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Low-Cost Countermeasures for Ameliorating Run-Off-the-Road Crashes

PAUL H. WRIGHT, JEROME W. HALL, AND PAUL L. ZADOR

This project sought to determine the effectiveness of various low-cost countermeasures for reducing the number of fixed object and overturning crashes. A survey was conducted of the 50 state highway and transportation departments. Responses to the questionnaire show that all states are using chevron markers, and a majority are using delineators and standard warning signs. Respondents thought that these devices were most effective for reducing run-off-the-road crashes, although little documentation was supplied to support this contention. Most states have established procedures for selecting the most hazardous run-off-the-road sites, but few have formal guidelines for selecting the specific countermeasures for use at these sites. A critical analysis is needed to determine the actual effectiveness of several commonly used low-cost countermeasures.

The problems of run-off-the-road (fixed-object and overturning) crashes in Georgia and New Mexico have been examined in previous research (1-3). One of the principal findings of these studies has been that these crash sites exhibit adverse geometric conditions to a much greater extent than does the roadway system in general. Techniques for improving the roadway alignment and creating a safe roadside are well established, but they are expensive. Consequently, their application on a broad scale exceeds the financial constraints of operating agencies.

Substantial cutbacks in the budgets of highway agencies have accentuated the need to identify low-cost countermeasures for ameliorating run-off-the-road crashes. Numerous techniques short of roadway reconstruction and roadside improvement have been suggested for reducing the frequency of these crashes; however, there is little documentation to show that they have been evaluated to determine their effectiveness. This paper examines the use and apparent effectiveness of low-cost countermeasures through a questionnaire survey of state highway and transportation departments and reviews the responses in light of the current technical literature.

SURVEY OF STATE HIGHWAY AGENCIES

In the spring 1982 a survey was conducted of all state highway agencies to determine their experience with various low-cost run-off-the-road countermeasures. The purpose of the survey was to identify which devices were in common use and to assemble research results on their effectiveness. Supplementary information was collected on techniques for identifying hazardous locations and countermeasure selection and the use of surrogate measures. The survey questionnaire is shown in Figure 1. The questionnaires were distributed on a geographic basis by researchers from the Georgia Institute of Technology and the University of New Mexico.

Replies were received from traffic, safety, and design engineers in 38 of the 50 states contacted. The engineers were in agreement on several issues, but the respondents also showed considerable disparity in their approaches to run-off-the-road crash problems.

Countermeasures Used by State Agencies (Question 1)

Question 1 sought to determine which of the low-cost countermeasures had been used by the agencies at new sites within the past 5 years to ameliorate fixed-object or rollover crashes. The question was specific; however, positive responses from some states may indicate that the devices were used as part of a continuing program of upgrading traffic-control devices. The question did not differentiate between states that had extensive experience with a particular device versus those states where a device had been used infrequently. More than half the respondents indicated that they used (a) chevron markers, (b) delineators, (c) standard warning signs and markings, (d) warning signs with flashing beacons, (e) rumble strips, and (f) reflectorized pavement markers on center lines.

The responses to this question are summarized in Table 1. The chevrons are used universally, although they have only been an official traffic control device for a relatively few years. Raised reflectorized markings were also used commonly, more often on center lines than on edge lines. Several techniques, such as reflectorized paint on fixed objects, are used infrequently.

Evaluation of Low-Cost Countermeasures (Question 2)

Slightly more than half of the respondents (20) indicated that their agency had evaluated one or more of the countermeasures. The agencies appear to view their principal task as operations rather than research, which may account for the relatively low extent of evaluation. However, a number of states had participated in multistate evaluations (4) of selected countermeasures.

The principal impetus for undertaking the evaluations appears to be the requirements embodied in federal highway safety legislation. Many of the evaluations make use of the traditional before-and-after approach--a recognized high hazard location is improved and the respective accident experiences are compared. The statistical weaknesses of this technique, which fails to account for relevant factors such as regression to the mean, have been documented (5), although most of the operating agencies are apparently unaware of these deficiencies.

A number of states indicated that they had conducted evaluations of specific improvement types but had not prepared written documentation of the procedures or results. Other agencies would benefit if such documentation were available.

Effective Existing Low-Cost Countermeasures (Question 3)

In the absence of extensive evaluations of most forms of remedial action, the engineer must rely on professional judgment to determine which improvements are most effective. This judgment is conditioned by education, experience, and familiarity with certain sources of technical information. This question sought to determine which countermeasures were thought to be most effective.

Although 20 different types of low-cost countermeasures were listed by the respondents, the most commonly cited improvements were chevron markers, delineators, and warning signs. Consensus on the effectiveness of other treatments was less common.

Table 2 summarizes the responses. Several countermeasures listed in this table, including guardrail, slope flattening, and skid treatment, may be effective although they are not necessarily low-cost improvements.

Promising or Unproven Countermeasures (Question 4)

We anticipated that some states had experimented with unique countermeasures that were not identified in question 1. This question sought professional input in order to identify promising techniques that might be effective in reducing the number or severity of run-off-the-road crashes. In response to this question, 12 states identified 21 promising countermeasures that might warrant further study. Reflectorized pavement markings on edge lines, rumble strips, and section contouring-slope flattening were each listed by two states, each of the 18 remaining countermeasures was identified by only one state. Several of the suggestions, which are given in Table 3, may deserve some additional attention; others appear to be improperly classified as unproven.

Use of Formal Guidelines for Selecting Sites for Improvement (Question 5)

Techniques used by highway agencies to identify hazardous locations vary among the states. One survey

Figure 1. Questionnaire sent to state highway agencies.

LOW-COST COUNTERMEASURES FOR RUN-OFF-THE-ROAD CRASHES

The University of New Mexico, in cooperation with the Georgia Institute of Technology, is conducting a nationwide study to identify and evaluate promising low-cost countermeasures for reducing the number and/or severity of roadside crashes. Your assistance in responding to this questionnaire would be sincerely appreciated.

1. Please indicate which of the following countermeasures were installed at new sites by your agency during the past five years for the purpose of decreasing the number or severity of fixed-object and rollover crashes. A "new site" is a location where the countermeasure had not previously been used.

Countermeasure	Installed at New Sites	
Standard warning signs	Yes ☐	No ☐
Standard pavement markings	Yes ☐	No ☐
Non-standard warning signs	Yes ☐	No ☐
Non-standard pavement markings	Yes ☐	No ☐
Reflectorized pavement markers on centerlines	Yes ☐	No ☐
Reflectorized pavement markers on edge lines	Yes ☐	No ☐
Reflectorized paint on trees, poles, etc.	Yes ☐	No ☐
Delineators	Yes ☐	No ☐
Chevron markers	Yes ☐	No ☐
Rumble strips	Yes ☐	No ☐
Warning signs with flashing beacons	Yes ☐	No ☐
Warning signs with traffic actuated flashing beacon	Yes ☐	No ☐
Traffic actuated warning signs	Yes ☐	No ☐
Other (please specify)	Yes ☐	No ☐

2. Please identify low-cost roadside crash countermeasures (from Question No. 1 or others) for which evaluation studies were conducted by your agency during the past five years. If a written report on the study is available, please enclose a copy and bill us for the cost.

Countermeasures Evaluated	Written Report Available	
________	Yes ☐	No ☐
________	Yes ☐	No ☐
________	Yes ☐	No ☐
________	Yes ☐	No ☐

3. Of all the existing low-cost countermeasures for reducing losses from fixed-object and rollover crashes, please list the three you consider to be the most effective.

First choice ________

Second choice ________

Third choice ________

4. Please list in order of preference any promising or unproven countermeasure (i.e., not yet in general use) which you think are likely to be effective in reducing the number or severity of fixed-object or rollover crashes.

First choice ________

Second choice ________

Third choice ________

5. Does your agency have formal guidelines for selecting sites for improvement? (If written guidelines are available, please enclose a copy.)

☐ Yes -- What are these guidelines based on (e.g., prior crash history, ADT, road geometry, etc.)? ________

☐ No ________

6. Does your agency have formal guidelines for selecting countermeasures at sites chosen for improvements? (If written guidelines are available, please enclose a copy.)

☐ Yes -- What are these guidelines based on (e.g., ADT, road design, costs, etc.)? ________

☐ No ________

7. There are numerous measures (i.e., surrogates) other than reductions in crashes that have been used to evaluate off-road fixed-object and rollover crash countermeasures (e.g., speed reduction, lane placement, compliance with the maximum speed limit). Please list up to three such measures you consider most satisfactory.

First choice ________

Second choice ________

Third choice ________

8. Person completing this questionnaire:

Name ________ Phone (___) ________

Address ________

9. Would you like to receive a copy of the survey results? Yes ☐ No ☐

- -

Please return the completed form to J. W. Hall, Bureau of Engineering Research, University of New Mexico, Albuquerque, New Mexico 87131.

Thank you for your cooperation.

Table 1. Run-off-the-road countermeasures installed by states at new sites during past five years.

Countermeasure	Installed	
	Number	Percent
Chevron marker	38	100
Delineator	35	92
Standard warning sign	34	89
Warning sign with flashing beacon	30	79
Standard pavement marking	28	74
Rumble strip	23	61
Reflectorized pavement marking on center line	21	55
Reflectorized pavement marking on edge line	15	39
Nonstandard warning sign	10	26
Other	9	24
Reflectorized paint on trees or poles	8	21
Warning sign with actuated flashing beacon	7	18
Traffic-actuated warning sign	5	13
Nonstandard pavement marking	3	8

Note: For survey purposes, a new site was a location where the countermeasure had not been used previously.

Table 2. Respondents' judgment of most effective low-cost countermeasures.

Countermeasure	Number	Percent
Chevron marker	26	68
Delineator	19	50
Warning sign	16	42
Standard pavement marking	9	24
Standard warning sign with beacon	6	16
Guardrail	6	16
Removal of fixed object	5	13
Rumble strip	4	11
Raised pavement marker	3	8
Shoulder or edge line striping	3	8
Delineators on trees or poles	3	8
Make object breakaway	3	8
Slope flattening	2	5
Reflectorized center line	1	3
Safe curve speed sign	1	3
Narrow bridge marking	1	3
Crash cushion	1	3
Traffic-actuated warning sign	1	3
Standard delineation	1	3
Skid treatment	1	3

(6) found that all states employ some criteria for identifying hazardous locations. Although the principal factor was generally the number of accidents, accident rates, accident severity, and economic loss were also used. Frequently different criteria were applied on different road systems.

Question 5 sought information on the more specific issue of how states select sites for improvements to reduce the number or severity of run-off-the-road crashes. Of the 38 respondents, 79 percent indicated that they had formal guidelines for site selection; the remainder apparently relied on the more general criteria used for selecting among all types of hazardous locations. Among states that had formal guidelines, the most commonly used factors were crash history and traffic volume. A few states included measures of roadway geometry in their site-selection process. Few states were able to comply with the request to provide a copy of their guidelines. Specific responses are summarized in Table 4.

The formality of the site-selection process appears to be limited by the completeness, accuracy, and compatibility of traffic record systems. States that reported better record systems appear to have more elaborate site-selection procedures.

Table 3. Promising or unproven countermeasures recommended by state transportation agencies.

Countermeasure	State
Reflectorized pavement markings on edge line	La., Ga.
Rumble strips	La., Ill.
Section contouring and slope flattening	Fla., N.C.
Breakaway utility poles	Calif.
Safer design of mailboxes	Calif.
Flexible delineator posts	Calif.
Guardrail with white reflective epoxy coating	Del.
Powder-coated reflectorized guardrail	Ga.
Tree removal within 30 ft of pavement	Ga.
Sloped end sections on drainage pipes	Ga.
Improved delineation and superelevation	Ga.
Wider shoulders	Ga.
Warning signs with flashing beacons	La.
Utility pole delineation	Md.
California-type warning signs	Md.
Clear Roadside Recovery Area	Minn.
Traffic-actuated warning signs	Miss.
Chevron markers	Mont.
Shoulder-mounted concrete rail	Mont.
Waterwall attenuator	Mich.
Shoulder clearing	N.C.

Use of Formal Guidelines for Countermeasure Selection (Question 6)

Once the guidelines identified from the responses to Question 5 have been applied and sites that warrant correction have been identified, a highway agency is confronted with the problem of choosing the appropriate countermeasure for each site. On a cost basis options range from relatively inexpensive signing to costly roadway alignment. In the presence of reliable data on the effectiveness of candidate countermeasures, the techniques of engineering economy could be used to determine the most suitable improvement; however, responses to question 2 indicated that few of the low-cost countermeasures have been evaluated for effectiveness. Several summary reports (6) provide information on medium- to high-cost improvements, but their reliability has been questioned.

Therefore, only 24 percent of the respondents indicate that they have formal guidelines for countermeasure selection. In addition to economic considerations, the responses indicate that engineering judgment plays a prominent role in countermeasure selection. Replies to this question, which are given in Table 5, suggest that states are less likely to have formal guidelines for improving run-off-the-road crash sites than for improving generally hazardous locations.

Use of Surrogate Measures of Effectiveness (Question 7)

Because run-off-the-road crashes are comparatively rare events, states may not want to await their occurrence to identify hazardous locations or to evaluate improvements. Several studies have examined other measures (e.g., speed variance) in an attempt to identify the relation between these surrogates and actual experience with crashes. Although problems with surrogates have been noted (5), a number have been suggested for use as measures of effectiveness (7).

Question 7 sought to determine which surrogates were most suitable for the evaluation of run-off-the-road countermeasures. The most frequently listed surrogate was speed reduction (12 states), followed by compliance with the speed limit, and reduction in public complaints and driver interviews. The responses indicated that the states have a moderate level of confidence in the use of surrogates, but, consistent with their infrequent post-implementation of remedial action, the states had little experience in the use of these measures at run-off-the-road crash sites. Table 6 lists the responses to this question.

EFFECTIVENESS OF COUNTERMEASURES

The questionnaire survey has provided a reasonably comprehensive picture of what actions the states are taking to reduce run-off-the-road crashes. As given in Table 1, the most commonly used forms of remedial action are those that support the principles of positive guidance by providing the driver with information on the desired travel path and speed. The appeal of these actions may be intuitive. The survey provided limited information about their proven effectiveness.

Chevron Alignment Signs

All states report use of chevron alignment signs to reduce the frequency of run-off-the-road crashes; however, relatively little research has been devoted to the evaluation of chevron alignment signs. Limited research tends to support engineering judgment that these devices may be effective in alerting drivers to the presence and sharpness of an upcoming curve. The West Virginia Department of Highways (8) placed chevron alignment signs at 62 locations where identified run-off-the-road accident problems exist. A preliminary before-and-after evaluation at 28 sites found a 49 percent reduction in the rate of nighttime run-off-the-road crashes. The Montana Department of Highways (9) installed chevrons at 5 hazardous locations along curved sections of high-

Table 4. Formal guidelines for site selection.

State	Formal Guidelines	Response
Ark.	No	Accident history
Ariz.	Yes	Computer-selected sites based on annual average daily traffic (AADT) and accidents
Calif.	Yes	Safety index (existing-expected accidents)
Colo.	Yes	Hazard index using accident history, severity, average daily traffic (ADT), and average rate for similar highways
Conn.	Yes	Crash history
Del.	Yes	Severity index, crash history, and site review
Fla.	Yes	Accident records, grouped single-vehicle roadside obstacle accidents by milepost and section
Ga.	Yes	ADT, geometry, accident history, funds, and benefit/cost ratio
Hawaii	No	
Iowa	Yes	Accident rates
Idaho	Yes	Prior crash history, ADT, and road geometry
Ill.	No	
Ind.	No	Based on investigation of site due to complaint from public, local agency, or internally
Kans.	No	
Ky.	No	
La.	Yes	Abnormal accident listings
Mass.	Yes	Crash histories, ADT, and hazard cost index
Md.	Yes	High accident sections of roadway based on accident rates
Maine	No	
Mich.	Yes	Identify control sections that have highest crash rates
Minn.	Yes	Crash history and geometry
Mo.	Yes	Accident history of location being considered for improvement
Miss.	Yes	Engineering study of ADT, road geometry, and crash history
Mont.	Yes	Prior crash history and road geometry
N.C.	Yes	
N. Dak.	Yes	Crash history, traffic exposure, roadway geometrics, improvement costs, and user complaints
N. Mex.	Yes	Accident history
Nev.	Yes	
N.Y.	Yes	Accident surveillance, crash rates, and geometrics
Okla.	Yes	Accidents
Oreg.	Yes	Index based on crash history, severity, and ADT
S.C.	No	
Tenn.	Yes	Critical accident rate method together with economic loss to develop priority and on-site studies
Tex.	Yes	Existing and expected accident frequency and severity (cost), ADT, and project cost
Va.	Yes	ADT, road geometry, crash history, and cost
Vt.	Yes	ADT and crash history
Wash.	Yes	Crash history
W.Va.	Yes	Federal Highway Program Manual 8.2.3. procedures

Table 5. Formal guidelines for countermeasure selection.

State	Formal Guidelines	Response
Ark.	No	
Ariz.	No	
Calif.	No	Engineering judgment
Colo.	No	Each identified location is studied as a unique problem
Conn.	No	Benefit/cost analysis using published data
Del.	Yes	Manual on Uniform Traffic Control Devices (MUTCD)
Fla.	No	Warrants for crash attenuators are being developed
Ga.	Yes	Benefit/cost ratio, right-of-way available, actual cost, ADT, reasonable alternative, road design
Hawaii	No	Countermeasure selected based on apparent need; e.g., raised pavement marker rumble strip to alert sleepy drivers before sharp curve
Iowa	No	
Idaho	Yes	Engineering judgment based on proved countermeasures
Ill.	No	
Ind.	No	Based on site investigation and engineering judgment
Kans.	No	
Ky.	No	
La.	No	Engineering study made by district traffic engineer
Mass.	No	
Md.	No	
Maine	No	
Mich.	Yes	Type C guardrail installed when ADT exceeds 30,000
Minn.	No	
Mo.	Yes	Guidelines based on benefit/cost ratio for each proposed countermeasure considered for implementation
Miss.	No	
Mont.	No	
N.C.	No	
N.Dak.	No	Engineering studies of sites usually determine specific improvements to be made on case-by-case method
N.Mex.	No	
Nev.	Yes	
N.Y.	No	
Okla.	No	
Oreg.	Yes	Pattern of accident experience and benefit/cost analysis based on collision diagrams
S.C.	No	
Tenn.	No	Technical guidelines from research reports and MUTCD
Tex.	Yes	Based on accident information and field visits
Va.	Yes	ADT, road design, costs, and accident data
Vt.	No	
Wash.	No	
W.Va.	No	

Table 6. Surrogate measures of effectiveness recommended by state transportation agencies.

