Evaluation of High-Speed Isolated Signalized Intersections in California

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High-speed isolated signalized intersections (HSISIs) are generally encountered after long uninterrupted and uncongested flow conditions, therefore catching some motorists by surprise. For this reason alone, approaches to HSISIs need to have safe and effective warning, control, and intersection geometric treatments. Characteristics at California HSISIs that relate to accident rates are identified. A new safety indicator was introduced: intersection approach accident rate. Variables investigated included advance warning signs with and without flashing beacons, signal timing and phasing, channelization, signal equipment configurations, shoulder widths and types, median widths and types, and approach speeds. Forty HSISIs out of the approximately 100 statewide were chosen for the analysis. Twenty were selected from the highest accident group and 20, from the lowest accident group. Statistical analysis identified relationships between approach variables and approach accident rates. The primary variables found to be significantly correlated to low accident rates on approaches to HSISIs were the presence of a separate left-turn phase, a raised median, wide paved shoulders, and an advance warning sign with a flashing beacon. A demonstration project and interim procedures for California are encouraged.

The primary purpose of the U.S. highway transportation system is the safe, fast, and convenient movement of vehicular traffic while contributing to society's overall quality of life. One part of that system is, of course, high-speed highway facilities that move vehicles rapidly with minimum interruption, one of the characteristics of many rural and some suburban state highways. Occasionally, it is necessary to install traffic signals on these roadways. Because these high-speed isolated signalized intersections (HSISIs) are often encountered after lengthy uninterrupted flow conditions, drivers are often surprised. Sometimes drivers do not expect the signals, do not pay close attention to the traffic control, or become 'hypnotized' by a long tangent segment. When signalized intersections are encountered under these conditions, there is concern about a higher potential for accidents, especially severe accidents. This situation makes it extremely important to make the high-speed approaches to intersections and the assignment of right-of-way at those intersections safe through effective warning and control measures. FHWA and the California Department of Transportation (Caltrans) recently sponsored research by Washington et al. in California that addressed this subject (*1*). This paper focuses on that research effort.

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RESEARCH OBJECTIVES

This research paper identifies approach characteristics that affect accident rates at HSISIs on California state highways. The results of this research can be used to become better informed as to HSISI safety characteristics and features. Control measures for improving intersection safety can also be identified and, where appropriate, implemented. This knowledge may promote more uniform design and operation of HSISIs. There are two specific research objectives; namely, to identify control measures or actions that will most likely reduce accidents at HSISIs and to develop procedures for using the results of this research.

SCOPE AND LIMITATIONS

The general scope of the research was to identify features or control measures that affect safety at HSISIs in California. By identifying these features, recommendations to improve approaches with high accident rates could be made. With recommended improvements, intersections could experience a decrease in accident rates.

Forty intersections were chosen for analysis. The intersections were to be representative of the most safe and the least safe HSISIs throughout the state of California. Accident data would be taken from the Caltrans-maintained Traffic Accident Surveillance and Analysis System (TASAS) data base. Although this research work was started in June 1989 and completed 2 years later, the accident data spanned from 1980 to 1990. Other data included advance warning, intersection geometry, and signal operations.

To identify variables for study, the research did not include review of any legal cases associated with HSISIs, because legal cases were few and, if pending, were sensitive to outside scrutiny. The research also did not attempt to review collision diagrams at selected intersections. Intersections were broken down into accident types sufficiently by the TASAS data base; therefore, collision diagrams would not have benefited the analysis.

The research involved only signalized intersections on California state highways. It was determined early in the study that the goal was to identify characteristics of signalized intersections that affect safety; therefore, presignalization data would not provide substantial useful information. The focus was to identify characteristics and features of HSISIs conducive to safe operation.

LITERATURE REVIEW

Because HSISIs are often encountered by surprise, the approaching motorist needs effective advance warning, efficient traffic control, and safe geometric features. For these reasons, HSISIs need to be studied to determine which features contribute to the safety of these intersections. No other studies found by the authors examined California HSISIs as comprehensively as this study. Other studies considered particular aspects of HSISIs in greater detail, and these will be reviewed in this section. A comparison of the findings discovered in the literature review with the results of this analysis has been made later in this paper. The comments that follow give a summary of previous research procedures and findings.

A 1984 study identified a prioritized list of problems at rural intersections (*2*). The most pressing problems in decreasing order of importance were (a) rural expressways where signals were unexpected, (b) intersections hidden by horizontal curves, (c) rural expressways with heavy truck traffic, and (d) intersections hidden by crest vertical curves. Some other circumstances listed as problems were (a) speed, (b) left-turn traffic, (c) left-turning drivers' misjudgment of speed of oncoming traffic, and (d) high volume of left-turning traffic without left-turn phasing. Also listed were significant sun interference, advertising signs drawing attention away from signals, urban intersections operating near capacity, last car passage at intersection, and long-range visibility. Countermeasures used to reduce problems at these sites in decreasing order of popularity were (a) detector placement and amber time adjustment, (b) activated Red Signal Ahead sign, (c) Prepare To Stop When Flashing signs, and (d) the flashing Signal Ahead sign. The basis for countermeasure installations were rear-end and right-angle accidents, red violations, speed problems, and truck accidents.

Barnack and the New York Department of Transportation's Safety Operations Unit conducted a study to determine the current state of the art in detector placement at traffic-actuated isolated intersections (*3*). At such locations an option or dilemma zone, defined by locations depicting deceleration rates between 12 and 8 ft/sec, catch drivers in the indecision of the amber light indication. The four-lane highway at Route 32 at 335, Albany, New York, was a three-phase, fully actuated controller. The study concluded that rear-end and right-angle accidents increase as detector distance from the intersection decreases.

Agent studied 65 rural high-speed intersections in Kentucky (*4*). Forty-seven intersections were signalized, and 18 were stop sign–controlled. Approach grade and curvature were typically level and straight. Approach and intersection features such as phasing, lighting, signing, geometry, signal timing, and speed limits were all tabulated and summarized in tables. Important characteristics and features for a safe intersection were (a) adequate sight distance, proper change intervals, and highly visible signal heads; (b) a red clearance interval for both through phases of traffic; (c) a green extension system for the major roadway to consider left-turn phasing; and (d) an advance warning sign used at less safe intersections.

