Abridgment

Flashing Signal Accident Evaluation

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ABSTRACT

In this study the relative accident impacts of flashing signal operation and stop-and-go signal operation in Oakland County, Michigan, were evaluated. Analyses were conducted to determine (a) if an accident problem exists at intersections where signals are in a flashing mode during off-peak, nighttime hours; (b) what levels of accident experience can be expected under different conditions and signal operations; and (c) appropriate criteria for making signal-operation decisions for off-peak, nighttime hours. The results of the study indicated that right-angle accidents are significantly overrepresented at four-legged, arterial intersections when signals are in a flashing mode during nighttime hours. A before-and-after analysis demonstrated that the severity of up to 100 percent of late night right-angle accidents can be reduced by eliminating flashing signal operation, with no significant effect on the frequencies of other accident types. The elimination of flashing signal operation appears to be effective in reducing nighttime, right-angle accident frequency and road agency liability exposure both at individual locations and systemwide. Factors that were found to be related to the level of right-angle accidents at flashing signal locations include (a) intersection type (i.e., three-legged or four-legged); (b) the functional classification of the intersecting roadways; (c) the hourly volume ratio (i.e., main street traffic volume to minor street traffic volume); (d) driver impairment; and (e) time of night. When making decisions regarding signal operation during off-peak, nighttime hours, right-angle accident frequency and rate should be primary factors in the decision-making criteria. Other criteria for making signal-operation decisions are presented for use when conditions favor the occurrence of right-angle accidents but none occurred during the review period.

During off-peak, nighttime periods, traffic signals are often placed on flashing operation (i.e., amber in one direction and red in the other) to reduce delay on the major street approaches to intersections. Although this practice improves traffic flow, flashing operation of traffic signals may have detrimental effects on traffic safety under certain conditions.

An analysis was conducted to determine

1. If an accident problem exists at intersections where signals are placed on a flashing mode during off-peak, nighttime hours;
2. What levels of accident experience can be expected under different conditions and signal operations; and
3. Appropriate criteria for the development of signal-operation procedures during off-peak, nighttime hours.

The relative accident impacts of flashing versus stop-and-go (i.e., standard green-amber-red cycle) signal operation in Oakland County, Michigan, were evaluated. The impetus for this study involved both safety and liability questions. The intent of this study was to determine how the Oakland County Road Commission could improve its liability posture and cost-effectively mitigate potential hazards on the county road system.

The study was conducted in two stages. The first stage involved a before-and-after analysis of accidents at six four-legged intersections where the hours of stop-and-go signal operation had been extended or where flashing operation had been eliminated. The next stage was a comparative analysis (i.e., with-and-without study) of accidents at intersections categorized by signal operation (i.e., flashing versus stop-and-go), by intersection type (i.e., three-legged, four-legged) and by the functional classification of the intersecting roadways.

PREVIOUS STUDIES

The FHWA report entitled "A Study of Clearance Intervals, Flashing Operation and Left-Turn Phasing at Traffic Signals," Volume 3 (1) provides the most comprehensive review of the relative accident impacts of flashing and stop-and-go signal operation. An extensive review of previous research is included in that report.

The primary result obtained in the FHWA study was that the number of right-angle accidents was significantly higher at flashing signal locations than at stop-and-go locations. The results of the FHWA study were used to derive guidelines for using flashing signal operation. A critique of these guidelines is included in this paper.

METHODOLOGY

The first stage of this study consisted of a before-and-after study of six signalized, four-legged intersections. The six study sites for the before-and-after analysis were chosen at random from a listing of pretimed signals where flashing operation had been eliminated. The only restrictive criterion in the selection of the study sites was that accident data be available for 3 years before and after the signal operation change. Paired t-tests were performed for the six study sites to determine if accident frequency and accident rate per million vehicles changed significantly in the after period. Accident types were categorized as right-angle accidents, left-turn accidents, rear-end accidents, and other accidents. An additional 10 intersections, where signals remained on flash operation during off-peak, nighttime hours throughout the study period, were randomly chosen to provide a control group for the before-and-after study and to supplement the analysis of other factors that may have some influence on accident levels. These factors included

1. Hourly intersection traffic volume;
2. Main street hourly volume to minor street hourly volume (i.e., the volume ratio) (2); and
3. Drinking involvement.

The second stage of the analysis consisted of a with-and-without study to compare the mean right-angle accident rates and frequencies per year-hour of flashing signal locations and stop-and-go locations. Flashing signal locations were categorized by intersection type and the functional classification of the intersecting roadways (Table 1).