Surrogate Measure of Effectiveness	No. of States
Speed reduction	12
Speed limit compliance	4
Reduction in public complaints and driver interviews	4
Fewer skid marks	3
Lane placement and shoulder encroachment	3
Severity	2
Brake applications	2
Pace narrowing	1
Site examination	1
Erratic maneuvers	1
Traffic conflicts	1
Roadway realignment	1
Improved skid resistance	1
Advisory speed compliance	1
Amount of maintenance costs incurred	1
Before and after studies at point areas	1
Enforcement of 55-mph speed limit	1
Enforcement and education regarding drunk drivers	1

way, each about 1-mile long, and recorded a 32 percent reduction in the nighttime run-off-the-road accident rate. These results appear promising; however, both studies had comparatively small sample sizes, and, because of the high accident experience in the before periods, regression to the mean has a significant effect on the results.

Post Delineators

More than 90 percent of the states reported the use of post delineators to reduce the frequency of run-off-the-road crashes. In comparison with chevrons, the delineators are a much older type of traffic control device; therefore, more research has been conducted on their effectiveness. A 1966 study (10) found that the use of post-mounted delineators can be an effective means of reducing crashes at sites where roadway curvature exceeds 5 degrees. Delineation was effective for curves between 5 and 10 degrees that have a central angle between 20 and 40 degrees. Based on this research, the central angle may be the better indicator of the need for delineation.

Another study (11) attempted to evaluate nine delineation configurations by using post-mounted delineators and other devices along one horizontal curve test section. The treatments were evaluated with surrogate measures. The researchers recommended that amber delineators be used for right-turning curves (on the left side of the roadway) and that crystal delineators be used for left-turning curves (on the right side). Post-mounted delineators were also recommended for two-lane rural roads, pavement width transitions, and all curves that have curvature greater than 5 degrees and have a central angle in excess of 20 degrees.

Standard Signs

Most of the states indicated that they used curve warning and advisory speed signs, although less than half thought that such signs were among the most effective countermeasures. Evaluations of the effects of standard signs on driver behavior have produced mixed results. Bezkorovainy (12) studied the influence of advisory speed limits at horizontal curves on spot speeds at 12 locations. He sought to determine the effects of a standard curve sign used with a standard advisory speed plate and with an experimental advisory speed plate that contained the words SLOW TO followed by the numerical value. The results implied that advisory speed signs are generally ineffective in changing the speed of drivers at the center of the curve. A special study indicated, however, that a 30-mph advisory produced a greater rate of deceleration along the approach to the curve than did a 50-mph advisory sign.

Lyles (13) evaluated five sign treatments for controlling driver speeds in the vicinity of hazardous horizontal curves on rural two-lane highways. The treatment included standard curve warning signs, advisory speed signs, and speed limit signs. Lyles reported that neither a single sign nor a group of signs was consistently more effective in decreasing the potential hazard at the curves. His work suggests that, when a hazardous curve exists, advisory speed plates and regulatory signs will be ineffective.

An FHWA study (14) of speed control signs concluded that passive signs were generally ineffective in slowing traffic as it passed through a small rural town. On the other hand, a before-and-after study of advisory speed limit signing in combination with curve warning signs appeared to reduce single-vehicle crashes significantly (15). On the basis of these conflicting results, a firm conclusion cannot be reached on the effects of these devices.

Pavement Markings

The standard pavement markings applicable to run-off-the-road crashes include painted center lines and edge lines. Three-quarters of the states reported the use of standard markings as a countermeasure, but only 24 percent think that standard markings are among the most effective forms of remedial action. Most of the studies of the effectiveness of pavement markings have been conducted on a limited scale. In one of the larger studies Taylor (11) reported an improvement in driver behavior, as measured by reduced variance of lateral placement, when a roadway that had a freshly painted center line was compared with the base condition of a weathered center line and no delineators. The addition of edge lines at horizontal curves (on roads where they do not exist on tangents) was found to improve lateral placement characteristics and possibly reduce accident experience. Paint, however, was judged inferior to raised pavement markings in most applications.

The use of retroreflective pavement markers has increased greatly in recent years. More than half of the states use them on center and edge lines. Although the markers are perceived favorably by the general public, comparatively few of the highway engineers thought that they were effective in reducing run-off-the-road crashes. Advantages claimed for markers over paint stripes include reduced maintenance and more positive all-weather, nighttime delineation. The markers have also been reported to be effective in delineating detours through construction zones (16).

Traffic performance studies have suggested that pavement markers are more effective than post-mounted delineators on isolated horizontal curves (17). Researchers (4) have reported that highway sections along tangents or along winding sites that have raised pavement markers along the center lines have lower accident rates than do those that have painted center lines. The results of the analyses were not as definitive for isolated horizontal curves.

The Florida Department of Transportation installed raised pavement markers along a 19-mile section of the main highway to Key West. The markers were placed along the center line (four abreast at 20-ft centers) and across the 4-ft-wide paved shoulders at a 45-degree angle. A before-and-after evaluation showed a 42 percent decrease in projected crashes and a 38.4 percent decrease in injury and fatal crashes. Fixed-object crashes decreased from 25 to 4 per year and run-into-water accidents decreased from 22.5 to 4 per year (18).

A study of the effectiveness of raised pavement markers along a rural horizontal curve in combination with painted edge lines (11) found that speeds of passenger vehicles were not affected by the markers. Vehicular placement variability, however, was reduced by the use of raised pavement markers. Of four configurations tested, raised pavement markers along the center line used with freshly painted edge lines produced less vehicular placement variability than did a painted center line, and drivers tended to adopt a more central position in their lane. In a related study, which may be inconclusive due to small sample sizes, a correlation was found between lateral placement variability and accident experience. Based on their conclusion that raised pavement markers show an advantage over a painted center line because markers cause drivers to move farther away from the center line and reduce variance in the travel path, the researchers recommended the use of these markers on hazardous horizontal curves.

Transverse Stripes and Rumble Bars

Although more than 60 percent of the states use rumble bars or strips to improve potential run-off-the-road sites, few consider them to be effective devices for this purpose. The technical literature suggests that they have an affect on driver behavior that may be time dependent. The Michigan Department of Highways (19) performed three experiments to evaluate the use of transverse pavement stripes and rumble bars. In all the tests the stripes and rumble bars were placed with variable spacing to give the illusion of acceleration to the driver traveling at a constant speed. The researchers report that the effect of yellow pavement striping was marginal. Before stripe installation the speed reduction through the highway construction area caused by normal sign obedience was slightly more than 4 mph. Immediately after striping the total speed reduction jumped to 8.3 mph. A month later, however, it dropped to 4.3 mph, which was close to the initial condition. Two kinds of rumble bars were tested, and both caused larger reductions in average speeds than did the colored stripes. However, the speed reduction obtained by these devices also diminished over time.

In a more recent experiment with these devices (20), the Transport and Road Research Laboratory found that their installation at the approaches to roundabouts on dual carriageways reduced speed-related accidents significantly. They were most effective in reducing fatal and serious injury accidents. They also had a greater effect during the daytime and on wet road surfaces.

An FHWA evaluation (14) of speed control for small rural towns showed that pavement markings and rumble strips were second (after traffic-actuated signs) in effectiveness at night as measured by the percentage of drivers who complied with the speed limit.

The Virginia Department of Highways and Transportation (21) reported that rumble strips installed along approaches to rural STOP intersections reduced the number of crashes. An analysis of nine rumble-strip locations showed an overall reduction of 37 percent in the total number of crashes.

Signs With Flashing Beacons and Traffic-Actuated Speed Violation Signs

Because of cost and power requirements, signs with flashing beacons and traffic-actuated speed violation signs may not be used as widely as some of the other treatments. Only seven states reported using them to alleviate run-off-the-road crashes, and only one state thought that they were highly effective. However, limited technical literature on these devices is moderately optimistic. Hanscom (22) reported speed reductions at critical curve locations in response to signing that employed flashing hazard beacons. In this study of signing to warn of wet weather skidding hazard he recommended that the beacons be activated at the onset of rainfall.

In a speed control study for small rural towns (14), traffic-actuated warning (speed violation) signs were the most effective system tested. They were found to reduce speed by 3 to 4 mph more than passive signs. Signs with flashing beacons were second in effectiveness during daylight, but they were found to reduce speeds by only 1 to 2 mph more than the passive signs. The researchers reported that the addition of flashing beacons to a sign produces a slight, but insignificant, increase in its effectiveness.

SUMMARY AND CONCLUSIONS

This study has attempted to determine the state of the art in using low-cost countermeasures to reduce the frequency and severity of fixed-object and overturning crashes. A questionnaire survey was distributed to state highway and transportation departments, and the responses were examined in light of the technical literature on this topic. Some limited conclusions can be reached based on this study.

Certain low-cost countermeasures appear to have a favorable impact on surrogate measures of effectiveness; however, separate studies of the same device have reached differing conclusions. Chevron signs have been used widely, and highway agencies consider chevrons the most effective low-cost devices for reducing run-off-the-road crashes. Although some limited studies suggest that these may be effective, the evidence is not conclusive. Delineation and standard warning signs are also used extensively, but there is less consensus on their effectiveness. Raised markers appear to be more effective than paint.

Most states have formal guidelines, typically based on crash history and average daily traffic, for identifying the most hazardous run-off-the-road sites. Despite evidence that roadway geometry is a principal contributor to these crashes, less than a quarter of the agencies consider this factor in site selection. Few states have formal guidelines for countermeasure selection.

Speed reduction is thought to be the best surrogate for evaluating the effectiveness of run-off-the-road improvements, although the literature suggests that lateral placement may be a better criterion. Actual postimplementation evaluation of these types of remedial action is comparatively rare. To assist the engineer in making the best use of limited funds, the need is critical for additional study of those countermeasures whose effectiveness has not been documented through comprehensive and statistically valid studies.

REFERENCES

1. P.H. Wright and L.S. Robertson. Priorities for Roadside Hazard Modification. Insurance Institute for Highway Safety, Washington, D.C., March 1976.

2. J.W. Hall and P.L. Zador. Survey of Single-Vehicle Fatal Rollover Crash Sites in New Mexico. TRB, Transportation Research Record 819, 1981, pp. 1-8.
3. P.H. Wright and P.L. Zador. Study of Fatal Rollover Crashes in Georgia. TRB, Transportation Research Record 819, 1981, pp. 8-17.
4. Science Applications, Inc. Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments for Rural Two-Lane Highways. FHWA, FHWA-RD-78-50, 51, 1978.
5. F.M. Council and others. Accident Research Manual. FHWA, FHWA-RD-80-016, 1980.
6. Highway Safety Improvement Programs. U.S. Department of Transportation, Annual Rept. 1978.
7. H. Lunenfeld. Evaluation of Traffic Operations, Safety and Positive Guidance Projects. FHWA, FHWA-TO-80-1, 1980.
8. Annual Evaluation Report, Pavement Marking Demonstration Program. West Virginia Department of Highways, Charleston, 1981.
9. Progress Report. Planning and Research Bureau, Montana Department of Highways, Helena, Jan. 1981.
10. W.C. Taylor and T.J. Foody. Ohio's Curve Delineation Program--An Analysis. Traffic Engineering, June 1966.
11. J.I. Taylor and others. Roadway Delineation Systems. NCHRP, Rept. 130, 1972.
12. G. Bezkorovainy and C.C. Ku. The Influence of Horizontal Curve Advisory Speed Limits on Spot Speeds. Traffic Engineering, Sept. 1966, pp. 24-28.
13. R.W. Lyles. An Evaluation of Warning and Regulatory Signs for Curves on Rural Roads. FHWA, FHWA-RD-80-009, 1980.
14. J.S. Koziol and P.H. Mengert. Evaluation of Speed Control Signs for Small Rural Towns. Public Roads, June 1977.
15. C.G. Hamner. Evaluation of Minor Improvements. California Division of Highways, Part 6, May 1968.
16. C.W. Niessner. Construction Zone Delineation (Raised Pavement Markers). FHWA, 1978.
17. Field Evaluation of Selected Delineation Treatments on Two-Lane Rural Highways. Alan M. Voorhees and Associates, Inc., FHWA-RD-77-118, 119, 1977.
18. Annual Report, Title II Safety Improvement Program. Office of Highway Safety, Florida Department of Transportation, Gainesville, Sept. 1981.
19. N. Enustun. Three Experiments With Transverse Pavement Stripes and Rumble Bars. Michigan Department of State Highways, Lansing, Final Rept., Oct. 1972.
20. R.D. Helliar-Symons. Yellow Bar Experimental Carriageway Markings-Accident Study. Transport and Road Research Laboratory, Crownthorne, Berkshire, England, TRRL Laboratory Rept. 1010, 1981.
21. An Evaluation of the Effectiveness of Rumble Strips. Virginia Department of Highways and Transportation, Richmond, April 1981.
22. F.R. Hanscom. Evaluation of Signing to Warn of Wet Weather Skidding Hazard. TRB, Transportation Research Record 600, 1976, pp. 20-27.

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Motorists' Reaction to Exclusive/Permissive Left-Turn Signal Phasing

MICHAEL A. PERFATER

The findings of a study of motorists' perceptions of exclusive/permissive (E/P) signal phasing at 10 intersections in Virginia are presented. Traffic volumes and conflict rates were counted at each site and accident files were investigated. In addition, 1,252 residences and small businesses in the vicinity of the sites were sent questionnaires to determine motorists' opinions and perceptions of E/P phasing. A total of 460 completed questionnaires were received and analyzed. Roughly one-third of those queried were confused by the E/P signal the first time they encountered it, but the confusion dissipated over time. Advance publicity of an E/P signal modification or installation and an explanatory sign placed adjacent to the signal head will do much to reduce motorists' confusion. More than 70 percent of those surveyed were in favor of E/P signal phasing and 77 percent thought that it reduced intersection delay. On-site observations revealed that vehicular conflicts at E/P intersections are most frequent at locations that have high volumes of turning vehicles and various movements of traffic. The conflict rate could not be attributed to any one characteristic of an intersection, however. The same was true for the accident rate.

Several means can be used to accommodate left-turn movements at signalized intersections. One of these is the recently introduced exclusive/permissive (E/P) left-turn signal phase, which permits left turns during the display of both the green arrow and the green ball. During the green-arrow phase the motorist is unopposed in making a left turn; during the green-ball phase he or she must yield to opposing vehicular traffic. The left-turn arrow may either follow or precede the green ball.

Several studies have been conducted nationwide to determine the best method for signalizing left-turn movements and as many as two dozen signal indications are available for use. One recent study conducted in Kentucky determined that E/P left-turn phasing is efficient because it results in fewer delays than other types of left-turn phasing; however, it was found to lead to an increase in accidents compared with exclusive phasing. The number of these mostly minor accidents decreased as drivers became familiar with the intersection. More than 90 percent of the drivers queried in that study were in favor of this type of signal, but many indicated that they had not understood the signal the first time they encountered it. They indicated that more advance publicity on the E/P signal was necessary (1).

The Virginia Department of Highways and Transportation has numerous E/P signal-phasing installations throughout the state and more are planned. To date, public reaction to this type of phasing has been favorable, except where accidents have occurred. The research council was asked to document the performance of these signals from the standpoint of public interpretation and understanding. Only the five-ball cluster system that features the exclusive left-turn phase before the green-ball phase was studied. The study included both surveys and on-site data analyses at 10 signalized intersections at various locations within the commonwealth.

METHODOLOGY

Four types of data were gathered for each of the sites. Traffic counters were installed on the roadway to determine the volume of through traffic. Then, on 2 successive days, observers were placed at opposite ends of the intersection for 10 hr to record conflicts. Five types of conflicts were recorded and the conflict volumes for the 2 days were averaged, as were the volumes of through traffic, which were also recorded for the 2 days. A procedure developed for a previous study was used to determine the left-turn conflicts (2). Observed conflicts were categorized as follows:

Type 1--The basic left-turn conflict caused by the turning vehicle crossing in front of or blocking the lane of an opposing through vehicle; a conflict was recorded when the driver of the through vehicle applied the brakes or weaved to evade the encroaching vehicle;

Type 2--A continuation of the first type in which the driver of a through vehicle that was following the first one also had to brake;

Type 3--The conflict caused by the vehicle entering the intersection after the E/P signal has turned red;

Type 4--The rear-end conflict in the left-turn lane occurring when the driver of the vehicle about to make the turn did not and the driver of the following vehicle had to brake or weave; and

Type 5--The conflict when left-turning vehicles overflowed the storage lane and blocked the through lanes.

The number of left turns made on the green arrow at each intersection was also recorded.

Once these data were collected residences and some small businesses located near each E/P intersection were mailed questionnaires that contained questions concerning the newly installed E/P signal.

Finally, accidents reported at each intersection both before and after installation of the E/P signal were tabulated. The after data included accidents reported during the period between the installation date and the date of the on-site evaluation, and the before data included accidents reported over a similar period of time before the installation.

Of the approximately 1,252 questionnaires distributed, 460 were returned, for a response rate of 36.7 percent.