A 1975 study conducted by the Stanford Research Institute (SRI) gathered data from 558 intersections coupled with accident reports on the 4,372 accidents that occurred at those locations (*5*). The intersections studied were taken from three San Francisco Bay Area counties: Alameda, San Mateo, and Santa Clara. The study covered the period between June 1973 and June 1975. SRI recommended the following countermeasures for the accident-related features at intersections in decreasing order of significance:

1. Sight distance must be unobscured on all approaches to an intersection [higher average daily traffic (ADT) requires greater sight distance].
2. For street signs, black lettering on a white background is more effective than reflective lettering on a dark green background, which is described and recommended in the *Manual on Uniform Traffic Control Devices* (*6*).
3. Intersections with left-turn lanes and ADT between 10,000 and 20,000 tend to have higher accident rates than equivalent intersections without left-turn lanes.
4. Intersections lacking raised pavement markers along the centerline striping are less safe than those with them.

A 1976 study attempted to develop guidelines for improving intersection geometrics and safety at rural municipalities (*7*). Data from more than 300 intersections in 42 towns in Virginia were included in the study. Accident data at these locations were taken for 24 months and included 2,300 accidents. The study concluded that poor driver sight distance on any of the approaches to an intersection tends to correlate with a higher-than-normal angle accident rate and that the standardization of signal displays should reduce accidents at high accident locations.

A 1980 study by Van Maren examined 61 rural multilane intersections in Indiana (*8*). Geometric and accident data were taken from each site and studied from 1974 through 1976. Multilane intersections in Indiana were a serious safety problem, having 25 times as many accidents per intersection as the average rural intersection. These intersections also had 5 percent of the accidents but accounted for only 1 percent of the rural intersections. The study concluded the following about multilane rural signalized intersections with high accident rates.

1. The presence of stop-line pavement markings on both the major and minor roadways decreases the accident rate.
2. The right-angle accident rate was reduced by route markers or advance warning signs, the route markers being the more effective of the two.
3. The presence of a horizontal curve on the roadway and a skew of the two roadways increase the accident rate.

A fairly recent study examined the accident rates related to traffic signal clearance intervals at high-speed (45 mph or greater) signalized intersections throughout the United States (*9*). Regardless of how the accident rates were calculated, it was determined that intersection groups with clearance intervals requiring a deceleration rate of greater than 10 ft/sec to stop in time for red had higher average accident rates than did intersections with longer clearance intervals.

A research investigation lead by Hammer studied the effectiveness of traffic signals in reducing accidents (*10*). Ninety of the California intersections were modified, and 202 intersections were new. A before-and-after study method was used.

Findings and recommendations due to the study included the following:

1. Multiphase signal operations should be provided as well as separate storage slots for high-volume left-turn movements.
2. Twelve-inch lenses should be used for mast arm–mounted installations.
3. Signalized intersections with a base accident rate of less than or equal to 0.6 accidents per million vehicle-mi will not experience a decrease in the accident rates due to improvements.
4. When left-turn channelization is signalized at a three-leg intersection, left-turn channelization should also be provided on the main line.

The main objective of a 1985 study was to review current traffic engineering practice relative to accident countermeasures at high-speed signalized intersections (*11*). Through its literature review and questionnaire the study found the following:

1. There were high accident rates at hidden intersections or rural expressways where intersections are unexpected.
2. At such intersections rear-end accidents were the most pressing problem; right-angle accidents and red violations were also of concern.

The study determined that the most dynamic traffic-actuated devices are the flashing Red Signal Ahead sign and its variations, the Prepare To Stop When Flashing sign, and flashing strobe lights.

A study by Lyles evaluated the effectiveness of advance warning signs at unsafe or hazardous intersections (*12*). The study concluded that some sign messages and configurations have more recognition and generate more motorist recall than others.

DATA FILES

To analyze intersection characteristics with regard to safety at HSISIs, a sample representative of all types and configurations of California HSISIs was needed. A list of criteria was established to ensure that the final data would be representative of HSISIs in California and be suitable for statistical analysis. The criteria used to develop the preliminary list of HSISIs were the following:

1. The intersection should be in a rural location;
2. The intersection must contain at least one approach with a posted speed of 50 mph or greater;
3. At least one of the approach legs must be a gate highway; and
4. The intersection must be signalized and have sufficient accident data for analysis.

The intersection selection process began with establishing a preliminary list of all intersections meeting these criteria. From this preliminary list of candidate intersections, 40 were chosen for in-depth study. A detailed description of this selection process is given in the following paragraphs.

Candidate Intersections

The preliminary list of candidate intersections was collected in two ways. The first method was to obtain a list of candidates through correspondence with signal design and operation engineers from the 12 Caltrans districts; a survey was sent to the districts to create this list. The survey responses yielded a list of approximately 80 candidate intersections. These intersections represented all Caltrans "types" of intersections: rural, suburban, and urban.

The second method of obtaining HSISI candidates involved a computer search. The computer search extracted data from the TASAS data base owned, maintained, and operated by Caltrans. The search in the statewide file was prompted with the keywords "rural," "outside city," and "signalized intersections." The computer compilation revealed 54 intersections not included in the district survey responses. Each district was contacted to determine if these additional intersections fit the criteria previously stated. Intersections that did fit these criteria were added to the preliminary list, and those that did not qualify (i.e., speed zones less than 50 mph) were discarded. From these two methods the preliminary list of 94 candidate intersections was established.

Accident Index

The next step in the selection process was to reduce the preliminary intersection list to include 40 sites as specified in the scope of the study. Forty intersections provided a sufficient data base while still being within the resources available to the project. Since the goal of the analysis was to determine how variables affect safety at HSISIs, locations with high and low accident rates were chosen for analysis so worst- and best-case intersections would be included in the sample.

