle route in both directions. Consequently, many bicyclists choose to use the Johnson Street-Gorham Street one-way arterial street pair on the north side of the Capitol.

BICYCLE LANE DESIGN

In order to provide a continuous and convenient bicycle facility through the corridor to the north of the Capitol, bicycle lanes were installed in September 1977 for the 1.3-mi Johnson-Gorham Street one-way pair. As shown in Figure 1, the most convenient extension of the eastbound bicycle lane on University Avenue required placing the exclusive bicycle lane on the left side of Johnson Street. That location allowed eastbound bicyclists on University to turn right onto Bassett Street (one-way southbound) and then turn left on Johnson without waiting for the green traffic signal at Johnson and Bassett. The left-side bicycle lane also minimized the conflicts with vehicles entering and leaving Johnson on the Capitol side (right-hand side) of the street. On Gorham Street the conventional placement of the on-street bicycle lane on the right side provided a direct connection to the existing westbound bicycle lane on University Avenue.

On Johnson Street west of Butler Street the 39-ft-wide pavement was restriped to provide a 6-ft bicycle lane on the left, two narrowed through traffic lanes, and a right-hand curb parking lane with no parking during peak hours. East of Butler Street the 44-ft-wide pavement was striped for a 13-ft combined parking and bicycle lane on the left side, a 10-ft through lane and a 21-ft combined through and parking lane. In contrast on Gorham Street, the combined 13-ft bicycle and parking lane was located on the right side and the two through vehicle lanes on the left side. Preferential lane signing and pavement markings were used to designate the intended uses of the bike lane; for example, "Left Lane-Bicycles and Left Turns Only" signs were placed in areas where parking was prohibited.

PURPOSE OF STUDY

The primary purpose of this study is to evaluate the effects of the new bicycle lanes in the Johnson-Gorham corridor on bicycle safety. A secondary purpose is to identify any differences in safety between the conventional right-side bicycle lane on Gorham Street and the left-side bicycle lane on Johnson Street. If accident problems are found, potential countermeasures will be identified.

STUDY METHODOLOGY

The purpose of introducing the bicycle lanes on Johnson and Gorham was to provide additional mobility to bicyclists by providing an alternative to either riding in the regular traffic lanes or using the sidewalks. The bicycle accident rate on Johnson and Gorham had not been viewed as being excessive. The general expectation, however, was that the number of bicycle accidents would be reduced or at least stay the same because the bicycle lanes would separate the bicyclists from both automobile and pedestrian traffic. The observed increase in bicycle accidents after the introduction of the bicycle lanes led to this overall study of the impact of the bicycle lanes on bicyle safety.

The methodology used for evaluating the safety impacts of the new bicycle lanes is that of a simple before-and-after study

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FIGURE 1 Location of Johnson Street and Gorham Street bicycle lanes.

involving a single location. There are four primary threats to the validity of a before-and-after study:

- History (other causes at the same time),
- Maturation (trends over time),
- Regression to the mean, and
- Instability because of chance or random fluctuations in the data (*2*).

Two of the four threats to validity, history and regression to the mean, do not appear to be relevant. During the 8-yr period chosen for the before-and-after study, no specific causes for changes in the bicycle accident rate, such as a major new educational campaign or enforcement of traffic regulations, were identified. Also, regression to the mean should not be a problem because the study location was not selected on the basis of prior accident experience. The remaining two threats to validity are discussed in the next sections.

TRENDS IN BICYCLE USE AND ACCIDENT DATA

As shown in Figure 2, the MDOT has historical data on bicycle accidents dating back to 1955. The dramatic increase in bicycle accidents that began in 1970 appears likely to be correlated with bicycle use as measured by total bicycle shipments to dealers in the United States (see Figure 2). The growth in bicycle availability in Madison no doubt preceded the national growth curve by at least 1 year.

A bicycle traffic counting program was begun by the MDOT in 1974. Initially, bicycles were counted at three intersections within the central Madison area where bicycle trips are concentrated. Counts at the intersections on the east and west side of the central area are continuing but the third intersection in the university campus area was dropped because of the large variation in the count volumes. All bicycles entering the two intersections are counted for 2 hr during the a.m. and p.m. weekday peak periods once a month. The intersection counts are factored to produce an estimate of total daily bicycle trips citywide based on a 1974 home interview survey of bicycle travel. The east-side count location at the intersection of Johnson and Franklin Streets is within the study corridor. Consequently, the citywide estimate of bicycle travel should provide a good estimate of bicycle use within the study corridor.

The bicycle lanes on Johnson and Gorham Streets were opened in September 1977. In order to take advantage of the bicycle use data dating from 1974 and to obtain the largest possible number of bicycle accidents, 4-yr before-and-after study periods ranging from September 1973 to August 1977 and September 1978 to August 1981, respectively, were selected.

A reasonable correlation exists between the total bicycle accidents and the citywide estimates of bicycle trips ($r = 0.518$) for the 1974 to 1981 time period (Table 1). When the low estimate of trips in 1978 is omitted, the correlation increases to 0.633. Thus, increased exposure provides a partial explanation for the observed increase in bicycle accidents citywide; however, the total bicycle accident rate still grew by 20 percent from before to after. When the total bicycle accidents for the before period are expanded by 7.7 percent to account for the

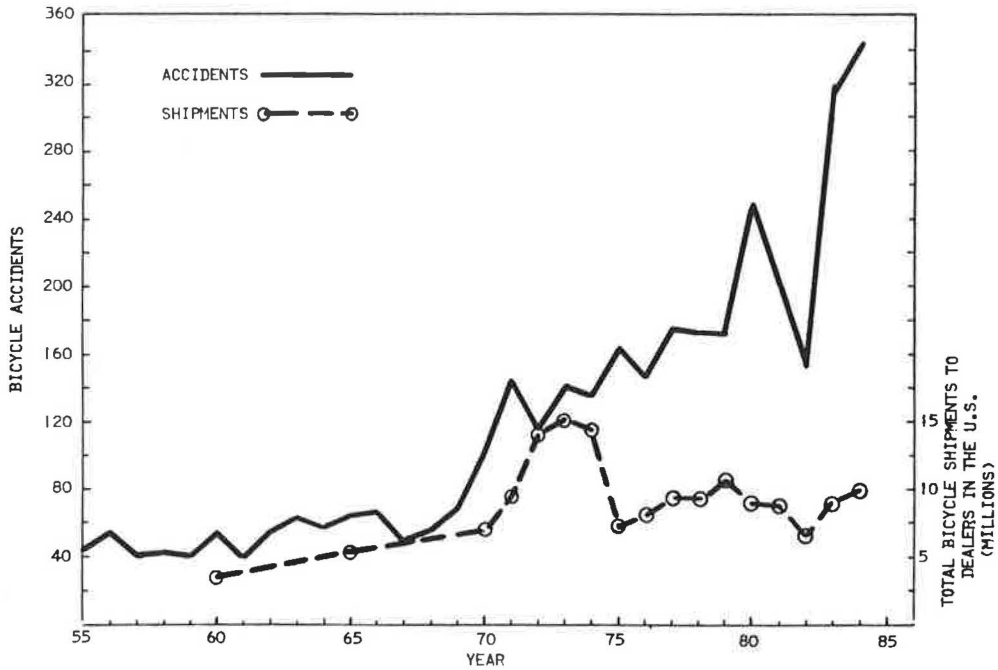

FIGURE 2 Bicycle accidents in Madison and total bicycle shipments to dealers in the United States.

TABLE 1 BICYCLE ACCIDENTS AND TRIPS IN MADISON, 1974 TO 1981

Year	Total Accidents	Johnson and Gorham Accidents		Estimated Daily Trips	Total Accident Rate per 1,000 Daily Trips
		Number	Percent of Total		
Before					
1974	135	7	5.2	86,000	1.6
1975	163	8	4.9	68,100	2.4
1976	146	12	8.2	79,000	1.8
1977	175	9	5.1	75,100	2.3
After					
1978	173	20	11.6	59,100	2.9
1979	172	8	4.7	77,400	2.2
1980	247	14	5.7	97,600	2.5
1981	200	9	4.5	97,900	2.0
Summary					
Before					
Total	619	36	5.8	308,200	2.0
Average	155	9		77,050	
After					
Total	792	51	6.4	332,000	2.4
Average	198	12.8		83,000	
Increase (%)	+27.7	+41.7	+11.1	+7.7	20
Expanded Before Accidents[a]					
Total	665[.001][b]	38.8 [0.03][c]			
Average	167[0.01][c]	9.7 [0.18][c]			
Increase (%)	+18.6	+31.4			

[a]Before accidents expanded by 1.077 to account for increase in daily bicycle trips.
[b]Level of significance of increase based on chi square (*2*).
[c]Level of significance of increase based on cumulative Poisson distribution.

increase in bicycle trips, the total accidents increased by 18.6 percent. As shown in the summary at the bottom of Table 1, the increase in total accidents is statistically significant at the 0.001 level based on a chi square test (*2*), whereas the increase in the average total accidents is significant at the 0.01 level based on the cumulative Poisson distribution.

The total bicycle accidents in the Johnson and Gorham study area corridor increased from 36 in the before period to 51 in the after period, a 42 percent increase. As shown at the bottom of Table 1, expansion of the before accidents in the corridor results in 38.8 accidents or an average of 9.7 per year. Based on the cumulative Poisson distribution, the increase in accidents (expanded before versus after) is statistically significant at the 0.03 and 0.18 levels for the total and average accidents, respectively.

The maturation or trends over time threat to the validity of the before-and-after analysis can now be addressed explicitly given the available data on total bicycle accidents in Madison and the annual estimates of daily bicycle trips. If no information on exposure as measured by the daily bicycle trips was available, then it would be reasonable to assume that the bicycle accidents on Johnson and Gorham would increase at the same rate as the total bicycle accidents. This would result in an estimated 36 × 1.277 = 46.0 accidents in the after period compared with 51 actual accidents. Based on a Poisson distribution with a mean of 46.0, 51 or more accidents would be expected 25 percent of the time. Thus, the increase from 46 to 51 accidents is not statistically significant.

An alternative interpretation of the available data is that the bicycle accidents on Johnson and Gorham are independent of the overall citywide accident trend and the only relevant "other" cause is the increased exposure. The time-series data on annual accidents for the before and after periods shown in Table 1 tend to support this hypothesis. Except for the first year of the after period (1978), the study-area accidents are consistent with the annual rates for the before period. This interpretation may increase the probability of a Type I error in which a statistically significant change is identified when in fact trends over time, not the bicycle lanes, are responsible for the change. This is good in that potential safety problems will be less likely to be overlooked. Consequently, this second interpretation will be emphasized in the subsequent analysis.

Another factor that would potentially affect the bicycle accident experience is change in the volume of traffic on Johnson and Gorham. Analysis of annual traffic count data for two locations on each street for the 8 years showed substantial year-to-year fluctuation but little overall change. The average volumes on Gorham declined by 5.3 percent from before to after, whereas the volumes on Johnson increased by 3.2 percent. Thus, any possible impact of the change in traffic volumes on bicycle accidents is likely to be small.

STATISTICAL METHODOLOGY

The last of the four threats to the validity of the before-and-after study, instability because of chance or random fluctuations, can be addressed directly using statistical tests. The null hypothesis for this study is that there is no change in the overall bicycle accident rate from the before to the after period in the study corridor where the accident rate is based on the estimated daily bicycle trips for the two time periods. An equivalent null hypothesis is that the number of before accidents, expanded by 7.7 percent to account for the increase in bicycle trips, is equal to the number of accidents in the after period.

The accidents for the before period are assumed to have a Poisson distribution with a mean equal to the number of accidents in the before period. Then, the probability that the observed number of accidents in the after period could have come from the same population as the before period can be computed from the cumulative Poisson distribution (*3*). If this probability is low enough, say 0.05 or less, then the hypothesis that the before and after accident levels come from the same population can be rejected. Thus, the introduction of the bicycle lanes has led to a statistically significant change in accidents. If there is a reduction in accidents from before to after, then the relevant equation for the cumulative Poisson distribution is

$$Pr(X_a \leq k \mid m = X_b) = \sum_{x=0}^{k} m^x e^{-m}/x! = 0.05 \tag{1}$$

where

X_a = number of accidents in the after period,
X_b = number of accidents in the before period, and
m = mean of the cumulative Poisson distribution.

If the accidents in the after period, X_a, satisfy Equation 1, then there is only a 5 percent chance that the after conditions are the same as the before conditions, that is, the distributions are significantly different at the 0.05 level. The percent accident reduction required to satisfy Equation 1 is given by

$$\%\text{ reduction} = \frac{k - X_b}{X_b} \times 100\% \tag{2}$$

Lunenfeld gives curves of percent reduction as a function of X_b for various levels of significance as shown in Figure 3 (*4*). The curves were originally developed by Michaels (*5*) and later expanded by Datta et al. (*6*).

In the present study, bicycle accidents, in general, increased from the before to the after period so the percent reduction curves were of limited use. Instead, the statistical significance of an increase in accidents from the before to the after period was determined directly from the upper tail of the cumulative Poisson distribution:

$$Pr(X_a > k \mid m = X_b) = 1 - \sum_{x=0}^{k} m^x e^{-m}/x! = 0.05 \tag{3}$$

at the 0.05 level of significance when the terms are the same as in Equation 1. For this study the tests for the statistical significance of changes in accident levels were based on either Equation 1 or Equation 3. The percent reduction curves were used only to provide a general indication of the magnitude of the change that would be statistically significant as a function of the number of before accidents.

CHANGES IN ACCIDENTS BY TYPE

The changes in bicycle accidents between the before and after period by accident type for Johnson Street, Gorham Street, and

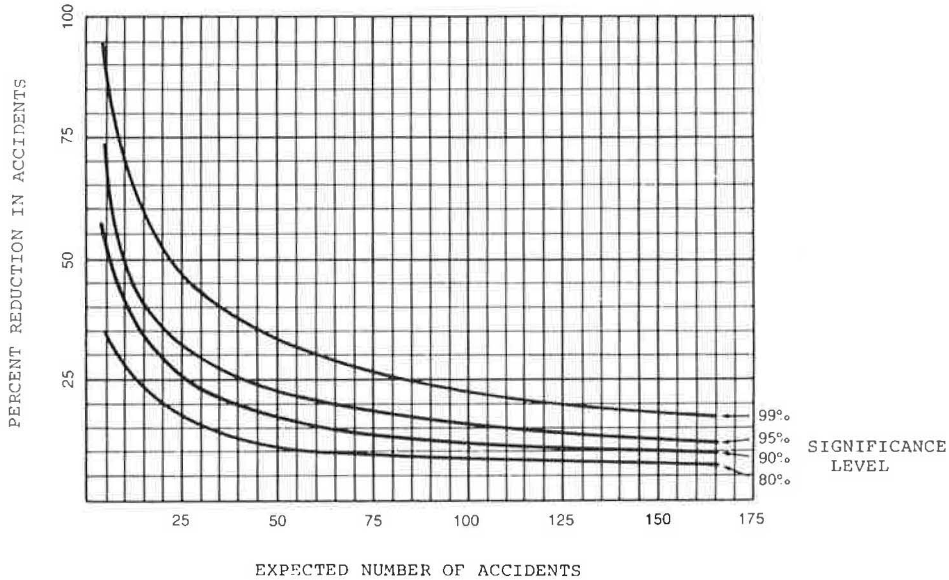

FIGURE 3 Statistical significance of percent reduction in accidents based on the cumulative Poisson distribution (*4*).

the total corridor are shown in Table 2. The before accidents are expanded by 7.7 percent to account for the difference in bicycle use between the before and after periods. For the corridor as a whole, the increase in midblock accidents is significant at the 5 percent level (95 percent confidence level) but the increase in intersection accidents is only marginally significant (18 percent level). Both Johnson and Gorham contribute to the increase in midblock accidents with the increase for Gorham significant at the 7 percent level. In contrast, the change in total intersection accidents is significant for Johnson but is insignificant (minor decrease) for Gorham.

Considering the overall change in bicycle accidents on Johnson and Gorham, it can be seen from Table 2 that there was a significant increase on Johnson (0.05 level of significance) but not on Gorham. Similarly, considering the individual categories of accidents, the changes in accidents tend to be more significant on Johnson than on Gorham; although the impacts on safety are mixed. These differences in significance level are

TABLE 2 STATISTICAL SIGNIFICANCE OF CHANGE IN ACCIDENTS

	Johnson Street				Gorham Street				Total			
Accident Type	Before[a] (no.)	After (no.)	Change[b] (%)	Level of Signifi-cance	Before[a] (no.)	After (no.)	Change[b] (%)	Level of Signifi-cance	Before[a] (no.)	After (no.)	Change[b] (%)	Level of Signifi-cance
Total	29.1	39	34	.05	9.7	12	24	–	38.8	51	31	.03
Intersection	18.3	24	31	.11	7.5	7	–7	–	25.8	31	20	.18
Midblock	10.8	15	39	.15	2.2	5	127	.07	12.9	20	55	.05
Angle	8.6	9	5	–	4.3	5	14	–	12.9	14	9	–
Northbound automobile	4.3	8	86	.08	4.3	5	14	–	8.6	13	51	.09
Southbound automobile	4.3	1	–77	.07	0.0	0	0	–	4.3	1	–77	.07
Automobile turns in front of bicycle	8.6	17	98	.007	3.2	5	56	–	11.8	22	86	.006
Automobile left turn	3.2	16	400	.001	0.0	0	0	–	3.2	16	400	.001
Automobile right turn	5.4	1	–81	.03	3.2	5	56	–	8.6	6	–30	–
Bicycle going contraflow	9.7	7	–28	–	0.0	2	–	.01	9.7	9	–7	–
On sidewalk or crosswalk	7.5	4	–47	.14	0.0	2	–	.01	7.5	6	–20	–
On street	2.2	3	36	–	0.0	0	0	–	2.2	3	36	–
Other	2.2	6	173	.02	2.2	0	–100	.11	4.3	6	40	–

[a]Before accidents multiplied by ratio of citywide estimate of bicycle trips for after versus before period, 332,000/308,200 = 1.077.
[b][(before-after)/before] × 100%.

in part the result of the substantially lower number of accidents on Gorham. As shown in Figure 3, much greater percentage changes are required to have a significant change when the number of accidents is small.

The total number of accidents on Johnson is three times larger than on Gorham in the before period and 3.25 times greater in the after period. This major difference may be explained in part by the higher volume of automobile traffic on Johnson [22,800 average daily traffic (ADT) on Johnson versus 17,700 ADT on Gorham]. Also, the much higher level of contraflow bicycle accidents on Johnson indicates that many bicyclists use Johnson (including legal use of sidewalks) for westbound travel against the flow of traffic. This would reduce the volume of bicycle traffic on Gorham. The relative volume of bicycle traffic on Gorham compared with Johnson may also be reduced by the availability of two other one-way westbound streets in addition to Gorham in the overall east–west corridor between the university and the near east side of Madison. No comparable eastbound alternative to Johnson exists.

In evaluating the four major accident categories at the corridor level (total accidents), only the "car turns in front of bike" category has a statistically significant change (0.6 percent level). Within that category, the increase in left-turn accidents is highly significant whereas the number of right-turn accidents actually decreased (significant at the 20 percent level). The left-turn accidents only occurred on Johnson Street, which is reasonable because the bicycle lane is on the left side of the one-way street. In the after period with the bicycle lane in operation, automobiles making left turns from Johnson into side streets must cross the bicycle lane, creating a potential for accidents. In the before period on Johnson, bicyclists traveling on the right side of the right lane created a potential conflict with right-turning automobiles. In fact, it is shown in Table 2 that right-turn accidents exceeded left-turn accidents on Johnson in the before period and that the decrease in right-turn accidents from before to after is significant at the 3 percent level. As expected with the addition of the bicycle lane on the right side of Gorham, right-turn accidents on Gorham increased although the increase is only marginally significant.

The greatest change in accidents between before and after occurred in the "left turns by cars in front of bike" category on Johnson—a fivefold increase. The comparable "right-turn" accident category on Gorham also experienced a substantial increase (56 percent). The nonstandard, left-side location of the bicycle lane on Johnson may be the primary reason for the difference in accident experience. Drivers do not expect bicyclists to be in the left-hand lane and bicyclists are more familiar with having automobiles on their left rather than on their right. Data on the year-to-year changes in the left- and right-turn accidents are presented in a subsequent section. The data suggest that the high level of after period accidents resulted from initial unfamiliarity with a novel situation because accidents dropped sharply after the first year of the after period.

The accident changes shown in Table 2 for the other major accident categories for Johnson and Gorham individually are not more than marginally significant except for the "other" category on both Johnson and Gorham. A detailed review of the reasons for each of the "other" category accidents did not reveal any clear relationship with the new bicycle lane.