RESULTS OF INTERSECTION ANALYSIS

Intersection Characteristics

The intersections evaluated are described in Table 1. Observations were made over a 2-day period and the volumes presented are averages. The average approach volume at the 10 intersections was about 5,780 vehicles/day. The highest count was 10,711 vehicles/day and the lowest was 3,134 vehicles/day. The intersections had an average turn volume of 908 vehicles/day, of which 401, or 44 percent, were made during the green-ball or permissive phase. This illustrates the additional number of left turns that can be made with permissive phasing. The reduction in delay and fuel use as a result of the permissive phase, although not measured in this study, is apparent.

Vehicle Conflicts

Types 1, 2, and 3 conflicts constituted almost 98 percent of the total conflicts counted. For this reason, types 4 and 5 conflicts were not considered to cause serious problems and thus will not be discussed. Type-3 conflicts were the most frequent--47 percent of those counted. Instances of high type-3 conflicts could not be attributed to any one characteristic of an intersection. This type of conflict tended to occur at intersections that have high approach volumes and are located away from shopping centers. Type-3 conflicts seem to result more from drivers being in a hurry than from a misunderstanding of the signal indications. Type-3 conflicts were relatively infrequent at high-volume shopping center intersections.

Type-1 conflicts (43 percent of those counted) were more frequent at intersections that have high volumes of turning traffic. Three of the four intersections that had the highest such volumes (green arrow and green ball) also had the highest rate of type-1 conflicts. Type-2 conflicts were generally rare (8 percent of those counted); the majority of them occurred at one intersection. That intersection allowed the greatest variety of traffic movements of all intersections studied.

Neither speed limits nor the length of time an E/P signal had been in place appeared to have any effect on conflict rates. At intersections that had high turn volumes an explanatory sign was important. One of the intersections that had the highest left-turn volumes and no explanatory sign had high ratios of type-1 and type-3 conflicts (Figure 1). Evidence also showed that the modification of an existing signal to one that contained an E/P phase may result in more conflicts than will the installation of a new E/P signal where no signal previously existed. In the latter case the intersections all exhibited relatively low conflict rates. On-site observers pointed out that intersections that have multiple right-turn-on-red alternatives appeared to create driver confusion and accompanying conflicts.

No single intersection characteristic that was responsible for vehicle conflicts could be found. Many possible culprits have been mentioned and, although a common denominator was not found, the observations revealed that the more movements that occur in an intersection the more likely that conflicts will occur.

RESULTS OF ACCIDENT ANALYSES

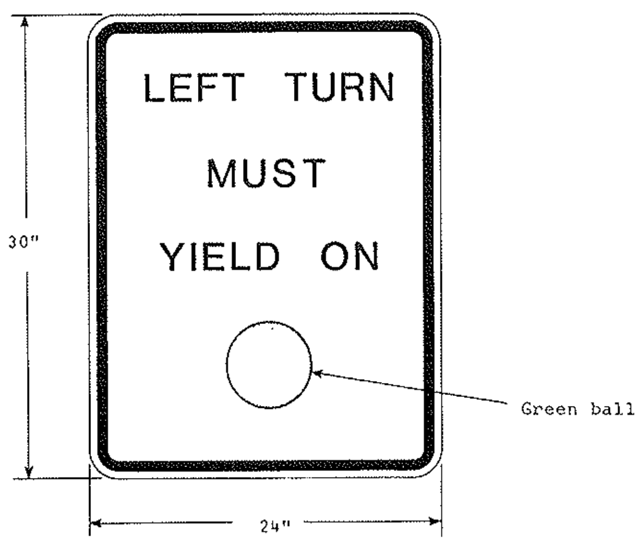
Accident data were analyzed for periods before and after installation of the signals. Where possible, this analysis included 1-year periods before and after installation. For three of the sites, due to the recency of the installation, only limited after data were available (3 to 6 months). For four sites, no before data were available.

Table 2 gives the total number of accidents that occurred at four intersections in the 1-year periods before and after installation of the E/P signals. At some intersections the total number of accidents declined over the 2-year period; however, the number of left-turn accidents increased. The breakdown at individual sites showed that the data from one site probably skewed this table such that little can be

Table 1. Summary of signal site intersections.

Site	Type	Location	Speed Limit (mph)	Approach Volume	Left-Turn Volumes	
					Green Ball	Green Arrow
1	4-lane urban arterial	City of Charlottesville	25	4,434	172	433
2	4-lane divided suburban arterial	County of Albemarle	45	10,711	649	977
3	2-lane urban arterial	City of Charlottesville	25	3,134	245	530
4	4-lane divided suburban arterial	County of Albemarle	45	8,401	616	296
5	2-lane suburban arterial	County of Chesterfield	45	3,255	183	128
6	4-lane divided suburban arterial	City of Virginia Beach	50	6,426	117	35
7	2-lane suburban arterial	County of Roanoke	35	3,449	275	265
8	4-lane divided urban arterial	City of Virginia Beach	45	5,493	721	813
9	4-lane divided suburban arterial	Prince William County	45	4,219	547	860
10	4-lane divided suburban arterial	Prince William County	45	8,272	491	734
Avg.				5,800	401	507

Figure 1. Supplemental E/P regulatory sign.



said about the increase or decrease in left-turn accidents during the 1-year period after the E/P signal was installed.

Table 3 gives the monthly distribution of all accidents subsequent to the installation of the E/P signals. The number of accidents decreased over time. In the first 6 months an average of 1.95 accidents/month occurred per intersection. During the second 6 months this number was reduced to 1.03 accidents/month. The decrease in left-turn accidents, however, was not as drastic. In the first 6 months after the E/P signals was installed the average for left-turn accidents was 0.63/month per intersection. During the next 6 months this rate was reduced to 0.53/month. Also, the table shows that left-turn accidents comprised anywhere from 23 to 100 percent of the total accidents at the 8 intersections. In the first 6 months after E/P installation 40.5 percent of the accidents recorded were related to left turns; in the next 6 months 60.0 percent were left-turn related. Thus, these data allow no conclusions as to the effect of the passage of time on the accident rate at E/P signalized intersections. The data are simply too limited. A more in-depth analysis of 25 to 40 intersections would be needed before any such conclusions could be drawn.

Table 2. One year before and after E/P installation accident summary.

Location	All Accidents		Left-Turn Accidents	
	Before	After	Before	After
Site 4	11	22	0	14
Site 5	6	3	0	1
Site 6	47	27	12	4
Site 7	6	6	4	4
Total	70	58	16	23

Table 4 represents the most conclusive evidence regarding the possible effect of E/P signals on accident rates at the intersections. The table gives before-and-after accident data for four E/P signal sites. Left-turn accidents increased by an average of almost 20 percent during periods after installation. Little can be said about individual intersections, except that the higher-volume intersections appear to show the greatest propensity for left-turn accidents. Individual intersection analyses would require more data that take into account the myriad of intersection characteristics that affect accident rates.

RESULTS OF QUESTIONNAIRE SURVEY

Motorist Familiarity With and Confusion at E/P Intersection

Respondents were asked to estimate the number of times each week that they made a left turn at an intersection pictured on the questionnaire. The respondents averaged about 8 turns/week; the greatest number made 11 or more turns/week. Only 7.4 percent of the respondents said that they made fewer than 3 turns/week at the intersection. This information established that those who participated in the survey were familiar enough with the signal to answer questions about it.

The responses to two questions aimed at determining the degree of confusion caused by the new signal showed that more than one-third of the motorists

Table 3. Distribution of accidents by month after E/P installation.

Month After Installation	Number of Accidents: Site 2 All Accidents	Site 2 Left-Turn Accidents	Site 4 All Accidents	Site 4 Left-Turn Accidents	Site 5 All Accidents	Site 5 Left-Turn Accidents	Site 6 All Accidents	Site 6 Left-Turn Accidents	Site 7 All Accidents	Site 7 Left-Turn Accidents	Site 8 All Accidents	Site 8 Left-Turn Accidents
1	7	3	2	2	0	0	2	0	0	0	0	0
2	4	3	3	3	0	0	2	0	0	2	0	0
3	2	0	1	0	1	0	4	0	4	1	0	0
4	2	1	0	0	1	0	4	0	1	0	3	0
5	3	1	2	1	1	1	4	0	0	0	0	0
6	3	0	3	1	0	0	3	1	0	0	2	1
7			3	2	0	0	5	1	0	0	2	1
8			1	1	0	0	2	1	0	0	5	1
9			2	2	0	0	0	0	0	0	1	0
10			0	0	0	0	1	1	0	0	0	0
11			4	3	0	0	0	0	0	0	2	2
12	—	...	1	0	0	0	0	0	1	1	1	0
Total	21	8	22	15	3	1	27	4	6	4	16	5

Table 4. Summary of left-turn accidents.

Site	Length of Reporting Period (months)	Accidents in Before Period: All	Left Turn: Number	Left Turn: Percentage of Total	Accidents in After Period: All	Left Turn: Number	Left Turn: Percentage of Total	Change in Left-Turn Accidents (%)
4	12	11	0	0	22	15	68.2	+68.2
5	12	6	0	0	3	1	33.3	+33.3
6	12	47	12	25.5	27	4	14.8	-10.7
7	12	6	4	66.7	6	4	66.7	0
Total		70	16	22.9	58	24	41.4	18.5

Table 5. Change in motorists' confusion over time.

Site	Time Since Installation (months)	Percentage of Confused Motorists: At First	Now	Change
1	24	3.6	0	100.0
2	24	17.2	10.3	40.1
3	17	6.5	0	100.0
4	16	38.3	19.1	50.1
5	12	26.2	8.2	68.7
6	12	50.0	27.3	45.4
7	9	31.8	4.5	85.8
8	7	36.5	9.5	74.0
9	5	61.5	9.6	84.4
10	5	71.4	38.1	46.6

Note: A total of 460 motorists responded to survey.

(36.5 percent) were confused the first time they passed through the intersection, but only 12.4 percent remained confused. Moreover, as given in Table 5, motorists' confusion about the E/P signal reduced over time at every site. However, the table also shows that the degree to which confusion reduced over time varied among the sites. For instance, the E/P signals at sites 1 and 2 had been in place for about the same length of time. The confusion disappeared at site 1 but at site 2 it dropped only 40 percent. The situation was similar for sites 9 and 10. These signals had been in place for the same amount of time, yet the responses showed that a great deal more confusion still existed at site 10 than at site 9. Obviously, factors other than unfamiliarity with a new type of signal were responsible for the continuing confusion. Such variables as speed limit, through volume, turn volume, intersection configuration, geometrics, and sight distance affect a driver's ability to understand the E/P signal indication.

Cross-tabulations between the responses to the question on confusion revealed that individuals who were still confused by the E/P signal were generally more negative toward it than were those who were not confused. Also, more often than not, those who were not confused had seen this type of signal elsewhere.

Respondents were overwhelmingly in support of placing a supplementary sign near the signal to explain that a left-turning vehicle must yield on a green ball (Figure 1). Only 9.3 percent thought that such a sign was unnecessary. Forty percent of the respondents thought that the best placement for such a sign would be adjacent to the signal head. Another 37.6 percent thought that the signs were necessary both adjacent to the signal head and in the median, where one exits. Note that five of the E/P signals, all located in cities, were not signed. For the surveys made at these five locations 67.8 percent of the respondents thought that a sign was necessary adjacent to the signal head, in the median, or both. For the five sites that included a supplementary sign this opinion was held by 86.6 percent of the respondents. However, all but one of the E/P signals not accompanied by the sign continued to confuse motorists. The addition of a sign might reduce confusion.

General Opinion About Impact of E/P Signals on Intersections

Each respondent was asked to give an overall opinion of E/P signal phasing at the intersection in question. Slightly more than 70 percent were in favor of this type of signal, about 11 percent were neutral, and about 17 percent were against it. Note

Site 9		Site 10		Average per Site		
All Accidents	Left-Turn Accidents	All Accidents	Left-Turn Accidents	Total Accidents	Left-Turn Accidents	Percentage Left-Turn to Total Accidents
5	4	3	1	2.4	0.75	53
0	0	2	2	1.5	1.25	73
3	1	4	4	2.4	0.75	37
2	1			1.9	0.29	23
				1.7	0.33	30
				1.8	0.33	27
				2.0	0.80	40
				1.6	0.60	38
				0.6	0.40	67
				0.2	0.20	100
				1.2	1.00	83
				0.6	0.20	33
10	6	9	7	1.49	0.58	44

Table 6. Summary of responses regarding intersection impacts of E/P signal.

Question	Percentage Responding (N = 460)		
	Yes	No	No Response
Has signal reduced delays?	77.0	19.3	3.7
Has signal created a hazard?	30.5	65.4	4.1
Have you been involved in a crash or near miss?	20.9	78.0	1.1

also that at E/P-signalled intersections where the conflict and accident rates were high public opinion generally was more negative than it was at less conflict- and accident-prone intersections.

Table 6 gives a summary of responses to questions concerning the impact of the E/P signal on the intersection. Overall, 70.0 percent of the respondents thought that E/P signal phasing had reduced delay. However, about 30.0 percent thought that a hazardous situation was created by the E/P signal and roughly 21.0 percent indicated that they had been involved in a crash or near miss at one of the E/P intersections. Cross-tabulations revealed the existence of some interesting relations between the answers to these questions and certain other variables. As would be expected, respondents who had a positive opinion about the E/P signal thought it had had a positive effect on the intersection; that is, it had reduced delays and had not created a hazard. Individuals who had seen this type of signal in other areas were more likely to think that the signal had had a positive effect on the intersection than were those who had not.

Both this and the preceding relation were significant at the 99 percent level of confidence. The implication here is, again, that familiarity with the E/P treatment tends to reduce apprehension about it. Furthermore, cross-tabulations showed that individuals who had seen the E/P signal in other areas were less likely to have been involved in a crash or near miss at the intersection. This relation was significant at the 95 percent level of confidence and exhibits the probability that advance familiarity with the E/P signal treatment might reduce vehicle conflicts and accident rates.

Advance Publicity: Will It Reduce Intersection Confusion?

Familiarity with the E/P signal is an aid to the motorist. To take this concept one step further would be to suggest that advance publicity on E/P installations would be of even more help. Although this suggestion is embodied in responses to previous questionnaire items, it is strengthened by responses to a question regarding the type of advance publicity that might be helpful. More than 82 percent of the respondents said that they had known nothing of the E/P signal until after it had been installed and they had entered the intersection.

Roughly 83 percent of the respondents thought that advance knowledge of the newly signalled intersection would have been beneficial to them. As was expected, the newspaper was considered the most effective method for publicity of this type (38 percent); a mailed flyer was the second most effective. This preference, then, indicates that, should a public information campaign be launched to inform the motorist that an E/P signal is being installed, a mailed flyer and newspaper coverage should be used. Radio and television coverage were not deemed to be as desirable and, therefore, should be used only minimally.

SUMMARY AND SUGGESTIONS FOR FURTHER RESEARCH

The study has shown that more than one-third of the motorists questioned were confused the first time they encountered E/P signal phasing. This confusion was found to dissipate over time at every test site. Familiarity with this type of signal treatment reduces motorists' confusion. Such confusion can be further reduced through advance publicity of the signal modification or new installation. The most preferred method of publicity was the newspaper, and a mailed flyer was the second most preferred. A sign placed adjacent to the signal head was also found to aid in the reduction of confusion. More than 90 percent of the survey respondents thought such a sign was helpful.

The majority of those surveyed (70 percent) were in favor of E/P signal phasing. About 77 percent thought that this treatment reduced delay at the intersection. Thirty percent, however, perceived that the E/P signal phasing had produced a hazardous situation. Those familiar with E/P signals tended to be more positive about this treatment than those who were unfamiliar with them.

Vehicular conflicts were most frequent at intersections that had high volumes of left-turning traffic and multiple avenues of movement. Indications are that intersections that have one or more right-turn-on-red movements may be prone to high conflict and accident rates. The conflict rate was never found to be attributable to any single intersection characteristic but was probably the result of the combination of several. Some evidence suggests that modification of existing signals may result in a slightly higher conflict rate than will the installation of a new signal, but the supporting data are sketchy at best. The same is true for accident rates. At best, all that can be said about accidents based on the data gathered in this study is that, in general, the ratio of accidents involving left-turning vehicles to all accidents that occur at the intersections increases after E/P signals are installed.

This study has made some determinations, but more work is still to be done. A study is under way at the research council to determine what types of intersections lend themselves to E/P signal treatment. To establish guidelines for the installation of E/P left-turn phasing at new locations and for modifying existing locations, a comparison is being made of existing E/P intersections and non-E/P intersections on the basis of such characteristics as approach and left-turn traffic volumes, traffic mix, speed limit, geometrics, sight distance, accident and conflict rates, intersection configuration, and commercial development.

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REFERENCES

1. K.R. Agent. An Evaluation of Permissive Left Turn Signal Phasing. Division of Research, Kentucky Department of Transportation, Lexington, April 1979.
2. K.R. Agent. Development of Warrants for Left-Turn Signal Phasing. Division of Research, Kentucky Department of Transportation, Lexington, April 1976.

Notice: The opinions, findings, and conclusions expressed in this paper are those of the author and not necessarily those of the sponsoring agencies.

Safety Effects of Rumble Strips on Secondary Roads

R.L. CARSTENS

Research was undertaken to identify specific locations where rumble strips could improve safety on rural secondary roads. Of the 685 rumble-strip installations on secondary roads in Iowa, 207 were selected for detailed study. At 88 locations a before-and-after comparison of the accident experience was made because accident records were available for at least one full year both preceding and following the installation of rumble strips. (Accident records were available only for 1977-1980.) The accident experience at the 119 locations that have rumble strips installed before 1978 was compared with a sample of comparable locations that do not have rumble strips. No difference was found in the accident experience at secondary road locations between the periods before and after the installation of rumble strips. Secondary road locations that have rumble strips for longer periods experienced slightly more accidents than did comparable control locations that did not have rumble strips. Comparisons were made on the basis of both the total number of accidents and the number of accidents attributed to running a stop sign. Furthermore, no correlation could be demonstrated between the occurrence of accidents at the locations in the sample and factors such as traffic volume, sight distance, and distance from the last stop.