An accident index was created by taking the candidate intersection's ratio of actual accident rate to expected accident rate. The expected accident rate is a Caltrans-determined rate considering average accident rates for intersections of the same type that are classified by number of lanes, type of terrain, average highway speed, and location, that is, two-lane highway in rolling terrain with approach speeds greater than 55 mph in a rural location. The candidate intersections were listed by descending accident index values for both rural and suburban classified intersections. For the 40 chosen sites they included the 20 intersections with the highest index and 20 with the lowest index. An equally important factor in yielding statistically meaningful results was to use sites with sufficient accident histories. The time frame for the accident rates ranged from 2 to 8 years. This long time frame helped reduce the regression-to-the-mean problem. All intersections with less than 2 years of signalized accident data were discarded. There was one exception to this. The intersection at Highway 99 and Garner Lane in Butte County with 1 year of accident data was added to the 40 chosen intersections to make the total used in the study 41. Its nearness to California State University campus in Chico was valuable during preliminary development of the data base, since short trips to the site aided in development of the field data collection procedures.

Location Classification

The last criterion to consider for intersection selection was location classification. According to the TASAS data base, there are three classifications of intersection location: rural, suburban, and urban. These classifications are based on nearby population densities and proximity to city limits. Since our preliminary list of 94 candidate intersections did not contain 41 rural classified intersections with sufficient signalized data, we had to consider other classifications. The project's goal was to analyze isolated intersections, so urban classified intersections were discarded, even though they might have met the approach speed criteria. The remaining rural and suburban classified intersections were used to devise the final list. The only changes made to this list were when field visits revealed that the intersection fell short of the necessary criteria (e.g., all approach speeds below 50 mph).

Final List

Creating a comprehensive list of variables to describe adequately the safety features of the 40 HSISIs was an essential part of the project. An effort was made to collect all data from reliable sources. Most of the data were collected from signal design and operations offices in the 12 Caltrans districts, Caltrans headquarter offices in Sacramento, statewide county public works offices, and field visits to the chosen intersections.

The data base consisted of information describing 41 intersections across California. Each intersection had from one to three accident periods used for analysis; no accident period was longer than 6 years or shorter than 2 years. Accident periods were chosen to start and end with a change in conditions at the intersection. A unique variable was created within the data base for use in the statistical analysis: the approach accident rate. Its units are total number of accidents involving vehicles on that approach per million entering vehicles on that approach. Left-turn, rear-end, right-angle, fatal, and injury accident rates were similarly calculated on an approach basis and included in the data base. When calculating approach accident rates, accidents involving vehicles on two approaches (i.e., right-angle and left-turn accidents) will be counted twice, once each on the two concerned approaches. This method of calculation results in one intersection accident's being counted on two approaches. This occurs for left-turn and right-angle accidents only, because rear-end accidents involve vehicles on one approach only. Caution was therefore used in using approach accident rates, and comparisons between approach accident rates and intersection accident rates are not useful. One record of data represents one time period for a particular approach at an intersection. There were 6 three-leg intersections and 35 four-leg intersections. This data amounted to 271 records, each with 102 fields. Each record contained data on one approach to one HSISI over a period during which geometric, traffic control, and operating conditions remained unchanged.

Each record contained fields arranged into the following groups of data: intersection location information, intersection accident data, approach accident data, signalization data (by approach), and signing and lane marking data. All collected data were tallied onto field collection sheets and manually transferred into a dBase III Plus file.

Also defined was a high-speed approach. A variable was created in the data base that contained the values of 1 for a high-speed approach and 0 for a non-high-speed approach. An approach was considered high speed if any of the following criteria were met: (a) it had an observed mean speed of 45 mph or greater; (b) it had an observed 85th-percentile speed of 50 mph or greater; (c) it was a state highway approach with no posted speed limit; or (d) it had a posted speed limit of 50 mph or greater. Exceptions occurred when none of these criteria was met, but the site visit revealed an approach with high-speed characteristics, that is, a rural location with no traffic control within 5 mi of intersection and high-speed traffic.

Following are statistics summarizing the accident history of the 41 intersections in the data base. There were 271 approach accident periods with 1,918 total accidents. There were 19 fatal, 795 injury, 1715 multivehicle, and 203 single-vehicle accidents. There were also 282 accidents in wet conditions and 457 nighttime accidents. Types consisted of 402 right-angle, 662 rear-end, and 326 left-turn accidents. A total of 1,395 persons were injured, and 21 persons were killed.

STATISTICAL ANALYSES

Standard statistical techniques were used and included difference in means test, difference in proportions test, analysis of variance, simple regression analysis, stepwise regression analysis, and Pearson Type III correlation analysis. For the last four analyses, SAS, which read the dBase file, was used. The data were assumed to meet the requirements for the statistical tests (i.e., normally distributed variances about the mean for regression analysis and hypothesis testing). The intended use of regression analysis was to aid in the identification of relationships between variables and accident rates. Because the use of regression was limited to linear models, better, nonlinear models could probably be developed that would describe better the relationship between some variables and approach accident rates. Since our project goal was not to predict accident rates, the regression models discussed and presented should not be used in this manner. The regression models are, however, useful in establishing that a relationship does in fact exist between an independent variable and the approach accident rate. The level of significance used throughout the statistical analysis was 5 percent.

A word of caution should be given concerning the use of comparative analysis (hypothesis testing) for data analysis. Comparative analysis will reveal statistically significant differences between groups of data. These analyses, however, do not necessarily suggest or determine the reason for these differences. Great caution must be used in assigning the cause for these differences. If care is not taken, some invalid conclusions could be drawn about the data, conclusions that are in fact statistically supported but not based on sound judgment. An example of this might be concluding that advance warning signs on approaches cause accidents. Suppose that statistical analysis revealed significantly higher accident rates on approaches with advance warning signs than approaches without advance warning signs: to assume that the signs caused the higher accident rates, when more likely the accident rates were high before the sign were installed, and the signs were ineffective, would be a poor assignment of causality even though it is statistically supported.

The first stage of the statistical analysis was to do a Pearson Type III correlation analysis between all variables in the data base. This exposed all of the significant correlations that deserved attention of further statistical analysis. The next stage of the analysis was to compare HSISIs in California results to previous research findings. This is done later in this paper. Similarities between variables in this study with previous findings validate the accuracy and completeness of the data base.