Finally, the changes in the two individual categories of angle accidents for Johnson are significant at better than the 10 percent level but move in opposite directions with the net result of little change for total angle accidents. In the after condition on Johnson, northbound automobiles must cross two lanes of traffic before crossing the left-side bicycle lane. Apparently, drivers are preoccupied with avoiding cars as they cross Johnson and thus fail to see bicyclists in the bicycle lane. In contrast, for the before condition, bicyclists in the standard location in the right-hand lane would be closer to northbound drivers and apparently more visible. Similar logic explains the observed reduction in accidents involving southbound drivers.

TIME-SERIES ANALYSIS

A year-by-year comparison of the Johnson and Gorham accidents with the total bicycle accidents (expressed as "Percent of Total") is shown in Table 1. The percentages vary within a narrow range of 4.5 to 5.7 percent except for one outlier at 8.2 percent in the before period and one at 11.6 percent in the after period. The overall correlation between the Johnson and Gorham and the total accidents for the 8-yr period is not large ($r = 0.423$), but when the after period outlier for 1978 is removed, the correlation increases substantially to 0.724. Thus, the year-by-year data suggest that the Johnson and Gorham accidents for 1978 should be analyzed as a special case.

The average annual number of Johnson and Gorham bicycle accidents during the before period equals 9.0. The cumulative Poisson distribution with a mean of 9.0 can be used directly to test the hypothesis that an observed number of accidents in a subsequent year comes from the before population. For 1978 with 20 bicycle accidents, the probability of 20 or more accidents occurring based on the Poisson distribution with a mean of 9.0 is only 0.001. Thus, it is clear that the level of Johnson and Gorham bicycle accidents in 1978 is significantly different from the before period. No adjustment for bicycle use is necessary because the estimated trips for 1978 are much lower than for the before period. Also, 1978 was not an abnormal year for total bicycle accidents in Madison.

DISTRIBUTION OF ACCIDENTS BY TYPE AND YEAR

As discussed previously, the aggregate data on accidents by year show that the accident rate in the first year of the after period was significantly higher than the average for the before period, but in subsequent years the accident rate was similar to the before period. In order to identify possible reasons for the observed increase in accidents, the distribution of accidents by type was tabulated for each year for Johnson and Gorham separately. The results for the most significant accident types are given in Table 3.

The time-series data in Table 3 show a marked increase in two types of accidents on Johnson in 1978 following the introduction of the bicycle lane. Comparison of these 1978 accident levels with the expanded annual averages for the before period shows highly significant statistical differences. The accidents for subsequent years are not significantly different from the before period averages except for the "left turns by car" category. A similar analysis for Gorham is not relevant because there is no clear initial increase in accident rates in 1978.

TABLE 3 DISTRIBUTION OF BICYCLE ACCIDENTS BY YEAR FOR JOHNSON AND GORHAM

	Johnson			Gorham		
Year	Total	Angle northbound	Left Turns by Automobile	Total	Angle northbound	Right Turns by Automobile
Before						
1974	5	1	1	2	1	0
1975	6	1	0	2	2	0
1976	8	0	1	4	1	3
1977	8	2	1	1	0	0
After						
1978	16[.004][b]	5[.005][b]	7[.001][b]	4	1	2
1979	7	1	4[.01][b]	1	0	1
1980	10	1	3[.05][b]	4	2	1
1981	6	1	2	3	2	1
Summary						
Before						
Average	6.75	1.0	0.75	2.25	1.0	0.75
Average × 1.077[a]	7.3	1.1	0.8	2.4	1.1	0.8
After average	9.8	2.0	4.0	3.0	1.2	1.2

[a]Expanded by 7.7 percent to account for greater bicycle use in after period.
[b]Indicates level of significance of accident rate for that year compared with expanded average accident rate/yr for before period.

The time-series data for Johnson and Gorham suggest that introduction of a left-side bicycle lane (Johnson) will result in an initial increase in accidents, whereas the more conventional right-side bicycle lane (Gorham) will not. After a reasonable period of time, neither bicycle lane location appears to cause additional accidents.

CONCLUSIONS

In comparing total bicycle accidents in Madison for the before and after periods, the statistical analysis shows that the after period total is significantly higher. Similarly, for the bicycle lane corridor on Johnson and Gorham, the after period accidents are significantly higher than the before period accidents. More detailed analysis, however, shows that when the atypical first year of the after period (1978) is removed, the accidents on Johnson and Gorham are not significantly higher than the before period. Time-series analysis of the Johnson and Gorham data by accident type shows that the primary sources of the 1978 atypical accident levels are the two Johnson Street categories: (a) angle accidents involving a northbound automobile and (b) automobiles making left turns in front of bicycles. Both of these accident types have a logical relationship to the left-side bicycle lane on Johnson. The accident levels for these two accident types were much reduced in subsequent years indicating that drivers and bicyclists were adapting to the presence of the left-side bicycle lane.

Given the initial adverse accident experience with a left-side bicycle lane in Madison, other similar new bicycle facilities should be implemented only in conjunction with special signing to alert both bicyclists and motorists to the potential hazards. At a minimum, signs identifying the existence, location, and intended use of the bicycle lane should be highlighted with red flags for the first several months. The signing should be designed to reduce the "angle" and "car turns in front of bicycle" accidents that were significant for the Johnson Street (left-side) bicycle lane. Special lane markings for the bicycle lane at intersections should also be considered.

It is possible that locating the Johnson Street bicycle lane on the right side of the street would have reduced the initial high-accident experience with the left-side bicycle lane. The right-side bicycle lane on Gorham did not experience a significant increase in accidents; however, the right-turn traffic volumes from Gorham across the bicycle lane are certainly much lower than the right-turn volumes that exist on Johnson. Detailed analysis of automobile turn and cross-traffic volumes on both Johnson and Gorham would be required to estimate accidents as a function of exposure to turning movements and cross traffic.

Overall, the bicycle lanes on Johnson and Gorham streets did not have a negative impact on bicycle safety. Except for the first year of bicycle lane implementation on Johnson Street, the bicycle lane corridor accidents did not increase significantly compared with significant increases in bicycle accidents citywide. Also, except for the first year of implementation of the left-side bicycle lane, there is no clear indication that left-side bicycle lanes are less safe than the conventional right-side bicycle lanes.

Communities that implement bicycle lanes should plan ahead to collect data on accidents and bicycle use so that even more comprehensive before-and-after studies can be completed. The data collection effort will also permit early identification of any safety problems in both the before and after periods.

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Abridgment

Evaluation of the Burke-Gilman Trail's Effect on Property Values and Crime

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The objective of this study is to determine what effect, if any, an 8-yr-old urban, bicycle and pedestrian rail-trail has had on property values and crime rates on property near and adjacent to the trail. Also evaluated is public acceptance of the trail and its effect on the quality of life of adjacent neighborhoods. The study is intended to help determine if additional trails should be developed along abandoned railroad rights-of-way. The scope includes a 7-mi section of a bicycle and pedestrian trail; 152 single-family homes and 607 condominiums adjacent to the trail; and 320 single-family homes within one block of the trail. The method used in this study includes random interviews with adjacent property owners and other residents within one block, interviews with police officers who patrol the area, interviews with real estate agents who sell properties in the area, and a survey of local real estate advertisements. The conclusion of this study is that this particular rail-trail is an amenity that helps sell homes and increases property values. The study also found that the trail has had little, if any, effect on crime and vandalism experienced by adjacent property owners, and that there is a very high level of public support and acceptance of the trail.

A recurring concern expressed by citizens living near proposed bicycle and pedestrian trails along abandoned rail corridors is that they will reduce property values, increase crime, and generally reduce the quality of life for people in adjacent neighborhoods. Although there are more than 100 trails on abandoned rail corridors in the United States, no systematic, comprehensive studies have been done to address these concerns. The result has too often been a political tug-of-war between trail promoters who are convinced that trails can improve and enhance a neighborhood and trail opponents who imagine every sort of social problem being imported into their neighborhood.

The Burke-Gilman Trail provided an excellent opportunity for conducting a case study on what effect, if any, an existing trail has had on property values, crime rates, and the quality of life of adjacent neighborhoods. The trail had been in use for about 8 years and went primarily through residential neighborhoods. After 8 years, any significant effect the trail may have had on property values, crime, and the quality of life would have occurred.

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The primary objective of this study, therefore, was to determine what effect, if any, the Burke-Gilman Trail has had on property values and crime rates of residents adjacent to and near the trail. A secondary objective was to measure public acceptance of the trail and its effect on the quality of life of adjacent neighborhoods.

The Burke-Gilman Trail is 12.1 mi long (9.85 mi are in Seattle) and 8 to 10 ft wide. In Seattle there are 152 single-family homes and 607 condominiums immediately adjacent to the trail and 320 single-family homes within one block of the trail. There is an average of 20 ft of shrubs or trees between the trail and the edge of adjacent properties. The trail passes through an industrial area, the University of Washington, and links six parks. The trail has an estimated three-quarters of a million users per year with about 80 percent of the users being bicyclists. The trail is not patrolled and there is no enforcement of trail regulations. There is no special lighting provided on the trail.

DATA COLLECTION

Data were collected in the summer of 1986 via telephone by interviewing 379 residents near and adjacent to the trail, 75 real estate agents who buy and sell homes near the trail, and 3 police officers who patrol neighborhoods adjacent to the trail. Residents were asked questions about their decision to buy their home and what effect they thought the trail would have on selling their home; what problems, if any, they had had with break-in and vandalism by trail users; and how the trail has affected their overall quality of life. Real estate agents were asked similar questions on how the trail affects the selling price of homes along the trail, and police officers were asked questions about break-ins and vandalizing of homes adjacent to the trail. A biweekly survey of newspaper real estate advertisements and real estate magazines was also conducted to determine whether homes were being advertised as being near or on the Burke-Gilman Trail. In total, seven surveys were conducted, using six different data sources.

An attempt was also made to compare the selling prices and assessed values of homes along the trail in comparable neighborhoods. However, because of the many variables that determine the value of a home, it was impossible to isolate the trail as a determinant of value using this method.

There were a total of six questions related to crime and property values that the study attempted to answer. Conducting seven different surveys using six different data sources allowed for comparison and cross checking of results. The assumption was made that consistent results would mean a higher level of confidence in the findings of each survey.

The first question the study attempted to answer was, what effect, if any, the trail has had on selling property adjacent to the trail. Residents who owned single-family homes and residents who owned condominiums adjacent to the trail were asked if, in their opinion, being adjacent to the Burke-Gilman Trail would make their home or condominium easier or more difficult to sell. Real estate agents were asked a similar question and real estate advertisements were surveyed to determine if properties were being advertised as being on the trail.

The results of the four surveys were consistent, with one notable exception. In all the surveys, the most frequent response was that being adjacent to the trail would have a positive effect on selling a particular property. About 70 percent of real estate agents and home owners and 88 percent of condominium owners believe that being adjacent to the trail would have a positive or neutral effect on selling a particular property. Advertisements in newspapers and real estate magazines promoted homes as being on the Burke-Gilman Trail, which indicates that being on the trail has a positive effect on selling homes. Newer owners who had recently been in the real estate market were quite positive about the trail.

Although only 9 percent of home owners and 1 percent of condominium owners believed the trail would make their property more difficult to sell, 30 percent of the real estate agents believed the trail would make properties immediately adjacent to the trail more difficult to sell, in spite of the fact that 43 percent believed that the trail would make homes easier to sell and 27 percent believed the trail would have no effect on selling homes adjacent to the trail. In reviewing the comments made by real estate agents, it appeared that there may be two separate but related reasons for this discrepancy. Agents who regularly sold homes along and near the trail were more likely to see it as an asset in selling homes. Agents who did not regularly work in areas near the trail were often less positive, indicating that they may have had one or two negative experiences with a potential client. The second factor appears to be the type of clients a particular agent had. Agents who had clients who were walkers, joggers, and bicyclists had a different perception of the trail than those who did not.

Given the consistency of the results from the four surveys, it is fair to say that the trail has a generally neutral to slightly positive effect on selling property adjacent to the trail. To potential buyers who are walkers, joggers, and bicyclists, the trail is generally an asset. Because more than two-thirds of Seattle residents participate in one or more of these activities, there is a large enough constituency to positively influence the selling of property along the trail and to explain why real estate companies promote homes and condominiums as being on the Burke-Gilman Trail. Additionally, it is predictable that new owners would view the trail favorably because the trail was there when they bought their property. People who do not like trails would not buy property on the trail.

The second question the study attempted to answer was, what effect, if any, the trail has had on the actual selling price of property adjacent to the trail Residents who own single-family homes and residents who own condominiums adjacent to the trail were asked if, in their opinion, being adjacent to the Burke-Gilman Trail would make their home or condominium sell for more, less, or have no effect on the selling price. Real estate agents were asked a similar question.

The results of the three surveys were again consistent, with one notable exception. In all the surveys the most frequent response was that being adjacent to the trail would have no effect on the selling price of property. The second most frequent response was that the trail would make the property sell for more, and the third was that the property would sell for less. New owners who had recently been in the real estate market were the most positive about the trail. About 76 percent of the home owners and 72 percent of the condominium owners who had bought their property after the trail was opened believed that the trail would have a positive or neutral effect on the selling price of their property. Conversely, only 4 percent of the home owners and 2 percent of the condominium owners believed the trail would make their property sell for less.

Although only 7.5 percent of the home owners and 2 percent of the condominium owners believed the trail would make their property sell for less, 25 percent of the real estate agents believed the trail would make the properties immediately adjacent to the trail sell for less, in spite of the fact that 32 percent thought the trail would make homes sell for more and 43 percent thought the trail would have no effect on the selling price of homes adjacent to the trail. As in the first question, there appear to be two reasons for this result. Agents who did not regularly sell homes along the trail were more likely to see the trail as decreasing the selling price of homes, indicating that they may have had one or two negative experiences with potential clients. The second reason appears to be the type of clients a particular agent happened to have. Agents who had clients who were walkers, joggers, and bicyclists had a different perception of the trail than those who did not.

The consistency of the survey results indicate that the trail has a neutral to slightly positive effect on the selling price of properties adjacent to the trail. It all depends on the prospective buyers. To some, the trail adds value; to others, it has no effect; and to others it reduces value.

The third question the study attempted to answer was, what effect, if any, the trail has had on selling property near, but not adjacent to the trail. Residents who owned single-family homes within one block of the trail were asked if, in their opinion, being near the Burke-Gilman Trail would make their home easier or more difficult to sell or have no effect on selling their home. Real estate agents were asked a similar question and real estate advertisements were surveyed to determine if properties were being advertised as being near the trail.

The results of the surveys were definitive and consistent. In the survey of property owners and real estate agents, the most frequent response was that being near the trail would have a positive effect on selling a particular property (52 percent of property owners and 75 percent of real estate agents). Additionally, advertisements in the newspapers and real estate magazines frequently promoted homes as being near the Burke-Gilman Trail. About 75 percent of the property owners and 100 percent of the real estate agents believed that the trail would have a positive or neutral effect on selling property within one block of the trail. None of the real estate agents and only 9 percent of the home owners believed the trail would have a negative effect on selling property within one block of the trail.

It is clear from the survey results that the trail has a very positive effect on selling property near the trail. Particularly impressive was the fact that not a single real estate agent believed the trail would have a negative effect on selling properties within one block of the trail.

The fourth question the study attempted to answer was, what effect, if any, the trail has had on the selling price of properties within one to two blocks of the trail. Residents who owned single-family homes within one block of the trail were asked if, in their opinion, location would make their homes sell for more, less, or have no effect on the selling price. Real estate agents were asked a similar question.

The results of the survey were again both definitive and consistent. One hundred percent of the real estate agents and 77 percent of the home owners believed the trail would have a positive or neutral effect on the selling price of homes within one block of the trail (real estate agents believed the trail would increase values on an average of 6.2 percent). None of the real estate agents and only 7 percent of the home owners believed that the trail would have a negative effect on the selling price of homes within one block of the trail.

The consistency of the survey results indicates that the trail has had a positive effect on the selling prices of homes within one block of the trail. Once again, the significant finding was that not a single real estate agent believed the trail would have a negative effect on the selling price of homes within one block of the trail.

The fifth question the study attempted to answer was, what effect, if any, the trail has had on crime rates on property adjacent to the trail. Residents who owned single-family homes adjacent to the trail were asked if, to the best of their knowledge, a trail user had ever vandalized their property or broken into their house. Three police officers who regularly patrol the neighborhoods adjacent to the trail were asked if homes along the trail experience a higher level of vandalism and break-ins.

The results of the two surveys were very consistent. The surveys of police officers and home owners both indicated that homes along the trail do not experience a higher rate of break-ins and vandalism than homes farther away from the trail. Vandalism and break-ins to homes by trail users are almost nonexistent. Home owners indicated that there are fewer than two incidents per year involving trail users. Police called these figures "insignificant" and "isolated cases."

Given the consistency of the results, it appears that homes along the trail do not experience a higher rate of break-ins and vandalism. There is, however, one point related to the survey of home owners that is a weakness in the study. Home owners indicated that there are an average of just under two incidents per year involving trail users. Although police officers called this insignificant, it was not determined with certainty if this represented two more incidents than took place in adjacent neighborhoods, or whether it simply meant that, twice a year, homes along the trail were involved in incidents that would have happened anyway. Police officers believed that the trail was used as a matter of convenience to burglars entering a home from the street side and then fleeing to the trail from the back side of the home. They stressed, however, that the trail had simply been an escape route, not a cause of the burglary and that the problem was easily solved by planting thorny bushes between homes and the trail.

Once the survey work was completed and the results were compiled, it was noted that residents along the trail should have been asked if break-ins and vandalism increased or decreased after the trail was opened. Several residents commented that they had had more problems when the right-of-way was still used for trains than they had had since the trail opened. No one said the situation was worse once the trail opened. However, it would have been useful to survey all the residents to get more complete results on this question.

The sixth and final question that the surveys attempted to determine was what effect, if any, the trail has had on the quality of life in neighborhoods adjacent to the trail. The survey results, taken as a whole, indicate that the trail has increased the quality of life in adjacent neighborhoods. When asked, 63 percent of the home owners who lived adjacent to the trail believed that the trail had increased the quality of life in their neighborhood. Only 5 percent believed it had decreased the quality of life, and the rest believed it had no effect or had no opinion. Police officers also indicated that the trail had had a positive impact on the neighborhood and suggested that more trails should be built. Finally, the public acceptance of the trail indicated that it had significantly contributed to the quality of life in the neighborhood. When asked, 100 percent of the residents along the trail felt the trail should be kept open.

CONCLUSIONS

All conclusions in this type of study are inherently subjective and may not necessarily be applicable to other trails. Nevertheless, the findings of the seven surveys conducted for this study strongly suggest that there is a relationship between the trail, property values, and the quality of life, and that certain conclusions with regard to their relationship are appropriate. The main conclusions of this study, therefore, are as follows:

- The Burke-Gilman Trail has had no significant effect on the value of homes immediately adjacent to the trail.
- Conversely, the Burke-Gilman Trail has not had a negative effect on the value of homes immediately adjacent to the trail.
- The Burke-Gilman Trail has significantly increased the value of homes near, but not on the trail (estimated at 6.5 percent).
- Homes and condominiums near and adjacent to the Burke-Gilman Trail are easier to sell because of their proximity to the trail.
- The existence of the Burke-Gilman Trail has had no discernible effect on crime rates experienced by residents who live adjacent to the trail.
- Trespassing has not been a problem for residents living adjacent to the Burke-Gilman Trail.
- There is an unusually high level of acceptance and support for the trail as a valuable public facility by residents who live adjacent to or near the trail.
- The Burke-Gilman Trail has had an overall positive effect on the quality of life in neighborhoods adjacent to the trail.

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Bicycle Accidents: An Examination of Hospital Emergency Room Reports and Comparison with Police Accident Data

JANE C. STUTTS, JOSEPH E. WILLIAMSON, AND FRANK C. SHELDON

Bicycle accident data collected by 10 North Carolina hospital emergency rooms during the summer of 1985 and 15 hospital emergency rooms during the summer of 1986 are analyzed and compared with North Carolina state police-reported data. Two-thirds of those treated in the hospital emergency rooms were children younger than age 15 and 70 percent were male. Only a fifth of the emergency room bicycle accident cases involved collisions with a motor vehicle, and only 10 percent appeared on state accident files. Results confirm that in addition to not providing any information on bicycle–nonmotor-vehicle accidents, police accident files miss a substantial portion of the bicycle–motor-vehicle accidents. Combining the emergency room data with information available statewide on hospital discharges, it was estimated that 800 children ages 0 to 19 are hospitalized annually in North Carolina for bicycle-related injuries, and 13,300 children receive emergency room treatment. Recommendations are given for continued research activities in the area and implementation of programs for reducing the frequency and severity of bicycle-related injuries.