The use of rumble strips on paved rural secondary roads has often been suggested as a means of enhancing safety. Rumble strips are used widely in some jurisdictions in advance of intersections controlled by stop signs. A few jurisdictions also make use of rumble strips in advance of railroad grade crossings or at other locations thought to require supplemental warning devices.

No definitive guidelines or warrants have been developed to suggest locations at which rumble strips should be installed. Some of the research reported in the literature indicates that they can be effective in reducing accidents at some locations. On the other hand, several studies of rumble-strip use have shown that the number of accidents does not change following the installation of rumble strips, although the number of certain types of accidents may be reduced.

BACKGROUND

Research was undertaken to identify specific locations where rumble strips could be expected to improve highway safety. Factors that were considered include intersection sight distances, approach gradients, accident experience, and distance from the last stop. These factors were quantified through a field inventory of selected locations in Iowa where rumble strips had been installed. Analysis of the correlation of these factors with safety made use of the accident records available in Iowa through the accident location and analysis system (ALAS).

The goal of the research was to improve safety on rural secondary roads by recommending guidelines or warrants for the use of rumble strips. To accomplish this goal those factors were to be identified and quantified that could be used to distinguish between locations where rumble strips could be shown to be effective in reducing accidents and those locations where no beneficial effect on accident frequency may be expected. The effect of each factor was to be quantified so that numerical warrants could be developed.

SURVEY OF RUMBLE STRIPS ON SECONDARY ROADS IN IOWA

Sample

The sample was developed by means of a mailed survey sent to each of the 99 county engineers in Iowa. Information was requested on all rumble strip locations on the secondary road system in the state.

Twenty-four counties reported that no rumble strips had been installed on secondary roads. Other counties reported from 1 to 41 locations at which rumble strips had been installed, for a total of 685 rumble strip installations. Of these 661 were at stop sign locations and 24 were at other locations, primarily at railroad crossings.

The sample for the field study was selected as follows:

1. Rumble strip installed in 1978 or 1979--a 100-percent sample;
2. Rumble strip installed in 1977 or earlier--a 50-percent sample with a maximum of six from any one county.

Locations to be inventoried for the sample of locations that have had rumble strips since at least 1977 were selected by using random numbers as grid coordinates to avoid a bias in designating the sample locations. Control locations for a comparison of accident experience were in the same county or a contiguous county in Iowa and were located and selected by the field crew to be comparable in terms of geometrics and traffic control. A location was excluded if there had been a significant change during 1977-1980 in traffic control, surface type, or any other characteristic that would invalidate a before-and-after comparison of accident experience at the location.

The number of locations included in the secondary road sample was as follows:

1. Before-and-after comparison of locations with rumble strips installed in 1978 or 1979, 88;
2. Locations with rumble strips installed in 1977 or earlier, 119; and
3. Locations without rumble strips for control purposes, 119.

The types of locations at which these rumble strip installations were located are shown in Figure 1. The number of locations of each type is given in Table 1.

Inventories and Analyses

An inventory of field conditions was performed at each of the 207 locations with rumble strips that were included in the data sample as well as at the 119 locations without rumble strips that were used for control purposes. Information was recorded in the field for all of the independent variables listed in Table 2 except those related to traffic volumes.

An accident record was obtained for each rumble strip location included in the sample and for asso-

Figure 1. Types of locations included in rumble strip sample.

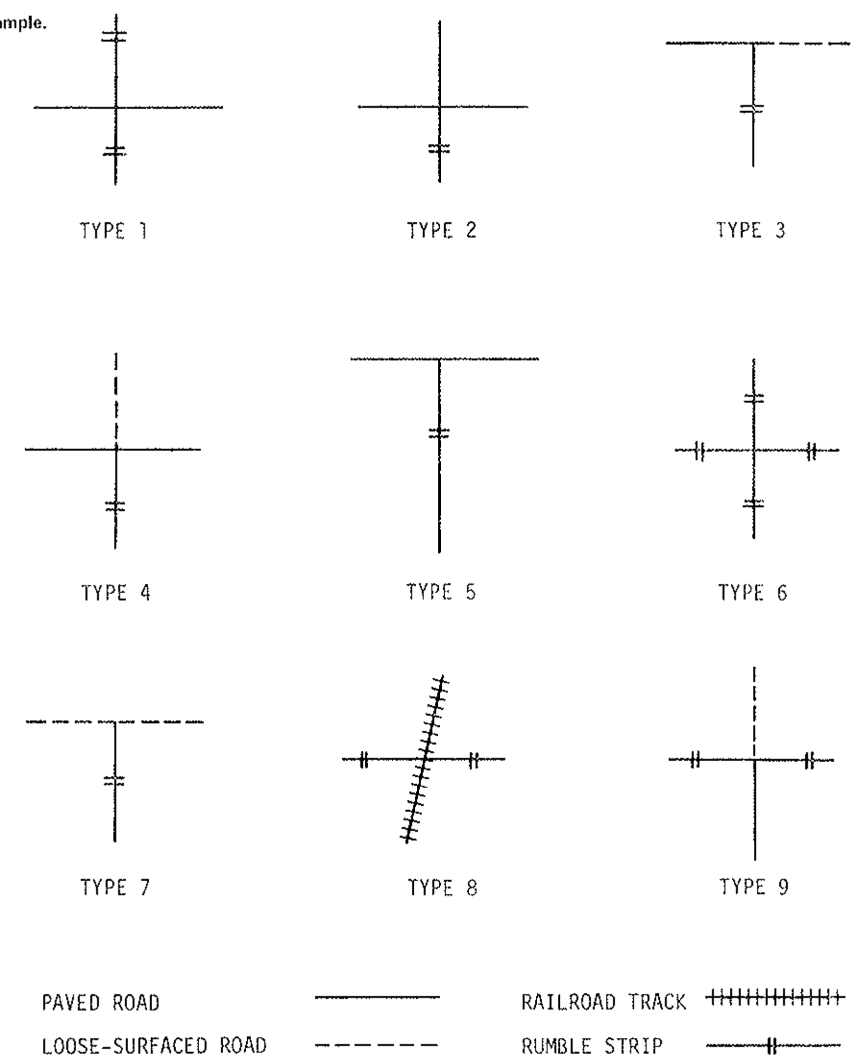


Table 1. Summary of secondary road sample by type of location.

Type of Installation	Number of Locations: Without Control	Pairs with Control
1	10	16
2	8	4
3	5	1
4	27	49
5	33	41
6	0	0
7	2	0
8	2	8
9	1	0
Total	88	119

Table 2. Variables used in models.

Code	Variable
Dependent	
NTA	Total accident rate at node (accident/million entering vehicles per year)
NRA	Run stop sign accident rate at node
Independent	
INTER	Intersection type (secondary or primary)
HWY	Highway type (T-type, RR-Xing, or other)
CONTROL	Type of control (one-way stop or others)
IANGLE	Intersection angle (degrees)
DUMMY	Presence or absence of rumble strip
MEV	Million entering vehicles per year
APPROACH	Approach volume for link with rumble strip
INTERVOL	Intersecting volume
VISIBLE	Distance stop sign is visible (ft; maximum of 1,000 ft)
SIDE	Number of driveways, field entrances, and gravel roads within 0.5 mile
RIGHT	Right sight triangle length (ft; maximum of 1,000 ft)
LEFT	Left sight triangle length (ft; maximum of 1,000 ft)
MILE	Miles of travel from last stop sign, reduction in speed to 30 mph or less, freeway entrance, beginning of pavement, or travel through incorporated city
EL	Difference in elevation, point 200 ft from intersecting road relative to center of intersection (in.)
WIDTH	Pavement width (ft)
FILLET	Length of intersecting fillet (ft)

Table 3. Mean values and standard deviations of dependent variables used in models.

Dependent Variable	Accident Rate (Accidents/MEV): Mean	SD
Rumble strips installed 1978-1979 (N = 85)		
Total accidents, before	1.244	2.335
Total accidents, after	1.236	1.887
Run-stop-sign accidents, before	0.588	1.674
Run-stop-sign accidents, after	0.608	1.439
Rumble strips installed before 1978 (N = 111)		
Total accidents	1.000	1.283
Run-stop-sign accidents	0.352	0.614
Control intersections, no rumble strips (N = 111)		
Total accidents	0.793	1.207
Run-stop-sign accidents	0.304	0.647

ciated control locations. This information was available only for calendar years 1977-1980 from ALAS, a computer-accessed accident record storage system maintained by the Office of Safety Programs, Iowa Department of Transportation.

Accident records were obtained to compare the accident experience at locations that have rumble strips with comparable locations that do not have rumble strips. One possible basis for comparison is the before-and-after experience at one location. Such a sample could be obtained for this research if rumble strips had been installed in 1978 or 1979. In these cases either one or two years of accident data were available for the period preceding installation of rumble strips, and either one or two years of accident data were available following their installation.

Rumble strips installed in either 1980 or 1981 did not have a sufficient amount of accident experience on which to base a comparison; therefore, such installations could not be included in the sample. On the other hand, if rumble strips had been installed in 1977 or earlier, a comparison of accident experience could be made with a location that was similar in all essential respects except for the absence of rumble strips. In these cases accident experience was compared for 1978-1980 for installations made in 1977, or for 1977-1980 for earlier installations. The year during which rumble strips were installed was always excluded from a comparison.

The 10 type-8 locations (railroad crossings) and the 1 type-9 location were deleted from the secondary road sample. No accidents were recorded at any of these locations during 1977-1980. Therefore, the inclusion of these unique installations in a larger sample could not contribute meaningfully to a data analysis. The remaining secondary road sample included 85 intersections with rumble strips installed in 1978 or 1979, 111 intersections with rumble strips installed before 1978, and 111 intersections without rumble strips.

FINDINGS

One of the purposes of the accident data analyses was to quantify the reduction in accidents at locations where rumble strips had been installed. A further purpose, assuming a safety benefit from installing rumble strips, was to identify the factors that distinguished locations that experienced a reduction in accidents following installation of rumble strips from those where no such reduction had occurred.

To accomplish this analysis the factors displayed in Table 2 were quantified. Two different dependent variables were used, the total accident rate at a location (NTA) and the rate for accidents involving a ran-stop-sign notation by the investigating officer (NRA). In both cases accident rates were expressed in the number of accidents per million entering vehicles (MEV).

Aside from NTA and NRA no effort was made to segregate accidents by type. The available data did not indicate that the frequency of any particular type of accident was influenced by the presence or absence of rumble strips.

Accident severity was not considered as a variable in this research. The results of an earlier study of experience in Iowa with rumble strips on county roads showed an almost perfect correlation between accident severity and the total number of accidents. The average severity was the same both before and after the installation of rumble strips. Furthermore, because the number of accidents typically occurring at the rural locations included in the samples for this study was so small, the random occurrence of a single fatal accident could have seriously distorted comparisons based on accident severity.

Average values for the dependent variables are given in Table 3. As indicated in the table, the differences in accident experience between comparable samples are not significant. For example, the average rates for total accidents are the same before and after rumble strip installation at the locations where rumble strips were installed in 1978 or 1979. The average rate for the run-stop-sign type of accident is 3 percent higher following the installation of rumble strips.

In a comparison of 111 intersections with rumble strips installed before 1978 with 111 comparable intersections without rumble strips the control locations show lower accident rates. The difference is 21 percent in the case of total accidents and 14 percent in the case of run-stop-sign accidents. These differences are not statistically significant.

Because no safety benefit is apparent from the installation of rumble strips on secondary roads, analysis of these data failed to identify any variables that were significantly associated with a favorable effect on accident experience. Regression analyses were undertaken by using several different subsamples based on the type of location. None was successful in demonstrating that rumble strips could be expected to improve accident experience in association with any particular characteristics of an intersection. Cross-classification analyses and discriminant analyses were equally unsuccessful.

Further evaluation were carried out by using only the before-and-after sample. No accidents were recorded at 28 of the 85 locations during both periods, before and after the installation of rumble strips. Accident experience improved following installation of rumble strips at 27 of the other 57 locations, worsened at 26 locations, and was unchanged at 4 locations. Analyses of single-vehicle run-off-the-road accidents at T-intersections showed no differences between the before and after experience. The proportions of accidents that occur at night also exhibited no change following the installation of rumble strips.

CONCLUSIONS

The frequency of accidents at rural locations on secondary roads was independent of the presence or absence of rumble strips. No factors were identified that characterize locations where a reduction in accident frequency could be expected to result from the installation of rumble strips. Although secondary road intersections that have accident rates higher than 2.5 accidents/MEV always showed a reduction in accident rate following the installation of rumble strips, this reduction would be expected by chance given the low traffic volumes and infrequent occurrence of accidents at these locations.

Notice: The research reported here was carried out by the Engineering Research Institute, Iowa State University. It was sponsored by the Highway Division, Iowa Department of Transportation, through the Iowa Highway Research Board. The author, however, retains responsibility for the interpretations of factual input to the research and for its findings and conclusions, which are not necessarily those of the Highway Division of the Iowa Department of Transportation.

Sign Vandalism—Costly and Dangerous National Problem

HIMMAT S. CHADDA AND EVERETT C. CARTER

Sign vandalism has become a costly and often deadly national problem. In addition to the millions of dollars in cost to replace vandalized signs, this situation denies motorists the critical information necessary for safe driving and increases the potential for severe traffic accidents. Nationally, the replacement costs for vandalized signs are startling—about $50 million annually in direct costs and indirect costs for injuries and tort liability claims of about the same magnitude. The accident statistics on fatalities, property damages, and personal injuries that result from vandalized or missing signs are frightening and point out the magnitude of the problem. Some jurisdictions have become alarmed at the increasing rate of sign vandalism and its adverse economic, social, and safety impacts. The nature, magnitude, and criticality of the sign vandalism problem requires a strong concerted effort at both the national and local levels to combat this costly and dangerous traffic safety problem. A grass roots approach is suggested for a full understanding of who vandalizes signs, why they do so, when and where sign vandalism is more pronounced, and the true consequences of this prankishness. Positive and problem-specific countermeasures (physical, legal, judicial and enforcement, and educational) that should be pursued at the national, state, and local levels are discussed in this paper. A systems approach framework for selecting countermeasures for local and problem-specific sign vandalism was developed and partly tested. This approach should be fully implemented.

Sign vandalism has become a costly and often deadly national problem. In addition to the millions of dollars taxpayers spend to replace vandalized signs, vandalism denies the motorists the critical information necessary for safe driving and increases the potential for severe and often tragic traffic accidents. Nationally, the replacement costs for vandalized sign are startling. According to FHWA estimates, total annual direct costs to the states, counties, and cities are $50 million (1). Indirect costs for injuries and tort liability claims are estimated to be the same. Accident statistics on fatalities, property damages, and personal injuries from vandalized or missing signs (especially intersection-control signs and STOP signs in particular) are rather frightening and are indicative of the magnitude of the problem.

State and local jurisdictions and the federal government have become alarmed at the increasing rate of sign vandalism and its adverse impact on local agency budgets and the safety of highway users. The nature, magnitude, and criticality of the sign vandalism problem requires a strong concerted effort at both the national and local levels to combat this costly and dangerous traffic safety problem.

SCOPE OF SIGN VANDALISM PROBLEM

Vandalism as defined in the Webster's Dictionary means "willful or malicious destruction or defacement of public or private property." In the area of traffic engineering, vandalism has affected different types of traffic control devices. Traffic control devices and equipment that are routinely vandalized include signals (especially lenses for pedestrian indications and pedestrian push buttons), signs (all types of regulatory, warning, informational, and directional), traffic cones, delineators, traffic counters, reflectorized pavement markers and buttons, and occasionally pavement markings.

In the past few years sign vandalism has created major hazards on national, state, and local highways, and in national parks, campgrounds, and forests. The problem becomes more acute each year. The escalating replacement and rehabilitation costs, the tort liability claims, and the ever-present danger to the motoring public are all of concern.

The impact of sign vandalism can be catastrophic. Missing or stolen signs, particularly STOP signs and other regulatory and warning signs at intersections, can result in needless and tragic traffic accidents. Precise statistics documenting accidents attributable to sign vandalism are not available; however, many fatal traffic accidents have been the direct result of sign vandalism. A recent survey of various states conducted by the National Safety Council (NSC) found that, in the seven states that kept records of sign vandal-related accidents, 14 fatalities were attributed to vandalism or theft of signs (2).

Costs associated with the replacement and rehabilitation of vandalized signs and the settlement of liability claims are startling. Thirty states reported in an NSC survey that costs ranged from $34,000 to $1.8 million, including inspection, material, labor, and liability settlements (2). The monetary costs alone are high, but the potential cost in lost human life is inexcusable.

The increasing costs of replacing vandalized highway traffic signs is becoming a serious concern. Approximately 10 percent of traffic signs must be replaced annually because vandals either stole, defaced, or mutilated them. Replacement costs hit all taxpayers in their pocketbooks.

Sign vandalizm is not limited to one geographic area or one political jurisdiction; it is universal. Sign vandalism is also widespread on forest service roads and campgrounds. According to a survey conducted by the U.S. Department of Agriculture Forest Service, Missoula, Montana, various districts of the Forest Service spent roughly $500,000 to replace vandalized signs in FY 1978; Overall, six percent of the total Forest Service sign inventory was vandalized in 1978, which amounted to about $3.25 million in damages (3).

A grass roots approach is necessary for a full understanding of who vandalizes signs, why they do, when and where sign vandalism is more pronounced, and what are the true consequences. Further, positive countermeasures--physical, legal, judicial and enforcement, and educational--should be pursued at the national, state, and local levels to combat sign vandalism.

ISSUES AND ASPECTS OF SIGN VANDALISM PROBLEM

Three major types of sign vandalism exist.

Destruction

Destruction includes traffic signs destroyed or damaged by bullets. Damage to signs may also be caused intentionally by flying objects (e.g., bottles, rocks, bricks, eggs, or tomatoes) thrown by vandals from moving vehicles. Damage to traffic signs can also be caused by physical force (e.g., the willful bending or twisting of the sign face, street name sign blades, or sign support; hitting with a hammer; cutting with a hacksaw; and other similar actions).

