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Effect of Pedestrian Signals and Signal Timing on Pedestrian Accidents

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The purpose of this study was to determine whether pedestrian accidents are significantly affected by the presence of pedestrian signal indications and by different strategies for signal timing. Data related to pedestrian accidents, intersection geometrics, traffic and pedestrian volumes, roadway environment, and signal operation were collected for 1297 traffic-signalized intersections in 15 cities throughout the United States. The data were analyzed by using various statistical tests, which included branching analysis, correlation analysis, chi-square analysis, and the analysis of variance and covariance. The results showed no significant difference in pedestrian accidents between intersections that had standard-timed (concurrent walk) pedestrian signals compared with intersections that had no pedestrian signal indications. In addition, exclusive-timed locations were found to be associated with lower pedestrian accident experience for intersections with moderate-to-high pedestrian volumes when compared with both standard-timed intersections and intersections that had no pedestrian signals. In some cases pedestrian accidents were also found to be significantly affected by other variables, including street operation (one-way and two-way streets), presence of local bus operations, and area type.

Recent pedestrian safety research has uncovered numerous problems regarding current pedestrian signalization practices. The lack of uniformity in strategies and devices for pedestrian signal timing has been thought to contribute to the ineffectiveness of the signals in achieving improved pedestrian safety. Further, pedestrians have expressed considerable confusion and misunderstanding regarding the meaning of the flashing DON'T WALK indication (or flashing hand) for the clearance interval and the flashing WALK indication (or flashing man) to warn pedestrians of turning vehicles. Such confusion over the meaning of pedestrian traffic-control devices may also contribute to pedestrian safety problems.

Although many problems have been attributed to the current uses of pedestrian signals, a literature review failed to find conclusive studies that adequately quantified the effect of pedestrian signals on pedestrian accidents. The effect of pedestrian signals on safety must be understood in order to determine whether the continued use of pedestrian signals is justified. The results of this analysis can help to determine whether changes are needed in the design and deployment of pedestrian signals.

The impact of the various pedestrian signal-timing schemes on operational strategies also need to be evaluated. Schemes for pedestrian signal timing include the following (1):

1. Concurrent (standard)--allows pedestrians to walk concurrently with the movement of traffic;
2. Early release--allows pedestrians to leave the curb before vehicles are permitted to turn;
3. Late release--holds pedestrians (with respect to vehicles) until a certain portion of the phase has been given to turning vehicles;
4. Exclusive--traffic is held on all approaches to allow pedestrians to cross any street; scramble (or Barnes dance) timing is a form of exclusive timing that also allows for diagonal crossings; and
5. Other--variations of the above where pedestrians are given different indications on parallel crosswalks to protect them during special traffic phases (i.e., special left-turn phases, or split phasing).

The purpose of this study was to determine whether pedestrian accidents at signalized intersections are affected by different uses of pedestrian signals and signal-timing schemes. We hoped that the results of this analysis would (a) help to identify the types of intersections or situations where pedestrian signals are most (or least) desirable from a safety standpoint and (b) aid in determining whether changes are needed in the design of pedestrian signals to improve their effectiveness. Such information should be of considerable value to the traffic engineering community, which is responsible for the installation and timing of pedestrian signals.

BACKGROUND

Although in recent years considerable research has been conducted regarding pedestrian safety, little has been published specifically on the issue of pedestrian signals and safety. In terms of the effect of pedestrian signals on accidents, Fleig and Duffy found no significant reduction in the proportion of unsafe acts or pedestrian accidents after the installation of scramble-timed pedestrian signals at 11 locations (2). Their accident data were limited to 27 accidents in the before period and 25 accidents in the after period, with each of these periods only one year in duration. The authors of the study concluded that pedestrian signals are not effective in reducing pedestrian accidents, but the limited data used raise questions about the statistical validity of this conclusion.

Several studies have been conducted concerning the effect of pedestrian signals on pedestrian compliance and behavior, which are sometimes considered to be indirect measures of pedestrian safety. A study by Abrams and Smith in 1977 concluded that higher pedestrian compliance rates are associated with late-release techniques and that early-release timing may provide an additional measure of safety,

but the benefits were not determined precisely (3). Scramble timing was found to be associated with higher violation rates than were other timing schemes (3). Mortimer conducted a study in 1973 to test compliance rates at pedestrian crossings with and without pedestrian signals (4). He found better signal compliance rates and fewer serious pedestrian-vehicle conflicts at intersections with pedestrian signals than at those without them.

Several other related studies have been conducted outside the United States regarding the effect of pedestrian signals on safety. A 1979 study in England by Inwood and Grayson found that push-button pedestrian signals (termed pelican crossings) are no more effective than black-and-white-striped crosswalks and flashing beacons (termed zebra crossings) in reducing pedestrian accidents (5). However, a study in Australia by Williams reported that accidents dropped by 60 percent at a group of locations that had pedestrian-actuated signals that were installed at former zebra crossings (6). The precise effect of each of these countermeasures was not determined. These studies were also inconclusive on the safety benefits of pedestrian signals.

Many studies conducted in the United States and abroad have used measures of effectiveness such as pedestrian compliance and behavior to evaluate the effect of pedestrian signals on pedestrian safety. However, a clear relation has not yet been established between pedestrian accidents and such surrogate measures. Although these past studies provide useful insights about pedestrian control at intersections, they do not provide sufficient information to establish the safety benefits of pedestrian signals. We therefore decided that a more-comprehensive analysis was warranted that would use several years of pedestrian accident data at a large number of urban intersections.

METHODOLOGY

The evaluation approach selected for this research involved the use of pedestrian accident experience instead of pedestrian behavior, compliance measures, or other accident surrogates to determine the effect of pedestrian signals and timing on pedestrian safety. The two types of accident analysis considered were (a) the analysis of pedestrian accident before and after the installation of a pedestrian signal and (b) a comparative analysis of accidents at locations with and without pedestrian signals. Before and after analyses can be used to determine cause-and-effect relations, preferably by using comparison sites and looking at accident trends over time in order to minimize the common threats to evaluation validity (i.e., regression-to-the-mean, changes in accident trends over time, compounding effects of other locational factors, and data instability). However, this analysis approach was rejected for this study due to (a) the small accident samples per site, (b) the difficulty in finding suitable sites (with several years of accident data before and after the installation of a pedestrian signal) and comparison sites, and (c) the problem of isolating the true effect of the pedestrian signals on pedestrian accidents from other locational features.