The traditional source of information on bicycle-related injuries and deaths is police accident data. North Carolina state accident files show 32 bicyclists killed and an additional 1,245 injured in 1986 (*1*). Nationwide, the National Safety Council reported 1,000 bicycle fatalities and 40,000 injuries (*2*).

These numbers clearly do not reflect the full extent of the bicycle accident problem. In their landmark 1977 study of bicycle–motor-vehicle accidents, Cross and Fisher estimated that only a third of all bicycle–motor-vehicle accidents are reported to the police, and that half of the unreported accidents are injury producing (*3*). Cross further concluded that 95 percent of all bicycling injuries do not result from collisions with motor vehicles (*4*).

One estimate of the overall magnitude of the bicycle accident problem comes from the Consumer Product Safety Commission, which operates the National Electronic Injury Surveillance System (NEISS). The NEISS is based on a representative sample of U.S. hospital emergency rooms. Using this data, the commission has estimated that 550,000 persons receive emergency room treatment each year for bicycle-related injuries (*5*).

The present study was carried out to examine the characteristics of emergency-room-reported bicycle accidents and to compare these with accidents reported on police accident files. The emergency room data were also used in conjunction with North Carolina hospital discharge data to estimate the number of children hospitalized and the number receiving emergency room treatment each year in North Carolina as a result of bicycle-related injuries.

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BACKGROUND

A sample of North Carolina hospital emergency rooms has been involved in the collection of supplemental data for bicycle-related injuries since 1984. The effort was initiated by Dr. Frank Sheldon at the Beaufort County Hospital in Washington, North Carolina and Dr. Joseph Williamson at Pitt County Memorial Hospital in Greenville, North Carolina. A pilot study carried out during the summer of 1984 at the Beaufort County Hospital showed 43 bicyclists treated over a 5-month period. At least half of the cases involved serious injury. However, a check of North Carolina accident files revealed only 29 police-reported accidents in the Washington area over a time span of 6 years.

Spurred by these findings, data collection activities were expanded to 10 North Carolina hospitals during the summer of 1985 and to 15 hospitals during the summer of 1986. A detailed report on the 1985 data is found elsewhere (*6*). The present paper combines the 1985 and 1986 surveys and focuses on comparison of the emergency room and police data bases and evaluation of the magnitude of the bicycle accident problem in North Carolina. A parallel paper presenting an epidemiologic examination of the emergency room data is being prepared for publication in the medical literature (*7*).

LITERATURE REVIEW

An in-depth review of the literature on bicycle accidents is contained elsewhere (*6*). Studies in the following categories were identified and examined:

- Hospital and emergency room–based studies including survey studies and retrospective analyses of hospital data;
- Population–based survey studies; and

- Studies based on police-reported accident data.

Emergency room surveys examining bicycle accidents have been carried out in Burlington, Vermont (*8*); Boulder, Colorado (*9*); Eugene, Oregon (*10*); Minneapolis, Minnesota (*11*); Oklahoma City, Oklahoma (*12*); King County, Washington (*13*); and Philadelphia, Pennsylvania (*14*), along with a number of hospitals in Australia (*15–17*), Great Britain (*18–20*), and Sweden (*21*). All of the studies clearly show that the young are disproportionately represented in bicycle accidents. Although reported percentages vary according to the nature of the study and characteristics of the cycling environment, the 5- to 14-yr age group generally accounts for 70 percent or more of the study population. Males also dominate by a ratio of at least 2 to 1.

The emergency room studies are a particularly valuable source of information on the nature of injuries encountered by bicyclists. By far the most frequently reported injuries are abrasions, lacerations, and contusions. In 60 to 70 percent of cases these are the most serious injuries. Fractures are cited in 15 to 25 percent of cases and head injuries in 10 to 25 percent. (The wide range to the latter is in part because of varying definitions of head injury.)

The majority of emergency-room-reported bicycle accidents do not involve a motor vehicle. Reported percentages vary widely, however, again reflective of the particular characteristics of the bicycling environment. Numbers range from 13 percent reported in the Minneapolis study (*11*) to 50 percent reported in the Boulder study (*9*).

The best estimate of the percentage of emergency room bicycle accident cases requiring hospital admission comes from an analysis of bicycle accident cases reported to the Massachusetts Statewide Childhood Injury Prevention Project (*22*). Overall, 6 percent of 573 injured riders required hospitalization; for those riders involved in collisions with motor vehicles, this figure increased to 27 percent. Other percentages reported in the literature are 8 percent for the Boulder, Colorado, study (*9*) and 13 percent for the King County, Washington, study (*13*). Both of the latter involved a higher than usual rate of bicycle-motor-vehicle collisions.

Although this discussion has focused primarily on emergency-room-based surveys of bicycle accidents, other studies have involved retrospective examination of hospital records or self-reported accident involvement through population surveys. All have helped to expand understanding of the nature and scope of the bicycle accident problem.

METHODOLOGY

Hospital Emergency Room Data

Hospital emergency room data were collected in two separate surveys—the first conducted mid-May through mid-September 1985 and the second June 1 through September 30, 1986. Ten hospitals participated in the first survey and 15 in the second. A listing of the hospitals and the number of cases submitted by each is given in Table 1.

TABLE 1 NUMBER OF CASES REPORTED BY PARTICIPATING HOSPITALS IN 1985 AND 1986 SURVEYS

Hospital	Number of Cases
1985	
Beaufort County	50
Cannon Jr. Memorial	10
Craven County Memorial	11
Edgecombe General	24
Memorial Mission	17
New Hanover Memorial	14
North Carolina Memorial	10
Onslow Memorial	19
Pitt County Memorial	55
Wayne County Memorial	11
1986	
Beaufort County	29
Cannon Jr. Memorial	9
Charlotte Memorial	16
Edgecombe General	12
Haywood County	3
Lexington Memorial	9
Memorial Mission	24
Moses Cone	3
Nash General	32
Northern Surry	76
Onslow County	13
Pardee Memorial	55
Pitt County	66
St. Josephs	13
Wayne County Memorial	45

Hospitals were selected by Drs. Sheldon and Williamson on the basis of their likelihood to participate and their geographic location in the state. Although there was a mix of urban and rural hospitals, no attempt was made to select a statistically representative sample. The distribution of the hospitals across the state for each of the surveys is shown in Figure 1.

No follow-up was made to assess the level of participation by the hospitals; however, examination of the returns shows consistent reporting throughout the 4-month data collection periods by about half the hospitals. About one-fourth submitted cases over a period of 1 month or less, and the remaining one-fourth appeared inconsistent in their reporting. In only one case was there an obvious bias to report only the most severe cases, and these data were excluded from the analysis. Hospitals also showed consistent reporting across the day of week and time of day variables, indicating participation by at least a good portion of the emergency room staff.

Copies of the survey forms are included as Figures 2 and 3. Following the 1985 survey, the form was revised and expanded to include more detailed information on the nature of the trip, the location and severity of injury, including an Abbreviated Injury Scale (AIS) score (*23*), and involvement of alcohol and drugs.

North Carolina State Accident Data

For comparison purposes, North Carolina police-reported bicycle accidents are examined for 1985 and 1986. In addition to

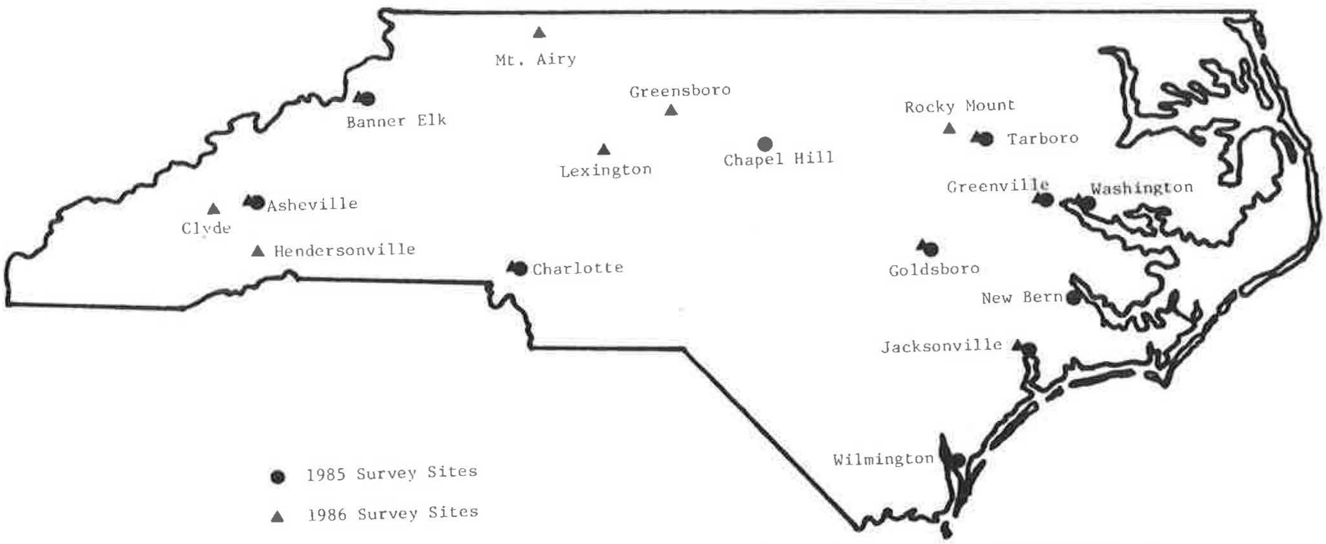

FIGURE 1 Location of hospitals participating in the 1985 and 1986 North Carolina bicycle accident surveys.

CHECKLIST OF INFORMATION
REGARDING BICYCLE ACCIDENTS

PATIENT NAME:

SEX:

AGE:

DATE OF ACCIDENT:

TIME OF DAY:

LOCATION (Street name if possible):

	YES	NO	REMARKS
1. Did accident involve automobile?	____	____	
2. Did accident involve another bicycle?	____	____	
3. Was accident reported to police?	____	____	
4 Was cyclist riding against traffic?	____	____	
5. Any mechanical defects to bike which may have caused the accident?	____	____	
6. Bicycle helmet worn?	____	____	
7. More than one person on bike?	____	____	
8 Did accident require visit to emergency room (or physician's office)?	____	____	
a. X-Ray Required	____	____	
b. Lacerations	____	____	
c. Abrasions	____	____	
d. Fractures/Dislocation	____	____	
e. Dental Injury	____	____	
f. Head Injury	____	____	
g. Admission to hospital required	____	____	
h. Fatality	____	____	
9. Brief description of accident:			
a. At an intersection	____	____	
b. At a driveway	____	____	
c. Midblock	____	____	
d. Sidewalk	____	____	
e. Railroad Crossing	____	____	
f. Other (Please Explain)	____	____	

10. Brief description of circumstances surrounding accident. (If need additional space, please use back.)

FIGURE 2 Survey form for 1985 emergency room bicycle accident study.

BICYCLE ACCIDENTS

Supplemental Data Form

Return to:
Dr. Joe Williamson
Dept. of Emergency Medicine
ECU School of Medicine
Pitt County Memorial Hospital
Greenville, NC 27834

Hospital: ____________

Patient Number: ____________

Sex: ____________

Age: ____________

Date of Accident: ____________

Time of Accident: ____________ ☐ a.m. ☐ p.m.

Location of Accident (city and/or county): ____________

Purpose of Trip:

__1 recreation	__3 errand
__2 commuting	__4 other (specify) ____________

Accident Type (Check one):

__1 intersection	__5 rural road (non-intersection)
__2 driveway	__6 RR crossing
__3 city street (non-intersection)	__7 other (specify) ____________
__4 sidewalk	

Location of Injury: (If more than one, number in order of severity, 1=most severe)

__1 head	__6 shoulder, upper arm
__2 face	__7 elbow, lower arm, hand
__3 neck	__8 hip, upper leg
__4 thorax	__9 knee, lower leg, foot
__5 abdomen, lower back	__10 other (specify) ____________

AIS Injury Severity (Most severe injury):

__ 0 No Injury
__ 1 Minor injury (e.g., soft-tissue wound, broken tooth, finger fracture)
__ 2 Moderate injury (e.g., non-dislocated fracture of mandible or ankle)
__ 3 Serious Injury (e.g., open and/or dislocated fracture, pneumothorax, or hemothorax)
__ 4 Severe, life threatening injury (e.g., splenic rupture)
__ 5 Critical injury (e.g.., intracranial hemorrhage, liver rupture)
__ 6 Maximum injury (unsurvivable)

Description of Injury(ies): ____________

Treatment:

__1 treated and released	__3 fatality
__2 admitted to hospital	

	Yes	No
Did accident involve automobile or other motor vehicle?	__	__
Did accident involve another bicycle?	__	__
Was accident reported to police?	__	__
Was bicyclist riding against traffic?	__	__
Was bicyclist riding on bicycle path or in marked bicycle lane?	__	__
Was bicyclist at fault?	__	__
Any mechanical defects to bike which may have caused accident?	__	__
Bicycle helmet worn?	__	__
More than one person on bicycle?	__	__
Alcohol/drugs involved?	__	__

Brief description of circumstances of accident. (If need additional space, please use back.)

FIGURE 3 Survey form for 1986 emergency room bicycle accident study.

comparing overall trends (age and sex of rider, motor vehicle involvement, rider injury, etc.), emergency room- and police-reported cases were matched on a case-by-case basis. This process required listing the police-reported cases sequentially by date along with pertinent identifying information such as age and sex of rider, location (county) and time of accident, and injury severity. The emergency room cases were then individually examined to determine whether or not they were duplicated on the state files. In a few cases it was necessary to examine the actual hard copies of the police accident reports because this allowed for comparisons of the emergency room accident description with the police officer's narrative description and diagram of the accident. Following this procedure it was possible to determine the percentage of emergency room bicycle accident cases found on the state accident files and the characteristics of these cases.

North Carolina Hospital Discharge Data

A final data set examined was 1980 hospital discharge data provided by the State Center for Health Statistics (1980 being the last year for which a complete sample is available). For purposes of the current study, information was obtained on the total number of pediatric hospital discharges statewide by age group and by cause of injury. The latter is reported using the "*E*" code (external cause of injury) classification (*24*), which includes categories of bicycle–motor-vehicle and bicycle–nonmotor-vehicle accidents. Hospital discharge data were available for an estimated 89 percent of all pediatric hospitalizations and *E* code information available for 67 percent of these cases (*25*). The data were adjusted to reflect statewide totals, assuming even distributions of the missing cases.

Data Analysis

Analysis of the hospital emergency room data is primarily descriptive and includes one-way frequency distributions and two- and three-way cross tabulations of the variables. Results for the 2 years (1985 and 1986) are tabulated separately but presented in parallel in the tables. Chi-square statistics are reported where appropriate, although small sample (i.e., cell) sizes limited the extent to which the data could be statistically examined. Also, the reader is reminded that the emergency room bicycle accident cases were not a randomly selected sample, and the reported descriptive results must be viewed with this limitation in mind. At the same time, the projected statewide bicycle-related hospitalizations and injuries are estimated using additional data sources and are not necessarily affected by this limitation.

RESULTS

Descriptive Analysis of Emergency Room Survey Data

A total of 244 bicycle accident cases was reported by the 10 hospitals participating in the 1985 survey, and 405 cases by the 15 hospitals participating in the 1986 survey. Because there were variations in the survey form and in the particular hospitals participating, results for the 2 years are kept separate in the analyses that follow.

The distribution of emergency room cases by rider age and sex is given in Table 2. For both surveys, males made up 70 percent of the reported cases. For the 1985 survey, 63 percent of the riders were under the age of 15, and for the 1986 survey 69 percent were under age 15. The largest single age category by far was 10 to 14 year-olds, representing over a third of the total number of cases reported.

Day of week and time of day information is depicted graphically in Figures 4 and 5. There are no clear day-of-week trends. For the 1985 survey, the number of accidents reported peaked on Wednesday; for the 1986 survey accidents peaked on Tuesday. Weekend accidents made up 28 percent of the 1985 sample and 31 percent of the 1986 sample. The greatest numbers of accidents occurred in the afternoon and early evening hours, with the 1986 sample skewed more toward the later hours.

Information on where the emergency room-reported accidents occurred is presented in Table 3. The lower percentage of intersection accidents for the 1986 survey may be partly the result of changes introduced to the survey form. It may also indicate that the hospitals participating in that particular survey served more rural locales. Nevertheless, it should be noted that the largest portion of accidents occurred on nonintersection road segments. There was also a high percentage of accidents occurring at or in driveways (17 percent for each of the samples) and accidents occurring at "other" locations (including off-road accidents in yards, parking lots, etc.).

TABLE 2 FREQUENCY OF EMERGENCY-ROOM-REPORTED BICYCLE ACCIDENTS BY RIDER AGE AND SEX

	1985						1986					
Age	Male	%	Female	%	Total	%	Male	%	Female	%	Total	%
0–4	4	80.0	1	20.0	5	2.1	11	52.4	10	47.6	21	5.2
5–9	39	68.4	18	31.6	57	23.5	71	62.3	43	37.7	114	28.2
10–14	69	75.0	23	25.0	92	37.9	106	74.1	37	25.9	143	35.3
15–19	18	64.3	10	35.7	28	11.5	47	83.9	9	16.1	56	13.8
20–24	13	61.9	8	38.1	21	8.6	16	76.2	5	23.8	21	5.2
25–29	11	91.7	1	8.3	12	4.9	12	66.7	6	33.3	18	4.4
30–39	11	68.8	5	31.3	16	6.6	9	56.3	7	43.8	16	4.0
≥ 40	6	50.0	6	50.0	12	4.9	13	81.3	3	18.8	16	4.0
Total	171	70.4	72	29.6	243		285	70.4	120	29.6	405	

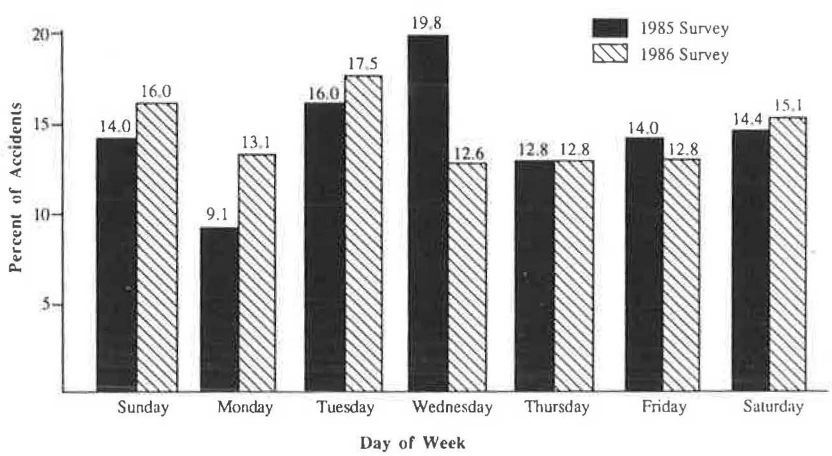

FIGURE 4 Distribution of emergency-room-reported bicycle accident cases by day of week.

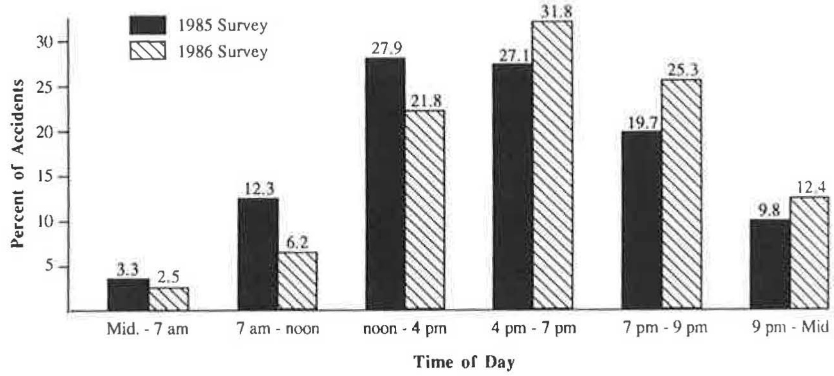

FIGURE 5 Distribution of emergency-room-reported bicycle accident cases by time of day.

TABLE 3 FREQUENCY OF EMERGENCY-ROOM-REPORTED BICYCLE ACCIDENTS BY ACCIDENT LOCATION

Location of Accident	1985 No.	1985 % of Total	1986 No.	1986 % of Total
Intersection	30	12.3	22	5.6
Driveway	42	17.0	69	17.4
Road segment (nonintersection)	94	38.5	–	–
City street	–	–	112	28.3
Rural road	–	–	85	21.5
Sidewalk	14	5.7	25	6.2
Railroad crossing	2	0.8	2	0.5
Other or unknown[a]	62	25.4	81	20.5
Total	244		396	

[a]Includes accidents occurring off-road, in yards, on dirt or private roads, in parking lots, and so on.