The most predominant destruction of traffic signs is by rifle shots, pistol fire, and shotgun blasts. This type of sign vandalism is common in the rural areas of many states. Sign damage caused by splattering of eggs, tomatoes, and the like on the sign face generally ruins the reflectivity of the sheeting and makes the sign unreadable and ineffective, particularly at night.

Figures 1-3 show various types of traffic signs vandalized by rifle, shotgun, and pistol shots. Figure 4a shows a street name sign twisted by vandals in Clark County, Washington, that consequently contributed to a fatal automobile accident. Figure 4b shows the solution used in this instance.

Mutilation

Sign mutilation occurs when the face of the sign or the sign support is altered in some manner. Sign mutilation is often accomplished by vandals using spray paint, posting political or similar unofficial sticker items on the sign face, altering the traffic sign messages (e.g., changing a speed limit from 25 mph to 85 or 125 mph), peeling off reflectorized sheeting from the sign face, and destroying the reflectors (used on sign messages or on borders) for improved night visibility. Spray paint appears to be the predominant means of mutilating sign faces, but signs are also defaced by paint and brush.

Figures 5-9 show examples of mutilated traffic signs. Such defaced regulatory signs can and often have resulted in serious automobile accidents.

Theft

Many students consider the removal of traffic signs from their support or the stealing of signs a harmless prank. In addition to stealing the sign faces, vandals sometimes remove or steal other parts of the sign structure such as the channels, pipes, street name sign blades, and other hardware. Traffic signs stolen from streets and intersections can be found in the dormitories, sororities, and fraternity houses of many American campuses.

Theft of regulatory signs, particularly STOP signs, often results in dangerous consequences. The potential for a serious or fatal accident is high, especially for motorists who are not familiar with the traffic control at a particular intersection.

Characteristics of Sign Vandals

People vandalize signs for various reasons, including the following:

1. Simply for sake of fun;
2. Defiance of authority;
3. Wall decorations, souvenirs, or trophies;
4. Scrap value of metal (mostly aluminum);
5. Gag or malicious behavior; and
6. Graffiti.

Sign vandals are almost always young people.

Disposition of Vandalized Signs

Stolen signs end up at various places. Most common among these are university dormitories, fraternities or sororities, bedrooms and basements, junk shops, ravines, creeks, and alleyways.

Types of Signs Commonly Vandalized

The STOP sign (R1-1) is probably the most often vandalized sign (i.e., either stolen, mutilated, or victimized with graffiti). Street name signs are a close second on the vandals' target list. Other signs commonly vandalized include various regulatory signs, warning signs, guide signs, and street name signs.

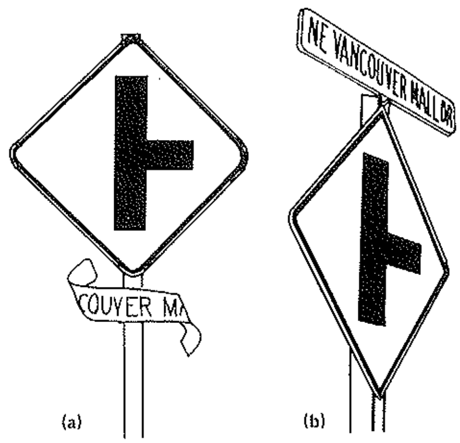
Street name signs are popular targets with certain groups of vandals. The street name signs that

Figure 1. Bullet-ridden STOP sign in Florida.

Figure 2. Curve warning sign damaged by rifle shots.

Figure 3. One-lane bridge sign victimized by buck shots.

Figure 4. Traffic and street name sign (a) twisted by vandals and (b) with mounting height increased to counter vandalism.



are most often stolen are associated with famous legends in popular books, rock groups, movie stars, or boy or girl friends. Experience in the urban counties of Maryland with street name sign vandalism highlights the magnitude of this problem. In Baltimore County, Maryland, the street name sign, YELLOW BRICK ROAD has been stolen 20 times in one year (the name Yellow Brick Road is connected with the popular Wizard of Oz). In Montgomery County, Maryland, street signs named KAREN PLACE and JUDY LANE each have been vandalized at least six times a year. In Howard County, Maryland, the street sign named MUSTANG PATH disappears the day after county crews install it.

In Anne Arundel County, Maryland, the story of the recent theft of the JOHNSON ROAD street sign is rather interesting. Two Johnson brothers who wanted to steal this sign at the Johnson Road and Johnson Avenue intersection failed in their initial attempt to remove the street name blades from the post. Subsequently, they brought a pickup truck and a hacksaw and were caught in the act when a resident called the police.

Similar experiences have been reported in other parts of the country. For example, in Arkansas, one of the most frequently stolen signs a few years ago was the BLACK OAK sign on AK-18 at the Black Oak, Arkansas, city limits (4). This occurred when the rock group, Black Oak Arkansas, was popular.

Spatial and Temporal Patterns of Sign Vandalism

Sign vandalism is not limited to one geographic area or one political jurisdiction. It has grown to be a universal problem. Sign vandalism covers all types of areas including urban developments, rural areas, forests, national parks, and campgrounds. In urban areas sign vandalism is more acute in residential areas, at intersections, pedestrian crossings, and in the vicinity of educational institutions. In rural areas signs are vandalized on Interstate roads, freeways, and other local roads. Sign vandalism on forest service roads, national parks, and campgrounds is also widespread.

Signs are vandalized all year, but experience indicates that vandalism becomes more pronounced during certain months, seasons, and community festivals. The following are typically high periods for sign vandalism:

1. Summer months when schools are closed,

Figure 5. Curve warning sign with advisory speed limit victimized by graffiti.

Figure 6. STOP sign defaced by spray paint.

Figure 7. Four-way STOP sign now displays class of 80.

Figure 8. Curve warning sign changed to killer turtle crossing.

Figure 9. Vandalized pedestrian warning sign.

2. Graduation time and the end of school year,
3. Hunting season,
4. Election time,
5. Halloween time,
6. First warm day of spring, and
7. Holiday periods.

Sign graffiti generally occurs at night.

<u>Safety Impacts of Vandalized Signs</u>

Sign vandalism results in economic, safety, and social impacts. Social impacts are somewhat difficult to quantify and are not discussed in this paper. Vandalism of regulatory signs, especially STOP signs, is most critical. Not only do missing, stolen, or vandalized signs deny the motorist important and often vital information about traffic controls and regulations but they also present a hazard. This vandalism can result in tragic consequences in terms of fatal and injury-type accidents.

From a safety standpoint, sign vandalism, especially sign removal by theft, is a significant factor in traffic accidents. Absence of traffic control signs creates confusion and safety hazards for all highway users. Several serious accidents (involving injuries and fatalities) and crashes have occurred because of missing or vandalized STOP signs. Missing street name signs deny motorists and operators of emergency equipment necessary directions.

Few states and local jurisdictions maintain records of automobile accidents attributable directly to sign vandalism. The following information has been developed on the basis of a review of available literature and documentation, press releases, newspaper stories, and discussions with local agencies and officials. The information, though somewhat informal, clearly highlights the hazardous and tragic consequences of sign vandalism.

An automobile accident that resulted in four fatalities (including two children) occurred in Salem County, New Jersey, on August 21, 1980, as the result of a missing STOP sign taken from one of the streets at the intersection hours before the accident (5). Unwarned, the driver of the ill-fated out-of-state automobile went through the intersection onto a highway and collided with a tractor trailer (6).

In Fairfax County, Virginia, an automobile accident involving a fatality was attributed to a missing STOP sign. The legal costs for this accident were reported to be in excess of $1 million. In McHenry County, Illinois, vandals removed a STOP sign from an intersection. Moments later an automobile accident occurred and four members of a family were killed in that collision.

In Clark County, Washington, a traffic sign twisted by vandals contributed to a fatal automobile accident (7). The legal and court costs of litigation resulting from this accident were approximately $1.5 million. King County, Washington, suffered a tragic fatality in 1976 that was directly attributed to sign vandalism (8). Again, in 1979 another sign vandalism-related accident occurred and the life of a Public Works Department employee was lost (8). The victim in this fatal accident was the father of four children (9).

An automobile accident in West Virginia involving out-of-state travelers resulted in six fatalities. This accident occurred because of a missing STOP sign that was stolen.

In Wisconsin, several automobile accidents involving injuries have occurred that could be attributed directly to vandalized signs. The most serious accident occurred during the Labor Day weekend in 1975 (10) in which a motorist was killed because of a missing STOP sign.

Costs Associated with Sign Vandalism

Several components of cost are associated with sign vandalism. These include sign replacement and rehabilitation costs (including inspection, material, and labor), medical costs (for injuries resulting from accidents), and tort liability settlements.

Sign replacement costs vary from $50 to $100/sign, depending on the type and size of sign. Sign replacement cost can be enormous when the unit replacement cost is multiplied by several thousand signs that have been vandalized. Local jurisdictions are hit hard by tort liability claims that can run from several thousand to a few million dollars, depending on the type of accident, the property damage, and the number of people killed. Two examples of tort liability settlements discussed in the previous section (Fairfax County, Virginia, and Clark County, Washington) are eye openers.

Some local jurisdictions and states have started to maintain separate records for the number of signs vandalized by type of sign and vandalism, hours spent in replacing and rehabilitating signs, cost data, and associated legal expenses. Thirty states that maintain sign vandalism data reported in response to a recent survey questionnaire that approximately 1.2 million vandalized signs were replaced during 1980 (2). On a national basis this figure can be safely extrapolated to approximately 2 million signs replaced due to vandalism. The same survey revealed two additional interesting facts.

1. Cost of signs vandalized ranged from $34,000 to $1.8 million each year for such items as inspection, material, labor, and liability settlements.
2. The average overall replacement due to vandalism or theft was 28 percent of all signs replaced, with percentages ranging from less than 10 percent to 71 percent for the 25 states that responded to this question.

Review of available literature and documents on sign vandalism and discussions with local agency officials revealed some interesting data on the number of signs vandalized and associated replacement costs. Some of the pertinent information is described in the following paragraphs.

Replacement costs for signs vandalized in New Jersey exceeded $1 million each year (5). One out of every 10 traffic signs is stolen annually. Vermont reported that 4,542 signs were vandalized in 1979, which cost taxpayers $182,469 at an average cost of $40/sign.

Georgia has experienced a chronic problem with sign vandalism. During a one-year period (1979-1980) 83,818 signs were reported vandalized, which cost the state taxpayers approximately $1,084,655 to replace. In Virginia more than 40,000 traffic signs are vandalized or stolen each year, which costs taxpayers approximately $1 million. The Washington State Department of Transportation estimated a sign vandalism cost in 1970 of $117,000 for the following types of vandalism: 21 percent gunshots, 50 percent defaced, and 29 percent stolen. According to a press release issued in 1976, the annual sign vandalism cost was estimated to be $270,000.

The Idaho Transportation Department estimated that the sign vandalism cost for one year was approximately $90,000. The Wisconsin Department of Transportation estimates the number of signs vandalized per year as follows:

Year	No. of Signs Vandalized	Percentage of Total Signs Replaced
1978	2,520	3.5
1979	2,129	2.8
1980	3,255	4.1
1981	2,551	2.8

Replacement costs on a yearly basis range from $175,000 to $227,850, based on a unit sign cost of $70.

Annual sign vandalism costs estimated by some other states are as follows:

State	Cost ($000s)
Montana	300
Alaska	100
South Carolina	500
New Mexico	300
Connecticut	60
Louisiana	70

Sign vandalism costs for counties vary considerably depending on the location and density of population. Typical estimates range between $10,000 and $100,000. Replacement and rehabilitation costs and tort liability settlement costs resulting from vandalized signs are astronomically high. A cost that can never be measured is the cost in deaths and injuries.

EFFORTS AND TECHNIQUES USED TO COMBAT SIGN VANDALISM PROBLEM

Sign vandalism is a national problem that will require a concerted effort at the national level and by state and local governments to correct and combat. Lawmakers, enforcement officials, and traffic engineering professionals recognize the need to curb the serious problem of sign vandalism. Sign vandalism is a crime and vandals should be charged with a criminal offense. Unfortunately, sign vandals are rarely caught. Prosecution and conviction for sign vandalism are difficult. Evidence is normally lacking unless a witness to the crime (usually a nearby resident) reports the incident to the police or the vandals are caught in the act.

Some local jurisdictions and states, where sign vandalism has resulted in tragic accidents have taken the lead in their efforts to counter this growing problem. Wisconsin, Virginia, New Jersey, South Carolina, Arkansas, and Mississippi have developed anti-sign-vandalism programs and legislation. Likewise, some local jurisdictions, for example, several counties in Washington State (King County, Clark County, Douglas County, and Spokane) have taken positive steps to combat sign vandalism (11).

Countermeasures, techniques, and efforts to combat sign vandalism developed and used thus far are categorized in the following sections.

Legal Countermeasures

Legal countermeasures include enactment of anti-sign-vandalism laws, rewriting of existing inadequate laws concerning prosecution and conviction of vandals, and the proper enforcement of these laws.

Wisconsin has enacted a new law dealing with sign vandalism. The following paragraphs highlight the major elements of the statute.

> 86.192 Penalty for injuring guide board, markers, etc., (1) No person may injure, deface or remove any sign, guide board, mile post, signal or marker erected by the state or by any municipality thereof for the warning, instruction or information of the public. The following warning shall be affixed to the front of each such sign, guide board, mile post, signal or marker: "WARNING $25 to $100 fine or imprisonment for removing or tampering with this sign."
>
> (1) No person may possess any sign, guide board, mile post, signal or marker of the type erected by the state or by any municipality for the warning, instruction or information of the public, unless the person can demonstrate he or she obtained it in a legal manner. Possession of such a sign, guide board, mile post, signal or marker creates a rebuttable presumption of illegal possession. In this subsection, "possession" means the presence of such a sign, guide board, mile post, signal or marker on premises owned or controlled by the person, including but not limited to a rented apartment, rented room or dormitory room. Persons who voluntarily notify a law enforcement agency of the presence on their premises of such a sign, guide board, mile post, signal or marker shall be exempt from prosecution under this subsection.
>
> (2) Any person who violates this section shall be fined $25 for the first violation, $100 for a subsequent violation, or imprisoned not exceeding 30 days for the first violation, or 60 days for a subsequent violation, or both fined and imprisoned at the discretion of the court. The court may, in addition, order any such person either to restore or replace any such damaged sign, mile post, signal or marker, or to pay the cost thereof.
>
> (3) On conviction of any person of a violation of this section, the person or persons who informed against and aided in the prosecution of such offence to conviction shall be paid by the court one-half of the amount of the fine paid into the court.
>
> (4) Any person who violates this section shall be fined up to $10,000 or imprisoned not more than 2 years, or both fined and imprisoned, if the injury, defacement or removal causes the death of a person.

The state made a successful campaign of publicizing the revised statute and the penalties associated with it. Sign vandalism has been reduced since the enactment of the law. During 1976 sign vandalism was reduced by 57 percent on the 12,000 miles of state trunk system (10). The New Jersey State legislature has passed a bill that imposes stiff penalties for sign vandalism offenses, including prison terms up to 10 years for the theft of a traffic sign, including street name signs (6).

Virginia, Texas, and Mississippi have also enacted similar laws to counter sign vandalism. Arkansas treats sign vandalism as a criminal offense that is punishable by a fine not to exceed $1,000 and possible imprisonment of up to one year (4). South Carolina also treats sign vandalism as a criminal offense. The law states (12):

> No person shall willfully without lawful authority attempt to or in fact alter, deface, injure, knock down or remove any official traffic-control device or any railroad sign or signal or any inscription, shield or insignia thereon or any part thereof.
>
> Violation of this law is a misdemeanor and if convicted the person could be fined $1,000 or imprisoned for not less than one year nor more than five years, or both. The convicted person's driver's license will be revoked for not less than five years, also.

Physical Countermeasures

Physical countermeasures include the following efforts:

1. Use of property identification seals or decals at the back of signs to prevent theft;
2. Use of vandal-resistant material on the sign face;
3. Use of vandal-resistant or tamper-proof hardware or fasteners;
4. Use of medium- and high-density plywood products for the substratum (13);
5. Raising of the height of street name sign blades to be out of reach of teenagers [Clark County, Washington, increased the height of road name signs after a fatal accident was caused by a twisted sign (7) (see Figure 4b). A similar problem with vandalized pedestrian signals in Baltimore was solved by raising the signals from 7 to 11 ft.];
6. Use of tough and impact-resistant panels for signs (e.g., Lexan, a product manufactured by General Electric Company);
7. Use of double name signs--one on each side of the post and the ends are riveted together for extra strength to deter twisting (7);
8. Use of vandal-resistant sign supports (e.g., Signfix, a product manufactured by Signfix at North America, Inc.);
9. Use of plywood backing to prevent signs from being bent or twisted by vandals (7);
10. Use of good sign maintenance practices including development and upkeep of a traffic sign inventory (an inventory of signs assists in the

location of signs on the road, identifies the type of signs, and ensures prompt replacement of reported missing or vandalized signs.);

11. Improved securing of sign posts to the ground or foundation to prevent their removal by vandals; and

12. Prevention of theft of signs by applying lock tight, a metal filler or adhesive, on the threaded connections or by peening the end of the bolt to prevent removal of signs from the post, as is done by Connecticut.

Educational Programs

Educational techniques used to combat sign vandalism include the following:

1. Recruit parents and school officials to identify and report missing or vandalized signs;
2. Formation of antivandalism committees with participation from citizens, civic groups, professional associations, and law enforcement officials;
3. Emphasis on economic costs and severe safety consequences of sign vandalism in driver education classes;
4. Seminars for young school children and teenagers emphasizing through the use of pamphlets, graphics, motion pictures, and slides the adverse effects of sign vandalism such as (a) how much it costs taxpayers for sign replacement, (b) the type of accidents that can occur, (c) how signs lose their reflectivity and effectiveness at night when defaced with spray paint or when shot with rifles or pistols, and (d) how signs lose reflectivity when beer, milk, and acidic products are thrown on them; and
5. Anti-sign-vandalism slogans and theme.