The comparative analysis approach involves the selection of a large sample of sites with and without pedestrian signals and the representation of various timing schemes. Intersections that have similar geometric or operational features are grouped together and accident data are compared for each group. This approach usually allows for the creation of a large data base without relying on sites where pedestrian signals have been added in recent years. The possible disadvantages with a comparative analysis are that no two intersections are exactly alike, so a large number of traffic, geometric, and operational data variables are needed for each site to help ensure reliability of results. A comparative analysis does not show cause-and-effect relation but does allow for determining relations among variables if the proper statistical tests are used. A comparative analysis approach was subsequently selected for this study.

Data Needs

Data needs were established based on the findings of the literature review, the objectives of the study, and the need to assess pedestrian accident experience and to characterize intersection locations to permit the isolation of influencing factors. The basic analysis approach was designed to compare the pedestrian accident experience between signalized locations with and without pedestrian signal indications. Since a variety of signal-timing schemes are used for pedestrian signals, it was deemed important to assess individually the effect of the various schemes on pedestrian accidents.

Independent variables were defined that would be appropriate for classifying each candidate intersection in terms of its design, operation, and environment. The prime requirement of such variables was that they represent different levels of opportunity for pedestrian accidents or should have some influence on the potential for an accident. Since pedestrian accidents are directly related to traffic and pedestrian volumes, these two variables were considered to be of major importance. Therefore, data on traffic and pedestrian volumes were collected for each intersection by leg (if available) within the period for which the accident data were available.

Additional independent variables used to describe the intersection characteristics were also identified. These variables included the following:

1. Design factors--number of lanes, intersection skewness, use and type of pedestrian signal, number of turn lanes or turn prohibitions, and street width;
2. Environmental factors--city, land use, area type, and functional classification; and
3. Operational factors--signal timing and phasing, provision for right-turn-on-red, bus operations, speed limits, one-way or two-way street operations, and parking.

The data analysis plan addressed the question of how many years of accident data would be necessary to provide sound statistical results. Although the use of pedestrian accident data was determined to be the most desirable method of measuring directly the effectiveness of pedestrian signalization options, the relative infrequency of pedestrian accidents at any location was recognized to create a problem in the statistical analysis of the data. Therefore, a conservative estimate indicated that about 1000 intersections were necessary, and 3 to 6 years of accident data per site, to ensure statistical reliability.

Copies of accident reports were obtained and reviewed before coding. All basic information about each accident, including who was at fault, the accident type, severity, contributing circumstances, and 20 other accident details, were entered into the data base. Accidents were included in the analysis only if they were within the influence of the intersection and thought to be related to a crossing maneuver at the signal. For example, highly unusual accidents (i.e., pedestrian falls from moving car, pedestrian is hit while standing on sidewalk, or

police officer directing traffic) were not included. Computerized accident files were used in 2 of the 15 cities because the accident report forms were not readily available.

Site Selection

The selection of suitable sites for this study required that candidate cities first be chosen to satisfy the following criteria:

1. Cities should be willing to cooperate in the study and provide necessary data;
2. Pedestrian and traffic volume data should be available at a large number of locations from counts conducted within the past five years;
3. Other required locational data (i.e., signal timing sheets, land use maps, bus maps, and dates of when any major locational changes were made) should also be readily available;
4. Accident data should be of high quality, accidents should be referenced accurately to the proper location, and accident-reporting levels should be relatively consistent;
5. Candidate cities should cover a wide geographic range throughout the United States and represent a variety of types, density, traffic laws, and pedestrian attitudes; and
6. Cities should have an adequate sample of types of pedestrian signals and signal-timing schemes.

Of the more than 70 U.S. cities originally contacted for use in the study, 15 were selected after we determined that they substantially met the above criteria. The only city found that had more than 20 exclusive-timed intersections was Denver, Colorado. A few exclusive intersections were found in New Haven, Connecticut; Waltham, Massachusetts; Washington, D.C.; Kansas City, Missouri; West Hartford, Connecticut; Richmond, Virginia; and Tampa, Florida.

Problems were also encountered in identifying sites that had early- or late-release timing. Only a very few locations that use this scheme were found in discussions with city traffic engineers. Most engineers were of the opinion that, after flows of either automobiles or pedestrians were initiated, it is difficult to interrupt them on the same phase. Hence, very little use is made of this timing scheme within the cities contacted. The resulting categories of pedestrian signal timing included the following:

1. No pedestrian signal,
2. Concurrent timing,
3. Exclusive (including scramble) timing, and
4. Other timing (split phasing or early or late release).

Cities were selected from several geographic regions to eliminate unwanted biases in the accidents related to climate, driver attitudes, systemwide accident characteristics, areawide safety emphasis, lifestyles, and local highway design standards. Furthermore, an attempt was made to avoid cities that were considered to be highly unusual in terms of pedestrian activity, attitudes, and behavior. A total of 1297 intersections in 15 cities across the United States were selected for inclusion in the study, as indicated in Table 1.

Within each of the cities selected for data collection, candidate signalized intersections with and without pedestrian signals were selected for analysis. The selection was based on the availability of the required intersection data and the need for a relatively uniform sample of typical intersection situations. Therefore, all of the locations selected for inclusion in this study had the following features:

1. All intersections had four approach legs without unusual features; offset intersection approaches, multiple legged intersections, and traffic circles were not selected.
2. All intersections had traffic signals; some had pedestrian signal indications and others did not.
3. All intersections were in urban or suburban areas.

The locations were different to some degree in terms of

1. The use of pedestrian signal-timing schemes (concurrent, no pedestrian signal, or exclusive),
2. The range of pedestrian volume (about 50-50 000 pedestrians/day crossing all approaches) and traffic volumes (about 1600-78 000 entering vehicles/day),
3. Land uses (commercial, residential, or recreational), and
4. A variety of other roadway features (number of lanes, turn prohibitions, or presence or absence of right-turn-on-red).

Data Collection

The data collection effort usually involved one or more visits to the appropriate offices in the selected cities. Data were compiled from traffic, accident, and roadway data files; maps; and computer outputs. The unavailability of certain data in some of the cities necessitated field surveys and pedestrian volume counts at most of the intersections. After the data were coded, they were checked by a series of manual and computerized reviews of the data files to ensure integrity. The corrected data file was condensed and reformatted to facilitate analysis by using the Statistical Package for the Social Sciences (SPSS) and Statistical Analysis System (SAS) statistical packages.