Additional accident information is summarized in Table 4. For the 1985 survey, 22 percent of the reported cases involved a motor vehicle and 20 percent were recorded as reported to police. Corresponding figures for 1986 were 15 percent and 13 percent, respectively. These differences may again be reflective of the urban or rural characteristics of the two survey samples. (For example, in the 1986 survey none of the 77 cases reported by Northern Surry Hospital in predominantly rural Surry County, North Carolina, involved a motor vehicle.) In any case, it is clear that the vast majority of bicycle accidents serious enough to require emergency room treatment do not involve a motor vehicle and are not reported to the police.

For the 1986 survey, reporting physicians were asked to determine from the patient's description of the accident who was at fault. Overall, the bicyclist was judged to be at fault in 63 percent of the accidents. For accidents involving a motor vehicle, the bicyclist was at fault in 55 percent of cases. Interestingly, there were no statistically significant differences by either age or sex of rider, although percentage at fault was slightly higher for the youngest and oldest age groupings.

Along with "at fault" data, information was obtained (in both the 1985 and 1986 surveys) on the percentages of cases involving wrong-way riding (i.e., riding facing traffic) and riding two or more on a bicycle. For the former, percentages ranged from 7 to 11 percent, and for the latter 8 to 11 percent. Younger riders (those 15 and under) were no more likely than older riders to be cited for wrong-way riding. Another causative factor, a mechanical defect of the bicycle (chain coming off, brakes not working, etc.), was reported in 12 to 16 percent of the cases. Again, there were no significant age differences.

One very important issue concerns helmet use. For the 1985 survey, 6 percent of the injured bicyclists were reported wearing a helmet. About half of these were in the 20- to 24-yr age

TABLE 4 ADDITIONAL CHARACTERISTICS OF EMERGENCY-ROOM-REPORTED BICYCLE ACCIDENTS

Accident Variable	1985[a] Yes (no.)	1985[a] %	1985[a] No (no.)	1985[a] %	1986[b] Yes (no.)	1986[b] %	1986[b] No (no.)	1986[b] %
Motor vehicle involved?	54	22.1	190	77.9	62	15.5	339	84.5
Another bicycle involved?	19	7.8	225	92.2	25	6.2	376	93.8
Accident reported to police?	49	20.1	195	79.9	52	13.1	344	86.9
Bicyclist at fault?	–	–	–	–	242	62.9	143	37.1
Bicyclist riding against traffic?	26	10.7	216	89.3	28	7.4	350	92.6
Bicyclist riding on bicycle path or bicycle lane?	–	–	–	–	7	1.8	380	98.2
More than one on bicycle?	27	11.1	217	88.9	34	8.5	364	91.5
Bicycle mechanical defect?	38	15.6	205	84.4	49	12.5	344	87.5
Helmet worn?	14	5.8	228	94.2	3	0.8	392	99.2
Alcohol or drugs involved?	–	–	–	–	21	5.3	375	94.7

NOTE: Dash = Information not available for 1985 survey.
[a]Totals less than 244 represent missing information.
[b]Totals less than 405 represent missing information.

category; the rest were spread evenly among the age groups. In 1986, only three bicyclists (all older than 15 yrs) were reported to have been wearing a helmet. This represents less than 1 percent of the total emergency room sample.

Information on alcohol or drug involvement was included in the 1986 survey. Although the overall percentage reported was 5 percent, the percentage is considerably higher for older bicyclists, as shown in Table 5. For the 122 riders 15 years of age and older, 21 (17.2 percent) were in accidents where alcohol was judged to have been involved. For riders age 20 and older, this percentage climbed to 23 percent. There was no significant difference in alcohol involvement for male versus female riders.

TABLE 5 FREQUENCY OF ALCOHOL INVOLVEMENT IN EMERGENCY-ROOM-REPORTED BICYCLE ACCIDENTS—1986 DATA

	Alcohol Involvement?				
Age Category	No (no.)	%	Yes (no.)	%	Total (no.)
0–14	274	100.0	0	0.0	274
15–19	48	90.6	5	9.4	53
20–24	16	80.0	4	20.0	20
25–29	12	70.6	5	29.4	17
30–39	13	81.3	3	18.3	16
40+	12	75.0	4	25.0	16
Total	375	94.7	21	5.3	396

TABLE 6 PERCENTAGE OF CASES WITH MODERATE OR WORSE INJURY (AIS ≥ 2) BY SELECTED RIDER AND ACCIDENT VARIABLES—1986 DATA

Variable Levels	Moderate or Worse Injury (AIS ≥ 2) (%)
Sex	
Male	22.2
Female	11.7
Age	
0–4	0.0
5–9	15.7
10–14	20.3
15–19	17.9
20–24	19.1
25–29	22.2
30–39	31.3
40+	43.8
Admitted to hospital?	
Yes	92.0
No	13.7
Motor vehicle involved?	
Yes	32.3
No	16.9
Reported to police?	
Yes	42.3
No	15.7
Alcohol or drugs involved?	
Yes	33.3
No	18.5

Concerning injuries, there was a total of seven fatalities reported—four in 1985 and three in 1986. All involved collisions with a motor vehicle. Ages of the fatally injured riders ranged from 6 to 20, and all but one were male. Two of the accidents occurred at intersections, one at midblock, and four on state highway or rural road segments. All of the fatally injured cyclists suffered a head injury, and none was wearing a helmet.

The percentage of cases requiring hospital admission was fairly consistent for the two samples: 5.8 percent in 1985 and 6.4 percent in 1986. AIS information, available for the 1986 sample, indicated that 81 percent of the injuries were minor (AIS 1), 12 percent moderate (AIS 2), 4 percent serious (AIS 3), and 3 percent severe, critical, or life threatening (AIS 4 or greater). Male riders were nearly twice as likely as female riders to experience an injury of AIS 2 or greater: 22 percent for males versus 12 percent for females ($p < .01$). The percentage of cases experiencing serious injury was also significantly greater for the oldest age groups, for accidents involving a motor vehicle, accidents reported to the police, and accidents involving alcohol or drugs (Table 6).

Concerning location and type of injury, results of the 1985 survey indicated that 14 percent of the riders suffered a head injury and 25 percent some form of fracture or dislocation. The most common injuries were abrasions and lacerations, affecting 71 percent and 45 percent, respectively.

Injury information for the 1986 survey was coded differently, with separate codes for location of injury and injury severity. Twenty-four percent of the 1986 sample had some sort of head injury and 17 percent an injury to the face (Table 7). Note, however, that injuries to the head can include lacerations, abrasions, and so on, and do not necessarily infer a head injury in the same sense as reported by the 1985 survey. Most frequent were injuries to the knee and lower leg (42 percent) and to the elbow and lower arm (37 percent).

Examining AIS information available for the 1986 data, the presence of a head injury was not found to be significantly associated with overall AIS injury severity, although trends were according to expectations (head injury present in 22 percent of cases involving only minor injury and 33 percent of cases involving moderate or greater injury). Injuries to the shoulder and arm were also associated with higher AIS scores. Examination of survey hard copies showed that the latter frequently involved fractures or dislocations.

In addition to the coded information summarized previously, considerable insight into the nature of bicycle accidents could be gained from the accident descriptions included at the bottom of the survey forms. These yielded information, for example, on the frequency of accidents caused by dogs, by "phantom" motor vehicles that leave the accident scene, and by feet, clothing, and so on becoming entangled in the bicycle spokes. All such information is of value in the planning of countermeasures to reduce the frequency and severity of bicycle accidents.

Comparison of Emergency Room and Police Data

The North Carolina Division of Motor Vehicles reports that, in 1986, 1,245 bicyclists were injured in police-reported traffic accidents and an additional 32 bicyclists were killed (*1*). These

TABLE 7 LOCATION AND SEVERITY OF INJURIES: 1986 EMERGENCY ROOM DATA

	Injury Severity					
Injury Location	Minor (AIS=1) (no.)	%	Moderate or Worse (AIS≥2)	%	Total Cases Reported (*N*=692) (no.)	%[a]
Head	73	74.5	25	25.5	98	24.3
Face	58	85.3	10	14.7	68	16.8
Neck	12	80.0	3	20.0	15	3.7
Thorax	23	76.7	7	23.3	30	7.4
Abdomen, lower back	23	85.2	4	14.8	27	6.7
Shoulder, upper arm	53	74.7	18	25.4	71	17.6
Elbow, lower arm, hand	112	76.2	35	23.8	147	36.4
Hip, upper leg	23	88.5	3	11.5	26	6.4
Knee, lower leg, foot	147	86.5	23	13.5	170	42.1
Other	33	82.5	7	17.5	40	9.5

[a]Percentage of riders (*N*=404) with injury at a given location.

figures are up considerably from the previous year, when 1,125 bicyclists were reported injured and 22 killed.

An examination of the 1985 police-reported data is contained elsewhere (*6*). The 1986 data were similarly examined for the present study. The combined results show that

- Less than half of the police-reported accidents involve riders under the age of 15, compared with two-thirds of the emergency-room-reported cases;
- Almost 85 percent of the riders in the police-reported data are male, compared with 70 percent in the emergency room data; and
- Police-reported accidents involve more serious injuries to the rider, with 2 percent of the riders killed, 26 to 27 percent seriously injured, and 41 to 42 percent moderately injured.

Although motor vehicles are only a factor in about one-fifth of the emergency room cases, virtually all of the police-reported cases involve collisions between bicycles and motor vehicles. Also, more than 95 percent of the police-reported cases occur either on local (city) streets or rural highways (including U.S. and North Carolina routes and secondary roads); only 2 or 3 percent are reported occurring at "off-road" locations such as parking lots, driveways, and so on.

A more direct approach used to compare the emergency-room and police-reported bicycle accidents involved a case-by-case matching of the two samples. As noted in the Methodology section, cases were considered a "match" if they occurred on the same date, at approximately the same time, in the same city or county, and involved a rider of the same age and sex. Where questions arose, actual hard copies of the accident reports, including the accident narrative and diagram, were viewed and compared with information on the emergency room reports.

Following this procedure for the 1985 data, only 26 of the 244 reported emergency room cases (10.7 percent) were found documented on state accident files. All but one of these 26 cases involved a motor vehicle. Out of the total of 244 emergency-room-reported cases, 54 involved a motor vehicle, so that the rate of reporting of bicycle–motor-vehicle accidents was 25/54 or 46.3 percent. Similarly, the rate of reporting for bicycle accidents not involving a motor vehicle was 1/190 or 0.5 percent.

For the 1986 data, a total of 42 cases, all involving a motor vehicle, was matched to the state accident files, producing a similar overall reporting rate of 42/405 or 10.4 percent. There were 16 additional cases of bicycle–motor-vehicle accidents not found on police files, so that the rate of reporting of bicycle–motor-vehicle accidents for this sample was higher at 42/58 or 72.4 percent. (It should be noted that one of the emergency-room-reported bicycle–motor-vehicle accidents that was not found on the state files involved a fatally injured 6-yr-old girl.)

The previous information is summarized in Table 8. These results clearly indicate that a substantial percentage of bicycle–motor-vehicle accidents are not appearing on police accident files. Virtually no non-motor-vehicle bicycle accidents appear on the files, even though many of these do occur on public roadways and result in serious injuries.

TABLE 8 COMPARISON OF EMERGENCY ROOM-REPORTED AND POLICE-REPORTED BICYCLE ACCIDENTS

	On State Accident File?					
Emergency Room Cases	Yes (no.)	%	No (no.)	%	Total (no.)	%
1985						
Motor vehicle involved	25	46.3	29	53.7	54	22.1
Non-motor vehicle involved	1	0.5	189	99.5	190	72.9
Overall	26	10.7	218	89.3	244	
1986						
Motor vehicle involved	42	72.4	16	27.6	58	14.3
Non-motor vehicle involved	0	0.0	347	100.0	347	85.7
Overall	42	10.4	363	89.6	405	

Statewide Projections for Childhood Bicycle Injuries

It was noted earlier that 5.8 percent of the 1985 emergency-room-reported cases and 6.4 percent of the 1986 emergency-room-reported cases required hospital admission. This information was combined with 1980 hospital discharge data from the State Center for Health Statistics to produce estimates of the numbers of children receiving emergency room treatment statewide for bicycle-related injuries, along with comparisons for other types of traffic injuries.

The reported number of North Carolina hospital discharges for bicycle-related injuries by age group is shown in Table 9. The unadjusted numbers at the top of the table are low, because they do not take into account the fact that discharge data were only available for 89 percent of all North Carolina pediatric hospitalizations, and *E* code information was only available for an estimated 67 percent of these cases (*25*). Incorporating these adjustments into the data produces the estimate of just over 800 children under the age of 20 hospitalized annually for bicycle-related injuries. Approximately 350 of these children are in the 5- to 9-yr age category and an additional 300 in the 10- to 14-yr age category. Only 18 percent of the hospitalizations are shown as resulting from a motor vehicle collision.

Survey data indicate that these hospitalized cases represent approximately 6 percent of emergency room cases occurring in the state. [This is identical to the percentage reported by Fried et al. (*22*), based on a larger representative sample of bicycle accidents reported to the Massachusetts-based Childhood Injury Surveillance Project.] Based on this percentage, estimates of yearly numbers of emergency-room-treated bicycle-accident cases for children younger than age 20 in North Carolina were calculated (Table 10). It is estimated that more than 13,000 children younger than age 20 are treated each year in North Carolina hospital emergency rooms for bicycle-related injuries.

TABLE 10 ESTIMATES OF YEARLY NUMBERS OF EMERGENCY-ROOM-TREATED BICYCLE-ACCIDENT CASES FOR CHILDREN YOUNGER THAN AGE 20 IN NORTH CAROLINA

Age Group (yr)	Estimated No. of Emergency Room Cases
0–4	800
5–9	5,800
10–14	5,000
15–19	1,700
Total	13,300

DISCUSSION OF RESULTS

Significance of Research

This study is part of a continued effort toward producing a more accurate assessment of bicycle accidents occurring in North Carolina. In the past the primary source of information on bicycle accidents and their resulting injuries has been state motor vehicle accident files. Such data do not present an accurate account of the full range of accidents and injuries occurring to bicyclists. This is true even for the relatively small percentage of accidents involving a motor vehicle.

Hospital records represent an alternative source of information on bicycle-related accidents and injuries. Retrospective analyses of hospital data have yielded considerable information about the number of bicyclists being injured and the significance of bicycle injuries compared with other types of injuries. However, examinations of bicycle-related accidents and injuries based solely on hospital emergency room or admissions records clearly cannot provide detailed information on the circumstances surrounding the accident, and it is this information that is critical to the development of effective countermeasures for reducing the frequency and severity of bicycle accidents.

To provide this information, additional data-collection activities are needed, either at the time of treatment or later, through follow-up contacts. The emergency room survey studies cited earlier are examples of this type of approach. The present investigation goes beyond these studies by also examining police-based data and drawing comparisons between the emergency room and police results. Thus, it is more able to address the question, "What do police reports fail to tell us about the nature and magnitude of the bicycle accident problem?"

Major Findings

Two key variables examined were the percentage of emergency room accidents involving a motor vehicle and the percentage reported to the police. Overall, 22 percent of the 1985 emergency room cases and 14 percent of the 1986 emergency room cases involved a motor vehicle. Only 10 percent of the emergency room cases were duplicated on state accident files; not

TABLE 9 NORTH CAROLINA PEDIATRIC HOSPITAL DISCHARGES FOR BICYCLE-RELATED INJURIES—1980 STATE CENTER FOR HEALTH STATISTICS DATA

	Age									
Cause of Injury	0–4 (no.)	%	5–9 (no.)	%	10–14 (no.)	%	15–19 (no.)	%	Total (no.)	%
Unadjusted data[a]										
Bicycle–motor-vehicle	3	10.0	30	14.3	35	19.6	19	30.6	87	18.1
Bicycle–non-motor-vehicle	27	90.0	180	85.7	144	80.4	43	69.4	394	81.9
Total	30	6.2	210	43.7	179	37.2	62	12.9	481	
Adjusted data[b]										
Bicycle–motor-vehicle	5.0		50.3		58.7		31.9		145.9	
Bicycle–non-motor-vehicle	45.3		301.9		241.5		72.1		660.7	
Total	50.3		352.2		300.2		104.0		806.6	

[a]Discharge data available for 89 percent of all pediatric hospitalizations. Cause (*E*-code) information available for 67 percent of reported cases.
[b]Assumes an even distribution for missing cases.

surprisingly, almost all of these involved a motor vehicle. The percentage of emergency-room-reported bicycle–motor-vehicle accidents located on state accident files was 46 percent for the 1985 survey data and 72 percent for the 1986 survey data.

Although the latter two percentages cover a wide range, they nevertheless stand as firm evidence that police accident data do not provide accurate accountings of the numbers of bicyclists injured in traffic accidents. In addition to missing a significant portion of the bicycle–motor-vehicle accidents, the police files provide almost no information on bicycle–non-motor-vehicle accidents. This was essentially the same conclusion reached by Cross and Fisher in their landmark 1977 study (*3, 4*). Consequently, what police files are able to tell us about the nature of bicycle accidents and the characteristics of injured riders is not necessarily reflective of the total accident picture.

Using the emergency room survey data in conjunction with hospital discharge data, it was estimated that 800 children younger than age 20 are hospitalized each year in North Carolina for bicycle-related injuries, and that 13,300 children receive emergency room treatment. Going one step further, it could be projected that 17,000 to 18,000 North Carolinians of all ages receive emergency room treatment each year for bicycle-related injuries (this on the basis that one-fourth of the hospital emergency room sample involved riders age 20 or older). Interestingly, the latter estimate agrees well with the U.S. Consumer Product Safety Commission's projection of 550,000 bicycle-related emergency room cases (all ages) occurring annually in the United States (*5*). On a purely population basis, North Carolina could expect to entertain 2.6 percent or 14,300 of these cases. Given the particular popularity of bicycling in North Carolina, it is not unreasonable to assume a figure considerably higher than this.

In addition to providing an alternative description of who is involved in bicycle accidents and when, where, and how these accidents occur, the emergency room survey data give a more detailed picture of the injuries resulting. In particular, the 1985 survey revealed that 14 percent of the emergency room cases suffered a head injury; for those hospitalized, this percentage increased to nearly a third. Reported helmet use was less than 6 percent for the 1985 survey and less than 1 percent for the 1986 survey.

Finally, the survey data provide additional detail on causative factors in bicycle accidents. Of interest here is that 7 to 11 percent of the reported cases involved wrong-way riding, 8 to 11 percent riding more than one on a bike, and 12 to 16 percent some mechanical defect of the bicycle. Perhaps contrary to expectations, older riders were found just as likely as younger riders to be cited for wrong-way riding, and were just as likely to be judged at fault in the accident. Alcohol played a particularly prominent role in the accidents of the older riders—cited in 23 percent of the cases for riders over the age of 19.

CONCLUSIONS AND RECOMMENDATIONS

Further research is needed to better define the nature and magnitude of the bicycle accident problem. Police-reported statistics, though frequently cited, represent only a small portion of the bicycle accident "iceberg." Unfortunately, the amount of highway safety dollars allocated to bicycle-related research has reflected a similar underappreciation of the bicycle accident problem.

Yet bicycles are a major source of injury, particularly to young people. The Consumer Product Safety Commission has identified bicycles as the leading cause of sports or recreational injuries seen in hospital emergency rooms. In children, bicycle crashes are one of the leading causes if not the leading cause of hospitalized head injuries (*26*).

Interest in bicycling continues to grow. The Metropolitan Statistical Bulletin reports that in 1981 there were 62 to 65 million bicycles in the United States, or one for every two registered passenger cars (*27*). In recent years, the increasing emphasis on physical fitness, the growth of bicycle commuting, and the growing popularity of bicycle riding have all contributed to a bicycling boom. One outcome of this growth is that the population of riders injured and killed in accidents has aged. What used to be primarily a "kid's" problem is today affecting more and more adults.

What can be done to alleviate this situation? The need for more research to examine the characteristics of bicycle accidents—both those involving a motor vehicle and those not involving a motor vehicle—has already been cited. Hospital-based studies and survey studies are two recommended approaches. Certainly the current study could and should be replicated using a larger and more representative sampling of cases.

Efforts might also be directed at improving police-based reporting of bicycle accidents. In North Carolina, only bicycle accidents involving a motor vehicle appear routinely reported to the Department of Motor Vehicles (DMV) to become part of the state's traffic records system. However, police officers frequently do investigate and file reports on non-motor-vehicle bicycle accidents that occur on the roadway, particularly if they involve injury. Although not forwarded to the DMV, these reports may be kept on file at the local level, and may even be retrievable by computer. A project aimed at collecting and examining data on all police-investigated bicycle accidents would appear to be of value. Ultimately, it may be recommended that local law enforcement agencies file and submit reports to the DMV on bicycle-only as well as bicycle–motor-vehicle accidents.