TABLE 1 Sample Sizes for Flashing Signal Location Categories

	Functional Classification		
Intersection Type	Arterial-Arterial	Arterial-Collector	Total
Four-legged, right-angle	29	17	46
Three-legged, T	22	14	36
Total	51	31	82

For each of these intersection types the mean frequency and rate of right-angle accidents per year-hour were calculated for hours when the signals flash. T-tests were conducted to determine if the means differed significantly from each other and from the mean for the hours of 11 p.m. to 6 a.m. at a sample of 21 four-legged intersections where the signals operate on a stop-and-go basis 24 hr a day. Accident data for 3 years were analyzed for all intersections. The statistical tests were conducted at the 0.01 level of significance.

RESULTS

The results of both the before-and-after study and the with-and-without study clearly indicated that significant reductions in nighttime right-angle accident frequency and rate can be attained by eliminating flashing signal operation at four-legged intersections of two arterial roadways. Four-legged intersections of arterial roadways where signals flash during off-peak, nighttime hours experienced significantly greater frequencies and rates of right-angle accidents than other intersection types. Table 2 gives a summary of the results of the with-and-without study. Other results obtained include

1. The rate of right-angle accidents for volume ratios of 2 to 1 or less was significantly higher than the rate for volume ratios of 4 to 1 or greater at flashing signal locations. This result confirms the findings of previous studies.
2. Hourly intersection traffic volume had a negligible impact on right-angle accident frequency during hours of flashing operation.
3. Drinking involvement was significantly over-represented in right-angle accidents at flashing signal locations.
4. Right-angle accidents at flashing signal locations peaked between midnight and 3 a.m., after which they dropped dramatically. Right-angle accidents at stop-and-go locations peaked between 2 and 3 a.m. (bars close at 2 a.m. in Michigan).
5. Although it was found that rear-end accident frequency was significantly higher at stop-and-go locations during late night hours, no significant difference in rear-end accident rates per million vehicles was found between the two operating modes. Therefore, the difference in rear-end frequencies may be attributable to the relative volumes of traffic at stop-and-go and flasher locations.

The results of this analysis confirm those of earlier studies that demonstrated significant differences in right-angle accident levels between the two operating modes. However, the results of this study indicate that the functional classification of the intersecting roadways and intersection type also influence right-angle accident levels at flashing signal locations.

OPERATIONAL CRITERIA

Although criteria exist for changing signal operation from stop-and-go to flash (3), criteria do not exist for reverting from flashing operation to stop-and-go operation. Because the results of this study indicate that right-angle accident frequency is significantly higher at four-legged, arterial intersections when signals flash during nighttime hours, the hourly frequency of right-angle accidents should be a primary factor in the development of criteria for eliminating flashing signal operation.

The FHWA study cited earlier suggested an accident warrant for eliminating flashing signal operation. However, the suggested warrant was erroneously based on the critical levels of right-angle accident frequency and rate at flashing signal intersections. Because the objective of eliminating flashing signal operation is to reduce right-angle accidents to levels experienced at stop-and-go locations, accident warrants should be based on the critical level of right-angle accidents at stop-and-go locations not flashing signal locations. Otherwise, many flashing signal intersections with right-angle accident problems, relative to stop-and-go intersection standards, would be overlooked for treatment. In summary, the accident warrants suggested by the FHWA are much too restrictive and should be lowered considerably.

Right-angle accident frequency provides a basis for reacting to an accident problem by altering the flash schedule. However, right-angle accidents during flashing signal operation are rare events, and some locations that exhibit conditions favoring

TABLE 2 T-Test Results: Comparative Right-Angle Accident Frequencies

Hourly Mean	Intersection Type (operation)	Arterial-Arterial, 4-Legged (flash)	Arterial-Collector, 4-Legged (flash)	Arterial-Arterial, T (flash)	Arterial-Collector, T (flash)	Arterial-Arterial, 4-Legged (stop-and-go)
0.224	Arterial-arterial, 4-legged (flash)		SIG	SIG	SIG	SIG
0.049	Arterial-collector, 4-legged (flash)			SIG	SIG	NS
0.019	Arterial-arterial, T (flash)				SIG	SIG
0.000	Arterial-collector, T (flash)					SIG
0.092	Arterial-arterial, 4-legged (stop-and-go)					

Note: α = 0.01, SIG = significant difference, NS = not significant.

right-angle accident occurrences may not be accident sites during the review period. The results of this study indicate that a high-risk situation occurs at four-legged intersections of two arterial roadways when traffic signals are in a flashing mode. Therefore, functional classification and intersection configuration provide appropriate surrogate criteria for making signal-operation changes during nighttime periods. (Although they were not analyzed in this study, arterial intersections with more than four legs should also be considered for the elimination of flashing operation.)