Analyzing intersections by approach may reveal relationships that may not be apparent when analyzing an intersection as an entity. For example, it is possible that an intersection with three high-speed approaches could have one approach with many accidents and two approaches with few accidents, therefore appearing to be an average intersection of that type. If higher-than-average accident rates could be determined on an approach basis, then these approach types could be identified for individual attention. The results of these statistical tests previously mentioned are discussed in the following.

Significant Correlations

One of the first steps in the statistical analysis was to do a Pearson Type III correlation, at a 5 percent level of significance, on all data base variables versus approach accident rates. These correlations were first done on all 271 approaches and then again on the 190 high-speed approaches. These correlations were used to identify the variables for further analysis with the results contained in Tables 1 and 2 and briefly discussed later.

Advance Warning Flashers

An advance warning flasher (AWF) in this study was considered to be a single entity consisting of an advance warning sign such as Signal Ahead in conjunction with at least one 12-in. flashing yellow beacon. An advance warning sign (AWS) is the same as an AWF but does not contain the flashing yellow beacon. Approaches in this study had the following groups represented: no advance warning; an AWF; an AWS; and both an AWF and an AWS at different locations on the approach.

- High-speed approaches with AWFs had significantly lower total, left-turn, right-angle, and rear-end approach accident rates than those without AWFs.
- High-speed approaches with AWFs had significantly lower ratios of nighttime accidents than those without AWFs,
- High-speed approaches without AWFs had no significant difference in accident rates compared with non-high-speed approaches without AWFs.
- The number of flashing lights per AWF sign, the distance from the intersection centerline to the AWF, and the location of the AWF (one side, both sides, or suspended above the roadway) did not have a significant effect on approach accident rates on high-speed approaches.
- For the location of flasher variable—on one side of the roadway only, both sides of the roadway, and suspended above the roadway—there were no significant differences between the approach accident rates among any combination.
- High-speed approaches with AWFs and AWSs did not differ significantly from high-speed approaches with AWFs, but without AWSs.

Advance Warning Signs

The statistical analysis conducted several tests to evaluate the effectiveness of AWSs.

- Accident rates on non-high-speed approaches with AWSs were significantly higher than non-high-speed approaches without AWSs.
- Similarly, high-speed approach accident rates on approaches with AWSs are significantly higher than approach accident rates on high-speed approaches without AWSs.
- A comparison between high-speed approaches with AWFs and AWSs versus high-speed approaches with AWSs only revealed no significant difference as well.
- Approach accident rates for high-speed approaches with AWSs only were significantly higher than accident rates on high-speed approaches without either AWSs or AWFs.

Table 3 shows the mean approach accident rates, standard deviations, and sample size for each of the groups. Approaches are listed according to increasing complexity of advance warning device.

Detector Placement

The detector setback—distance from the loop detector to the center of the intersection in feet—was one of the data base variables. Regression analysis showed that a more significant model results when considering high-speed approaches rather than all approaches. Table 2 shows the regression analysis for the model approach accident rate as a function of detector setback.

Left-Turn Movements

Two variables in the data base pertained to left-turn movements. One was the observed number of left-turn lanes present on the approach and the other was the presence or absence of a separate left-turn phase. Of the 190 high-speed approaches, 126 approaches had left-turn lanes and left-turn phases, 40 approaches had neither lanes nor phases, and not 1 approach had a left-turn phase without a lane. Looking at high-speed approaches only, there were significant correlations between both variables and all types of approach accident rates, that is, left-turn, right-angle, rear-end, and total (approach). About 90 percent of the approaches with left-turn lanes had a separate left-turn phase also. Considering only the two left-turn independent variables, stepwise regression revealed that for high-speed approaches the presence of the left-turn phase variable was the only variable significantly correlated to approach accident rates.

A test of the difference in means between the approach accident rates for two groups was compared. Approach accident rates on high-speed approaches without separate left-turn phases were significantly higher than approaches with

TABLE 1 Summary of Test of Difference in Means

Control	MAAR	SD	n	Range	Signif Diff	LoS%
w/o AWF	2.54	2.95	99	0.1 - 12.9	w/o > w/	0.02
vs						
w/ AWF	1.20	1.15	91	0.0 - 7.28		
	MLTAR					
w/o AWF	0.71	1.37	99	0.1 - 12.9	w/o > w/	0.02
vs						
w/ AWF	0.21	0.35	91	0.0 - 1.78		
	MRAAR					
w/o AWF	1.05	1.73	99	0.0 - 11.1	w/o > w/	0.03
vs						
w/ AWF	0.41	0.51	91	0.0 to 2.42		
	MREAR					
w/o AWF	0.37	0.34	99	0.0 - 1.85	w/o > w/	0.44
vs						
w/ AWF	0.25	0.26	91	0.0 - 1.17		
	MPN/D					
w/o AWF	0.43	0.44	99	0.0 - 2.50	w/o > w/	3.14
vs						
w/ AWF	0.30	0.35	91	0.0 - 2.50		
	MAAR					
High-speed approaches	2.54	2.95	99	0.1 - 12.9	NO	25.5
vs						
Non high-speed approaches	2.27	2.46	81	0.0 - 13.3		
	MAAR					
w/ AWF & AWS	1.57	1.17	14	0.18 - 3.3	NO	9.68
vs						
w/ AWF	1.13	1.14	77	0.0 - 7.3		
	MAARNH					
w/ AWS	2.64	2.53	43	0 - 11.6	NO	7.35
vs						
w/o AWS	1.85	2.34	38	0 - 13.3		
	MAAR					
w/ AWS	2.65	2.92	99	0.1 - 12.9	w/o < w/	0.01
vs						
w/o AWS	1.09	1.07	91	0.0 - 7.28		
w/ AWS	2.83	3.10	85	0.1 - 12.9	NO	6.18
vs						
w/ AWS and w/ AWF	1.57	1.17	14	0.18 - 3.34		
	MAAR					
w/ AWS	2.83	3.10	85	0.1 - 12.9	w/o < w/	0.87
vs						
w/o AWS & w/o AWF	0.84	0.48	14	0.21 - 1.52		
	MAAR					
w/o Left-turn phase	3.61	3.37	64	0.21 - 12.9	w/o > w/	0.01
vs						
w/ Left-turn phase	1.04	0.77	126	0.00 - 4.28		
	MREAR					
w/o Left-turn phase	0.41	0.39	64	0.0 - 1.85	w/o > w/	0.26
vs						
w/ Left-turn phase	0.26	0.25	126	0.0 - 1.17		
	MLTAR					
w/o Left-turn phase	1.08	1.62	64	0.0 - 7.84	w/o > w/	0.01
vs						
w/ Left-turn phase	0.16	0.23	126	0.0 - 1.11		
	MAAR					
Flat median	2.28	2.78	117	0.00 - 12.9	Flat > Raised	0.05
vs						
Raised median	1.30	1.34	73	0.11 - 7.28		