DATA ANALYSIS

A comprehensive statistical analysis was undertaken on the data files to determine the effects of pedestrian signals on accidents. It was recognized at the outset that small samples of pedestrian accidents per site would exist, which would produce a skewed (nonnormal) distribution of accidents by site. This required the selection of not only a large number of sites and three to six years of accident data but also the selection of appropriate statistical tests. The analysis first included a review of accident characteristics to provide an understanding of the factors associated with pedestrian accidents. Next, correlation analysis was used to determine what traffic and roadway variables were most highly related to pedestrian accidents. A branching analysis was used to indicate variables that explained the most variation in pedestrian accidents and to identify the breakpoint levels that were important in subsequent statistical tests.

Based on the results of the correlation and branching analysis, chi-square and analysis of variance and covariance tests were applied. The chi-square test was used to compare the distributions of accidents for locations with and without pedestrian signals and for different timing schemes (i.e., concurrent versus exclusive timing) for various data groups. Finally, analysis of variance and covariance tests were used to isolate the effect of pedestrian signals and timing on accidents while controlling for other influencing variables.

Table 1. Summary of intersections from each city used in the study.

City	Locations: No Pedestrian Signal	Concurrent Timing	Exclusive Timing	Other Timing	Total	Accident Data-Collection Period	Total No. of Pedestrian Accidents
Albany, NY	9	0	0	0	9	1976-1980	17
Chicago, IL	112	112	0	12	236	1977-1980	635
Columbus, OH	1	46	0	3	47	1978-1980	54
Denver, CO	0	16	39	0	55	1978-1980	34
Detroit, MI	62	108	0	0	170	1978-1980	222
Grand Rapids, MI	7	9	0	0	16	1978-1980	10
Kansas City, MO	10	28	1	0	39	1978-1980	11
New Haven, CT	27	0	13	0	43	1977-1979	43
Richmond, VA	84	2	11	0	97	1978-1980	55
Seattle, WA	41	99	0	0	140	1974-1979	342
Tampa, FL	21	21	16	0	58	1977-1980	33
Toledo, OH	66	113	0	5	184	1976-1980	198
Waltham, MA	0	0	11	0	11	1977-1980	2
Washington, DC	68	104	10	5	187	1974-1979	425
West Hartford, CT	0	0	5	0	5	1976-1980	0
Total	508	658	109	22	1297		2081

Characteristics of Pedestrian Accidents

The accident data collected and analyzed consisted of 2081 accidents that occurred at the 1297 intersections shown in Table 1. The analysis period ranged from three to six years in each city based on the availability of historical accident data. Most of the accident data used in this study was associated with intersections in five large urban areas (Chicago, Illinois; Washington, D.C.; Toledo, Ohio; Detroit, Michigan; and Seattle, Washington) that represented more than 70 percent of the locations and 88 percent of the accidents in the sample.

The characteristics associated with the pedestrian accidents are summarized in Table 2, including details on accident severity, pedestrian age and sex, collision type, pedestrian action, and driver action. Only 29 (1.4 percent) of the 2081 accidents resulted in a pedestrian fatality; the vast majority (93 percent) of the accidents were injury accidents. In addition, 98 collisions (4.7 percent) involved no injury to the pedestrian.

Summaries of accidents by age and sex of pedestrians indicate that more than 40 percent of the accidents involved young and elderly persons and males are hit more often than are females. The designation of accident type was based on driver intent at the intersection (i.e., straight or turning right or left). The most common type of pedestrian accident involved a through vehicle (60.3 percent). Right-turning movements accounted for 14.8 percent of the accidents; left-turning vehicles were involved in 22.5 percent of the accidents.

The determination of pedestrian and driver action involved review of hard copy accident reports to determine whether the accident was caused by a hazardous pedestrian action (i.e., walking or running against the signal) or a hazardous driver action (i.e., run red light or failure to yield on a turn). The investigating officer's remarks and description of the accident and site condition were the basis for this determination. For those accidents where the pedestrian action could be determined, the pedestrian was crossing with the signal in 49.2 percent of the accidents. For the 1446 accidents where the driver action could be determined, 41.5 percent were judged to be driving safely at the time of the accident and were not judged at fault in the accident. This indicates that approximately one-half of the pedestrian accidents at intersections are caused by pedestrians in violation of the traffic or pedestrian signal. In the other one-half of the pedestrian accidents, the pedestrians were following the instructions of traffic or pedestrian signals but were struck by motorists who failed to observe or yield to pedestrians in time.

Correlation Analysis

The purpose of this analysis was to determine which independent variables (i.e., traffic, roadway, and signal variables) to include in subsequent analyses based on their relations to each other and accident data (dependent variables). Pearson's correlations were computed for various combinations of continuous dependent and independent variables to determine those combinations that have the strongest interrelations. The correlations between key dependent variables and independent variables were generally low (r-values of less than 0.6). The strongest of these relations were found between mean pedestrian accidents per year and both pedestrian volumes and vehicle volumes. Generally low correlations were expected due to the wide variety of features of the intersections that influence the pedestrian accident experience at a location. No attempt was made to improve the correlations through the inclusion of multiple independent variables by stepwise linear regression analysis or through data stratification. The decision was made to proceed to other analysis techniques (branching analysis and analysis of covariance) to further quantify the effect of individual variables on pedestrian accidents.

Branching Analysis

A branching analysis was conducted on 1289 signalized intersections to determine what traffic and roadway variables explain the most variation in pedestrian accident experience. Also, we hoped that the analysis would identify breakpoint levels of pedestrian and traffic volumes, based on pedestrian accident experience, for data stratification in subsequent analyses. The results of the branching analysis (shown in Figure 1) indicated the following:

1. Pedestrian volume is the variable that explains the greatest amount of variation in pedestrian accidents (14.9 percent of variance explained).
2. After several groupings of pedestrian volume were tested, the most-important breakpoint in pedestrian accidents occurs for a pedestrian average daily traffic (ADT) level of 1200. In fact, for the 609 locations that had pedestrian ADTs less than 1200, the mean annual pedestrian accidents per location was 0.178, compared with 0.553 for loca-

tions that had pedestrian ADT of 1200 or more. Another breakpoint occurred at a pedestrian ADT of 3500.

3. The most-important breakpoints in the traffic volume data (in terms of pedestrian accidents) occurred at ADT levels of 27 500 and 18 000.