Some examples of anti-sign-vandalism slogans and themes include the following:

1. Stop-sign vandalism is killing us (Wisconsin),
2. Sign vandalism kills real people,
3. Quit making traffic sign souvenirs (Alaska),
4. Save signs--save lives (King County, Washington),
5. Stop sign destruction (King County, Washington),
6. Do your part--report sign destruction (King County, Washington), and
7. Save a sign--save yourself (Douglas County, Washington).

Figure 10. Sassy, the sign bird, sign.

Public Information Campaigns

Some of the efforts for minimizing sign vandalism include the following:

1. Statewide media campaign on sign vandalism (a program targeted at the teenage audience),
2. Publicizing the state statute and penalties associated with sign vandalism crime (Wisconsin has made extensive use of this approach), and
3. Proclamation of Highway Sign Amnesty Month or Week by the state and local jurisdications [This technique has been used successfully in Wisconsin; the Highway Sign Amnesty Month campaign harvested more than 2,500 signs and markers plus traffic cones, barricades, flares, and utility hole covers (10). A similar amnesty campaign at Rutgers University produced a significant response by college students (14)].

South Carolina conducted an antivandalism campaign in 1979. It consisted of news releases to the media, statewide distribution of antivandalism posters, and a memorandum to school officals (11). Virginia's Department of Transportation Safety has produced a 15-min, 16-mm color film, "Designs of Life," related to the hazards created by removing traffic signs. The film is designed for use in high school driver education classes. Virginia also has developed a series of radio spots that have an antivandalism message (60 sec, 30 sec, and 15 sec). These are used primarily by local radio stations as public service announcements. Some states have placed warning decals on the back of traffic signs to inform would-be vandals about the ownership and legal consequences of stealing the signs.

Clark and King Counties, Washington, have conducted antivandalism campaigns, including countywide educational programs, public service announcements, and sign-up programs (11). Clark County has developed a novel public information technique and logo entitled, Sassy, The Song Bird says--save your signs--save yourself (see Figures 10 and 11). The purpose is to enlist the support of children. Additional concepts for eliciting the interest of children, with Sassy as the main character include a Sassy costume design contest, a parade contest (with costumes), advertisements in the paper, and a traffic sign coloring contest (7,11).

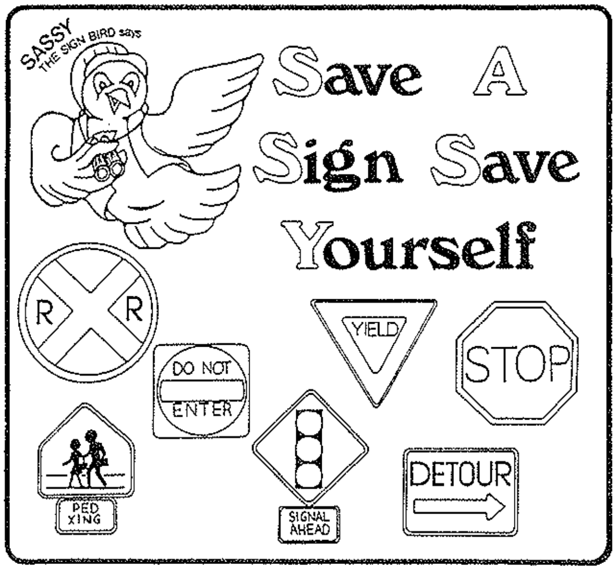
A nonprofit organization, Vandalism Limited Concern, established in Seattle, Washington, has addressed vandalism from several points of view: use of vandal-proof hardware, conduct of vandalism countermeasure symposium, and other programs to educate the public about the harmful effects of vandalism (15).

Summary

The major thrust of anti-sign-vandalism efforts described falls into three distinct categories:

1. Emphasis on laws and associated penalties for sign vandalism, as in Wisconsin;
2. Emphasis on the detrimental effects of sign vandalism and positive educational and public information programs, both Clark and King Counties, Washington, follow these concepts; and
3. Physical actions to deter vandalism. (Although only limited data are available on the effectiveness of most physical countermeasures, the

Figure 11. Sassy, the sign bird, contest poster.



results from some applications indicate a definite reduction in vandalism.)

The success of each technique can be measured by the end result; i.e., reduction in sign vandalism. The techniques described have reduced the incidence of sign vandalism. Wisconsin's campaign to eliminate sign vandalism was an overwhelming success--sign vandalism was reduced by 57 percent on the state trunk system in 1976 and a savings of $240,000 was realized. When county and municipal roads are included the estimated cost savings is approximately $500,000 (10).

The anti-sign-vandalism campaigns used by both Clark and King Counties, Washington, have also shown encouraging results. Data from King County show a progressive drop in sign vandalism since the inception of the program in January 1980 (16,17). A comparison of data for the first 6 months of 1979 and 1982 shows a reduction in sign vandalism ranging from 61.8 percent (March) to 49.6 percent (February).

Overall experience with the Washington and Wisconsin approaches is too limited to generalize the outcome for universal application. An appropriate blend of the approaches may be more desirable.

Figure 12. Decision process for selection of countermeasures.

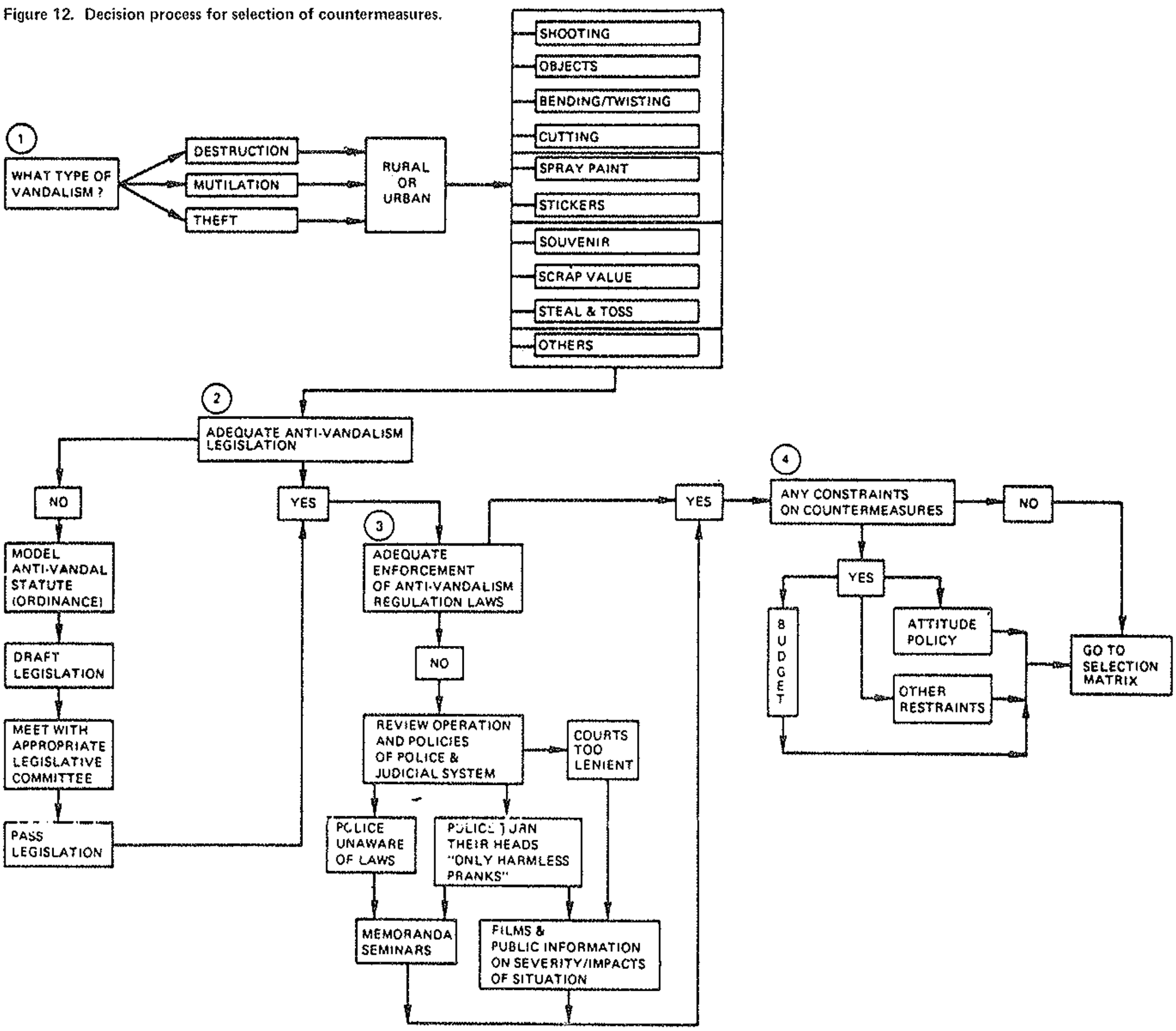


Figure 13. Matrix of sign vandalism problem versus countermeasures.

Counter-Measures / Type of Sign Vandalism Problem	Use of Plywood Signs		Use a Graffiti Resistant Finish		Use of Vandal Proof Fasteners		Continue With all Feasible Countermeasures →	
	COST	Range in% Reduction	COST	Range in% Reduction	COST	Range in% Reduction		
Shooting in Rural Areas	Moderate	10-20	High	0-5%	Low	0%		
Graffiti in Urban Residental Areas	Moderate	0-10%	High	25-50%	Low	0%		
Signs Being Stolen	Moderate	10-15%	High	0-%	Low	40-60%		
Continue for each Type of Problem								
↓								

Overemphasis on criminality and penalties can possibly be counterproductive and may even increase sign vandalism in some areas. Some of the educational programs are less expensive and may be more beneficial in the long run. A balanced technique, involving the best elements of all approaches, deserves serious consideration.

A SYSTEMS APPROACH TO SELECTION OF COUNTERMEASURES

In order for an agency to select appropriate countermeasures, the vandalism problems must first be identified and defined. The agency personnel should then decide what countermeasures are available as well as any constraints on the use of any of them. Finally, the major objective of the selection process is to choose countermeasures that are most cost effective in preventing, discouraging, and mitigating the effects and minimizing the costs of the particular sign vandalism problem. A two-stage approach to selecting countermeasures is proposed as follows:

1. Flow diagram (decision process for selecting countermeasures)--step-by-step procedures that allow one to gradually focus on the types of countermeasures that would be applicable for the specific problem and environment (see Figure 12), and
2. Matrix of sign vandalism problems versus countermeasures--following the above step-by-step screening process, the selection matrix will allow reasonable choices of problem-specific countermeasures to be made quickly (see Figure 13).

For example, if theft of traffic signs is the predominant vandalism problem in a particular area, it can be prevented by using countermeasures that include the following:

1. Physical--use of vandal-proof hardware (e.g., tufnuts), improved mounting of signs (increase in sign height), improved structural components (e.g., channel and foundation), and improved street lights (especially if vandalism incidents occur at night);
2. Enforcement--stakeout in area of sign vandalism; and
3. Educational--educating teenagers about the adverse impacts of sign vandalism.

Physical countermeasures may prove more effective or even cost effective to curb the sign vandalism problem, especially in rural areas. Enforcement and improved street lights may be more effective in deterring sign vandalism in urban areas. Stakeout by enforcement personnel tends to be expensive and thus is not generally cost effective.

SUMMARY

This paper has attempted to identify, describe, and emphasize the major issues and characteristics of the sign vandalism problem. The seriousness of the problem warrants a concerted effort to correct it. Various countermeasures--physical; legal, judicial, and enforcement; and educational and public information--have been discussed. A potential systems approach that uses the best elements of the various countermeasures to solve the problem has also been suggested. It is hoped that this paper will stimulate public agencies and researchers to continue their efforts toward a systematic, cost-effective, and lasting solution to this serious national problem.

REFERENCES

1. Request for Proposal Prospectus for RFP DTFH61-82-R-00230, Sign Vandalism Countermeasures. FHWA, July 1982.
2. National Safety Council Conducts State Survey on Traffic Sign Vandalism. National Safety Council, Chicago, Press Release, June 11, 1982.
3. J.J. Driessen and T. Nettleton. District Esti-

mates of Vandalism to Forest Service Road and Campground Signs. Equipment Development Center, U.S. Forest Service, Missoula, Mont., Feb. 1982.
4. The Advance Monticellonian. Black Rock, Ark., June 1980.
5. Opinion. Woodbridge, N.J., Sept. 29, 1980.
6. Star-Ledger. Trenton, N.J., Oct. 7, 1980.
7. County Thwarts Vandals with New Sign and Post. Rural and Urban Roads, Sept. 1979, pp. 60-61.
8. J.W. Guenther. Presentation to American Public Works Assn., Vancouver, April 9, 1981.
9. Seattle Post-Intelligencer, Seattle, April 19, 1980.
10. J. Fernan. Remarks on Sign Vandalism. Illinois Traffic Engineering Conference, Urbana, Sept. 16, 1977.
11. J.P. Klippert. A Program to Reduce Traffic Sign Vandalism. Paper presented at the Washington State Chapter, American Public Works Assn., 1980.
12. South Carolina Highways. South Carolina Department of Highways and Public Transportation, Columbia, Oct. 1979.
13. T.H. Moran. Vandalism and Other Abuse Tests on Highway Signs of Various Base Materials. Douglas Fir Plywood Assn., Tacoma, Wash., Tech. Rept. 65, March 23, 1955.
14. Motor Club News. Motor Club of America Companies, Newark, N.J., Undated.
15. J.P. Klippert. Traffic Sign--Vandalism. Paper presented to American Public Works Assn., Vancouver, April 9, 1981.
16. J.P. Klippert. Presentation to Association of Washington Cities, Spokane, June 17, 1982.
17. Cutting Traffic Sign Vandalism. APWA Reporter, Chicago, Ill., Oct. 1982, pp. 20-21.

Public Good Relative to Right-Turn-on-Red in South Carolina and Alabama

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The effects of South Carolina's and Alabama's right-turn-on-red (RTOR) laws on highway safety, fuel consumption, and air pollution were investigated. Accidents at signalized intersections involving right-turning vehicles (RT) before and after the passage of RTOR laws in both states were studied and compared with accidents at signalized intersections that did not involve vehicles making a right turn (NRT). Data for two years before and three years after the effective date of South Carolina's RTOR law were analyzed; the Alabama data included three years before and five years after. The findings of this study indicated that the rate of change of RT property damage accidents in South Carolina was significantly higher for RT property damage accidents in the after period than the corresponding change for NRT accidents. The rate of change of RT property damage accidents in Alabama was not found to be significantly higher for RT accidents in the after period than the corresponding change for NRT accidents. The findings of this study also indicated that there was no significant difference in the rates of change of RT fatality or injury accidents when compared with the corresponding change for NRT fatality or injury accidents in both South Carolina and Alabama. This study could find no evidence that pedestrian accidents in either state increased as a result of RTOR operations. A further analysis was performed on fuel and travel time savings resulting from RTOR operations. Based on the findings of this study and the benefits estimated, no changes are warranted in either Alabama's or South Carolina's RTOR law, and the laws should remain in effect.

Right-turn-on-red (RTOR) is now permitted in some form in all of the states. Adoption of RTOR was accelerated in 1975 after Congress passed the Energy Policy and Conservation Act, which requires each state to develop a state energy conservation plan. One of the requirements of this plan is state adoption of RTOR. In addition, an FHWA study (1) undertaken after the passage of the Conservation Act reported that the RTOR feature would increase intersection capacity, reduce delay especially for right-turning vehicles, and reduce fuel consumption and automobile emissions. The study further reported that the number of accidents as a result of the adoption of RTOR would be insignificant.

Despite the results of many other studies supporting the fuel savings from RTOR and supporting the general conclusion that RTOR does not significantly lower the safety of signalized intersections (SIs), RTOR operations have recently become the subject of much scrutiny. Vast amounts of data have been generated both in favor of and against RTOR. A study by Zador (2) reported that the increase in the overall frequency of RTOR crashes in the states that adopted permissive RTOR laws exceeded by more than 20 percent the comparable change in states that retained the same laws. Furthermore, this study reported that pedestrian accidents had increased substantially after the adoption of RTOR. The increase among children was reported as 30 percent, the increase among adults was about 100 percent, and among the elderly the increase was about 110 percent. Computer files of all accidents reported to the police were obtained from six study states (New Jersey, Oklahoma, South Carolina, Tennessee, Virginia, and Wisconsin) and three comparison states (Maryland, Texas, and Washington) for 1974-1977 for use in this study. The RTOR accident experience in the comparison states may not be comparable with the data from the study states because of possible differences in drivers and demographic factors. The data from half of the comparison states were for an after period of 1 year or less. This is probably not sufficient time for the drivers to adjust to the effects of the change in the law.

More recently, Hochstein (3) stated that RTOR accident data, fuel savings, psychological impact, installation and maintenance costs, and legal liabilities have not been researched thoroughly. Hochstein made the point that the federal bureaucracy entered the engineering domain with rules and regulations to promulgate a traffic policy based on questionable research and data. Hochstein based most of his remarks on data obtained from the Zador report (2).

Inasmuch as the RTOR traffic operations feature continues to be a controversial issue, we decided to review the effects of RTOR in South Carolina and Alabama. These states were chosen because a sufficient time had elapsed since the passage of the law, and both states had accident data readily accessible through the Records Analysis for Problem Identification and Definition (RAPID) System (4).

South Carolina passed RTOR into law on February 15, 1977, and the law became effective on May 16, 1977. Similarly, in Alabama the RTOR law was passed and became effective on August 18, 1976. In both cases this law permitted right-turn-on-red except at locations where it was specifically prohibited by traffic signs. Before to the passage of the law RTOR was sign permissive (i.e., prohibited except at locations where it was permitted by traffic signs).