Other factors related to right-angle accidents at flashing signal locations include the time of night and the volume ratio. As mentioned earlier, right-angle accidents at flashing signal locations dropped dramatically after 3 a.m. In addition, four-legged intersections with hourly volume ratios of less than 2 to 1 demonstrate significantly higher rates of right-angle accidents than those with ratios greater than 4 to 1 when signals are flashing.

Although sight distance was not analyzed in this study because none of the sample flashing signal locations exhibited sight restrictions from a stopped position, eliminating flashing operation of signals at intersections where sight distance is limited should be considered. Minimum sight distance can be determined using the computational procedures outlined by AASHO (4).

IMPACTS OF FLASH ELIMINATION

The right-angle accident reduction benefits resulting from flash elimination must be weighed against the expected advantages. Increased delay will result, and rear-end accidents, which are generally less severe than right-angle accidents, may increase. However, these disadvantages can be minimized through signal optimization, synchronization, altering cycle lengths, or semiactuation.

Eliminating flashing signal operation will also result in increased emissions of hydrocarbons and carbon monoxide. The total tonnage increases in these pollutants would appear to be significant when analyzed at all intersections in question for a period of 1 year or longer. However, short-term (1 or 8 hr) concentrations should not measurably change, and people will not be affected by an increase in air pollutants.

HUMAN FACTORS

Human factors must be considered when making signal-operation changes during off-peak, nighttime hours. Of primarily importance in this regard are (a) driver impairment, (b) driver expectation, and (c) driver frustration.

Right-angle accidents involving impaired drivers are overrepresented at flashing signal locations relative to stop-and-go locations during the same nighttime hours. This conclusion may indicate a possible perception problem for impaired drivers when faced with a flashing signal. Further research is necessary to determine if this is the case. Regardless, driver impairment must be considered. Signals are normally placed on flashing operation during time periods when drivers are most apt to be tired or under the influence of drugs or alcohol. Stop-and-go operation should be considered until at least 1 hr after bars close.

Another factor to be considered is that of driver expectation. A well-established practice in traffic engineering is to provide drivers with uniform traffic control devices, thereby decreasing driver confusion and enhancing driver expectancy. Flashing signals provide drivers with a set of stimuli that differ from those that they encounter during normal, daytime driving. This may lead to confusion of drivers faced with a flashing signal.

Finally, driver frustration can be expected when drivers are forced to stop for signals during nighttime, low-traffic periods. Such situations are thought to breed contempt and disregard for traffic signals, although documented evidence to support this argument is lacking. However, the evidence suggests that drivers are more apt to stop for a steady red signal, thus reducing the chances of an accident. Nevertheless, attempts should be made to reduce delay and driver frustration through the signal timing alternatives mentioned previously.

LIABILITY IMPLICATIONS

General trends among transportation agencies include the recent surge in litigation and growing concern for reducing liability exposure. Plaintiffs have sometimes argued that flashing signal operation was a casual factor in right-angle accidents at intersections. When this factor is coupled with allegations of limited corner sight distance, the road agency stands to lose a great deal of money.

To reduce road agency liability exposure, it is necessary to identify and treat areas of risk. The analyses in this study indicated that the risk of right-angle accident occurrences at four-legged arterial intersections is higher when signals operate in a flashing mode than when they operate in a stop-and-go mode. Thus, treatment could be justified from a risk management standpoint.

CONCLUSIONS

This study has evaluated the relative accident impacts of flashing signal operation and stop-and-go signal operation during off-peak, nighttime hours. The results of this study indicate that right-angle accidents are significantly overrepresented at four-legged, arterial intersections when signals are in a flashing mode during nighttime hours. T-type intersections and arterial-collector intersections, where signals flash part time, experience significantly fewer right-angle accidents than the other intersection types analyzed.

Other factors that were found to be related to the rate of right-angle accidents at intersections where signals flash at night include the volume ratio, driver impairment, and time of night. Four-legged intersections with hourly volume ratios of 2 to 1 or less (typical for four-legged arterial intersections) experience a significantly greater number of right-angle accidents than those within volume ratios of 4 to 1 or greater. In addition, drinking involvement was overrepresented in right-angle accidents at flashing signal locations relative to stop-and-go locations. Further research is necessary to determine why. Finally, right-angle accident levels at flashing signal locations dropped dramatically after 3 a.m. Consideration should be given to extending stop-and-go operation until at least that time.