4. Beside pedestrian and traffic volume, other variables that were found to be of some importance in explaining pedestrian accidents included bus operation (a bus route on one or more of the streets at the intersection), street operation (one-way versus two-way streets), percentage of vehicle turns, intersection design, area type (CBD, fringe, or residential), and street approach width.

Table 2. Summary of pedestrian accident data.

Classification	Characteristics	No.	Percent
Accident severity	Fatal injury	29	1.4
	Nonfatal injury	1935	93.0
	No injury	98	4.7
	Unknown	19	0.9
	Total	2081	
Age group[a]	0-15	225	22.0
	16-59	504	49.4
	≤60	186	18.2
	Unknown	106	10.4
	Total	1021	
Sex of pedestrian	Male	546	53.5
	Female	465	45.5
	Unknown	10	1.0
	Total	1021	
Driver intent	Straight	1256	60.3
	Right turn	308	14.8
	Left turn	468	22.5
	Other or unknown	49	2.4
	Total	2081	
Pedestrian action[b]	No hazardous action	475	49.2
	Hazardous action	449	46.5
	Unknown	42	4.3
	Total	966	
Driver action[c]	No hazardous action	600	41.5
	Hazardous action	805	55.7
	Unknown	41	2.8
	Total	1446	

[a]Excludes accidents from Washington, DC, and Chicago, IL.
[b]Excludes accidents from Washington, DC; Chicago, IL; and Richmond, VA.
[c]Excludes accidents from Washington, DC.

5. Although all intersections in the analysis had a traffic signal, the presence or absence of a pedestrian signal indication had no significant effect on pedestrian accident experience.

Further branching analysis was conducted separately for the following three groups of intersections:

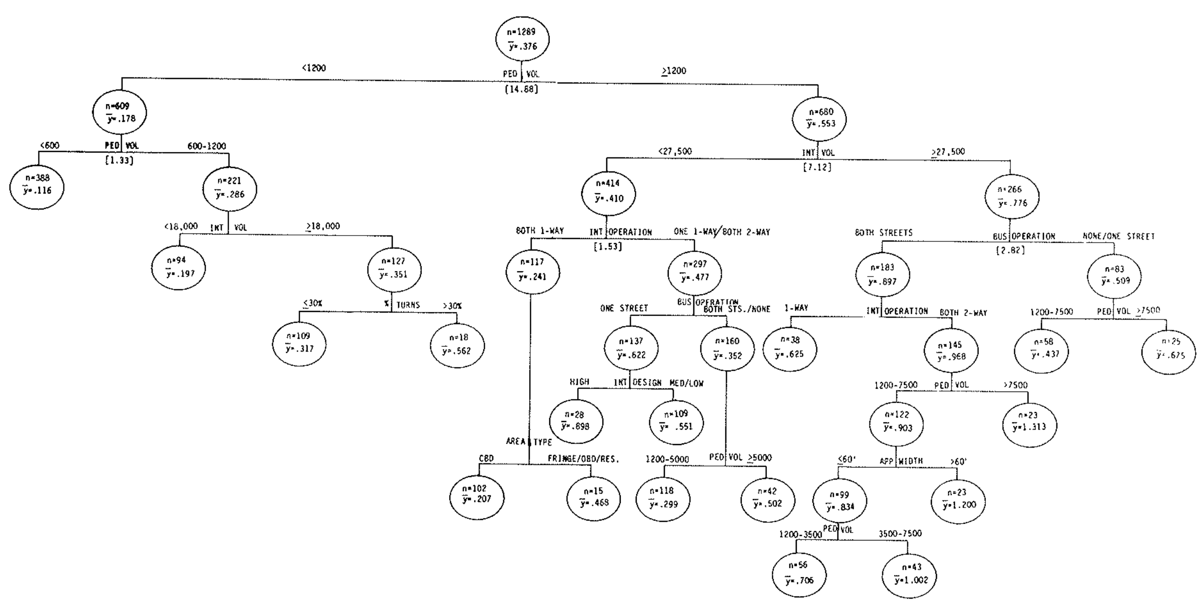
1. The 507 intersections that did not have pedestrian signals,
2. The 652 locations that had concurrent pedestrian signals, and
3. The 109 locations that had exclusive pedestrian signal timing.

The following general conclusions were found:

1. The presence of buses was found to be an important factor in pedestrian accidents for location groups above 1000 pedestrians/day for locations that had concurrent pedestrian timing and also for locations that did not have pedestrian signals;
2. For exclusive-timed signals that had pedestrian ADT above 8000, pedestrian accidents were much lower at the intersection of two one-way streets than for intersections of two-way street approaches;
3. For intersections that did not have pedestrian signals on bus routes and ADT above 1000, a higher accident experience was found at residential intersections compared with nonresidential areas; and
4. The presence of a wide street width (i.e., greater than 50 ft) was associated with higher pedestrian accidents for some categories of roads that had pedestrian ADTs above 1000.

Three classes of traffic volume were chosen based on breakpoints determined from the branching analysis to assess the sensitivity of pedestrian accidents as a function of pedestrian and traffic volume, as illustrated in Figure 2. Intersection classes of pedestrian and traffic volume were grouped together and the pedestrian accidents for three years were plotted. Three traffic volume groups and 11 pedestrian volume groups were used to illustrate the expected number of pedestrian accidents at an intersection for a three-year period.

Figure 1. Branching analysis by using mean pedestrian accidents per year.



The plots include intersections that did not have pedestrian signals and also those that had concurrent pedestrian signals (since no significant difference was found in pedestrian accidents between these two groups). The curves show the sensitivity of pedestrian accidents to traffic and pedestrian volumes. Calculation of correlation coefficients (Pearson's r) is not appropriate in this case because each data point represents the mean accident experience of numerous intersections in a particular volume class.

Based on the results of the branching analysis, a breakdown analysis was used to summarize average pedestrian accidents for various classifications of traffic volume, pedestrian volume, and signal-timing scheme (Table 3). This table provides a simplistic description of the trends in pedestrian accidents in relation to pedestrian signalization and volume factors. These results are not sufficient, however, to make conclusive statements relative to these trends without further testing of the true effects by using more sophisticated analysis of variance

Figure 2. Relation between pedestrian volume and pedestrian accident experience for three levels of vehicle volumes.