Signif Diff = Statistical significance exists at 5% level
LoS% = Level of significance in percent
MAAR = Mean total approach accident rate on high-speed approaches
MLTAR = Mean approach left-turn accident rate on high-speed approaches
MRAAR = Mean approach right-angle accident rate on high-speed approaches
MREAR = Mean approach rear-end accident rate on high-speed approaches
MPN/D = Mean proportion of night to day accidents on high-speed approaches
MAARNH = Mean total approach accident rate on NON high-speed approaches
AWF = Advance warning sign accompanied by a flashing beacon
AWS = Advance warning sign

TABLE 2 Summary of Regression Analysis

Indep. Variable	Depend. Variable	Parameter Estimate	t-Statistic Value	Obs	Probability F>F.05	R^2
AAR				91	64.7	1.9
	Type of AWF *	NS	NS			
	Location of AWF *	NS	NS			
	No. Lights per AWF	NS	NS			
	Dist to AWF	NS	NS			
AAR				190	0.01	8.4
	Intercept	3.36	8.69			
	Detector SetBack	-0.004	-4.16			
AAR				190	0.01	26.3
	Intercept	3.61	200			
	Lt-Trn Phase *	-2.57	67.2			
	No. Lt-Trn Lanes	NS				
AAR				190	0.17	6.57
	Intercept	2.46	117			
	Raised Median *	-0.87	6.30			
	Median Width	-0.04	4.91			
AAR				271	0.01	5.67
	Intercept	2.81	11.5			
	Paved Shoulder Width	-0.19	-4.02			
AAR				190	0.01	10.2
	Intercept	3.24	9.76			
	Paved Shoulder Width	-0.27	-4.63			
AARAA				190	0.01	14.0
	Intercept	2.65	13.4			
	No. BackPlates	-0.67	26.3			
	No. Thru Faces	0.60	9.4			
	No. Mast Arm Faces	NS				
	No. 12" Faces	NS				
AARNHS				81	0.11	12.7
	intercept	-1.62	-1.4			
	inter-green time	0.85	3.4			
AAR				190	0.15	5.24
	intercept	5.40	4.9			
	inter-green time	-0.61	-3.2			

AAR = Approach accident rate for high-speed approaches
AARAA = Approach accident rate for all approaches
AARNHS = Approach accident rate for non high-speed approaches
AWF = Advance warning sign accompanied by a flashing beacon
Obs = Number of observations in data set
F = F-ratio test value for model
F.05 = F-ratio at 5% level of significance
R^2 = Coefficient of determination of model in percent
t-Statistic = Significance test of independent variable, ≥ 1.65 to be significant
NS = Not significant for entry into model
* = Indicates a dummy variable (Present = 1, Not present = 0)

TABLE 3 Summary of Advance Warning on HSISI Approaches

Type of Advance Warning on Approach	Mean Approach Accident Rate	Standard Deviation	Observations
1. None	0.84	0.48	14
2. AWS's	2.83	3.10	85
3. AWF's	1.13	1.14	77
4. Both AWS's and AWF's	1.57	1.17	14

left-turn phases. The test also showed that left-turn and rear-end accident rates were also significantly higher on approaches without left-turn phases.

Median Type and Median Width

The type of median and the width of the median in feet on an approach did not show significant correlation (level of significance less than .05) with approach accident rates for all approaches, but it did correlate significantly for high-speed approaches. A stepwise regression analysis for high-speed approaches, taking into account median type and width, revealed that the type of median explains more of the variation in approach accident rates than does the width of the median. Table 2 shows the stepwise regression parameter estimates. This is supported by Table 1, which shows the test of the difference in means between approach accident rates for two high-speed approach groups: raised medians and flat medians. The table shows that accident rates for approaches with flat medians are significantly greater than approach accident rates for approaches with raised medians.

Paved Shoulder Width

The data base contained a variable paved shoulder width that revealed the width of the paved shoulder (in feet) measured from the right edge of the outside lane line to the edge of the paved roadway. In considering all 271 approaches, analysis of variance shows that the approach accident rate is a negative function of paved shoulder width. This shows that the wider the paved shoulder, the lower the approach accident rate. Table 2 shows the regression model results for approach accident rate as a function of paved shoulder width. The correlation of approach accident rate and paved shoulder width is greater for the 190 high-speed approaches. Table 2 shows the regression model for high-speed approaches only.

Signal Hardware Configuration

The four variables that constitute signal hardware configuration are discussed in this section. Initial analysis showed no significant correlations among signal hardware configuration variables and the 81 non-high-speed approaches; therefore, the remaining analysis is in regard to the 190 high-speed approaches only. The four variables with their summary of statistics are (a) total number of signal faces with backplates; (b) number of through signal faces; (c) total number of mast arm–mounted signal faces; and (d) total number of signal faces with 12-in. lenses. Stepwise regression revealed that the most significant variables that affect approach accident rates on high-speed approaches are the total number of signal faces with backplates followed by the number of through faces on the approach. Neither of the remaining two variables was significant enough for inclusion in the model. Table 2 shows the final model's estimated statistical parameters. The model shows an inverse relationship between the number of signals with backplates and approach accident rates. The model also shows a direct relationship between the number of through faces on the approach and approach accident rates.