Concerning hospital-based sources of information on bicycle accidents and injuries, in response to the growing recognition of injuries as a major public health problem, there is a trend across the country toward implementing trauma registries and other large-scale injury surveillance systems. In North Carolina, a grant was recently awarded to develop a statewide trauma registry to monitor the care of severely injured patients treated at the state's six major trauma centers. Parallel efforts are under way to develop a statewide plan for emergency-room-based injury surveillance under a grant from the Centers for Disease Control in Atlanta, Georgia. Such systems, when operational, have the potential for yielding information on large numbers of bicycle-related injuries, as well as how these injuries compare with other forms of trauma.

In addition to these research efforts, there are actions that can be taken now to reduce the frequency and severity of bicycle accidents. Most important is to encourage helmet use by all bicyclists, young and old, riding on the road or off. Head trauma is the leading cause of death in fatal bicycle accidents. Weiss (*28*) notes that "pediatricians and family physicians have a unique opportunity to provide education to families and communities about the importance of using helmets." In Madison, Wisconsin, a multipronged mass media campaign was carried out to increase helmet use by that city's large population of older cyclists (*29*); and the Harborview Injury Prevention Center in Seattle, Washington, has prepared a guide for local communities interested in developing a children's bicycle helmet safety program (*30*).

Schools should also adopt instruction in bicycle safety as part of their physical education curriculum, if possible including "on road" training. Considering the popularity of bicycling as a lifetime sport, the lack of attention devoted to its instruction in the schools appears unjustified. Effective bicycle education programs have already been developed, so that at this stage the greatest need is for some mechanism for placing such a program in the schools and funding to make it possible. Ideally, this should be accomplished at the state level, although individual communities or school systems could also take the initiative.

There are other steps that communities can take to lower their bicycle accident count. Enforcement of traffic laws, even for the very youngest riders on the street, has been shown to significantly reduce the frequency of bicycle–motor-vehicle accidents (*31*). Attention should be directed toward educating older cyclists on the dangers of mixing drinking and riding. Communities might also adopt a pin-map approach to examining their own patterns of bicycle accidents to determine if any specific problem locations need attention.

Obviously there is much that can and should be done. As in other areas of injury prevention, people from many different areas of interest need to become involved—educators, physicians, law enforcement officers, transportation engineers, researchers, and state and local government officials. The present investigation, which has pooled the resources of so many, is a step in this direction.

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Abridgment

National Survey of Metropolitan Bicycle-on-Train Programs and a Proposal for the San Francisco Bay Area CalTrain System

ROGER HOOSON

An April 1987 study that explored the key elements of urban bicycle-on-train programs in North America, in order to analyze the feasibility of allowing bikes on the CalTrain commuter rail service between San Francisco and San Jose, is summarized in this report. In the course of the study, virtually every North American rail operator was contacted. It was found that 12 North American rail systems currently allow bikes during certain hours. A matrix, included with this report, provides quick comparisons of each operator's permit requirements, time restrictions, maximum number of bicycles allowed, and minimum age restrictions for bicyclists. Twelve aspects of bicycle-on-train programs are examined in separate sections of the text. Aspects include legal liability and claims, permits, time restrictions, and the process of boarding trains and storing bicycles. Most systems require permits, allow a relatively small number of bikes to be carried only during off-peak hours, and have had no problems with injuries or claims. Several alternatives to allowing bicycles on trains are discussed. The report concludes with a summary of the study's recommendation that another CalTrain bicycle-on-train demonstration program be allowed but only if a relatively unique local liability issue can be resolved without additional compensation to the contractor railroad. A limited number of bicycles would be allowed only during off-peak periods and only with permits.

Bicycle groups have long urged the San Francisco–San Jose CalTrain commuter railroad to allow standard, full-size bicycles on board its trains. A 4-month demonstration program in 1982 showed significant demand, but the program was not made permanent because the private railroad over whose tracks CalTrain operates would not agree to its continuation without substantial payments to cover perceived additional liability and claims exposure. Yet 12 North American urban and commuter rail systems now allow bicycles (up from two in 1980), and 400 bicycle lockers are in use at 18 CalTrain stations on the San Francisco Peninsula. In an October 1987 survey, 10 percent of CalTrain riders said they would "often" take a bicycle aboard CalTrain during off-peak periods if it were allowed.

In April 1987, CalTrain staff completed a 34-page study that examined the feasibility of a new bicycle-on-train program. The study looked closely at the elements of all 12 North American programs, as well as the unique local characteristics of the CalTrain service. Research methods included phone interviews with staff at virtually all North American urban rail systems, a literature review, an assessment of the 1982 CalTrain demonstration program, and a staff inspection trip to CalTrain rail cars with personal bicycles.

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A dozen aspects of bicycle-on-train programs were separately discussed in the study, which concluded with a short discussion of alternatives and a set of recommendations for a CalTrain program. The 12 aspects are discussed in the following paragraphs. System-by-system comparisons for some aspects are also presented in the matrix accompanying this report (Table 1).

- *Type of bicycle allowed.* Only nonmotorized bicycles are permitted. Some systems have dimension restrictions, including two systems with a 1 ft 10 in. width restriction that technically rules out wide-handlebar mountain bikes (unless bars are turned). But this rule apparently is not enforced.
- *Condition of bicycle.* Six systems require that bicycles be clean and free of sharp projections.
- *Station rules.* Most systems ban bicycle riding within station areas. Bicyclists must use either stairs or elderly-handicapped elevators for vertical circulation and cannot use escalators. New York area railroads require the use of stairs, the Washington and Miami Metrorail systems require elevators, and the Bay Area Rapid Transit District (BART) and Boston's "T" rapid transit systems allow use of either.
- *Boarding the train.* Nine systems restrict bicycles to specific cars on the train, with seven systems requiring use of the last car. Seven systems have high-level platforms that line up with car floors at every station. But on three systems heavily used by bicyclists, some or all stations have low-level platforms, requiring cyclists to climb car steps. This would also be true on the CalTrain system.
- *On-board bicycle storage.* Once bicyclists are aboard trains, all systems require that they hold their bicycles. At most properties, the storage area is close to the entry door. On rapid transit systems, bicyclists may sit down in a seat close to the door. On commuter railroads and the San Diego Trolley, bicyclists must stand up in the entry areas. For the CalTrain service, limited storage room in the entry vestibules led to the recommendation that bicycles be wheeled down the aisle and stored at the north end of the train. Most systems restrict the number of bicycles that can be carried per train. Four is the most common number; however, BART allows seven.
- *Time restrictions.* In general, North American bicycle-on-train programs are designed for off-peak users. Most rail properties believe trains are too crowded during rush hours to permit bicycles. "Off-limits" peak periods average 3 hr in the morning and 3 hr in the evening. Six systems allow early

TABLE 1 NORTH AMERICAN BICYCLE-ON-TRAIN PROGRAMS

SYSTEM	PERMIT					Max. # Bicycles/ Train	Min. Age (with older user)	TIME RESTRICTIONS					
	By Mail	Validity Period	Waiver	Photo ID	Fee			Early AM	Peak	Midday	Eve.	Sat.	Sun.
Bay Area Rapid Transit District Oakland	Yes	3 years	Yes	No	$3	7 (last car)	14 (less)	OK before 6:30a	Some reverse commute only	OK 9:00a -3:30p	OK after 6:30p	OK	OK
Metropolitan Transit Board/ San Diego Trolley Inc.	No+	2 years	Yes	Yes	$3	2 per car	16	OK before 6:00a	Not allowed	OK 9:00a -3:00p	OK after 6:00p	OK	OK
Metropolitan Atlanta Rapid Transit Authority	N/A	N/A	N/A	N/A	N/A	No rule (last car)	No rule	Not allowed	Not allowed	Not allowed	Not allowed except midnite -2:00a	OK	OK
Metro-Dade Transportation Administration, Miami	No	Un-limited	Yes	Yes	$5	4 (last car)	16	Not allowed	Not allowed	OK 10:00a -4:00p	OK after 6:30p	OK	OK
Washington, D.C. Metropolitan Area Transport Authority	No	5 years	Yes	Yes	$15	4 (last car)	16 (12)	Not allowed	Not allowed	Not allowed	OK after 7:00p	OK	OK
Port Authority Trans-Hudson, New York City	Yes	Un-limited	No	No	Free	2 per car	No rule	OK before 6:00a	Not allowed	OK 9:30a -3:00p	OK after 6:30p	OK except 7a-2p (east) 1p-7p (west)	OK
Long Island Rail Road New York City	Yes	Un-limited	No	No	$5	4/ flexible (front & rear cars)	No rule	OK before 6:00a (west) 7:00a (east)	Not allowed	OK 9/10 am-3/4 pm	OK after 7:00p (west) 8:00p (east)	OK except some blackout periods in summer	OK except some blackout periods in summer
Metro-North Commuter Railroad New York City	Yes	Un-limited	Yes	No	$5	4 (north cars)	No rule	OK before 6:00a (south) 7:00a (north)	Not allowed	OK 9/10 am-3/4 pm	OK after 7:00p (south) 8:15p (north)	OK	OK
Massachusetts Bay Transportation Authority Boston (Rapid Transit Only)	No	2 years	Yes	Yes	$5	2 (last car)	16 (12)	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	OK except Thanks-giving to Xmas
Societe De Transport De La Communaute Urbaine De Montreal (Rapid Transit Only)	N/A	N/A	N/A	N/A	N/A	4 (last car)	16	Not allowed	Not allowed	Not allowed	OK after 7:00p	OK	OK
Canadian Pacific Railway Company Montreal (STCUM Contract)	N/A	N/A	N/A	N/A	N/A	No rule (last car)	16 (less)	Not allowed	Some reverse commute only	Not allowed	Allowed on certain trains	OK	OK
Toronto Transit Commission	N/A	N/A	N/A	N/A	N/A	*	No rule	OK before 6:30a	Not allowed	OK 9:30a -3:30p	OK after 6:30p	OK	OK

* Bicycles permitted at discretion of vehicle operator
\+ Administered by American Youth Hostels

morning use, before the peak period (see Table 1). Two systems, BART and Montreal's CP Rail, permit limited peak period travel in the "reverse commute" direction. On BART, only one San Francisco station may be used during this period. Seven of the 12 systems permit bicycles during the midday period on weekdays, and 10 allow them in the evening. Eleven systems (all except Boston) permit some Saturday travel. All allow travel on Sunday, with some exceptions during holiday periods, for specific summer weekend trains and for four downtown Boston stations. The New York–New Jersey Port Authority Trans-Hudson Corporation (PATH) service does not allow Saturday use during times of peak shopping travel. A similar restriction in San Diego was recently lifted. Most systems reserve the right to ban bicycles from specific trains without notice in the event of crowding or for other reasons.

- *Permits.* Eight systems require permits to bring bicycles aboard trains. This includes all of the heavily used systems and all but one of the U.S. systems. Permits typically are required for three reasons: (a) to get cyclists to sign waivers, (b) to familiarize cyclists with rules, and (c) to allow properties to revoke the permits of problem cyclists. With one exception, permits must be obtained from a central location by mail or in person, which discourages out-of-towners or casual users. The one exception, BART, allows individuals to obtain a free 3-week pass once a year from station agents. American Youth Hostels sells all passes in San Diego and some passes in New York. In Boston it is necessary to obtain a pass during working hours, and in Washington, D.C., only one Saturday a month is set aside for pass processing, plus two weekdays. Fees and validity periods for permits are shown in the matrix (Table 1). Six systems require cyclists to sign waivers as part of the permit process (see *Legal liability*, next) and four issue a photo identification card, which must be displayed when on railroad property.
- *Legal liability.* A major concern of many U.S. rail operators, waivers form a key part of many permit agreements. Although there is no record of a single lawsuit or significant claim at any system, the potential always exists. Many waiver agreements have two parts: first, a release of liability for negligence on the part of the transit property and, second, an agreement to indemnify and hold harmless the transit system for the cyclist's negligence. Liability has been the main issue holding up a CalTrain bicycle-on-train program. A solution may now be at hand, on which local counties appear close to agreement, on use of self-insurance funds to cover any claims or lawsuits that might arise (the state will not indemnify private contractors). No transit system has a special insurance set aside to cover bicycle incidents, and claims personnel at key properties appear completely satisfied with current arrangements.
- *Bicycle fares.* Though bicycle fares are common in Europe, no North American system uses them. This may be partly because of the use of permits instead. In addition, most systems have extra space to accommodate bicycles without revenue loss during off-peak periods. CalTrain, however, may implement a modest bicycle charge as security against conceivable minor claims.
- *Age restrictions.* Seven systems have a minimum age requirement for bicyclists, which is 16 years except for BART's, which is 14. However, on four systems, younger cyclists can travel with a cyclist of 16 years of age or older.
- *Disciplinary measures.* Line staff or police enforce most rules, although decisions to revoke permits are made by management. At BART, decisions on disciplinary measures, as well as other aspects of the bicycle program, are made by a monitoring committee of management and cyclists.
- *Marketing.* Marketing programs can reach two potential audiences: experienced bicyclists or the general public. Possible media for reaching experienced bicyclists include regulatory information and "how to" brochures, bicycle shop and bicycle organization outreach, and promotion by bicycle groups such as American Youth Hostels. Rider newsletter features and public service announcements are more appropriate for the general public. Which market to emphasize may depend on the ease or difficulty of occasional bicyclists using the particular system.

Four alternatives to bicycles on trains were examined in the study. Two involve more use of bike lockers. In one, individuals would be encouraged to own two bicycles and store one at each end of the trip. In the other, the state (or counties) would buy and lease bicycles for local travel, as is done at many Japanese rail stations. The other alternatives include encouraging more use of folding bicycles (allowed now), and a parallel bus or van service for bicyclists. No alternative seemed attractive to local cyclists, so they were not explored further.

Taking national experience and local conditions into consideration, the study concluded with a set of recommendations for a CalTrain bicycle-on-train program. These have since been adjusted slightly in consultation with a local county to accommodate the counties' proposed assumption of liability exposure.

The revised recommendations propose a 1-yr demonstration program, assuming final resolution of the liability issue. Permits would be used, chiefly because of tight on-train clearances and car steps that could result in injury or conflicts with other passengers. Only off-peak use would be permitted, and there would be a limit of three bicycles per train, stored initially in the aisle at the north end of the train. Because of the three-bicycle limit, cyclists at certain stations would receive preferred boarding, depending on the specific train. Finally, a 50 cent bicycle fare would be charged, with the aim of covering any minor claims that might arise.

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Nonmotorized Urban Transport in India

V. SETTY PENDAKUR

India had 12 cities with populations of more than 1 million in 1981 and will have 24 cities with populations of this size by the year 2000. Nonmotorized transport modes (walk, bicycle, cycle rickshaw, and tonga) are important components of the urban transport system. Travel by these modes ranged from 26 percent (Bombay) to 56 percent (Bangalore) in large cities and 56 percent (Vadodara) to 69 percent (Jaipur) in small cities. Urban poverty persists in India. Data from 9 cities indicate that nonmotorized transport is quite significant and particularly so to the urban poor. Although transport modernization is likely to take place gradually, urban planners must incorporate nonmotorized travel into their analysis and transport planning.

Despite various efforts to modernize urban transport systems in India, the nonmotorized modes persist. The primary reason for such survival is that these modes are cheap and often as efficient as motorized modes. The poor walk or bicycle, not for keeping fit, but primarily to save money. Modernizing urban transport systems and providing additional transport supply is quite costly. However, allocations for urban transport have met approximately 10–15 percent of the estimated needs during VII five year plan (1982–1987) and there is no reason to believe that allocations will expand during the 1987 to 1992 period (*1*). This means that the nonmotorized transport modes will remain for the time being.

Four large Asian countries—Bangladesh, India, Indonesia, and Pakistan—contain about two-thirds of the world's absolute poor (*2*). India displays economic vitality and dire poverty concurrently. Recent estimates of poverty based on the definition of a 2,100 daily caloric intake as suggested by the National Planning Commission of India indicate that 60 to 70 percent of urban residents are poor (*3*). For example, Bombay is a wealthy city whose total value of goods and services exceeds the GNP of several Asian countries. Yet, in 1981, 71 percent of Bombay households had a monthly income of less than (U.S.) $50, which is below the poverty line accepted by the government.

In 1981, India's population was 665 million, of which 24 percent was urban. The urban population is expected to increase to 28 percent (280 million) of a total of 1.0 billion by the year 2001. There were 12 cities with a population of one-half to one million in 1981. Their number is expected to increase to 24 by 2001.

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URBAN TRAVEL PATTERNS

Urban travel data for large and smaller cities are presented in Tables 1 and 2. Large cities have mature and diverse transport modes. These systems are generally overcrowded throughout the day. Among the large cities, Bombay alone has a good network of commuter trains. In other cities, public transport primarily means buses. Nonmotorized modes varied from a low of 26 percent in Bombay to 62 percent in Ahmadabad.

In smaller cities, the trip lengths are smaller. In these cities, nonmotorized trips are a higher proportion and varied from 56 percent in Vadodara to 69 percent in Jaipur. These trips decrease with the increase in the city size. Mode choice and city size relationships are shown in Figure 1.

Walking is the dominant mode: 15 percent in Bombay, 43 percent in Bangalore and Ahmadabad. The choice of walking trips is influenced by trip lengths, weather, alternative modes of transport and their cost, and the poverty levels. Bicycle trips amounted to 10 percent in Bombay and 26 percent in Jaipur. The bicycle is popular among the poor if they can afford to own one and also, in general, among the students.

Urban travel mode choices by the poor and very poor are presented in Tables 3 and 4, respectively. The relationship between income and mode choice is presented in Figure 2. Although mode choices are influenced by trip length, weather, and cost of other alternatives, income is the dominant determinant of mode choice. With increasing incomes, people shift to more comfortable and convenient motorized modes.

URBAN TRANSPORT POLICY

Urban transport systems in India function in an environment characterized by (a) large-scale poverty resulting in an inability to pay and (b) lack of adequate financial resources to create additional transport supply. These conditions are changing slowly but are not expected to change drastically over the next 20 years. On the other hand, urban transport policy goals and planning principles in India are heavily biased in favor of motorized vehicles, ignoring the nonmotorized modes used by a large segment of the population (*4–6*). It is as if these modes (walk, bicycle, and cycle rickshaw) do not exist and, if they do, they will somehow disappear during the next planning period. This situation is not unique to India. In many developing countries, the policy goals are to eliminate the nonmotorized modes and assume that they will fade of their own accord (*7–10*). Although transport modernization must take place, and

TABLE 1 URBAN TRAVEL—LARGE METRO AREAS, 1981

		Transportation Mode (%)				
	Population (millions)	Walk	Bicycle	Cycle Rickshaw	Tonga	Total Nonmotorized Trips
Bangalore	2.9	43.4	12.0	<0.1	0.3	55.7
Bombay	8.2	15.0	10.0	1.0	<0.1	26.0
Delhi	5.7	28.7	14.8	3.0	<0.1	46.5
Madras	4.3	20.0	20.0	<0.1	0.2	41.0
Ahmadabad	2.5	43.2	18.0	0.2	0.2	61.6

TABLE 2 URBAN TRAVEL—SMALL METRO AREAS, 1981

		Transportation Mode (%)				
	Population (millions)	Walk	Bicycle	Cycle Rickshaw	Tonga	Total Nonmotorized Trips
Visakhapatnam	1.3	42.4	11.6	4.6	0.5	59.1
Vadodara	0.8	40.1	15.1	0.5	0.2	55.9
Jaipur	1.0	39.5	26.5	2.7	0.3	69.0
Patna	0.9	35.8	12.5	17.6	0.4	66.3

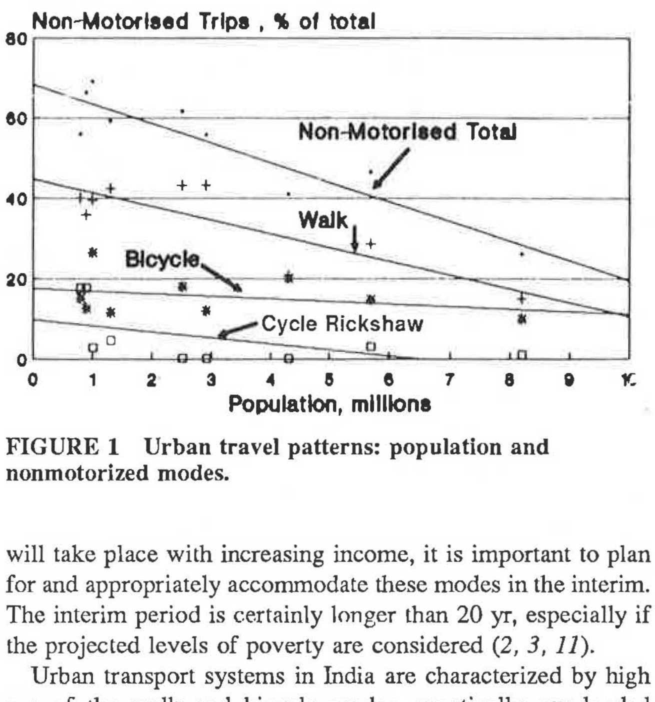

FIGURE 1 Urban travel patterns: population and nonmotorized modes.

will take place with increasing income, it is important to plan for and appropriately accommodate these modes in the interim. The interim period is certainly longer than 20 yr, especially if the projected levels of poverty are considered (*2, 3, 11*).

