RELATIONSHIP OF ACCIDENT PATTERNS TO TYPE OF INTERSECTION CONTROL

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

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

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

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

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PREVIOUS STUDIES

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

2-Way Control

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

4-Way Control

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

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

Traffic Signals

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

DATA COLLECTION AND REDUCTION

Data Collection

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

Data Reduction

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

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

   b. 4-way stop
   c. Signal

Each cell contained the following information:

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

CHOICE OF MEASURES OF EFFECTIVENESS

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

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

DATA ANALYSIS

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

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

Analysis of Variance

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

Table 1. Virginia accident study.

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

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

Table 2. Cincinnati accident study.

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

Table 3. Jurisdictions providing accident data.

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

Table 4. Results of ANOVA.

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

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

Table 5. Independent variables for regression analysis.

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

of 5 variables previously described.

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

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

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

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

Regression Analysis

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

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

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

Hypothesis Testing

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

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

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

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

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

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

	Signals	
Intersection	Warranted	Not Warranted
Signalized	MOE	MOE
Not signalized	MOE	MOE

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

Table 6. Results of regression analysis.

Dependent Variable	Control	$\bar{x}$	R	Level of Significance														
				x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
Accident evaluation index	Signal	1.45	0.573			0.95					0.95		0.95		0.90			
	Stop sign	1.77	0.763	0.95		0.95		0.90	0.95		0.90	0.95	—[a]	0.95				0.90
Injury and fatality accidents	Signal	0.319	0.403			0.95				0.95	0.95			0.95			0.95	
	Stop sign	0.366	0.528							0.90	0.90		—[a]		0.90			
Rear-end ratio	Signal	0.327	0.444										0.95			0.90		0.90
	Stop sign	0.134	0.634				0.95			0.95	0.95		—[a]	0.90				
Severity index	Signal	2.63	0.362	0.90		0.95						0.90			0.90			
	Stop sign	6.44	0.389								0.90		—[a]	0.90				
Right-angle ratio	Signal	0.233	0.392	0.95		0.95			0.95			0.90		0.90	0.95		—[a]	
	Stop sign	0.500	—[b]															
Log of accident evaluation index	Signal	2.85	0.627				—[a]				0.95		0.95					—[a]
	Stop sign	2.94	—[b]															
Total accidents	Signal	16.78	0.390							0.95	0.90		0.90		—[a]			
	Stop sign	8.87	—[b]															

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

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

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

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

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

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

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

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

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

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

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

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

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

CONCLUSIONS

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

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

Table 10. Summary of hypothesis testing.

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

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

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

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

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

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