OBJECTIVE AND METHOD OF STUDY

The objective of this study was to examine the characteristics of right-turn accidents at signalized intersections and to determine if the RTOR traffic operations measure as passed into law caused a significant increase in traffic accidents in South Carolina and Alabama.

Accident data used in this study were obtained from computer tapes of traffic collisions reported in South Carolina during 1976-1980 and in Alabama during 1974-1981. The RAPID software (4) was used for retrieval of data from the computerized records. Because of a possible bias resulting from the inability of the accident investigator to determine whether a particular accident involving a right turn at a signalized intersection (SI) occurred during a red or green phase, the following classifications of accidents were used:

RT--An accident occurring at a SI with a functioning signal in which at least one of the involved vehicles was turning right.

NRT--An accident occurring at a SI with a functioning signal in which none of the involved vehicles were turning right.

These classifications permitted an analysis of the frequency of accidents at SIs involving right turns and the frequency of accidents not involving right turns both before and after the passage of the RTOR laws.

For the purpose of analysis, the period 1976-1977 will be considered as the before period in South Carolina, thus allowing the motorist 7.5 months after the effective date of the RTOR law for recognition and acclimation to the change. The years 1978-1980 will be the after period for South Carolina. Similarly, the years 1974-1976 were taken as before and the interval 1977-1981 was considered as the after period for Alabama.

ANALYSIS

Accident Experience

Accident frequencies for RT accidents and NRT accidents at SIs are given in Tables 1 and 2. By using the geometric mean the average percentage of change was calculated for each type of accident. For example, the geometric average change for the first row of Table 1 is given by

$$g = [(76{,}492/72{,}216) \times (81{,}609/76{,}492) \times (80{,}674/81{,}609) \times (74{,}936/80{,}674)]^{1/4} - 1 = (74{,}936/72{,}216)^{1/4} - 1 = 1.0093 - 1 = 0.0093 = 0.93 \text{ percent} \quad (1)$$

The results from Tables 1 and 2 show that the average change for all reported accidents in South Carolina was 1.15 percent as compared with 4.44 percent for NRT accidents and 7.97 percent for RT accidents. These percentages were, respectively, 0.52, -0.66, and -2.39 for Alabama. Thus, the data in Table 1 for South Carolina show a slight upward trend for the 5-year span 1976-1980 and for Alabama the trend is positive for all accidents but downward for NRT and RT categories. Because data for South Carolina were not sufficient to examine trend and seasonality, a simple before-after χ^2 test was conducted. The results are given in Table 3. As discussed previously, the 2-year before period actually includes 7.5 months of operations after the effective data of the RTOR law (May 16, 1977), thus the motorist is given time to become aware of and acclimated to the change.

The null hypothesis tested was that no difference exists in the change (from before the law to after) of accident frequencies at SIs for RT and NRT categories in South Carolina. As seen from the results in Table 3, the null hypothesis is rejected at the 5 percent level; therefore, the rate of change (before versus after) of accidents was significantly greater

Table 1. Number of all accidents and accidents at signalized intersections involving RT and NRT in South Carolina, 1976-1980.

Accident Type	1976	1977	1978	1979	1980	Average Change (%)[a]
All Accidents						
Property damage only	72,216	76,492	81,609	80,674	74,936	+0.93
Injury	14,020	14,175	15,486	15,952	15,328	2.25
Fatality	708	818	788	795	752	1.52
Total	86,944	91,485	97,883	97,394	91,016	1.15
Signalized Intersection NRT						
Property damage only	7,493	8,563	9,186	8,939	8,865	4.29
Injury	1,684	1,829	1,956	2,039	2,059	5.15
Fatality	24	29	20	23	24	0
Total	9,201	10,421	11,162	11,001	10,948	4.44
Signalized Intersection RT						
Property damage only	750	948	1,059	1,112	1,027	8.18
Injury	89	78	98	100	112	5.91
Fatality				2	1	
Total	839	1,026	1,157	1,214	1,140	7.97

[a]Calculated by using the geometric mean (see Equation 1).

Table 2. Number of all accidents and accidents at signalized intersections involving RT and NRT in Alabama, 1974-1981.

Accident Type	1974	1975	1976	1977	1978	1979	1980	1981	Average Change (%)[a]
All Accidents									
Property damage only	82,759	89,793	90,922	97,282	103,913	102,914	91,217	82,642	-0.020
Injury	17,264	18,663	19,506	21,112	23,352	23,270	21,904	21,113	2.92
Fatality	800	797	833	931	977	863	810	812	0.21
Total	100,823	109,253	111,261	119,325	128,242	127,047	113,931	104,567	0.52
Signalized Intersection NRT									
Property damage only	16,000	16,731	16,572	17,567	18,189	18,322	16,175	14,615	-1.29
Injury	2,840	3,109	3,236	3,392	3,616	3,686	3,384	3,368	2.47
Fatality	20	43	20	31	29	27	23	22	1.37
Total	18,860	19,883	19,828	20,990	21,834	22,035	19,582	18,005	-0.66
Signalized Intersection RT									
Property damage only	1,688	1,725	1,618	1,798	1,868	1,863	1,653	1,412	-2.52
Injury	117	111	129	149	137	144	125	112	-0.62
Fatality	0	0	0	2	1	1	1	0	
Total	1,805	1,836	1,747	1,948	2,006	2,008	1,779	1,525	-2.39

[a]Calculated by using the geometric mean.

Table 3. Chi-square test results for all NRT and RT accidents at signalized intersections before and after RTOR law in South Carolina.

Accident	Before	After	Total
RT	1,865	3,511	5,376
NRT	19,622	33,111	52,733
Total	21,487	36,622	58,109

Note: $\chi_0^2 = 13.283 > \chi^2(0.05, 1) = 3.84$ . . . Reject H_0: There is no significant difference in the change of accident frequencies at SIs for RT and NRT operations.

for RT than the corresponding change in NRT accidents at SIs for the time periods tested.

For Alabama, there were 8 years of data (1974-1981) and thus, on a quarterly basis, 32 data points were available to remove the effects of seasonality and trend from the data. The control group used to both estimate the seasonal factors and determine the slope of the trend line was all accidents in Alabama excluding all those at SIs. The estimates of seasonal factors for winter, spring, summer, and fall are, respectively, $Sn_1 = 0.94175$, $Sn_2 = 1.00220$, $Sn_3 = 0.99378$, 0.99378, and $Sn_4 = 1.06227$. These factors were computed by using the method of centered moving averages (5). The deseasonalized data for the control group were then used to obtain the trend line

$$d_t = 21{,}745.041 + 81.1405\ t,\ t = 1, 2, 3, \ldots, 32$$

based on a quarterly average of 23,088.86 accidents. Because the quarterly average for all NRT (property damage plus injuries) was 5,032.66, the trend slope for NRT accidents is approximately

$$b_{11} = (5{,}032.66/23{,}088.86)\ (81.1405) = 17.69$$

Similarly, the trend slope for property damage only (PDO) and injuries (INJ) were computed, respectively, to be $b_{12} = 14.744$ and $b_{13} = 2.9463$. For RT accidents the trend slopes are $b_{21} = 1.61$, $b_{22} = 1.497$, and $b_{23} = 0.113$ for the categories of All, PDO, and INJ, respectively. These slopes were used to detrend the deseasonalized data. The deseasonalized quarterly data are given in Tables 4 and 5. Table 6 gives the statistics of NRT and RT accidents, where B refers to the time period before the RTOR law (1974-1976) and A refers to the time period after the RTOR law (1977-1981). The original observations were based on monthly data; therefore, the quarterly averages $\bar{X}_B$ contained 36 (12 x 3) monthly observations and $\bar{X}_A$s was based on 60 monthly averages. Therefore, by the central limit theorem, both $\bar{X}_B$ and $\bar{X}_A$ are approximately normally distributed. Furthermore, the standard errors of the means (s.e.) for before and after are obviously significantly different (except in the case of injuries), so that the t-test (called t' for unequal variances) was conducted (6). The results of the t'-test are summarized in Table 7, which gives in all three categories

$$t'\ (RT) < t'\ (NRT)$$

that is, the effect of the intervention (RTOR law) at a SI was relatively more significant for NRT than for RT accidents. Also, the only statistically significant difference was found in the case of NRT injury accidents. For the RT accidents, the quarterly average number of accidents decreased after the RTOR law for the All and PDO categories and slightly increased (but not significantly) for the INJ category. However, the increase in quarterly average NRT accidents for the INJ category cannot be attributed to the RTOR law because the NRT accidents had no vehicle turning right during the accident interval. Finally, the average number of accidents (after removing seasonality and trend) decreased (not statistically significant) after the RTOR law for the All and PDO categories but increased (not significantly) for the INJ category. Therefore, the law had no overall significant effect on average quarterly number of accidents in Alabama.

A χ^2 test (with r = 1 df) similar to Table 3, using the deseasonalized and detrended data, gave $\chi_0^2 = 0.901$ with the critical level $\hat{\alpha} = \Pr.\ (\chi^2_{r=1} \geq 0.901) = 0.343$. Thus, the hypothesis of no difference in frequency of accidents at SIs for RT and NRT accidents before and after the intervention could not be rejected for Alabama. By using the raw data the value of χ_0^2 was computed to be 0.894 resulting in $\hat{\alpha} = 0.345$ (this is in direct contrast to South Carolina's $\chi_0^2 = 13.283$).

Severity

The analysis of the data in Tables 1 and 2 revealed that the greatest percentage of change in RT accidents in South Carolina was in the PDO category. The next step was to test the injury-fatality acci-

Table 4. Detrended and deseasonalized NRT data for Alabama.

Year	Quarter	Property Damage Only	Injury	All Accidents
1974	1	3950.2	703.1	4653.3
	2	2927.8	728.5	3656.3
	3	4148.9	705.6	4854.5
	4	3835.5	693.3	4528.8
1975	5	3905.0	696.7	4601.7
	6	3942.8	753.6	4696.4
	7	4322.3	836.7	5159.0
	8	4161.5	783.2	4944.7
1976	9	4166.7	795.4	4962.1
	10	4058.4	787.7	4846.1
	11	3800.4	728.3	4528.7
	12	3936.9	818.4	4755.3
1977	13	4104.5	734.7	4839.2
	14	3952.5	811.9	4764.4
	15	4274.8	829.2	5104.0
	16	4362.7	867.9	5230.6
1978	17	4179.4	750.5	4929.9
	18	4324.6	883.9	5208.5
	19	4342.7	869.8	5212.5
	20	4245.3	912.6	5157.9
1979	21	4513.3	858.7	5372.0
	22	4082.0	867.2	4949.2
	23	4291.7	846.9	5138.6
	24	4128.9	873.5	5002.4
1980	25	4140.0	838.4	4978.4
	26	3620.9	720.7	4341.6
	27	3439.8	773.7	4213.5
	28	3448.7	765.7	4214.4
1981	29	3367.4	799.1	4166.5
	30	3026.1	719.8	3745.9
	31	3229.8	731.8	3961.6
	32	3200.5	780.2	3980.7

Note: $tr_t = d_t = 4740.78 + 17.69\ t$ for all accidents.

Table 5. Detrended and deseasonalized quarterly RT data for Alabama.

Year	Quarter	Property Damage Only	Injury	All Accidents
1974	1	396.7	32.8	429.5
	2	390.1	33.7	423.8
	3	446.3	21.8	468.1
	4	437.4	27.7	465.1
1975	5	425.7	22.8	448.5
	6	409.1	34.2	443.3
	7	404.1	27.4	431.5
	8	445.5	23.6	469.1
1976	9	420.8	26.6	447.4
	10	366.2	43.8	410.0
	11	389.0	30.0	419.0
	12	381.1	24.0	405.1
1977	13	427.5	28.2	455.7
	14	433.0	49.3	482.3
	15	414.2	39.6	453.8
	16	435.4	27.4	462.8
1978	17	397.2	26.8	424.0
	18	412.1	45.9	458.0
	19	470.7	18.0	488.7
	20	472.8	38.2	511.0
1979	21	478.3	45.4	523.7
	22	403.1	26.4	429.5
	23	438.5	29.6	468.1
	24	412.2	34.0	446.2
1980	25	439.4	21.6	461.0
	26	376.2	30.0	406.2
	27	324.9	30.1	355.0
	28	358.2	31.6	389.8
1981	29	327.2	28.6	355.8
	30	294.4	24.5	318.9
	31	306.8	20.7	327.5
	32	302.3	24.6	326.9

Note: $tr_t = d_t = 431.42 + 1.61\ t$ for all accidents, $t = 1, 2, \ldots 32$.

Table 6. Quarterly statistics before and after RTOR law for RT and NRT in Alabama.

Category	Accident Type	1974-1976		1977-1981	
		Quarterly $\bar{X}_B$	s.e. of $\bar{X}_B$	Quarterly $\bar{X}_A$	s.e. of $\bar{X}_A$
NRT	All	4765.58[a]	55.62[a]	4725.60	114.39
	PDO	4013.04	45.41	3913.74	104.14
	Injury	752.54	14.53	811.81	13.65
RT	All	438.40	6.38	427.25	13.95
	PDO	409.33	7.53	396.22	13.12
	Injury	29.03	1.82	31.03	1.93

[a] $\bar{X}_B = (4653.3 + 4656.3 + \ldots + 4755.3)/12 = 4765.58$

$$\hat{\sigma}_B = \left[\sum_{i=1}^{12} (X_i - 4765.58)/11\right]^{1/2} = 192.680$$

where $X_i = 4653.3$, $X_2 = 4656.3, \ldots, X_{12} = 4755.3$.

$Se(\bar{X}_B) = \hat{\sigma}_B/\sqrt{12} = 55.622$.

Table 7. Results of t-test for NRT and RT accidents in Alabama.

Statistic	NRT Accidents			RT Accidents		
	All	PDO	Injury	All	PDO	Injury
t'-test	-0.3144[a]	0.874	2.973	-0.727	-0.867	0.754
Degrees of freedom	27.5[b]	26	29	26.7	29.6	31
Critical level, $\hat{\alpha}$, for two-sided test	0.767[c]	0.391	0.0059	0.474	0.393	0.46

[a] $t' = (\bar{X}_A - \bar{X}_B)/\sqrt{Se^2(\bar{X}_A) + Se^2(\bar{X}_B)} = (4725.60 - 4765.58)/\sqrt{114.39^2 + 55.62^2} = -0.31432$.

[b] $\nu = [Se^2(\bar{X}_A) + Se^2(\bar{X}_B)]^2/\{[Se^4(\bar{X}_A)/n_A + 1] + [Se^4(\bar{X}_B)/n_B + 1]\} - 2 = (114.39^2 + 55.62^2)^2/[(114.39^4/21) + (55.62^4/13)] - 2 = 29.445 - 2 = 27.5$.

[c] $\hat{\alpha} = Pr \cdot (t_{\nu=27.5} \geq 0.3144) = 0.767$.

dents for RT and NRT operations. The null hypothesis tested was that no difference exists in the frequency of RT and NRT injury-fatality accidents before and after the effective date of South Carolina's RTOR law. The results in Table 8 show that the null hypothesis could not be rejected at a significant level as large as 37 percent ($\hat{\alpha} = 0.37$). Therefore, we conclude that there is no significant difference between NRT and RT injury-fatality accidents at SIs for the time periods tested. A similar χ^2 test for Alabama gave $\hat{\alpha} = 0.104$. However, such a small critical level was mostly caused by the significantly larger average number of accidents per year for the after period than the average during

Table 8. Chi-square test results for NRT and RT injury-fatality accidents at signalized intersections before and after RTOR law in South Carolina and Alabama.

Accident	Before	After	Total
South Carolina[a]			
RT observed	167	313	480
NRT observed	3,566	6,121	9,687
Total	3,733	6,434	10,167
Alabama[b]			
RT observed	384.4	620.50	1,004.9
NRT observed	9,030.50	16,236.20	25,266.7
Total	9,414.90	16,856.70	26,271.60

[a] $\chi_0^2 = 0.894 < \chi^2 (0.05; 1) = 3.84$. Cannot reject H_0: There is no difference in the change (from before to after) of accident frequencies at SIs for RT and NRT operations in South Carolina.

[b] $\chi_0^2 = 2.652 < \chi^2 (0.05; 1) = 3.842$. Cannot reject H_0: There is no difference in the change (from before to after) of accident frequencies at SIs for RT and NRT operations in Alabama, at the 5 percent level of significance.

Table 9. Chi-square test results for NRT and RT property-damage-only accidents at signalized intersections before and after RTOR law in South Carolina and Alabama.

Accident	Before	After	Total
South Carolina[a]			
NRT observed	16,056	26,990	43,046
RT observed	1,698	3,198	4,896
Total	17,754	30,188	47,942
Alabama[b]			
NRT observed	48,156.4	78,274.7	126,431.1
RT observed	4,912.0	7,924.4	12,836.4
Total	53,068.4	86,199.1	139,267.5

[a] $\chi_0^2 = 12.924 > \chi^2 (0.05; 1) = 3.84, \ldots$ Reject H_0: There is no difference in the change (from before to after) of property damage accidents at SIs for RT and NRT operations in South Carolina.

[b] $\chi_0^2 = 0.155 < \chi^2 (0.05; 1)$. Cannot reject H_0: There is no difference in in the change (from before to after) of property damage accidents at SIs for RT and NRT accidents in Alabama.

Table 10. Percentage of NRT and RT property-damage-only accidents by estimated cost of total property damage for South Carolina.