Urban transport systems in India are characterized by high use of the walk and bicycle modes, practically overloaded public transport, and lack of financial resources to make quantum jump improvements. Furthermore, the majority of the urban dwellers are poor and they are the primary users of nonmotorized transport. These differences require different approaches to transport analysis and development. For example, it should be mandatory to require assessment of impacts on the poor whenever new transport investments or regulations are proposed. Emphasis should be placed on nontransport solutions to transport problems.

Urban transport policy issues and conclusions are summarized in the following paragraphs:

- *Walking trips.* Fifteen to forty-three percent of all trips are made by walking. Therefore, adequate and continuous footpaths and safe and convenient crossings should be provided. Thirty-five to seventy-eight percent of all trips by the poor are made by walking. The poor walk primarily for economic reasons. Thus, short trips should be encouraged by providing adequate housing near employment centers and decentralizing work places, reducing the need for long trips.
- *Bicycle trips.* Ten to twenty-seven percent of all trips are made by bicycle. Therefore, adequate and continuous cycle paths should be provided, as well as safe and convenient interchange systems when the bicycle paths share the same roads with other traffic. Easy access to bicycles could be encouraged by increasing production of bicycles; promoting installment-purchase and bicycle-for-hire operations; encouraging short trips by providing adequate housing near employment centers; and decentralizing work places, reducing the need for long trips.

TABLE 3 URBAN TRAVEL BY THE POOR

			Transportation Mode (%)			
	Monthly per Capita Income (Rs)	Distance to CBD (km)	Walk	Bicycle	Cycle Rickshaw	Total Nonmotorized Trips
Dakshin puri	117	14	58	14	<1	72
Shakar pur	193	8	43	5	4	52
Poonna mallee	161	21	35	15	<1	50

TABLE 4 URBAN TRAVEL BY THE VERY POOR

	Monthly per Capita Income (Rs)	Distance to CBD (km)	Transportation Mode (%) Walk	Bicycle	Cycle Rickshaw	Total Nonmotorized Trips
Nand Nagri	91	25	42	3	2	47
Kesava Perumal	54	5	41	21	9	71
1,200 slums (avg)	84	NA	78	5	1	84

NOTE: NA = not applicable.

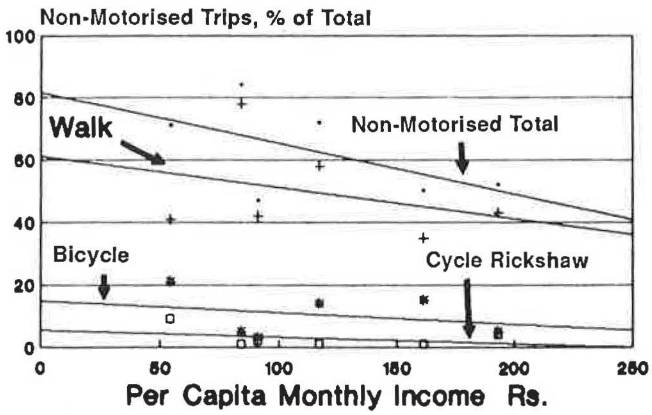

FIGURE 2 Urban travel patterns: income and mode choice.

• *Cycle rickshaw trips.* Cycle rickshaws are a significant part of the urban transportation system, particularly in smaller urban areas. One to eighteen percent of all trips are by cycle rickshaw. Modernization and motorization of rickshaws will take place eventually. Until then, nonmotorized rickshaws are required by the public. Regulatory barriers to new supply should be removed, new supply should be provided where there is a demand, and research should be undertaken on how the economic productivity of the rickshaw can be increased.

• *Nonmotorized urban transport as a whole.* The highest priority should be given to moving people using the most common transport modes, including walking and using bicycles and public transport. Design guidelines must be developed for safely and adequately handling mixed traffic. In addition, urban planning should incorporate the goal of reducing trip lengths, particularly to work places. Finally, urban transport studies must include data and analysis of walking and bicycle trips.

Some key areas needing further research are

• Applicability of the concept of equal and universal value of time: Do time-savings have equal monetary value or benefit to all persons? What increments of time-savings are significant to whom?

• Road user space and cost allocation: How are priorities established for vehicle mix and cost allocation?

• Modal efficiency: If bicycles are energy efficient and universally available even to poor households, should bicycle ownership and use be encouraged?

• Transport modernization: What are the most suitable strategies for transport modernization without increasing the cost of transport?

Although it is necessary to gradually modernize urban transport, it is important to include all nonmotorized modes within the system. It cannot be assumed that adequate financial resources will always be available or that the poor will pay for time-savings. It is important to protect the interests of the poor and at the same time provide adequate and efficient transport. Such goals can and should be complementary.

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Motorcyclists: Who They Are and Why They Do What They Do

PETER J. COOPER AND J. PETER ROTHE

From 1985 to 1987, the Insurance Corporation of British Columbia in Canada undertook a major research initiative on motorcycle riders with emphasis on safety-related factors and the effectiveness of formal rider training. Intensive, open interviews were held with riders, and a comprehensive telephone interview was given to 877 riders in British Columbia, approximately half of whom had completed a formal course of instruction. In addition, an analysis was made of the records of all British Columbia riders involved in accidents during 1984. The results of this work emphasize the difficulties involved in mandating accident or injury countermeasures dealing with items of clothing or protective gear. These are in direct conflict with the motorcyclist's image, which lies behind his reason for riding in the first place. The amount and type of exposure were found to be the most important determinants of accident frequency, and no evidence could be found to support a conclusion that formal motorcycle training was effective in reducing subsequent motorcycle accident risk.

Motorcyclists are high-profile subjects of much speculation and empirical investigation. Traffic safety researchers often ask questions such as "Why do motorcyclists drive the way they do?" "What are the characteristics responsible for their risky driving behavior?" and "To what extent are motorcyclists who have no formal training different from those who have?" Answers to these questions were readily found in the literature. For example. Hurt et al. (*1*) and Mortimer (2) established that young males (age 16 to 24) are overrepresented in motorcycle crashes. Jonah et al. (*3*) concluded that less educated riders had a higher incidence of both recorded accidents and accidents reported in interviews. Motorcycle riding experience was a significant characteristic according to E. Dwyer and T. McCord (New York State Motorcycle Rider Education Evaluation Project, 1985), Hurt et al. (*1*) and Mortimer (2). They concluded that a significant number of motorcycle accidents occurred within the first 6 months of motorcycle riding. Further, Hurt et al. (*1*) found that approximately 50 percent of their accident-involved riders did not possess a valid operator's license and that motorcycle riders with previous traffic citations and accidents were overrepresented in the accident data.

Combined with the "who are they?" descriptions are definitions of "why do they ride like that?" Most predominant are images of risk takers or thrill seekers (*4*). Motorcyclists engage in risk-taking behavior that deviates from assumed normal behavior (*5*), and the act of simply riding a motorcycle is in itself risky because the probability of being injured in an accident is many times that of a car driver.

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One predominant belief is that driver training is required to compensate for the motorcyclists' characteristics. Hurt et al. (*1*) found that most riders involved in accidents had no formal training. The authors suggested that training programs reduced accident involvement and led to fewer injuries. Jonah et al. (*3*) and Mortimer (2) came to the opposite conclusion when they controlled for confounding factors such as driver training self-selection and riding exposure.

Previous studies, although rigorous in empirical design, made assumptions about (a) the motorcycling reality on the street, and (b) the dynamics of a motorcycle and rider training program. To explicate the hidden dimensions of motorcycle riding, the differences between trained and untrained riders, and the characteristics demonstrated in accidents, information was accumulated from extended interviews with motorcyclists, participant observation of a motorcycle rider training course, telephone questionnaires, and accident analyses.

MOTORCYCLISTS ON THE STREET

Semistructured interviews were conducted with 100 motorcyclists. Rather than determining statistical frequencies, the interviews sought to uncover the kinds of realities that exist. After a search for patterns of motorcycling entry points, the following categories emerged as the basis for an etiology of motorcycle riding:

- *Initial entrance into motorcycling is the result of a person's psychological drive toward risk taking.* Challenge was a noteworthy entry point.
- *Initial entrance into motorcycling is the result of a practical, conscious decision to partake in a recreational event that promises pleasure while maintaining a level of safety.* Motorcyclists who began riding for recreation or pleasure often did so by experimenting. They wanted to do something different and exciting. They wanted to try something different from their routine lives, "to just go out there and have a good time." Some decisions to ride motorcycles reflected a normative order of progression. For example, a group of motorcycle riders progressed from small bikes to large bikes or from passenger to operator.
- *Initial entrance into motorcycling may be the result of incomplete social adjustment. There is a view of social norms that is marginal according to societal standards.* Some motorcyclists began riding to share a way of life considered to be outside mainstream society. They joined rider groups or motor-

cycle clubs to partake in a lifestyle that absolves them of many societal standards and norms. The motorcycle is the symbol for such groups, which abide by norms and rituals that are distinguishable from society's concept of customary conduct.

• *Initial entrance into motorcycling is the result of economic considerations.* A fourth predominant reason for individuals to begin motorcycle riding is practicality or necessity. In short, the motorcycle is "the only transportation they could afford."

Role Imagery of Motorcyclists

The motorcyclist's self is an extension of others' perceptions. On a Harley, the riders defined themselves as the "lone riders" or "outlaws" who dress and act in ways to fit that look. They are confident—a breed apart.

> Everybody that is on a bike feels that they're the modern-day cowboy. Especially . . . on a Harley, they all feel a little bit of an independent, carefree rider. That's the way they see me. I don't want to be perceived as an outlaw because I don't think I'm that kind of a person. I want to get on a bike, sometimes I don't care, sometimes I do.

Sexual identification often emerged when discussion revolved around self-image. A psychological principle of self-definition for a man is "how the lady sees him seeing her in a situation." Not surprisingly, therefore, some motorcyclists' image of self is attraction to women.

The "who am I in relation to the other" concept often gets acted out in "getting kicks." For physical and mental thrill, some motorcyclists said that they "speed," "do wheelies," "ride down sidewalks," and generally "show off." They recognized that such actions form poor images for motorcyclists. The "who am I" becomes "what I am like, you don't like."

Nearly all motorcyclists had biographical accounts of riders "racing the roads," "driving like jerks," "cutting people off," or "being crazy." It was an everyday assumption that other motorists define motorcyclists in a derogatory way, yet many riders did not place themselves in this mold. They considered themselves as "just riders" who are "normal road users." They described themselves as not having the attitude problem that many other riders have.

Motorcyclists as Organization Members

Motorcyclists come from a variety of backgrounds with unique interests, but their common tradition is the act of motorcycle riding. On a continuum, the "organization" of motorcyclists is composed of unorganized groups at one end and highly organized ones at the other. The most highly organized are the motorcycle gangs, who sustain a total life commitment to the group's entity, structure, purpose, and leadership. Less highly organized groups, such as the "touring clubs" are more dependent on particular people and planned events. The least organized groups represent people whose only identification is certain motorcycle types or makes that symbolize their interests. Four types of motorcycles that define groups are Harleys (or hogs) (the most common), sport bikes, dirt bikes, and "Gold Wings."

Among motorcycle riders is a large percentage of individuals not organized into any group. Their only qualification for organizational membership is the possession and riding of a motorcycle. This aggregate has open membership and no authority. Although the members do not know each other, they greet each other on the highway.

Different recognizable groups of motorcyclists wear clothes that are intended to reflect their images of self. For example, it would be unusual to see a Harley rider wear a streamlined, high-technology helmet or a sleek set of matching leather jacket and pants. Yet sport bikers driving Interceptors or Ninjas do not tend to wear faded, studded blue jean vests covering black T-shirts. The type of motorcycle, meaning of motorcycling, and style of driving produce different dress codes.

Motorcyclists and Freedom

Freedom is a concept relevant to motorcycling. Motorcyclists reason through their biking activities in terms of "freedom to" or "freedom from." Interviewees tended to interrelate individualism and freedom. When speaking about reasons for riding, they stressed freedom from external restraints.

Often, freedom and rebellion mean speed. Fast driving becomes the experience for self and communicates to other road users the intuitive sense of danger and excitement. High-speed riding with competent maneuvering amplifies the image of power and freedom. It makes for a smooth, visible performance.

Safety and Motorcyclists' Reality

When exploring safety and motorcyclists, it is useful to start with the assumption that motorcycle riders share a collective belief in the "cult of the individual." Individualism is the core of morality in the motorcycle riding world. Yet safety legislation supports conformity to the ideologies of the majority. It regulates behavior. Deviation from the law challenges the order, bringing with it negative sanctions. Hence, laws concerning safety restrict individuality and freedom.

Traffic laws were designed to control social behavior and to maintain the condition of a vehicle. However, the laws most relevant to motorcyclists define physical turf: body and clothing. The most contentious component of safety laws is helmets. The key question on helmet wearing is not the extent to which helmets promote safety, but rather the extent to which the meaning of helmets contradicts the bedrock meaning of riding. Choices become major issues, resulting in the argument that the government should not force individuals to protect themselves. Consider the following responses to the question, "Do you wear a helmet?":

> If I have a choice, I don't. Normally I don't. I like to just walk out of my house, get on my bike and ride. It's a thing to it, it's no preparation . . . Just get on it and go, the way it should be.

> I just feel that government's got their nose in enough of our affairs. You don't need it with helmets.

> If I had a choice, I'd say I probably wouldn't except if the weather was bad. The helmet is definitely safer, wearing one. But that's a choice thing.

> I don't wear a helmet unless it's compulsory by law. Because they're not designed to protect against anything but the skipping blues and low-speed impacts. They impair vision, hearing. So, I don't wear a helmet unless I have to do it and then I'll wear the most minimal amount of protection that I can get away with under the law.

On the other hand, personal accident experiences have produced decisions for some motorcyclists to wear helmets. Other riders, broadly grouped as sport riders or their look-alikes, wear helmets for both image and safety. They resolve the demands of safety and freedom by stressing looks and sport-bike recognition. The laws are upheld, the image is saved, and the wearing behavior as generally regarded by other riders as being "cool." It is an image-maintenance choice.

STATISTICAL TRENDS FOR TRAINED VERSUS UNTRAINED RIDERS

Statistical data were collected in order to explore the objective reality of rider characteristics and safety. First, a telephone survey was undertaken of 877 current motorcycle riders, of which 418 had successfully completed a particular formal motorcycle training program during 1981 and 1982 before licensure. Fifty-seven had failed the formal training but had subsequently begun riding during this period, and 402 had become insured for motorcycle riding in 1981 and 1982 without taking any formal training whatsoever. Complete driver records covering up to 7 yr of past accident and conviction history were obtained for 863 (98.4 percent) of the riders.

The details, strengths, and shortcomings of the training program were uncovered by means of participant observation. The results of this evaluation, unfortunately, cannot be included in this paper because of space limitations.

The questionnaire administered over the telephone was a comprehensive one covering 34 questions related to demographics, riding exposure, attitudes, and riding characteristics. The driver record information was hand-searched to differentiate accidents and convictions related to motorcycle riding from those that occurred when the subjects were operating other vehicles and to ascertain details of the accidents related to motorcycle use. Because riders taking formal training are more likely to be young and female than those not taking training, our sample was stratified to match trained and untrained groups by age group and gender.

Univariate Comparisons

First, differences were examined on a univariate basis using the chi-square nonparametric test. In terms of riding exposure, the greatest of the two significant differences was in the number of months of reported riding experience. The untrained riders, even though licensed in the same period as the trained ones, reported over twice as much past riding experience as the latter. Because the samples were matched by age, the most likely conclusion is that the untrained riders had gained considerable unauthorized experience before licensure. The only other significant difference was where most riding took place. A greater percentage (39.0 percent) of trained riders reported doing most of their riding on the highway than did the untrained group (at 23.6 percent). This may reflect added confidence attained by the trained riders as a result of the comprehensive formal road training sessions.

The possibility of unofficial experience for untrained riders before taking out a license or insurance was strengthened by the fact that fully 23.1 percent of the untrained riders were not properly licensed as compared to only 3.9 percent of the trained group. The difference was highly significant. It is of interest to note that the majority of the unlicensed riders were not regular commuters, whereas the overwhelming majority of properly licensed riders were. In terms of the motorcycle used, although there was no difference in engine-size distribution between trained and untrained riders, a significantly higher proportion of trained riders were currently using borrowed machines (5.4 percent versus 2.3 percent for untrained operators).

Demographics related to education and marital status were similar for both groups of riders, with the exception of the percentage who had completed post-secondary school education (that is, had graduated from university, college, or trade school). Of the trained riders, 53.3 percent were graduates compared with 41.4 percent of those untrained—a significant difference.

One of the major areas of difference between trained and untrained riders was in their attitudes toward clothing and protective gear. In terms of special clothing, significantly more trained (88.3 percent) than untrained riders (73.4 percent) reported wearing protective accoutrements such as gloves, boots, and so on, and almost twice as many (71.1 percent as opposed to 34.9 percent) said they usually wore bright-colored or fluorescent clothing or accessories. Attitudes toward helmets also showed highly significant differences. Untrained riders were more likely to disagree with the notion that only properly tested and approved helmets should be worn and were much more likely (44.9 percent) to believe that helmets impaired hearing and vision than were the trained group (29.6 percent). In line with the foregoing, the untrained riders were also significantly more likely to feel that the advertised protection afforded by helmets is overrated (29.6 percent versus 14.2 percent for trained riders) and more likely to view helmets as uncomfortable and unsafe (10.8 percent versus 4.8 percent, respectively).

Multivariate Analysis

A multiple discriminant analysis was performed among the three training-related groups: noncourse takers, those who successfully completed the course, and those who took the course but failed the test at the end. Rider accident and conviction records were included. The significant results ($p \leq .01$) are shown in Table 1.

An examination of the means of the significant variables tabulated in Table 1 revealed that there were no significant differences between those who passed the training course and those who failed, with the exception of the proportion of persons age 45 and older (45 percent of the course failures were 45+ whereas only 10 percent of those successfully completing were in this group). Even had the sample size been higher in the failure group, the other variable means were so

TABLE 1 SIGNIFICANT DISCRIMINANT ANALYSIS RESULTS

Variable	Number	Partial R^2	*F*-Statistic	Probability *F*	Wilks' Lambda	Probability Lambda	Avg. Squared Canonical Correlation (ASCC)	Probability ASCC
Number of months riding	1	0.123	39.5	0.0001	0.8772	0.0000	0.0614	0.0000
Licensed to ride	2	0.139	45.5	0.0001	0.7552	0.0000	0.1228	0.0000
Wear bright clothes	3	0.094	29.1	0.0001	0.6844	0.0000	0.1590	0.0000
Age 45+	4	0.066	19.8	0.0001	0.6392	0.0000	0.1904	0.0000
Think helmets overrated	5	0.040	11.7	0.0001	0.6134	0.0000	0.2041	0.0000
Most riding on highway	6	0.019	5.5	0.0045	0.6017	0.0000	0.2104	0.0000
Wear protective gear	7	0.017	4.8	0.0086	0.5915	0.0000	0.2161	0.0000

similar to those in the successful group that it is unlikely any additional variables would have shown significance. In further discussion, it will therefore be sufficient simply to describe the difference between successful course takers and nontakers. The means or percentages of the significant variables are given in Table 2.

TABLE 2 COMPARISON OF SUCCESSFUL COURSE TAKERS WITH NONTAKERS

Variable	No Training	Successfully Completed Training
Self-reported riding experience (months)	122.4	61.1
Properly licensed for motorcycle (%)	76.8	98.9
Wear bright clothing when riding (%)	37.5	71.4
Think helmet protection overrated (%)	28.5	9.3
Most riding done on highway (%)	23.6	39.0
Wear protective gear when riding (%)	71.2	87.4

The interesting thing about the results in Table 2 is that, with the exception of self-reported experience, all the differences between trained and untrained riders were behavioral in nature. Being properly licensed, wearing the right clothing, and having positive attitudes toward helmets all reflect attitudes that are held by safety-conscious people and that are reinforced during formal training. The highway riding differential could represent a higher level of self-confidence on the part of those who have taken a course of instruction that includes instilling familiarity with highway operation.