Intergreen Time

An intergreen time variable equal to the sum of the yellow clearance interval plus the all-red time was created from the data base. A correlation analysis was run showing Pearson correlation coefficients between approach, left-turn, right-angle, and rear-end accident rates versus intergreen times. This correlation was run on three groups: all approaches, non-high-speed approaches, and high-speed approaches. Table 4 shows Pearson Type III correlation coefficients and their corresponding levels of significance. The results indicate a significant negative correlation between intergreen time and approach accident rates on high-speed approaches, a significant positive correlation between intergreen time and approach accident rates on non-high-speed approaches, and relatively little correlation between intergreen time and approach accident rates for all approaches. Two models with approach accident rate as the dependent variable and intergreen time as the independent variable were developed for high-speed and non-high-speed approaches. The results of these two models are shown in Table 2, which shows that approach accident rates are a negative function of intergreen time for high-speed approaches and are significant. It also shows that approach accident rates are a positive function of intergreen times for non-high-speed approaches and, again, are significant.

DISCUSSION OF RESULTS AND CONCLUSIONS

The purpose of this section is to present and discuss the results of the statistical analysis, to compare the results to literature

TABLE 4 Pearson Correlation Coefficient Values for Intergreen Time over Level of Significance

Inter-Green Time On:	Approach Accident Rate	Left-turn Accident Rate	Right-angle Accident Rate	Rear-end Accident Rate
High-speed approaches $n = 190$	**-0.23*** 0.15%	**-0.26** 0.03%	**-0.23** 0.14%	**0.10** 15.7%
Non high-speed approaches $n = 81$	**0.36** 0.11%	**0.20** 7.80%	**0.35** 0.16%	**0.26** 2.06%
All approaches $n = 271$	**-0.06** 31.2%	**-0.11** 6.57%	**-0.07** 23.5%	**0.17** 0.53%

*Pearson Correlation Coefficients in Bold Type; given in percent.

search findings, and to suggest which improvements to HSISIs might reduce approach accident rates. All of the following suggestions are based on the assumption that improvements should be considered on high-speed approaches with substantially higher than average approach accident rates over a sustained time period. Approaches with approach accident rates near or below average cannot be expected to experience accident rate reductions from suggested improvements. Approaches that benefit from improvements will most likely see a decrease in the approach accident rate over time.

AWFs seem to improve the safety of an approach to an HSISI, which is in agreement with Eck and Sabra, who found the flashing Red Signal Ahead and its variations the most effective advance warning signs (*11*). Because of these intersections' isolation, motorists tend to drive with less attention on the roadway than they would where a series of signalized intersections exists. Apparently, a flashing light draws the attention of drivers.

AWSs with no flasher have traditionally been installed on approaches to intersections with high accident rates. According to Lyles, the traditional "black cross" sign and the Vehicles Entering sign are less effective AWSs than signs accompanied by a flasher (*12*). Similarly, our analyses indicated that AWSs had little affect on approach accident rates, which may be due to the excessive use of warning signs. This excessive use may reduce a sign's impact on drivers. It was assumed that advance warning devices were installed on approaches where higher-than-average accident rates either existed or were expected and would explain the low approach accident rates associated with approaches with no advance warning.

In 1982 Barnack found that rear-end and right-angle accidents decrease as the distance from the detector to the intersection increases (*3*). Our results support those findings for approach accident rates, most significantly the approach right-angle accident rates followed by left-turn rates. The rear-end accident rates appeared to be unaffected.

An intergreen variable defined as the sum of the amber and all-red time was used to evaluate clearance intervals. A study in 1985 by Zador et al. determined that intersections with short clearance intervals are statistically correlated with higher-than-average accident rates (*9*). Similarly, our data showed that intergreen interval lengths correlated negatively with approach accident rates.

The two variables in the data base dealing with left-turn movements on an approach were the presence or absence of a left-turn phase and the presence or absence of a left-turn lane. This analysis suggested that the presence of a separate left-turn phase appeared to reduce approach accident rates at HSISIs, which is consistent with the findings of Agent (*4*). He found that left-turn phasing tends to reduce accidents between left-turning vehicles and opposing traffic. Rear-end accident reduction, directly associated with the existence of a left-turn lane, was also lower; whereas left-turn accidents, more related to the existence of a phase, were observed to be less frequent as well. David and Norman recommended that left-turn lanes should be added to an intersection only when traffic volumes warrant installation, not specifically to reduce accident rates (*5*). If a left-turn lane is added to an intersection, a separate phase for left-turns should also be added.

The type and width of a median separating directional traffic streams at an HSISI seem to influence approach accident rates. Approaches with raised medians have approach accident rates about 40 percent lower than approaches possessing medians level with the travel lanes. Wider medians generally have lower approach accident rates than narrow medians. Since widening a median may necessitate acquiring right-of-way or reducing lane and shoulder widths, installing a raised median may be a better choice for modifying medians. Installing a raised median in combination with a separate left-turn lane is attractive, because it would provide a protected left-turn pocket and would also maximize the modification effort. Installing a raised median may cause problems in colder climates where snow removal is frequent.

The paved shoulder width within sight distance of the intersection appeared to be directly related to approach accident rates. This may be an effective accident countermeasure because widening the paved shoulder may increase sight distance on an approach, and it is an easier approach modification for most rural intersections than some other improvements would be. Although not directly related to shoulder widths, providing adequate sight distance on an approach to an intersection was recommended by Hanna et al. (*7*), David and Norman (*5*), and Agent (*4*).

Signal equipment features, the number of backplates, and the number of through faces on the approach were all related to the approach accident rates at HSISIs. The addition of backplates must make signal face indications more visible to the oncoming driver, because they apparently reduced approach accident rates. Agent stated that highly visible signal heads are an important feature for a safe intersection. Approach accident rates seemed to increase as the number of through faces on the approach increases. An explanation for this may be that high numbers of through signal faces have been installed at complex intersections at which approaches tend to have higher accident rates; consequently, a positive correlation may be expected. Therefore, nothing conclusive can be said about the number of signal faces on an approach.

In conclusion, several actions should improve safety at HSISIs. The following actions should bring about reductions in approach accident rates at HSISIs identified as high accident locations. These issues should also be considered for new signal installations.