Although it was not analyzed in this study, sight distance is an important consideration in the review of intersection signal operation. Eliminating flashing signal operation at intersections with sight restrictions should reduce right-angle accident frequency.

Right-angle accident frequency and rate should be major factors in the development of criteria for eliminating flashing signal operation. Accident warrants should be based on the critical levels of right-angle accidents at stop-and-go locations, not flashing signal locations. Surrogate criteria may also be used to make decisions regarding nighttime signal operation. The results of this study indicate that a high-risk situation occurs at four-legged intersections of two arterial roadways when signals are in a flashing mode. Therefore, appropriate criteria could include both intersection type and the functional classification of the intersecting roadways.

The elimination of flashing signal operation at high-risk locations during off-peak, nighttime hours appears to be effective in reducing right-angle accident frequency and road agency liability exposure at individual locations or systemwide. Of course, trade-offs must be made in terms of vehicle delay, potential increases in rear-end accidents, and possibly in terms of driver disregard for signals. However, these disadvantages can be effectively dealt with by other means.

Discussion

Olga J. Pendleton*

The primary purpose of this discussion is to recommend a statistical method, which is more powerful in detecting true differences in accident frequencies in before-and-after designs, to be used on the type of data collected in this study.

The statistical methods that were used in this study are quite common and widely practiced in the accident frequency analysis of before-and-after designs. These methods, unfortunately, require stringent normal distribution assumptions or large sample sizes to effectively determine differences in accident frequencies. These statistics, namely the t-test for comparison of means and the z-test for comparison of proportions, are widely used because they are easy to apply and most researchers encountered them in their training in classical statistics. Unfortunately, variables encountered in the field of accident analysis (i.e., accident frequencies and rates) are not normally distributed and the sample sizes required to appeal to asymptotic normal theory are not practically attainable. The assumptions in performing a t-test include, for example, the assumption that the variances of the two comparison populations are equal. According to the data presented in Tables 1 and 2, for example, this assumption appears to be violated in this study. The sample variances of the before-and-after sites differ in magnitude by factors of 272 and 479, respectively, and far exceed the critical value of 4, which is the maximum amount these variances can differ to validate the homogeneity assumption.

The method of analysis proposed in this discussion is the analysis of a before-and-after design with a comparison group, and the recommended statistical procedure for estimating treatment effectiveness is the cross-product ratio. The details of this method can be found in a publication by Griffin (5), and the advantages of this design along with other statistical tests for evaluating treatment effectiveness can be found in the Accident Research Manual (6).

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The before-and-after design with a comparison group could be implemented in this study as follows: Suppose the traffic signal at a particular site was in flash mode from 11 p.m. to 6 a.m. before June 1 and then returned to normal operation after June 1. A comparison group would be defined as the number of accidents that occurred between 6 a.m. and 11 p.m. before and after June 1. Then one could address the question: Was there a significant change in accident frequency, caused by the flashing mode operation, above and beyond any change in accident frequency that might have been expected at that site because of normal fluctuations in accident patterns? That is, if the number of accidents that occurred between 6 a.m. and 11 p.m. increased after June 1, the number of 11 p.m. to 6 a.m. accidents might have been expected to increase during this time also. If so, was this increase of the same order of magnitude or did the signal change from flashing to stop and go result in a significant decrease relative to the comparison group? If the 11 p.m. to 6 a.m. accident frequency decreased over this period (Figure 1), the effect of the signal operation mode change would be even more dramatic.

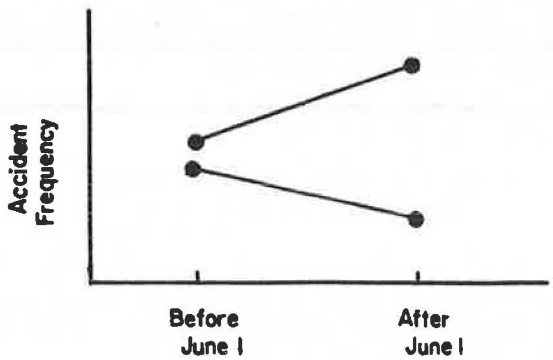

FIGURE 1 Changes in accident frequency.

A hypothetical numerical example will be used to illustrate this method. Consider the following accident frequency table that might reflect the relationship shown in the figure.