Finally, it is important to note that when the effects of other variables concerning riding exposure, rider characteristics, and attitudes and behaviors were taken into account, there were no significant differences in accident or conviction history between trained and untrained riders.

RIDER CHARACTERISTICS INFLUENCING SAFETY PERFORMANCE OF SURVEYED RIDERS

In preliminary examination of the data, one of the first noticeable characteristics was the strong relationship between past accidents or violation convictions when the subjects were riding their motorcycles and those when they were driving other vehicles. The majority of subjects were licensed for passenger vehicles in addition to motorcycles. Many of the characteristics that make for a good or bad car driver may also apply to motorcycle riding.

Because rider characteristics that are correlated with violations may be different from those rider characteristics that are correlated with accidents, the group of dependent variables was divided into two subsets: other vehicle and motorcycle violations and other vehicle and motorcycle accidents. The research questions then became: (a) Does a significant structural relationship exist between motorcyclists' traffic violations (differentiated by whether or not they were operating a motorcycle at the time) and a set of other driver characteristics? and (b) Does a significant structural relationship exist between motorcyclists' accidents (differentiated for motorcycle and other vehicle operation) and a set of other driver characteristics?

To answer these questions, canonical analyses (CAs) were performed using various combinations of dependent variables. Canonical analysis is a generalized form of multiple regression that involves forming two linear combinations of variables—those on the dependent side (accidents and violations in this case) and those on the independent side. The canonical correlation is the correlation between the two linear combinations; the square of the canonical correlation (R_c^2) is an estimate of the variance shared by the two canonical variates (*6*). The exact relationships between individual variables must then be explored using multiple analysis of variance techniques. The major advantage of CA in this case was its ability to account for relations among the dependent variables of motorcycle accidents, other-vehicle accidents, motorcycle convictions, and other-vehicle convictions.

Approximate normality is a prerequisite for variable distributions used in multivariate analyses. The dependent variables of accident and conviction rates (adjusted to account for different lengths of riding experience) had to be normalized using a square root transformation. All class or categorical variables were effect-coded for this analysis procedure.

Two canonical analyses were performed: one between motorcycle convictions/other-vehicle convictions and motorcycle rider characteristics, and the other between motorcycle accidents/other-vehicle accidents and motorcycle rider characteristics. The significant results for accidents are illustrated in Table 3.

The next stage in the analysis was to incorporate these independent variables into a series of multiple analyses of variance (MANOVAs). All main effects and interactions to the third level were run using procedures for unbalanced cell design. No disordinal interactions were found and thus the main effects could be considered valid.

The directions of the significant effects were further examined in a series of one-way analyses of variance (ANOVAs)

TABLE 3 RESULTS OF CANONICAL CORRELATION ANALYSIS BETWEEN ACCIDENTS AND MOTORCYCLE RIDER CHARACTERISTICS

	First Canonical Variate		Second Canonical Variate	
Variables	Structural Coefficient	Standardized Coefficient	Structural Coefficient	Standardized Coefficient
Accident sets				
Y_1 = other vehicle	1.00	1.00	−0.01	−0.14
Y_2 = motorcycle	0.13	0.01	0.99	1.00
Proportion of variance (total = 1.00)	0.51		0.49	
Redundancy (total = 0.22)	0.12		0.10	
Driver characteristics set				
Do not ride to work or school	0.08	0.10	−0.49	−0.30
Major moving violations—other vehicle	−0.48	−0.28	−0.05	0.01
Minor moving violations—other vehicle	−0.46	−0.23	−0.13	−0.11
Major moving violations—motorcycle	−0.23	−0.07	−0.50	−0.40
Major operator violations—other vehicle	−0.44	−0.24	0.04	0.06
Major behavioral violations—other vehicle	−0.43	−0.28	−0.04	0.02
Age 16–19	0.41	0.38	0.24	−0.03
Minor operator violations—other vehicle	−0.40	−0.12	−0.11	−0.02
Days per week riding	0.20	0.15	0.37	−0.01
Minor moving violations—motorcycle	−0.19	0.07	−0.35	0.02
Marital status	−0.30	−0.04	−0.23	−0.04
Motorcycle training—passed	0.30	−0.07	0.05	−0.41
Riding experience—49–72 months	0.04	−0.15	0.30	0.37
Canonical correlation (R^2)	0.49		0.44	
Canonical R-squared (R_c^2)	0.24		0.20	
Probability > F	0.0000		0.0000	

using Tukey's studentized Honestly Significant Difference (HSD) range test to assess significance between pairs of categories. The resulting findings were as follows:

- Other-vehicle convictions
  - The age group 16 to 19 was associated with a significantly higher average number of other-vehicle convictions per rider than any other age groups, except for that of ages 20 to 24, which had less but not significantly so;
  - Other-vehicle convictions per rider increased with the level of self-reported motorcycle riding experience;
  - Males had more other-vehicle convictions per rider than females;
  - Other-vehicle convictions per rider decreased as the number of days per week riding the motorcycle increased;
  - Those who did not wear bright-colored clothing while riding had more other-vehicle convictions per rider than those who did;
  - Unlicensed motorcycle riders had more other-vehicle convictions per rider than properly licensed riders; and
  - Average other-vehicle convictions per rider increased with the engine size of the motorcycle operated.
- Motorcycle convictions
  - The age group 16 to 19 had significantly more motorcycle convictions than all other age groups and the group 20 to 24 had significantly more convictions than all age groups above it.
  - Male riders had more motorcycle convictions than females.
  - The number of motorcycle convictions per rider increased with the number of days per week the motorcycle was ridden.
  - The number of motorcycle convictions per rider increased with the percentage of time spent riding at night.
  - Those who rode to work or school in all weather had significantly more convictions than those who rode to work or school only in good weather; and those who rode to work or school only in good weather had significantly more motorcycle convictions than those who did not ride to work or school at all.
  - Average motorcycle convictions per rider increased with the engine size of the motorcycle operated.
  - Unmarried riders averaged more convictions than married riders.
  - Riders who reported wearing bright-colored clothing when riding had fewer average convictions than those who did not.
  - Those with motorcycle training had fewer average motorcycle convictions than those who had not taken training.
- Other-vehicle accidents
  - There were no significant differences among 16 to 19, 20 to 24, and 25 to 29 age groups (although the younger groups had the higher average number of accidents), but those from 30 to 34 and older had significantly fewer other-vehicle accidents age than those from age 16 to 19; and those from 35 to 39 and older had significantly fewer other-vehicles accidents than those from age 20 to 24.
  - Those who had passed the motorcycle training course had lower average other-vehicle accidents per rider than those who had not taken the course.
  - Those who had convictions for either minor or major operational violations, minor or major moving viola-

tions, or major behavioral violations when operating other vehicles also averaged significantly more other-vehicle accidents than those who did not have such convictions on their records.

- Motorcycle accidents
  - The number of motorcycle accidents per rider increased with the number of days per week of reported riding.
  - The number of motorcycle accidents per rider increased with the percentage of time of reported riding at night.
  - Those who rode to work or school in all weather conditions had significantly more motorcycle accidents per rider than those who rode only in good weather, and the latter had significantly more than those who did not ride to work or school at all.
  - Those who had convictions for minor or major moving violations when riding a motorcycle also averaged significantly more motorcycle accidents than those who did not have such convictions on their records.

Motorcycle training is noticeably absent from these results as a factor influencing motorcycle accident involvement. Its presence as a variable accounting for fewer other-vehicle crashes, however, suggests that it is likely a function of other behavioral and attitudinal characteristics. Because this was an important area of concern, additional analysis was done using only those accidents and violation convictions occurring within each rider's first year of riding experience (i.e., immediately subsequent to training). Again, no evidence of training as a significant factor in predicting subsequent motorcycle accident involvement was found, but the importance of the early years of experience in terms of conviction and accident accumulation is evident in Figures 1 and 2, respectively.

Another variable not apparently affecting motorcycle accident rate was engine size. The results suggest that engine size may only be important in that it represents the choice of a certain group of riders who have a predisposition toward unsafe

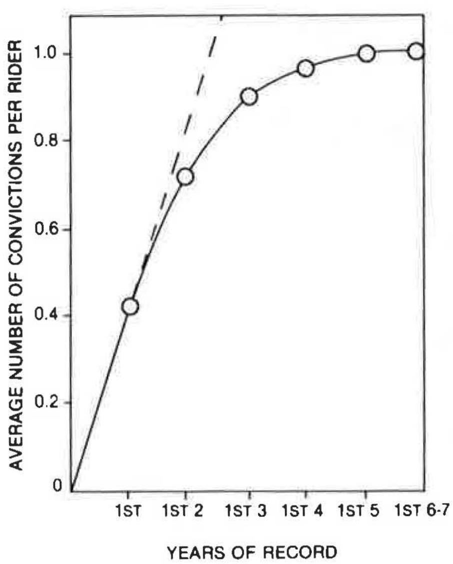

FIGURE 1 Accumulation of motorcycle convictions by years of official riding experience.

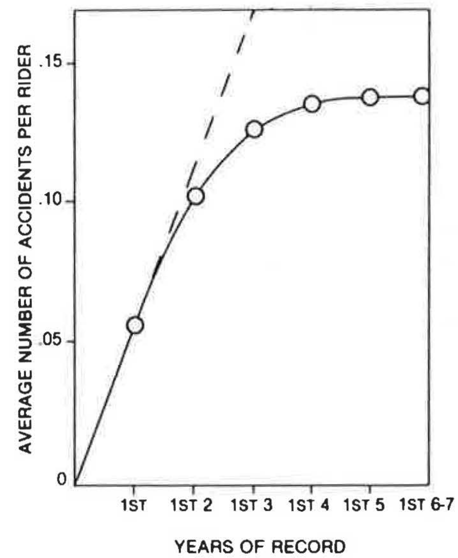

FIGURE 2 Accumulation of motorcycle accidents by years of official riding experience.

behavior. Rather than representing a handling problem, therefore, size may simply be a characteristic of motorcycles favored (because of image) by those more likely to have poor riding or driving attitudes and behaviors. This postulate is supported by the fact that persons operating large motorcycles were found to have more convictions while driving other vehicles than were users of smaller motorcycles.

MOTORCYCLISTS IN THE ACCIDENT DATA BASE

Using a joint data base combining police accident reports, driver record files, and insurance data, a data set was created containing 620 accident-involved motorcycle riders. The independent variables available for analysis after normality tests were as follows:

- Rider age,
- Motorcycle engine size,
- Riding experience,
- Previous alcohol conviction (yes/no),
- Motorcycle ownership (yes/no),
- Helmet worn at time of accident (yes/no),
- Probable causer of accident (yes/no),
- Time of day of accident (day/night),
- Road conditions at time of accident (good/bad),
- Location of accident (city/highway), and
- Passenger carried at time of accident (yes/no).

The dependent variables used were past numbers of accidents and convictions per year of riding experience. A multiple discriminant analysis was performed between high and low accident and conviction rate riders.

The most efficient independent variable by far in explaining past accident variance was past conviction rate. Riding experience at the time of the accident of record was also found to be significant in discriminating high-rate from low-rate groups. The high-accident rate group had the lower average experience and, as before, the highest proportion of drinking-driving offenders, probable accident causers, and those carrying passengers. Age was not a significant factor in itself, although younger riders were more likely to be carrying a passenger (Figure 3).

For the high-conviction rate group the proportions of those with previous drinking-driving offenses, those considered at fault, and those carrying a passenger in their latest accident were greater than for the low-conviction rate group. Age was marginally significant, with the high-rate group having a lower average age. The major results for both convictions and accidents are summarized in Figure 4.

One of the important findings from the analysis of population and accident data when compared with the previously reported survey results was that the more attitudinal and behavioral variables were available, the less important became large-scale class and demographic variables such as rider gender, motorcycle engine size, and rider age. Young male riders of large motorcycles are not excessively at risk because of these factors but rather as a result of image-related attitudes and behaviors to which these factors are related. Broad, epidemiological categorization can hinder understanding.

RECOMMENDATIONS

The following recommendations result from the major research findings:

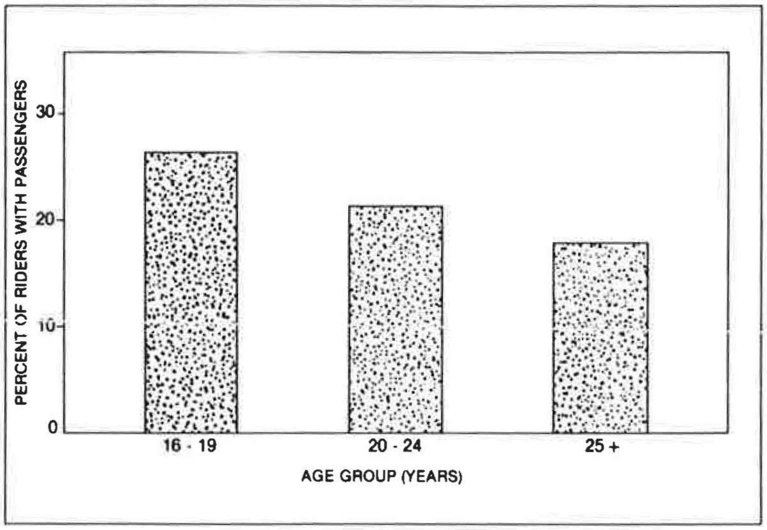

FIGURE 3 Propensity for motorcycle operators to carry passengers as a function of operator age.

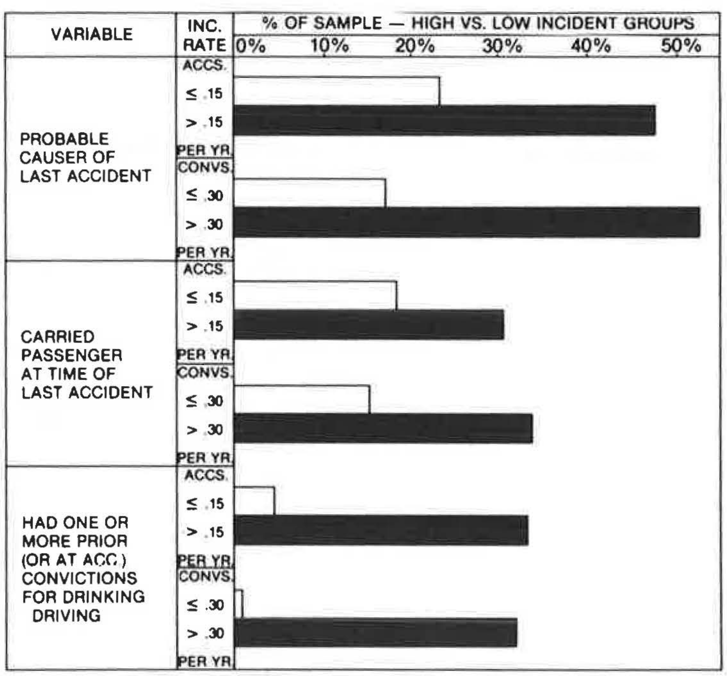

FIGURE 4 Critical safety related variables for accident involved riders.

• Motorcycle rider training courses should be more attentive to education than training. It is necessary to understand the social and existential conditions of riding and the influence of experience, images, and expectations on motorcycling and learn about structural determinants of choice and decisions, to enhance a greater likelihood for safer riding practices. There should be an emphasis on identifying potentially hazardous situations and avoiding them rather than on simply controlling the motorcycle.

Motorists should be made aware of the motorcyclists on the road, and their rights and privileges, and of poor motorcycle visibility to other road users. Greater awareness of these factors may contribute to motorists' being more observant on the road and more aware of motorcyclist roles.

• Education and motorcyclist awareness programs should stress the concept of individual identity with motorcycle helmet and other safety equipment wearing, using the sport bikers as an example of how helmets, besides being safe, look good.

• Motorcycle rider training programs should pay greater attention to reasons for riding and selection of motorcycles.

• Aspects of riding such as the carrying of passengers and the accumulation of traffic violation convictions could be considered as part of a provisional (restricted) licensing system for novice riders.

• Because rider exposure factors (e.g., riding in all-weather conditions, riding at night, etc.) are key variables in explaining accident variance, additional emphasis might be placed on these situations in training programs; otherwise restrictions could be applied to novice riders.

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A Heuristic Shortest-Path Method for Emergency Vehicle Assignment—A Study on the Mexico City Network

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The immediate needs of a city struck by a disaster are quick and safe evacuation of its inhabitants and prompt search and rescue operations conducted by emergency personnel. If the city's road network has suffered capacity losses because of floods, building rubble, or structural failures, a shortest-path algorithm with the aid of a computer serves as a useful tool in assigning the emergency vehicles to routes that remain open in the aftermath of the disaster. If the city network is large, the shortest-path algorithms consume large memory and execution time on a microcomputer. If the algorithm needs to operate in real-time conditions, the savings in these factors become very important. Heuristic methods have been developed to reduce the computer storage and execution time. One such heuristic method is being examined for its accuracy compared with conventional shortest-path algorithms, which build the entire shortest-path tree before selecting the path between an origin-destination pair. The suggested heuristic method alleviates the need to build the entire tree, yet proved to yield the same results as the total-path enumeration method in 99 percent of the cases when applied to the Mexico City network.

A disaster, either natural or man-made, leaves a trail of destruction wherever it strikes. When it strikes an urban area, the consequences are collapsed buildings, damaged roads, and, above all, loss of lives and injuries to the inhabitants. In such a situation, the rescue personnel are called upon and play an important role in evacuating the injured in a quick and safe manner, so as to minimize the suffering and loss of lives. The rescue operations involve dispatching the rescue vehicles along the shortest paths to the points of incidence or to shelters.

Even though the actual transportation infrastructure may suffer only little damage, the streets are susceptible to blockage by rubble from damaged buildings and by people gathered to learn of their relatives' welfare. In such a situation, rescue vehicle personnel have no way of knowing which path would be open or which would be the quickest one to take. If computer data on the streets of the network are already available, these can be updated based on the current status of the streets and used with a shortest-path algorithm to determine the shortest paths between any two points in the network. The label-correcting method is one such algorithm.

If the network is large, the shortest-path algorithm consumes more memory and execution time on a microcomputer. In order to save memory and execute the algorithm in a quicker and more efficient way, a system of partitioning (heuristic method) has been designed. Here, when looking for the shortest-path, only those nodes that are within a restricted circular area are considered for determining the shortest path, instead of the whole network. The shortest path thus obtained is assumed to be the true shortest path. With a view to determining the accuracy of this partitioning technique, a sensitivity analysis was performed using a computer program.

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EMERGENCY VEHICLE ASSIGNMENT

The most important objective of any Emergency Management System is to save human lives when a disaster strikes an inhabited area. The disaster could be an earthquake, a tornado, or a nuclear disaster, among others. Evacuation planning and operations are the major activities in the preparedness and response phase of emergency management. The main objective is to shift the inhabitants of danger-prone areas to disaster shelters quickly and safely. Automobiles are generally the major means of conveyance in such a situation. In order to achieve quick evacuation, the emergency vehicles must be assigned to the shortest paths between their origin points (rescue control center and evacuation areas) and destinations (evacuation areas and shelters). Some disasters, such as the September 1985 Mexico City earthquake (*1*), may cause considerable damage to the street network in a city, thereby disabling the use or reducing the capacity of some streets in the network. In such cases, because the shortest paths depend on the status of the streets, there is need for a flexible computer-aided software package, which will facilitate the addition or deletion of links of a network to reflect the real situation and then determine the shortest paths between the desired points. This would help the decision makers in assigning the emergency vehicles to the most suitable paths.

An interactive microcomputer package has been developed, known as Transportation Emergency Decision Support System (TEDSS) (*2–4*), incorporating these facilities, among others. It is a user-interactive package offering considerable flexibility in graphically updating the network conditions whenever required. A heuristic shortest-path finding method, as described later in this paper, has also been incorporated to aid decision makers in quickly assigning the emergency vehicles to desirable routes.

HEURISTIC SHORTEST-PATH FINDING METHOD

The label-correcting method of determining the shortest path, with suitable modifications incorporating the heuristic method, has been adopted in developing the computer package.

Label-Correcting Method

The label-correcting method is an efficient way to determine the shortest paths from a given origin (root) node to all other nodes in the network. It must be used for each origin in turn to obtain the shortest paths from that origin to all other nodes of the network. The algorithm employs a process whereby the network nodes are scanned iteratively to find a better (shorter) path than the current one, from the root to the node being scanned. This is done by comparison of labels. Every node has a label, which represents the distance from the root to that node, along the (current) shortest path. Apart from the label, each node also has a predecessor variable that keeps track of the node that precedes it in the (current) shortest path. These variables are updated when a new shorter path is found. When a link is examined, the distance to get to the beginning node of the link plus the length of the link is compared with the current label of the end node. If the current label represents a longer path, it is changed and set equal to the label of the beginning node plus the length of the link. If the current label represents a shorter path, it is kept the same. When no better path can be found from the root to any of the other nodes in the network, the algorithm terminates. The cost of travel could also be in terms of time instead of distance (*5*).