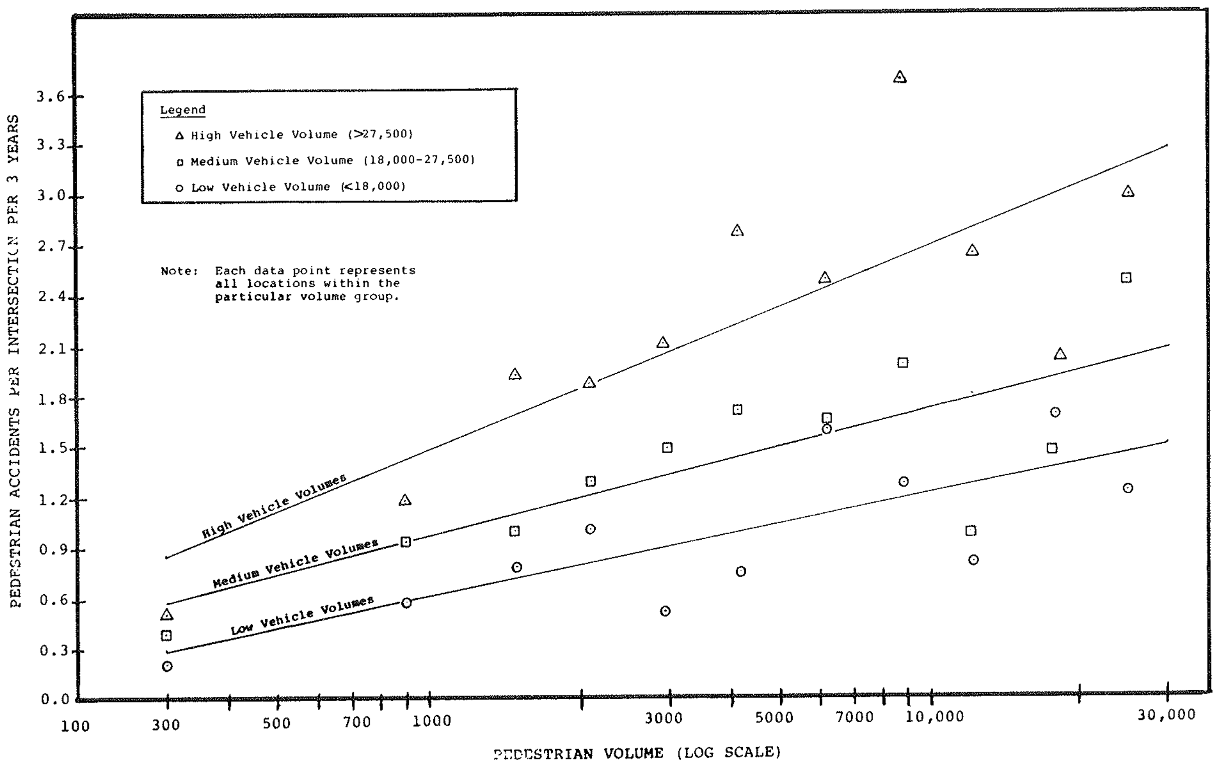


Table 3. Summary of pedestrian accidents per year per site by pedestrian signal type and volume class.

Volume Class	No Pedestrian Signal Indication: Mean Annual Pedestrian Accidents per Intersection	No Pedestrian Signal Indication: Intersections	Concurrent Pedestrian Signal Timing: Mean Annual Pedestrian Accidents per Intersection	Concurrent Pedestrian Signal Timing: Intersections	Exclusive Timing: Mean Annual Pedestrian Accidents per Intersection	Exclusive Timing: Intersections
Low pedestrian volume, 0-1200, and low vehicle volume, 0-18 000	0.09	127	0.14	120	0.11	12
Medium pedestrian volume, 1201-3500, and low vehicle volume, 0-18 000	0.28	46	0.25	27	0.40	8
High pedestrian volume, >3500, and low vehicle volume, 0-18 000	0.25	16	0.50	22	0.29	21
Low pedestrian volume, 0-1200, and medium vehicle volume, 18 001-27 500	0.19	84	0.21	78	0.08	10
Medium pedestrian volume, 1201-3500, and medium vehicle volume, 18 001-27 500	0.41	51	0.41	61	0.20	8
High pedestrian volume, >3500, and medium vehicle volume, 18 001-27 500	0.65	37	0.52	89	0.21	25
Low pedestrian volume, 0-1200, and high vehicle volume, >27 500	0.23	74	0.28	92	0.17	12
Medium pedestrian volume, 1201-3500, and high vehicle volume, >27 500	0.52	47	0.73	79		
High pedestrian volume, >3500, and high vehicle volume, >27 500	0.88	26	0.91	90	0.66	13

Table 4. Distribution of locations by pedestrian accident experience and signal timing scheme.

Pedestrian Volume per Day	Pedestrian Accidents per 3 Years	Intersections with No Pedestrian Signals		Intersections with Concurrent-Timed Pedestrian Signals		Intersections with Exclusive-Timed Pedestrian Signals	
		No.	Percent	No.	Percent	No.	Percent
<1200	0	177	62.1	155	53.4	25	73.5
	>0 to 1	71	24.9	81	27.9	5	147
	>1 to 1.5	14	4.9	17	5.9	2	5.9
	>1.5	23	8.1	37	12.8	2	5.9
	Total	285		290		34	
≥1200	0	57	25.5	64	17.4	32	42.7
	>0 to 1	64	28.7	99	26.9	25	33.3
	>1 to 1.5	29	13.0	46	12.5	3	4.0
	>1.5 to 2.25	28	12.6	58	15.8	7	9.3
	>2.25	45	20.2	101	27.4	8	10.7
	Total	223		368		75	

Table 5. Summary of results from the chi-square analysis.

Comparison	Pedestrian Volume	Difference Distributions[a]	χ^2	df	Level of Significance
No pedestrian signal versus concurrent-timed pedestrian signal	<1200/day	No	5.630	3	
	≥1200/day	No	8.664	4	
No pedestrian signal versus exclusive-timed pedestrian signal	<1200/day	No	2.197	3	
	≥1200/day	Yes	13.492	4	0.01
Concurrent-timed pedestrian signal versus exclusive-timed pedestrian signal	<1200/day	No	5.410	3	
	≥1200/day	Yes	32.240	4	0.01

[a]Significant at the 0.05 level of confidence.

tests or considering in greater detail the influence of the many other geometric, traffic, and locational factors.

Chi-Square Analysis

The chi-square test was used to test for a statistically significant association between pedestrian accidents and pedestrian signal timing schemes (including the no-pedestrian-signal situation). The chi-square test was determined appropriate for use in this study because it can relate a continuous, nonnormal variable (i.e., Poisson distribution of accidents) to one or more categorical variables (i.e., categories of pedestrian signal timing).