	1976		1977		1978		1979		1980	
Cost	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT
Less than $200	19.9	14.5	21.3	15.9	21.7	15.1	16.5	11.7	14.6	11.0
$200-$499	46.2	33.5	42.1	28.8	39.6	26.0	39.1	24.8	36.2	21.9
$500-$999	23.0	25.1	24.0	25.4	24.8	25.3	25.0	26.1	25.3	24.8
$1000-$1499	5.5	12.4	6.6	13.4	7.7	14.2	9.9	14.6	10.8	15.7
$1500-$1999	2.5	5.5	2.9	6.4	2.8	7.2	3.9	7.3	6.1	8.0
$2000-$2499	0.9	3.1	1.2	3.7	1.1	4.3	1.9	5.3	3.2	5.9
More than $2500	2.1	6.0	1.9	6.3	2.3	7.9	3.6	10.3	3.8	12.6

Table 11. Percentage of NRT and RT property-damage-only accidents by estimated cost for total property damage for Alabama.

	1974		1975		1976		1977		1978		1979		1980		1981	
Cost	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT
Less than $600	84.8	69.85	81.7	65.8	79.8	61.7	74.5	57.9	70.7	55.4	68.8	50.2	64.2	47.4	60.6	45.5
$601-$1200	10.8	18.9	13.3	20.6	14.1	21.8	17.1	22.6	18.9	22.4	20.5	23.2	22.1	23.1	22.4	22.1
$1201-$2000	3.6	8.1	4.0	9.7	4.5	11.2	6.3	12.5	7.3	13.6	7.1	15.6	8.7	16.3	10.4	17.3
$2001-$3000	0.5	1.9	0.6	2.3	1.0	3.0	1.3	4.1	1.7	4.6	2.0	5.5	2.9	6.1	3.5	6.6
$3001-$4000	0.2	0.9	0.3	1.0	0.3	1.4	0.4	1.8	0.8	2.4	1.0	3.1	1.5	3.8	1.8	4.4
$4001-$5000	0	0.3	0.1	0.3	0.2	0.4	0.2	0.5	0.2	0.6	0.3	1.0	0.3	1.2	0.5	1.6
$5001-$6000	0.2	0.2	0.1	0.2	0.1	0.3	0.2	0.4	0.2	0.6	0.2	0.8	0.4	1.1	0.6	1.2
$6001-$8000	0	0	0.1	0.1	0.1	0.2	0.1	0.2	0	0.3	0	0.4	0.2	0.6	0.4	0.8
More than $8000	0.1	0	0	0.1	0.1	0.2	0.1	0.2	0.2	0.3	0.2	0.5	0	0.6	0	0.7

the before period in the NRT group, but this was not so for the RT group.

The results of the analysis of accident trends revealed that in South Carolina there was a significant difference between all RT and NRT accidents but no significant differences were found between RT and NRT injury-fatality accidents before and after RTOR law. The next step was to examine the severity of RT and NRT accidents at SIs. By using the null hypothesis that there is no difference between property damage accidents at SIs for RT and NRT accidents before and after the effective date of South Carolina's RTOR law, the data in Table 9 were tested for significance by using the χ^2 test. The null hypothesis is rejected at the 5 percent level. From Tables 1 and 2, the average change in percent for RT property damage accidents was approximately twice the average change for NRT property damage accidents for the 1976-1980 period in South Carolina. Thus, we conclude that PDO accidents for RT increased at a significantly faster rate than property damage accidents for NRT operations at SIs. However, a similar χ^2 test (using the deseasonalized data) for Alabama gave $\chi_0^2 = 0.155$ for which $\hat{\alpha} = 0.694$ (i.e., for PDO accidents no significant difference between the change from before the law to after in RT and NRT operations was found).

The percentage of property damage accidents in South Carolina for RT and NRT operations is shown in Tables 10 and 11 for selected ranges of property damage costs. Property damage costs included the estimated cost of all vehicular damage and property damage costs. In Tables 10 and 11 the estimated property damage costs for RT accidents were much lower than the equivalent costs for NRT accidents. For example, an average of 84 percent of the RT accidents in South Carolina resulted in property damages less than $1,000 as compared with only 69 percent of the NRT accidents. In Alabama an average of 90.5 percent of RT accidents had property damage cost less than $1,200; however, this figure for the NRT accidents was 78.5 percent.

The percentage of NRT accidents that resulted in an injury-fatality was about twice the percentage of RT accidents that resulted in an injury-fatality. By using data from Tables 1 and 2, 18.2 percent (15.9

Table 12. Total victims and pedestrian victims of RT and NRT accidents at signalized intersections in South Carolina and Alabama.

		RT Accidents			NRT Accidents		
State	Year	Pedestrians	Total Victims	Percentage Pedestrians	Pedestrians	Total Victims	Percentage Pedestrians
South Carolina	1976	19	112	17	119	2,267	4.5
	1977	21	99	21.2	130	2,914	4.5
	1978	25	125	20	150	3,015	4.9
	1979	34	143	23.8	144	3,101	4.6
	1980	33	140	23.5	169	3,126	5.4
Total		132	619	21.3	712	17,859	4.8
Alabama	1974	22	117	18.8	147	2,860	5.1
	1975	17	111	15.3	137	3,152	4.3
	1976	15	129	11.6	138	3,256	4.2
	1977	24	151	15.9	131	3,423	3.8
	1978	15	138	10.9	127	3,645	3.5
	1979	23	145	15.9	122	3,713	3.3
	1980	11	126	8.7	129	3,407	3.8
	1981	14	112	12.5	126	3,390	3.7
Total		141	1,029	13.7	1,057	26,846	3.9

Table 13. Chi-square test results for NRT and RT pedestrian accidents at signalized intersections before and after RTOR law in South Carolina and Alabama.

State	Before	After	Total
South Carolina[a]			
NRT observed	249	463	712
RT observed	40	92	132
Total	289	555	844
Alabama[b]			
NRT observed	422	635	1,057
RT observed	54	87	141
Total	476	722	1,198

[a] $\chi_0^2 = 1.01 < \chi^2 (0.05; 1) = 3.84$. Cannot reject H_0.

[b] $\chi_0^2 = 0.1374 < \chi^2 (0.05; 1)$. Cannot reject H_0: There is no significant difference in the change (from before to after) of pedestrian accident frequencies at SIs for NRT and RT categories in Alabama.

percent in Alabama) of all NRT accidents for the before and 18.2 percent (17.2 percent in Alabama) in the after period resulted in an injury-fatality as compared with 8.95 percent (6.63 percent in Alabama) for before and 8.4 percent (7.25 percent in Alabama) in the after period for RT accidents. Thus, the proportion of injury-fatality accidents to all accidents has not changed significantly during the 5-year period in South Carolina or the 8-year period in Alabama. During these periods there have only been three fatal RT accidents in South Carolina and only five in Alabama.

Some of the important findings in this section are as follows:

1. The increase (from before to after) of RT PDO accidents was significantly greater than the corresponding increase in the NRT category. For Alabama the decrease (from before to after) of RT PDO accidents was not significantly lower than the decrease in NRT accidents.
2. The average property damage costs for RT accidents was much lower than the average property damage costs for NRT accidents in both states.
3. RT injury-fatality accidents as a percentage of total accidents at SIs did not increase significantly for the after period. NRT injury-fatality accidents as a percentage of total accidents at SIs remained practically unchanged from the before to the after period.

Pedestrian Involvement

Pedestrian safety at RTOR intersections is of major concern. Wide ranges of pedestrian involvement in RTOR accidents have been reported. McGee (7) reported that the percentage of RTOR accidents involving pedestrians varied from 0 to 33 percent. Zador and others (2) reported that pedestrian crashes increase substantially as a result of RTOR. Certainly, the RT operation at a SI represents a potential vehicular-pedestrian conflict regardless of whether the vehicle is turning right on a red or a green signal phase.

Pedestrain involvement in South Carolina accidents at SIs for RT and NRT operations is given in Table 12. For South Carolina accidents involving RT, approximately 1 out of every 5 victims was a pedestrian (1 in 7 for Alabama) whereas the ratio was approximately 1 out of every 21 for NRT accidents (1 in 25 for Alabama). These results confirm the high involvement of pedestrians as victims in RT accidents.

To determine if pedestrian involvement in RT accidents has increased as a result of RTOR law, the null hypothesis that no difference exists between pedestrian involvement in RT and NRT accidents before and after the effective date of the RTOR law was tested. The χ^2 test in Table 13 was used to show that the null hypothesis cannot be rejected for either South Carolina or Alabama (the respective critical levels are 0.299 and 0.711). Thus, we conclude that there is no statistically significant difference between RT and NRT pedestrian accidents before and after RTOR. There is no reason to suspect that pedestrian accidents involving RT operations have increased after the adoption of RTOR in either state.

Some of the important findings in this section are as follows.

1. Approximately 1 out of every 5 victims of a RT accident was a pedestrian in South Carolina (1 in 7 for Alabama) whereas only 1 out of every 21 (1 in 25 for Alabama) victims was a pedestrian in NRT accidents at signalized intersections.
2. The difference was not significant between pedestrian accidents involving RT and NRT operations before and after the effective date of the RTOR law in both states. Therefore, we conclude that no statistically significant increase in pedestrian accidents has resulted from the RTOR laws.
3. In South Carolina the percentage of pedestrian involvement remained constant for both RT and NRT categories; however, in Alabama the percentage

Table 14. Percentage of accidents at signalized intersections by RT and NRT categories.

Year	NRT (%) S.C.	NRT (%) Ala.	RT (%) S.C.	RT (%) Ala.	Percentage of Total Accidents that Occurred at Traffic Signal S.C.	Percentage of Total Accidents that Occurred at Traffic Signal Ala.
1974		91.27		8.73		20.50
1975		91.55		8.45		19.88
1976	91.64	91.90	8.36	8.10	11.55	19.39
1977	91.04	91.50	8.96	8.50	12.55	19.22
1978	90.61	91.59	9.39	8.41	12.59	18.59
1979	90.06	91.65	9.94	8.35	12.54	18.92
1980	90.54	91.67	9.46	8.33	13.24	18.75
1981		92.20		7.80		18.68

of pedestrian involvement showed a slight declining trend.

RTOR AND PUBLIC GOOD

Reported estimates of decreases in fuel consumption and travel time that result from RTOR operations vary widely according to the assumptions made by the investigators or because of the environmental conditions under which the study was conducted. Chang and others (8) reported a 6 percent decrease in fuel consumption and a 12 percent decrease in travel time after the introduction of RTOR in downtown Detroit. Lieberman (9) made a comparison of a signal system with and without RTOR. His results indicated a 4 percent decrease in fuel consumption and a 6 percent reduction in emissions. Obviously the number of SIs with RTOR and the number of vehicles that execute the RTOR maneuver are the primary factors in estimating the savings in fuel and travel time. South Carolina has approximately 1,800 SIs; about 90 percent (1,620) of these permit RTOR. In 1980 there were 2.07 million registered vehicles and 1.95 million licensed drivers in South Carolina, which generated 22.66 billion vehicle miles of travel (10). About 30 percent of the vehicle miles of travel was urban. One source (2) estimated that RTOR operations would produce an annual savings of up to 1.3 gal of fuel/registered vehicle. For South Carolina, using this value, the savings in fuel is estimated to be approximately 2.7 million gal/year. Another benefit would be the reductions in vehicle emissions that would be realized from RTOR operations. For each 650 gal of fuel consumption by an idling engine, emissions consist of 2,430 lb of carbon monoxide, 160 lb of hydrocarbons, and 50 lb of nitrogen oxides (11). Based on the estimated annual fuel savings of 2.7 million gal, the following reductions in emissions would be realized:

1. Carbon monoxide--5,047 tons,
2. Hydrocarbons--332 tons, and
3. Nitrogen oxides--104 tons.

In addition to the estimated savings in fuel and reductions in vehicle emissions, time savings are available to drivers because of reduced stopped delay at traffic signals. For progressive signal systems, the RTOR operation enables the vehicle turning right to join the progressive movement on the other street because it would be passing through the intersection during a green phase (i.e., turning right on red), thus further reducing stopped delays. The estimated range of time saved by the driver varies from 0.3 to 1.7 hours per driver per year (2). For South Carolina drivers the estimated time saved would range from 0.6 to 3.3 million hours. The preceding analysis could be repeated for Alabama. In 1980 Alabama had approximately 2.5 million licensed drivers, and approximately 26.01 billion vehicle miles were driven in this state. Since Alabama has approximately the same rural-urban mix, a factor of 1.2 may be applied to the above figures to generate comparable Alabama information.

Costs are usually associated with benefits. For RTOR operations these costs would result from an increase in RTOR accidents. Table 14 gives the percentage of accidents at SIs, computed using the totals in Tables 1 and 2 for NRT and RT categories. For example, the percentage for 1976 under the RT category in South Carolina is simply:

[839/(839 + 9201)] 100 = 8.36 percent

The last column in Table 14 gives the percentage of total accidents that occurred at SIs. From the data shown, the increase in South Carolina in RT accidents has been very small and is estimated at approximately 1 percent due to RTOR. There was a decrease of about 0.15 percent in this measurement for Alabama. We may calculate that the percentage of accidents that occur at SIs is (52,733 + 5,376/464,722) x 100 = 12.5 percent of the total reported accidents in South Carolina (19.21 percent for Alabama). Thus, the annual increase in accidents in South Carolina that result from RTOR operations based on a 5-year average is approximately 116 accidents (0.01 x 0.125 x 92,944). Most of this increase was in property damage (Table 1).

Some of the important findings in this section are as follows:

1. The estimated annual fuel savings in South Carolina that resulted from reduced stopped delays due to RTOR is 2.7 million gal (3.24 million gal for Alabama) based on a savings of 1.3 gal/registered vehicle.
2. The estimated annual reduction in vehicle emissions resulting from reduced stopped delays due to RTOR is as follows (a) carbon monoxide--5,047 tons for South Carolina and 6,056 for Alabama, (b) hydrocarbons--332 tons for South Carolina and 398.4 for Alabama, and (c) nitrogen oxides--104 tons for South Carolina and 124.8 for Alabama.
3. The estimated annual time savings by drivers resulting from reduced stopped delays due to RTOR varies from 0.6 million hr to 3.3 million hr based on a savings of 0.3 to 1.7 hr/year/driver.
4. The increase in RT accidents attributed to RTOR operatons was about 1 (-0.15 for Alabama) percent of the total accidents occurring at signalized intersections. About 12.5 (19.21 in Alabama) percent of the total reported accidents in South Carolina occur at signalized intersections.
5. The increase in annual accidents in South Carolina attributable to RTOR operations is about 116 accidents, consisting mostly of rear-end PDO accidents. However, in Alabama the number of accidents due to RTOR decreased at an annual rate of about 33.

CONCLUSIONS AND RECOMMENDATION

South Carolina's RTOR law, which permits RTOR except at locations where it is specifically prohibited by traffic signs, was passed into law on February 15, 1977, and the law became effective on May 16, 1977. Before the passage of this law South Carolina prohibited RTOR except at locations where it was permitted by traffic signs. A similar set of circumstances also transpired in Alabama, which passed its RTOR law, effective immediately, on August 18, 1976. The most significant difference in the average percentage of change between RT and NRT accidents was in the higher rate of change in PDO accidents for RT operations. A slight increase was measured in South Carolina, but in Alabama there was a corresponding reduction. The average rate of change for injury accidents was about the same for both RT and NRT accidents in both states. RT accidents tend to be less severe and have lower property damage costs when compared with all signalized intersection accidents. As a result of several statistical tests, we concluded that there was no significant difference in pedestrian involvement in RT accidents before and after the effective date of the RTOR law compared with all pedestrian accidents at signalized intersections.

Approximately 116 accidents/year can be attributed to South Carolina's RTOR operations and no significant increases were found in Alabama. An analysis of the data indicated that most of the increase in RT accidents was in the category of property-damage-only and involved rear-end collisions.

Numerous economic benefits result from RTOR operations, including savings in fuel consumption, reduced vehicle emissions, and time savings to the drivers. For the two states these benefits are summarized as follows:

1. Fuel savings--59.4 million gal/year;
2. Reduction in vehicle emissions per year--(a) carbon monoxide--11,103 tons, (b) hydrocarbons--730.4 tons, and (c) nitrogen oxides--229 tons; and
3. Times savings per year--1.3 to 7 million hr.

Based on the findings of this study, no changes are warranted in South Carolina's or Alabama's RTOR law and these laws should remain in effect.

REFERENCES

1. H.W. McGee, W.A. Stimpson, J. Cohen, G.F. King, and R.F. Morris. Right Turn on Red, Vol. J. Alan M. Voorhees and Associates, McLean, Va., Final Tech. Rept., FHWA-RD-89, 1976.
2. P. Zador, J. Moshman, and L. Marcue. Adoption of Right Turn on Red: Effects on Crashes at Signalized Intersection. Insurance Institute for Highway Safety, Washington, D.C., 1980.
3. S. Hochstein. Now Is The Time For All Good Traffic Engineers To Come To The Aid of Their Profession and Save the Country from RTOR. Institute of Transportation Engineers Journal, Vol. 51, No. 5, Washington, D.C., May 1981.
4. D.B. Brown. Records Analysis for Problem Identification and Definition System Overview. Auburn Univ., Auburn, Ala., Version 3.2, Oct. 1978.
5. B.L. Bowerman and R.T. O'Connell. Forecasting and Time Series: An Applied Approach, Duxbury Press, North Scituate, Mass., 1979.
6. A.H. Bowker and G.J. Lieberman. Engineering Statistics. 2nd ed., Prentice-Hall, Englewood Cliffs, N.J., 1972.
7. H.W. McGee. Accident Experience With Right Turn on Red. TRB, Transportation Research Record 644, 1977, pp. 66-75.
8. M.F. Chang, L. Evans, and R. Herman. Observations of Fuel Savings Due to the Introduction of RTOR. Traffic Engineering and Contol, Vol. 18, No. 10, London, Oct. 1977.
9. E.B. Lieberman and S.A. Cohen. New Technique for Evaluating Urban Traffic Energy Consumption and Emissions. TRB, Transportation Research Record 599, 1976, pp. 41-45.
10. 1980 South Carolina Traffic Accidents. South Carolina Department of Highway and Public Transportation, Columbia, 1981.
11. C.W. Dale. Procedures for Estimating Highway User Costs, Fuel Consumption and Air Pollution. FHWA, April 1981.