A sequence list keeps track of the nodes and maintains the most efficient order for the nodes to be examined. All the nodes that have yet to be examined as well as those requiring further examination are included in this list. Initially, the origin node, which is the only member of the sequence list, is examined by testing all the nodes that can be reached by traversing only a single link. If the label test is met, the label and predecessor lists are updated and the node is placed in the sequence list. After complete examination of a node, it is deleted from the list. When there is no node left in the sequence list, the algorithm terminates. Now, the predecessor list is traced back from a node under consideration to the root node to get the shortest path between the two (*5*).

In the computer implementation of the label-correcting method, the links are identified by their end nodes. Without elaborating, it can be said that all the nodes of the network are to be examined at least once by the algorithm (*5*). This implies the use of more computer memory and a higher execution time. The heuristic method developed is capable of bringing about savings on these.

The Heuristic Method

The heuristic method of determining the shortest path adopted in TEDSS uses a system of partitioning. In this technique, when the label-correcting algorithm looks for the shortest path, it is made to scan only those nodes that are within a reasonable proximity to the origin and destination nodes. This area is defined by a circle with center at the midpoint of line joining the origin and destination nodes and with initial radius as mentioned in the two cases described later. If a path from an origin to a destination could not be found by examining all the nodes within this circle, the radius of search is incremented by 25 percent, and all the nodes within the new circle are examined for a possible path. Incrementation of radius continues until a path (or the shortest among the different paths formed by the nodes within the circular area) between the origin and the destination is found. This path is assumed to be the true shortest path.

There is potential for savings in microcomputer memory by using the partitioning technique. This can be realized through reduced array size allocation for the various lists such as label list, sequence list, and so on that are maintained for each node by the label-correcting algorithm. The amount of memory savings depends on the number of nodes in the network. Also, if the origin and destination nodes are nearer, the partitioning technique is capable of saving more memory and vice versa. The execution of partitioning technique is also faster in a microcomputer.

Two cases of partitioning technique have been considered:

- *Case 1.* Partitioning is done using half the straight-line distance between origin and destination nodes as the initial radius of search, with the center at midpoint of the line joining them. The method can be illustrated better by considering the following network of 8 nodes and 12 links (Figure 1). If the partitioning technique were applied to this network in order to determine the shortest paths between Nodes 3 (origin) and 4 (destination), the computer program would initially consider only Nodes 3, 4, and 5, which fall within the restricted region represented by the solid-line circle. Then, the label-correcting method searches for the shortest path. Thus, either Path 3–4, or 3–5–4 would be chosen as the shortest path, depending on their length. If no path could be found in the first attempt between Nodes 3 and 4, the radius of search is incremented by 25 percent, and so on, until a shortest path is found. The method can be appreciated better in large networks, when the origin and destination nodes are farther apart, with many connecting links.

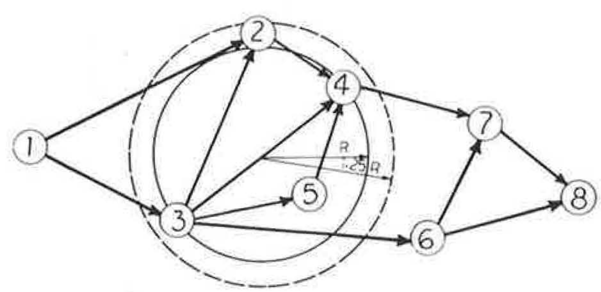

FIGURE 1 Illustration of partitioning technique.

- *Case 2.* This case is very similar to the first, except that the initial radius of search is 1.25 times half the straight-line distance between the origin and destination nodes. Considering the same network as in Figure 1, the restricted region of search is represented by the broken-line circle. Thus, in the initial search, Nodes 2, 3, 4, and 5 would be considered for placement in the shortest path and the shortest path would be one among 3–2–4, 3–4, or 3–5–4, depending on their lengths.

Although the partitioning method described has been designed to be computer efficient, it has a limitation. The method gives the shortest path between the origin and the chosen destination only, whereas the standard label-correcting method gives the shortest paths from the origin to all other nodes in the network. Thus, if there were a choice of destinations, the standard label-correcting method, in one run, would enable the user to know the nearest destination, whereas the partitioning technique would have to be run a number of times (equal to the number of destinations) to determine the nearest destination. However, when the destination is fixed, the partitioning technique can be used advantageously and efficiently.

MEXICO CITY NETWORK—THE STUDY AREA

Mexico City was shaken by a powerful earthquake on September 19, 1985, which left in its wake an emergency condition. Apart from causing heavy loss of human lives and damage to buildings, the extensive destruction left a highly restrictive transportation network and the status of the various street links in the city center was unknown to the emergency crew. This rendered the dispatch of emergency vehicles increasingly difficult, because emergency units had to make numerous attempts and diversions to reach the incident points. A comprehensive data bank on the latest street conditions and a computer program incorporating a shortest-path algorithm would have enabled dispatchers to quickly direct vehicles to incident points and shelters through the most accessible routes. It is believed that in such situations, the heuristic shortest-path method would further reduce the decision time on route selection.

This sets the background for considering the Mexico City network, on which a considerable amount of data is available to judge the usefulness and accuracy of the heuristic method. The Mexico City network, with 288 nodes and 763 links, is shown in Figure 2, where the heavy lines indicate arterial streets. It is seen from the figure that the network is of grid

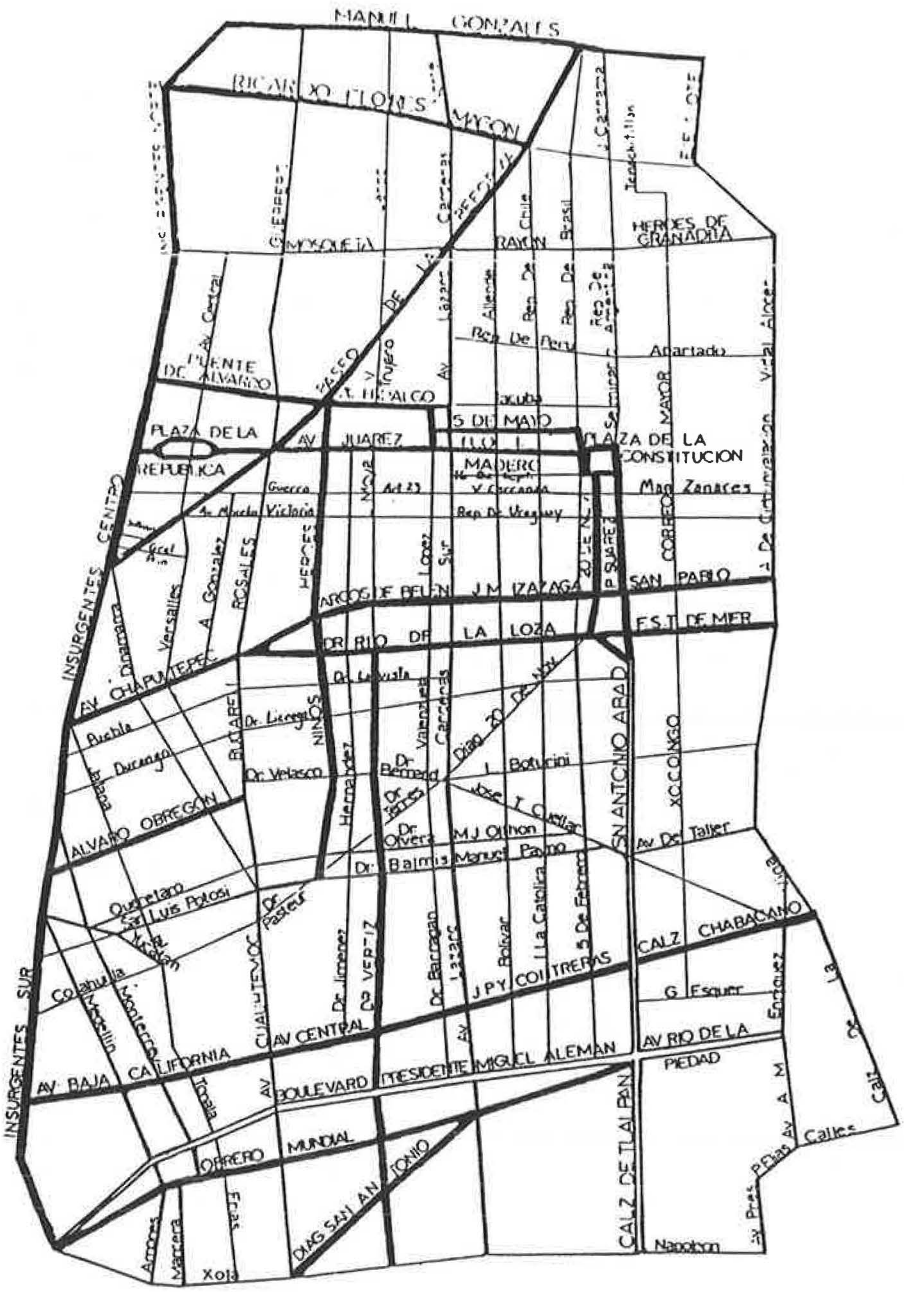

FIGURE 2 Mexico City network.

pattern predominantly. Shortest paths were established between 100 random pairs of origin-destination in the network shown. These paths were then used to assess the accuracy of the heuristic technique described.

TWO CASES OF SHORTEST PATH

The shortest path could be either distance- or time-based.

Distance-Based Shortest Path

The distance-based shortest path is based on the simple rule that the shortest path between any two nodes is the one for which the sum of the link lengths is the least among the various possible routes.

Time-Based Shortest Path

Also included in the computer program is an option to use time-based shortest path. This option is useful when the emergency vehicles are to be routed along with normal flow of traffic (i.e., when the normal traffic flow is not disrupted for the sake of movement of emergency vehicles). Because the travel time in this case depends not only on the distance, but also on the traffic flow and capacity, a link performance function must be used for converting distance to travel time. A Davidson-like link performance function, given by Equation 1, has been adopted in this study. Although the original Davidson's function, developed based on queueing considerations, is asymptotic to a capacity flow (Figure 3), in the equation the travel time has been restricted to a maximum of six times the free-flow travel time, based on actual sample observations in Mexico City.

$$t_a = \min\left\{ t_a^0\left[1 + J\frac{\gamma x_{a,\,peak}}{C_a - \gamma x_{a,\,peak}}\right], 6\,t_a^0 \right\} \qquad (1)$$

where

t_a = travel time on link a,

t_a^0 = free-flow travel time on link a,

J = a model parameter,

γ = time-of-day parameter,

$x_{a,\,peak}$ = peak-hour volume on link a, and

C_a = capacity of link a.

Using the actual traffic flow data of Mexico City, the values for parameters J and γ were calibrated and were found to take the following values:

J = 0.5

γ = 1.0 for day-time peak

= 0.7 for day-time off-peak

= 0.5 for nighttime peak

= 0.0 for nighttime off-peak

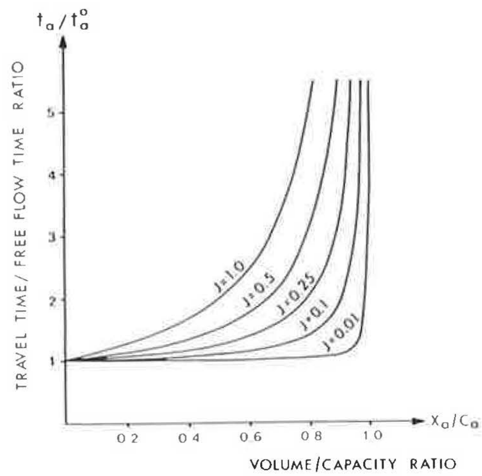

FIGURE 3 Davidson's link performance function (5).

ACCURACY OF HEURISTIC METHOD (PARTITIONING TECHNIQUE) AS APPLIED TO MEXICO CITY NETWORK

With a view to determine the accuracy of shortest paths obtained by the two cases of partitioning technique discussed earlier, 100 pairs of random numbers, in the range of minimum and maximum node numbers of the network, were generated using a computer program and were considered as origin-destination nodes, thus eliminating any bias in sampling. The computer program developed accesses the input data for Mexico City network and is used with slight modifications to represent the following three methods:

- *Method 1*: Partitioning technique with initial radius of search equal to half the straight-line distance between origin and destination nodes (this was already incorporated in TEDSS),
- *Method 2*: Partitioning technique with initial radius of search equal to 1.25 times the radius as in Case 1, and
- *Method 3*: Where the whole network is considered.

For each pair of 100 random origin-destination combinations, the shortest path (both distance- and time-based) were recorded using each of the three methods just listed, and the results were compared.

An example of computer display of shortest paths obtained by the three methods using the computer package TEDSS is shown in Figure 4. The program interacts with the user and on inputting the origin and destination node numbers (or the cross-street names forming the nodes), the computer displays the shortest path, separately and as a blinking path in the network, and the shortest distance. The listing of the path can also be obtained immediately. These features would greatly assist the rescue crew in dispatching the emergency vehicles along the shortest paths. From the figure, it is seen that, to travel from Node 117 to 168, Method 1 gives a longer path as the shortest, whereas Methods 2 and 3 give the same result, which is the true shortest path.

The findings of the previous analyses appear to favor the heuristic method as shown in the comparison of computer

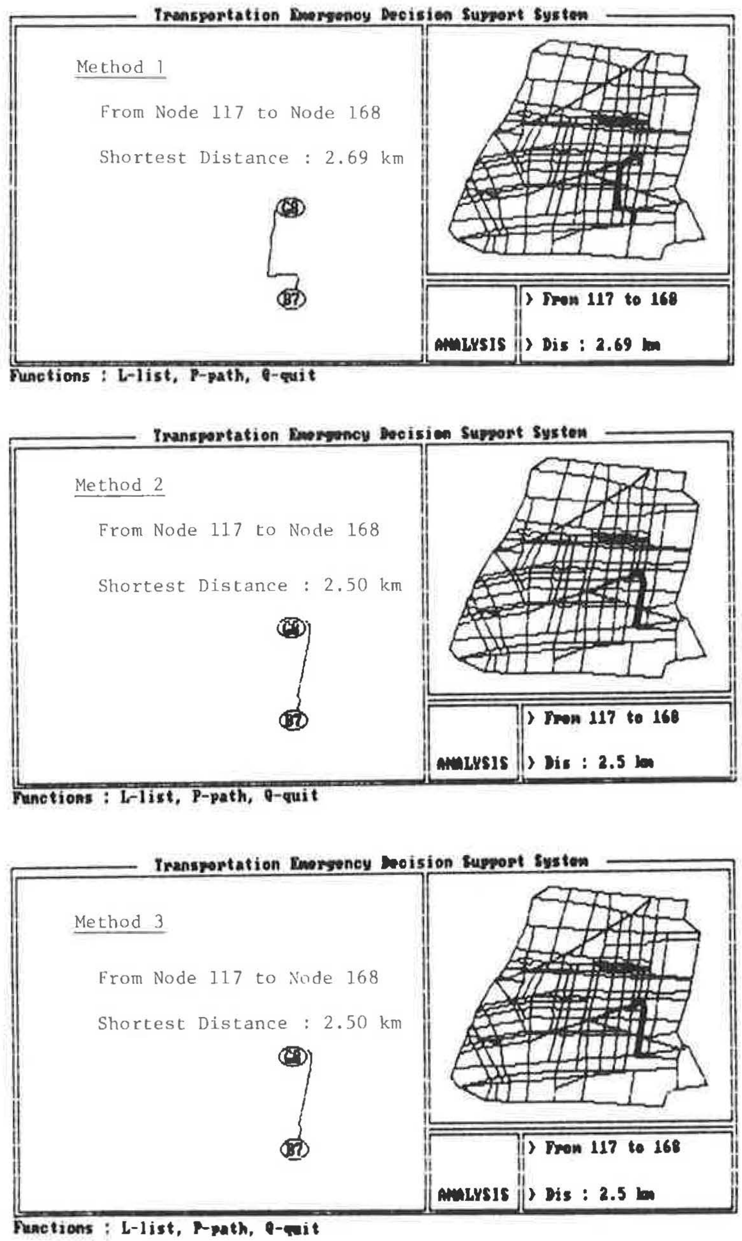

FIGURE 4 Example of comparison of shortest paths by different methods.

execution times in Table 1 and in the comparison of differences in shortest paths.

	Differences in Shortest Paths Between	
Shortest Path	*Methods 1 and 3 (%)*	*Methods 2 and 3 (%)*
Distance-based	10	1
Time-based	23	4

Based on these findings, the following conclusions supported by statistical evidence can be drawn:

• Ten of the 100 sample distance-based shortest paths obtained using the first method (partitioning technique with initial radius of search equal to half the straight-line distance between the origin and destination nodes) were different from and longer than the true shortest paths obtained by considering the whole network. However, based on statistical hypothesis testing, it can be concluded that only 5 percent of the shortest paths

TABLE 1 COMPARISON OF COMPUTER EXECUTION TIMES (distance-based shortest paths)

Execution Time (sec)	Percentage of Cases		
	Method 1	Method 2	Method 3
≤1	41	33	
2	19	20	
3	20	10	
4	11	16	
5	5	12	
6	3	6	
7	1	3	100

obtained by the partitioning technique are different from the true shortest paths, at 1 percent significance level. The test is shown below.

Null hypothesis: $H_0 : f = 0.05$
Alternate hypothesis: $H_1 : f \neq 0.05$

where f is the true population proportion of differences in the shortest paths by the two methods. Let $\hat{f}$ represent the above proportion for the sample population. Then, based on the Central Limit Theorem (CLT), the test statistic

$$Z = \frac{(\hat{f} - f)}{S}$$

is assumed to be normally distributed with a mean of 0 and standard deviation of 1, where

$$S = \left[\frac{f(1 - f)}{n} \right]^{1/2}$$

is the standard deviation of $\hat{f}$ and n is the sample size.

For a significance level of $\alpha = 0.01$, the decision rule for a two-tailed test is

Reject H_0 if $Z > 2.57$ or $Z < -2.57$

Accept H_0 if $-2.57 \leq Z \leq 2.57$

For the data of this problem,

$$S = \left[\frac{(0.05)(0.95)}{100} \right]^{1/2} = 0.0218$$

and

$$Z = \frac{(0.10)(0.05)}{0.0218} = 2.294$$

Hence, H_0 cannot be rejected and therefore it is concluded that the hypothesis is statistically valid.

- Only 1 percent of the distance-based shortest paths obtained using Method 2 (partitioning with initial radius of search equal to 1.25 times half the straight-line distance between the origin and destination nodes) was different from and longer than the true shortest paths obtained by considering the whole network. Statistical hypothesis test at $\alpha = 0.01$ also supports this conclusion.
- In the case of time-based shortest paths, the percentages (based on the sample study) for the above two cases were 23 and 4, respectively. However, based on statistical hypothesis tests, it can be concluded that only 15 percent of shortest paths obtained by Method 1 and 2 percent of those obtained by Method 2 are different from and longer than the true shortest paths obtained by considering the whole network.
- In the case of distance-based shortest paths, it is interesting to note that about 63 percent of the longer shortest paths was less than 10 percent longer than the true shortest paths.
- About 56 percent of the longer shortest time-based paths was less than 20 percent longer than the true shortest paths.

DISCUSSION AND CONCLUSIONS

- The percentage variation in shortest paths, using the partitioning techniques, to the true shortest paths can be to some extent attributed to the configuration of the network considered. However, by using a higher initial radius of search (i.e., 1.25 times half the straight-line distance between the origin and destination nodes, and center at midpoint of the line joining them) greater accuracy appears to result in shortest-path determination without the need to consider the whole network. Thus, it may be worthwhile to adopt this heuristic method for shortest-path determination when the network is large.
- The partitioning of the network is based on the physical distance between the origin and destination. This is the case even for the shortest-path determination based on time. This, however, does not appear to be a major limitation, as depicted through the time-based shortest-path results.
- Although the execution times on a microcomputer for determining the shortest paths by the different techniques are in the range of seconds (Table 1), the savings achieved by adopting the partitioning technique may still be critical in large networks or in the process of evacuation of the seriously injured. For this study, a personal computer with a speed of 12 MHz was used. Where slower speed microcomputers are used, the savings in execution time may become even more important.
- The case study was on Mexico City network, which is of grid pattern predominantly. This may be a possible reason for greater accuracy in shortest paths obtained using partitioning techniques.

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