Distributions of locations that had various pedestrian signal schemes were established separately for locations that had pedestrian volumes less than 1200/day and locations that had 1200 or more pedestrians/day (Table 4). Four to five ranges of pedestrian accidents (per three-year period) were developed for use in the chi-square analysis. The number and percentage of locations that fall into each category are given in Table 4, which indicates a highly skewed (i.e., Poisson) distribution for each group of locations. The break point of 1200 pedestrians/day was used to separate the data set because of its importance in explaining variation in pedestrian accidents (as found from the branching analysis).

The results of the chi-square analysis are summarized in Table 5 and indicate the following:

1. No significant difference was found in pedestrian accident distributions when comparing locations that did not have pedestrian signals to locations that had concurrent pedestrian signals. This was true for both groups of pedestrian volume (i.e., <1200 and ≥1200 pedestrians/day).
2. For intersections that had fewer than 1200 pedestrians/day, no significant difference was found in pedestrian accident distributions when comparing exclusive-timed pedestrian signals with both the no-pedestrian-signal groups and also locations that had concurrent pedestrian signals. The low number of exclusive-timed signals (34) in this volume category may have caused this result.
3. For intersections that have 1200 or more pedestrians/day, a significant difference was found between accident distributions for exclusive-timed pedestrian signals compared with locations that did not have pedestrian signals as well as locations that had concurrent pedestrian signals (0.01 level of confidence in each case). A higher proportion of exclusive-timed locations were in the low accident groups than in the concurrent signal group or the no-pedestrian-signal group.

Analysis of Variance and Covariance

The statistical investigations were pursued to a still higher level in an attempt to explain the findings of the previous analyses. This involved the use of analysis of variance and covariance techniques. The analysis of variance method was used to divide the observed variation in experimental data into parts, and each part is assigned to a known source or variable. The purpose of the analysis was to determine whether a particular part of the variation is greater than would be expected by chance. The null hypothesis generally assumed for the analysis of variance was that the mean of the sample data is not significantly different.

The analysis of covariance is similar to the analysis of variance, but it allows for the inclusion of covariates in the analysis to adjust the dependent variable (i.e., pedestrian accidents per year) for continuous variables where appropriate. For example, the continuous covariates selected and used in most of the analysis of variance tests were pedestrian volume and traffic volume. This allowed for determining the true effect of pedestrian signals on pedestrian accidents while controlling for the effects of varying levels of pedestrian and traffic volumes. Examples of the discrete (noncontinuous) variables included in the analysis included street operation, absence or presence of right-turn-on-red regulations, bus operation, area type, and others.

The final selection of variables used in the

analysis of variance analysis was based on the results of the correlation analysis, the branching analysis, and preliminary analysis of variance runs. The dependent variables used the analysis of variance runs included various types of mean annual pedestrian accidents, including total accidents, right-turn accidents, left-turn accidents, and total turn accidents.

The independent variables used in one or more of the analysis of variance runs as covariates included the following:

1. Total traffic volume [annual average daily traffic (AADT)],
2. Right-turn traffic volume (AADT),
3. Left-turn traffic volume (AADT),
4. Total turning traffic volume (AADT), and
5. Total pedestrian volume (AADT).

The analysis of variance runs were made with varying combinations of the following classification variables:

1. Area type code,
2. Street operation,
3. Signal operation code, and
4. City code.

Numerous analysis of variance tests were undertaken by using the SPSS program to address several basic issues.

Issue 1: Are Mean Pedestrian Accidents per Year Significantly Affected by the Presence of Various Types of Pedestrian Signal Timing Schemes?

The mean pedestrian accidents per year are significantly affected by the presence of various pedestrian-timing schemes (at the 0.001 level) when adjustments are made for pedestrian volumes, traffic volume, and street operation. The lowest adjusted mean accidents per year occurred for exclusive timing (0.22), and the highest was for concurrent pedestrian signals (0.40). Other values included no pedestrian signal (0.36) and other semi-exclusive or protected signals (0.38).

Similar comparisons were also made for the mean turning pedestrian accidents per year. The independent variables included operation code (i.e., one-way or two-way combinations), pedestrian volume, and total vehicle turning volume. There were significant differences in the mean pedestrian accidents for the various signal timing schemes. For both types of pedestrian accidents, exclusive-timed locations had the lowest mean accidents per year. Details of the results are given in Table 6.

Issue 2: Is there a Significant Difference in Pedestrian Accidents between Intersections that Did Not Have Pedestrian Signals and Intersections that Had Concurrent Pedestrian Signal Timing?

The total mean pedestrian accidents are not significantly different (at the 0.05 level of confidence) between intersections with no pedestrian signals compared to intersections with standard pedestrian signals, when adjustments are made for pedestrian volume, traffic volume, and street operation code. This finding agrees with the findings from the chi-square test.

Similar comparisons were also made for mean turning pedestrian accidents per year. The independent variables included operation code, pedestrian volume, and total vehicle turning volume. There was a significant difference (at the 0.05 level) between no pedestrian signal locations and locations that had concurrent pedestrian signals for the mean pedestrian turning accidents per year. The analysis also indicated that locations that did not have pedestrian signals had significantly fewer pedestrian turning accidents than those that had concurrent pedestrian signals. However, the sample size for turning accidents is small, and further in-depth testing should be done to verify this apparent affect. Details of the results are given in Table 6. This finding may be the result of pedestrians' failure to be cautious of turning vehicles at locations with pedestrian signal heads.

Comparisons of mean annual pedestrian accidents were made between locations that did not have pedestrian signals and those that had concurrent pedestrian signals for the cities of Chicago, Detroit, Washington, Toledo, and Seattle (individually and as a group) to determine whether similar results were found in each major city. Again, the independent variables were traffic volume, pedestrian volume, signal operation, and street operation. No significant difference in pedestrian accidents was found in any city between intersections that did not have pedestrian signals versus intersections that had concurrent pedestrian signals. This finding tends to indicate that regional differences did not bias the results. The concurrent signal timing fared best in Seattle than in any other city when compared with locations that did not have pedestrian signals (although the difference in accident means was not significant in any city). This trend might be explained, since Seattle probably has lower pedestrian violation rates (and better compliance to pedestrian signals) compared with the other large cities in the sample. As signal compliance increases, their effect on pedestrian safety should improve. When a similar analysis was conducted for the five cities combined (also controlling for the differences in the local accident experience), no significant differences were found in either the total mean pedestrian accidents or the mean turning pedestrian accidents. These findings are summarized in Table 7.