1. AWSs with flashing beacons are the most effective type of advance warning device.
2. A flashing beacon should be added to an AWS to improve its effectiveness.
3. Detectors in advance of intersections should be provided.
4. Signal heads should have backplates.
5. A separate left-turn phase should be added to an approach with an existing left-turn lane, and a left-turn lane should be installed only if justified by left-turn accidents or traffic volumes.
6. Wide, raised medians should be provided.
7. Widening the paved shoulder may be an effective improvement to use in conjunction with installation of an AWF or a left-turn lane and phase.
8. By providing channelization, left-turn phasing, and medians the roadway will take on the appearance of an urban street. Signals on urban streets are expected by motorists.
9. A demonstration project should be implemented on higher-speed approaches with higher accident rates to verify these conclusions.

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DISCUSSION

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It is indeed a great temptation when confronted with an accident data base with more than 100 data elements to run the data through a gauntlet of statistical tests in order to ascertain some relationship between the data elements and the causes of accidents. The authors are not the first—nor, unfortunately, will they be the last—to analyze mechanically large numbers of accident data without apparent understanding of the relationships of the data elements to each other (and not just the physical data elements) and without understanding of the quality control problems of even the finest data bases. They then compound their analysis by considering only the best- and worst-case scenarios in their study design, thus introducing a considerable bias into their analysis. Some of the recommended practices in the conclusion of the study represent sound engineering practice, but others—such as detector placement and use of raised medians—are supported only by a mechanical relationship of accident data elements and do not necessarily represent sound practice.

This discussion focuses on two main areas of concern: (a) the flaws in the study design and (b) the larger issue of using accident data in safety and operations research.

STUDY DESIGN

A common flaw in most safety analyses is that the study is focused on the "high accident locations" since those are usually identified as the problem. Much work has been done in recent years on the problem of regression-to-the-mean and its effect on accident studies. The use of longer analysis periods lends a little, perhaps, to the stability of the data, yet the number of accidents is still a statistic and that statistic is still subject to regression-to-the-mean if the highest (or lowest) accident sites are used in the analysis. The authors mention that the 41 intersections (44 percent of the candidates) used in the study represent 93 percent of the range of intersection indexes and therefore represent good coverage for the purposes of the study. Actually, this means that only 7 percent of the range of intersection indexes represents 56 percent of the candidate intersections. If the middle group had been used instead of the two extreme groups, the study intersections might have presented a more representative view of relationships between features and safety, assuming that it is possible to establish this relationship through accident data.

The accident data used in the analysis span different time periods for each approach or approach condition and cover an overall range of 11 years. A lot of things can happen over 11 years. Accident reporting climates and policies change; vehicle designs change; driver expectations and driver habits change; traffic operations and levels of congestion change—some very quickly in a state such as California. The authors took some of the physical changes into consideration by creating a new approach record when there was a change in one of the variables under study. This analysis method assumes that only those variables under study affect safety at the intersection. The other artifacts of time, however, have a much greater effect on the number of reported accidents than any of the physical elements of the intersection.

There are 271 accident approaches (records) used in the study. These contain 1,918 reported accidents, or only about 7 accidents per record. This means that there are only one or two of any particular accident type (e.g., right angle, left turn) per average approach. There is, however, no truly average intersection. The study base contains the best and the worst intersections, so there is a fairly large difference in the number of accidents per each approach record. Many of the best-case intersection approaches probably have only one or two accidents and have no left-turn or right-angle accidents, for example. These zero-case scenarios are associated with the physical conditions at the intersections and the associations

are assumed to have a cause-effect relationship. In fact the relationship is due to statistical artifacts or other environmental circumstances.

The list of study intersections in Section 4.0 was quite revealing. One factor that stood out at a glance was the apparent difference in the number of years that the best- and worst-case intersections had been signalized. The 20 highest accident intersections (omitting the one that had been included for convenience) had been signalized for an average of 12 years. The lowest accident intersections had been signalized for an average of 7½ years. This implies that there may be a vast difference in the operational and environmental factors for each group, which have a far greater impact on safety than the design factors being studied.

In the discussion of results and conclusions, the authors recommend practices that they believe are supported by their study. Some of these practices are supported by other research or by sound engineering judgment. Two of the recommendations, however, are somewhat troublesome. The authors recommend the installation of a raised median when a left-turn lane is added. Many highway agencies have had bad experiences with curbs and raised medians in high-speed areas. Raised curbs violate the clear roadside concept and can cause vehicles to vault and overturn when vehicles strike them at high speeds. Perhaps the relationship between flat medians and increased accidents was due to higher accident rates in high-volume areas with narrow or painted medians. The environmental and operating conditions for those approaches with raised medians are probably much different than those with flat medians. The authors state that "caution should be used" in drawing conclusions from the analysis when the results don't make sense (e.g., increased accident rates where advanced warning signs are present as opposed to where they are not). Perhaps caution should also be used in drawing conclusions from the data even when they do not necessarily violate common sense. The authors also recommend the placement of detectors "as far from the intersection as design standards will allow" whatever that means. In general, detectors on high-speed approaches are indeed farther from the stop line than detectors on low-speed approaches. Detector placement is governed primarily by approach speed, detector design and controller settings of vehicle extension times, passage times, and intergreen times. The authors suggest that moving detectors back 100 ft can reduce approach accident rates by 10 percent. I would suggest that "caution should be exercised" in signal design before accepting this premise, which is based solely on some mechanical correlation of accident data elements.

GENERAL USE OF ACCIDENT DATA

About the only thing one can conclude for certain when looking at a computer printout of accident data at an intersection is that some set of traffic events occurred somewhere, sometime. Hopefully, the events that are coded and recorded for the location of interest did actually occur there and not somewhere else. The problems of accident data quality are nearly universal and are too numerous to be mentioned here. In my own considerable experience in making accident studies, I found it not just useful but absolutely essential to pull hard copies of the reports from the microfilm files in order to make an intelligent assessment of the possible safety problem at a location. If the authors intend to do follow-up studies as they indicate, I would suggest that they also pull copies of the reports and reconstruct a data base that has been sanitized of as many reporting and recording errors as is possible to find. They may be astounded to find how many errors reside in accident data bases that are generally regarded as being complete and of high quality.