	No. of Accidents	
	6 a.m. to 11 p.m.	11 p.m. to 6 a.m.
Before June 1	20	15
After June 1	30	5

The number of 11 p.m. to 6 a.m. accidents was reduced by 67 percent after the signal was returned to stop-and-go mode. However, this reduction underestimates the effect of signal change because it does not take into account the fact that there was a 50 percent increase in 6 a.m. to 11 p.m. accidents during this same period (probably because of increased traffic volume). A better estimate of the percent reduction is obtained using the cross-product or log-odds ratio, which is the ratio of the 6 a.m. to 11 p.m. accidents to the 11 p.m. to 6 a.m. accidents. That is,

$$\text{CPR} = (20/30)/(15/5) = [(20)(5)]/[(30)(15)] = 0.22 \quad (1)$$

This reduces to a ratio of the product of the diagonals in the table. The estimate of the percent reduction is then

$$(\text{CPR} - 1) \times 100 = 78 \text{ percent} \quad (2)$$

or there was a 78 percent reduction in the number of accidents between 11 p.m. and 6 a.m. after June 1. If (CPR - 1) had been positive, this would have meant there was an increase in 11 p.m. to 6 a.m. accidents.

Obtaining the estimate is only part of the analysis. The next step is to ask if this reduction or increase was statistically significant. This is equivalent to asking if the CPR is equal to 1. The test is a normal z-test and is computed as

$$z = \ln(CPR)/[(1/20) + (1/30) + (1/15) + (1/5)]^{1/2} = -2.54 \tag{3}$$

which is significant at the 5 percent level.

This discussion has focused on the analysis of a single site; methods exist for combining sites, but such methods should be used with caution.

This study attempted to use a control group defined as a similar site over the same time period. The selection of a comparison group defined by complementary hours at the same site has the advantage that differences in exposure or roadway geometrics are minimal because the site of the comparison group is the same. Of course, inherent in this is the assumption that these site variables are equal for the two daily time periods. This is sometimes a problem, especially for the variable exposure. However, most exposure variables, such as average daily traffic or vehicle-miles of travel, are only available in daily units, not hourly, so they are difficult to control for in any analysis. They surely are not reflected in the simple t-test on means or the z-test on proportions using the before-and-after experience of the test site alone.

In summation, the before-and-after design with a comparison group could be easily implemented in this study and is more powerful in evaluating the effect of changing flashing signals to stop and go. Another powerful design would require changing these same signals back to flashing and examining a before-and-after design with a comparison group.

Author's Closure

Pendleton's discussion is an informative dissertation on research design and statistical methods for accident countermeasure evaluations. As indicated by Pendleton, more powerful research designs than those used in the evaluation are available to researchers. Nevertheless, it is unlikely that the results would have been drastically different if the designs or statistical methods suggested by Pendleton had been used in this study.

Pendleton is correct in that the use of a t-test in before-and-after designs requires a normal distribution assumption. As a general rule, accident frequencies more closely follow a Poisson distribution. However, applying a Poisson comparison of means test will demonstrate similar, significant results.

Pendleton also discusses the advantages of the before-and-after design with a comparison group. A variation of this research design was used in this study. The Accident Research Manual (6) describes a comparison group as a culled sample of locations demonstrating qualities similar to those of the test group locations before treatment. In this study, the test group was randomly chosen from a listing of intersections where flashing signal operation was eliminated in the after period. The comparison group was randomly chosen from a listing of intersections that retained flashing signal operation in the after period. Admittedly, the two groups were not identical, but they were very close to equal before treatment of the test group.

In conclusion, it is unlikely that different study designs or statistical methods would have resulted in less significant results. In fact, two different research designs and a variety of statistical methods were used in this study, and the same conclusion was derived from both study designs. It was clear that the elimination of flashing signal operation is effective in reducing late night, right-angle accidents at intersections.

The reader need only review the data to observe the dramatic effects of eliminating flashing signal operation. For example, in two-thirds of the before-and-after test sites, 100 percent reductions in right-angle accidents were noted after flashing signal operation was eliminated. The average accident reduction for all test sites was greater than 97 percent. These reductions were experienced even though right-angle accident frequency at the comparison sites increased by almost 36 percent during the study period.

At one of the comparison sites, an average of more than 10 right-angle accidents occurred annually during flashing signal operation. Flashing signal operation was eliminated at this location in 1982. In the year following flash elimination, no right-angle accidents occurred during the hours in which the signal had operated on flash. Total accidents at this intersection (for a 24-hr period) were reduced by more than 33 percent. Given these and similar examples of dramatic reductions in accident frequency, statistical analyses may not even be necessary to demonstrate the effectiveness of eliminating flashing signal operation.

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The opinions and viewpoints expressed in this paper are entirely those of the author. They do not necessarily reflect the viewpoints or policies of the Oakland County Road Commission or any federal or state transportation agencies.

Publication of this paper sponsored by Committee on Traffic Control Devices.