Issue 3: Is the Difference Significant in Pedestrian Accidents between Intersections that Did Not Have Pedestrian Signals and Intersections that Had Exclusive Pedestrian Signal Timing?

The mean pedestrian accidents per year are significantly different between intersections with exclusive timing schemes compared with intersections with no pedestrian signals (at the 0.001 level) when controlled for street operation, pedestrian volume, and traffic volume. The mean adjusted pedestrian accidents at exclusive locations (0.15/year) is significantly lower than for no pedestrian signal (0.33/year). The chi-square analysis confirmed this finding for locations that had pedestrian ADTs above 1200.

Similar comparisons were also made for mean-turning accidents per year. The independent variables included operation code, pedestrian volume, and vehicle turning volume. In each case, the mean adjusted accidents per year were significantly lower at exclusive-time locations than at locations that did not have pedestrian signals (at the 0.01 level of confidence). Details of the results are given in Table 6.

Issue 4: Is there a Significant Difference in Pedestrian Accidents Between Intersections that Have Concurrent Pedestrian Signal Timing and Intersections that Have Exclusive Pedestrian Signal Timing?

The total mean pedestrian accidents are signifi-

cantly different (at the 0.001 level) between intersections that have standard pedestrian signal timing and intersections that have exclusive pedestrian signal timing when accounting for the effects of street operation, pedestrian volume, and traffic volume. The mean adjusted pedestrian accidents at exclusive locations (0.27/year) is significantly lower than the mean pedestrian accidents for standard signal timing (0.43/year).

Similar comparisons were also made with mean turning accidents per year. The independent variables included street operation, pedestrian volume,

Table 6. Summary of analysis of variance results for different pedestrian signal alternatives.

Comparison	Dependent Variable	Alternative	Adjusted Mean	Control Variables	Significant Difference[e]	Level of Significance
All pedestrian signal alternatives	Mean pedestrian accidents per year	No pedestrian signal[a] Concurrent[b] Exclusive[c] Other[d]	0.36 0.40 0.22 0.38	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	Yes	0.001
	Mean pedestrian turning accidents per year	No pedestrian signal[a] Concurrent[b] Exclusive[c] Other[d]	0.13 0.17 0.01 0.20	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	Yes	0.001
No pedestrian signal indication versus concurrent pedestrian signal timing	Mean pedestrian accidents per year	No pedestrian signal[a] Concurrent[b]	0.36 0.40	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	No	0.130
	Mean pedestrian turning accidents per year	No pedestrian signal[a] Concurrent[b]	0.12 0.15	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	Yes	0.048
No pedestrian signal indication versus exclusive pedestrian signal timing	Mean pedestrian accidents per year	No pedestrian signal[a] Exclusive[c]	0.33 0.15	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	Yes	0.001
	Mean pedestrian turning accidents per year	No pedestrian signal[a] Exclusive[c]	0.11 0.00	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	Yes	0.001
Concurrent pedestrian timing versus exclusive pedestrian signal timing	Mean pedestrian accidents per year	Concurrent[b] Exclusive[c]	0.43 0.27	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	Yes	0.001
	Mean pedestrian turning accidents per year	Concurrent[b] Exclusive[c]	0.17 0.03	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	Yes	0.001

[a]n = 508. [b]n = 658. [c]n = 109. [d]n = 22. [e]Significant at the 0.05 level of confidence.

Table 7. Summary of analysis of variance results by city.

City	Dependent Variable	Alternative	Adjusted Mean	Sample Size	Control Variables	Significant Difference[a]	Level of Significance
Chicago	Mean pedestrian accidents per year	No pedestrian signal Concurrent	0.60 0.72	112 112	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	No	0.137
Detroit	Mean pedestrian accidents per year	No pedestrian signal Concurrent	0.44 0.44	62 108	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	No	0.919
Seattle	Mean pedestrian accidents per year	No pedestrian signal Concurrent	0.45 0.39	41 99	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	No	0.443
Toledo	Mean pedestrian accidents per year	No pedestrian signal Concurrent	0.15 0.25	66 113	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	No	0.078
Washington	Mean pedestrian accidents per year	No pedestrian signal Concurrent	0.37 0.40	68 104	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives	No	0.591
Chicago Detroit Seattle Toledo Washington	Mean pedestrian accidents per year	No pedestrian signal Concurrent	0.41 0.44	349 536	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives, city code	No	0.375
Chicago Detroit Seattle Toledo Washington	Mean pedestrian turning accidents per year	No pedestrian signal Concurrent	0.15 0.17	349 536	Pedestrian volume, total traffic volume, street operation, pedestrian signal alternatives, city code	No	0.193

[a]Significant at the 0.05 level of confidence.

and total vehicle turning volume. The exclusive-timed intersections had significantly lower accident experience than the standard-timed signal locations.

Issue 5: What Traffic, Geometric, and Operational Variables Have a Significant Effect on Pedestrian Accidents at Signalized Urban Intersections?

Based on numerous analysis of variance runs, variables that have a significant effect (at the 0.05 level) on total pedestrian accidents for some intersection groups include the following:

1. Urban area type (suburban streets had significantly higher pedestrian accidents than did those of other areas,
2. Street operation (intersections of two one-way streets had significantly lower pedestrian accidents than intersections of two, two-way streets), and
3. The presence of bus routes on one or both streets of the intersection was associated with higher pedestrian accidents for some intersection subgroups.

SUMMARY AND CONCLUSIONS

This paper summarizes the study undertaken to determine the safety benefits derived from the use of pedestrian signals. The research approach involved the collection, reduction, and analysis of accident, traffic, and design data for 1297 urban intersections (which had 2081 pedestrian accidents over a three- to six-year period) in 15 cities. The signalization options included no pedestrian signals, standard (concurrent) timing, exclusive timing, and other timing schemes. Insufficient samples were available from the other category for statistical analysis.

The use of concurrent-timed pedestrian signals was found to have no significant effect on pedestrian accident distributions (based on chi-square test) or pedestrian accident frequencies (analysis of variance and covariance) for a sample of more than 1100 locations that represented these two groups. This finding was also true for the five largest cities in the data sample (Chicago, Washington, D.C., Detroit, Seattle, and Toledo).