Some researchers have attempted to find out how many accidents go unreported. No one has come up with a definitive estimate yet, but strong evidence suggests that most accidents are never reported to anyone. This, of course, can lead to a great deal of bias in reported accidents. How well do accident data bases represent the real safety picture? What kind of meaningful conclusions can be drawn from a data base that is heavily biased even before the study begins? In fact, the more basic question to be asked is, How well does accident frequency or rate represent the relative safety of a location? Accidents at any location must be considered as very rare events when compared with the number of vehicles passing that location. Accidents are usually due to driver inattentiveness, impairment, inexperience, or plain bad judgment. The accident reports often do not reflect that, and traffic control devices and geometric design problems can become convenient methods of avoiding culpability for the accident. No one will argue that improved signal conspicuity is a bad idea, but the safety relationship between signals with 8-in. lenses and those with 12-in. lenses, or between signals with and without backplates, is very difficult to assess and probably cannot be assessed properly through accident studies.

Because the inadequacies of accident data are painfully apparent, much attention has been given to "accident surrogates," most notably, traffic conflicts. There have been two main drawbacks in the United States to the more extensive use of these surrogates. One reason is that the data must be collected, and accident data are readily available in neat computer format. The other reason that practitioners have been reluctant to use surrogates is that good strong relationships between the surrogate and the hard accident data frequently do not exist. The safety community is guilty of being locked into an accident mind-set. We are all concerned with the terrible toll of traffic accidents, and political pressure is brought to do something to reduce the number of accidents. We collect and analyze accident data to see how well our efforts are paying off. I suggest that reported accidents have only a very casual relationship to safety and that operational measures that we regard as surrogates are far better indicators of safety than accidents. In fact, I would even venture that operational measures are the true indicators of safety and that accidents are really the surrogates that are difficult to correlate to safety.

DISCUSSION

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Laboratory and field studies serve complementary purposes and should be performed with program leadership in concert

when affordable. This paper is a field study. The authors take on self-leadership by using the results from some excellent research literature. There is no reference to laboratory studies, probably because there is not much of substance or quantity to refer to; perhaps this is a problem that we have always had in highway research programs.

Some criticism of field studies appears to come from a laboratory orientation, and vice versa. Because of the very nature of field studies, variations among sites in the same category, continuous changes in site conditions over time, restrictions in the acceptability of candidate sites to any study, availability of comparable data, the accessibility of relevant and sensitive measures of performance, and the limited resources available for any comparative study, an academic laboratory approach to field studies should never be considered—and was not in this case.

The general correlational approach used is a good one, and it is apparent that the authors have a better-than-average feel for the advantages and disadvantages of this analytical approach. Multiple regression techniques and bias-checking techniques may also have been of help.

The use of accidents only to represent safety performance is unfortunate, given the many studies available that have successfully employed more active, sensitive, and controllable measures of effectiveness such as erratic maneuvers, approaching speed profiles, speed variances, and encroachments. However, credit must be given for the introduction of a new safety indicator, intuitively derived—the intersection approach accident rate. It appears that the target audience is the administration level, and that this is a usual effort to struggle to make something of accident measures.

When accidents are used as a measure, original reports should be used. Reports should be read and culled. Computerized accident information should not be used for many reasons, two of them being the annual instability of the category definitions and the high error rates inherent in using predetermined categories for ex post facto purposes. The paper does not state how it addressed this problem.

Administrators have traditionally regarded accidents as the ultimate measure of performance of safety programs and have insisted on the use of accident measures in many statistically based comparative studies in the field. However, most researchers who have used accidents in comparative studies and have studied quasiexperimental design and analysis should view accident measures as the lesser of many variables that can be used to show a relationship. Accident measures continue to be used because of the reader market for this information, not because of their inherent value. The disadvantages of using accidents in measures of performance are too numerous to discuss here. However, it should be said that a $1 million analysis in each project more often than not would overcome the more serious defects inherent in accident data collection.

Accident measures used only to describe the problem may play a practical and useful part in better understanding the general nature of conditions at intersections.

AUTHORS' CLOSURE

Most of the excellent comments raised by the discussants were carefully considered and debated among us during the course of the project. We certainly agree that caution should be used in drawing conclusions from the data in this project and, for that matter, all such projects.

Our data base was carefully compiled, checked, and rechecked. We do not claim that it is error-free but are confident that any errors that exist are not substantial. The data were compiled from a Caltrans data base called TASAS. Accident data are coded by location by Caltrans technicians who are experienced in the process and familiar with the highway system. Location errors are minimal; probably fewer occurred than would have had an outside consultant or university employee compiled the data from original collision reports. Also, other coding errors occur—as do officer errors on the original reports.

Certainly, reporting practices and other global changes in highway safety occurred during the 11-year study period. These simply could not be controlled, and we do not claim that the statistically significant findings we make explain all the variation in accident rates. We heartily agree that one or more of the involved drivers must take most of the responsibility for most of the accidents. We did not base any of our findings on a single record of about seven accidents. Instead, we based our findings on accidents grouped for dozens of intersection approaches. The paper clearly presents sample size for each analysis. The comparisons were not necessarily made between the highest-accident-rate intersections and the lowest-accident-rate intersections. Groupings for the difference in means tests, for example, were made on the basis of an independent variable (i.e., presence of warning sign) found to be significantly correlated to accident rate in our entire data base.

We would certainly be interested in using a surrogate for accidents if one were readily available; however, we doubt that a reliable surrogate will be available anytime soon. In the meantime, we suggest that the U.S. Department of Transportation and TRB support the funding of a major comprehensive study that clearly identifies the various limitations of accident data collection and analysis methods. In addition, this study should examine the accuracy effects of these limitations and ways to minimize those effects or to modify accident data to improve accuracy. Transportation professionals would most likely appreciate such information.

We are not "guilty of being locked into an accident mind-set"; we are anxious to involve both accidents and other measures of safety in our future work. We are certainly not alone when we state that at this time we are not ready to accept outright that "operational measures are the true indicators of safety."

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