The presence of exclusive-timed, protected pedestrian intervals (including scramble-timed intersections) was associated with significantly lower pedestrian accident experience when compared with locations with either concurrent-timed pedestrian signals or no pedestrian signals, when controlled for other important data variables (analysis of covariance). This finding was supported by the result of the chi-square test for intersections that have pedestrian volumes above 1200. However, this finding was not found for intersections that had pedestrian volumes less than 1200/day, possibly due to the limited sample of exclusive-timed signal locations within that volume category.

The number of pedestrian accidents that involved turning vehicles was found to be significantly higher for locations that had concurrent-timed pedestrian signals than for locations that did not have pedestrian signals when other important variables were controlled (analysis of covariance). However, this finding is not conclusive and cannot be strongly supported due to a small sample of turning pedestrian accidents. Further testing is needed to confirm this finding, but such a trend could possibly be explained by the possibility that pedestrians are often less cautious or fail to look around for turning vehicles at locations that have a WALK signal, particularly if they feel an added sense of protection when they see the WALK signal.

Several operational variables were found to have a significant effect on pedestrian accidents at urban signalized intersections. The branching and regression analysis indicated that pedestrian volume is the single-most-important variable in explaining the variation in pedestrian accidents and a significant, direct relation exists. The most-important breakpoints occur at pedestrian volume levels of 1200 and 3500 pedestrians/day (branching analysis).

Traffic volume is the second-most-important variable in explaining pedestrian accidents, and it also has a significant, direct relation to pedestrian accidents (branching analysis, regression, and analysis of covariance). The important breakpoints occur at traffic volume levels of 27 500 and 18 000 vehicles/day. Other variables were also found to have an important effect on pedestrian accidents.

RECOMMENDATIONS

The results of the analyses show that standard-timed (concurrent) pedestrian signals have no significant effect on pedestrian accidents compared with locations that do not have pedestrian signals. In fact, one analysis indicated that a significantly higher number of turning accidents are associated with concurrent pedestrian signal timing compared with intersections that do not have pedestrian signals (although not conclusive). The presence of exclusive-timed pedestrian signals are associated with significantly lower pedestrian accidents compared with the absence of pedestrian signals and the presence of standard-time pedestrian signals, particularly for locations that have moderate-to-high pedestrian volumes (more than 1200/day). However, many U.S. cities discourage the use of exclusive-timed (or scramble) pedestrian signals, since increased pedestrian and vehicle delay have been associated with such timing.

Concurrent timing is by far the most commonly used pedestrian signal timing. However, the use of pedestrian indications with concurrent timing was not found to be effective in reducing pedestrian accidents. Several possible reasons for their lack of effectiveness in reducing pedestrian accidents include the following:

1. Pedestrian respect for and compliance with pedestrian signal indications is poor in most cities. Violations of the DON'T WALK message are higher than 50 percent in many cities. This disrespect and violation of the pedestrian signals is a major reason for their ineffectiveness in reducing pedestrian accidents.
2. The presence of a pedestrian signal indication may tend to create a false sense of security and may cause many pedestrians to have the mistaken impression that they are fully protected and have no reason to use caution. The absence of a pedestrian indication at a signalized locations sometimes gives pedestrians the feeling that they are on their own. This could cause many pedestrians to exercise more caution regarding turning vehicles.
3. The use of the flashing WALK has been shown in other studies to be ineffective in adequately warning pedestrians to watch for turning vehicles. In fact, one study found that only 2.5 percent of the pedestrians understood the intended meaning of the flashing and steady WALK indications. Also, many states have not incorporated the flashing WALK signal into their state policies, which has caused nonuniformity in the use of pedestrian signal messages in the United States.
4. Some studies have found that the flashing DON'T WALK indication (clearance interval) is also not well understood by many pedestrians, and many

pedestrians believe that traffic will be released during the flashing DON'T WALK interval.

5. Pedestrian-actuation devices are used too infrequently by pedestrians and, therefore, the use and respect for pedestrian signals may be minimized at such locations. One study showed that they are used by less than 35 percent of the pedestrians in crossing at many sites.

The results of this analysis, although they raise questions about the effectiveness of pedestrian signalization, are not believed to justify the elimination of pedestrian signals. We recommend that city and state agencies take a closer look before indiscriminately installing pedestrian signals at all traffic signalized locations. Such pedestrian signals are expensive to install and maintain (for a large number of sites), and they may not be justified at many locations. Based on the findings of this study, further research may be desirable to further quantify the optimal use of pedestrian signals, including the following topics:

1. Determine the effect of intersection type on pedestrian safety by considering differences in functional classifications, lane configuration, crosswalk length, and special signal phasing;
2. Assess the effect of regional differences in pedestrian behavior, accident reporting, and pedestrian enforcement policies;
3. Investigate further the influence of pedestrian activities related to accident experience by type of pedestrian signal timing; and
4. Assess the impacts of general pedestrian compliance and understanding of signal indications on accident experience.

Only after the completion of such additional research can revised policies and practices be implemented.

Also, further efforts should be made to determine means to improve the effectiveness of standard pedestrian signals by making them more understandable, particularly in terms of the flashing WALK and the flashing DON'T WALK intervals. Also, efforts should be undertaken to determine the appropriateness of the pedestrian signal warrants currently given in the Manual on Uniform Traffic Control Devices (7) to determine whether more-realistic warrants are justified.

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Pedestrian Flows at Signalized Intersections

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Early techniques for dealing with pedestrian flows at signalized intersections were concerned with the minimum green time needed for crossing a street and often did not treat green time as a function of the number of people who cross. Recently, new knowledge has been gained about characteristics of pedestrian flow, including relations among speed, flow, and density. In the Interim Materials on Highway Capacity, a method is presented for pedestrian flows and queues at intersections. Some flaws in the method are examined here and a different approach for analyzing the problem is presented.

The presence of pedestrians can have important effects on the operation of signalized intersections. Pedestrian crossing times can often determine minimum green times, and, therefore, minimum cycle lengths (1, p. 810). If insufficient crossing time is provided, pedestrians in crosswalks may adversely affect vehicular capacity and, of course, their own safety. Various methods have been proposed for ensuring adequate pedestrian crossing times (1-3). Three of these methods are discussed below.

The Interim Materials on Highway Capacity (4, pp. 115-147) contain a more-comprehensive procedure for the analysis of pedestrian requirements at signalized intersections. The procedure provides for the analysis of space requirements (for queuing and circulation) on the sidewalk at intersections and for determining needed crosswalk widths. Unfortunately, the procedure has some severe shortcomings. The purpose of this paper is to review the above