Highway Safety: Twenty Years Later

JULIE ANNA CIRILLO and FORREST M. COUNCIL

ABSTRACT

In 1970 a review was conducted of research and evaluation studies that analyzed some 57 highway-related safety countermeasures. As a result of that review only eight countermeasures were identified for which good to excellent estimates of effectiveness had been made. Although for most safety countermeasures it is known whether the countermeasure is better than nothing, it is often not known under what condition a countermeasure is most effective or how effective. Reviewed in this paper is what is known about the effectiveness of various safety countermeasures, as well as what is not known. Countermeasures discussed include various roadside hardware devices as well as geometric features. The reasons for the lack of knowledge are also discussed. This discussion focuses on the quality of safety evaluation studies and methods for improving the quality of these studies are recommended.

In 1970 after years of research related to roadway safety, Solomon, Starr, and Weingarten reviewed research and evaluation studies that analyzed 57 highway-related safety countermeasures (1). The authors believed that they had found "good to excellent" estimates of effectiveness for only 8 of the 57 countermeasures; for the remaining 49, effectiveness estimates were ". . . based either on engineering judgment, involved only fair or poor data, or were little more than guesses." In the past 14 years, the situation has improved somewhat as is evidenced by a reduction in fatality rate from 5.2 to 2.7 per 100 million vehicle miles of travel. Much of this improvement has been the result of increased safety funding, both in terms of increased roadway research funding from the Federal Highway Administration (FHWA) and increased funding for trial programs or countermeasures related to the driver and the vehicle from the National Highway Traffic Safety Administration.

Indeed, in discussing a given countermeasure, if the question is asked: "Is this countermeasure better than the 'do nothing' alternative?" the answer can usually be given with some certainty. For most countermeasures, a study or series of studies have been conducted that, when combined, give a fairly clear indication of whether the treatment has any degree of effectiveness. Consider the example of providing a 30-ft clear roadside. From past studies, little doubt exists that providing a 30-ft clear roadside will reduce both the frequency and the severity of run-off-road type collisions.

On the other hand, if the question concerning countermeasure effectiveness is more specific and concerns "How much better is the countermeasure than the 'do nothing' alternative for a specific type of roadway or accident situation?" or, "How much better is one countermeasure than a similar countermeasure?" then the answer cannot be given with much certainty. For example, although it is logical that clear roadsides would be more beneficial on curves than on tangent highway sections because of the increased probability of a vehicle leaving the pavement, the difference between the effectiveness on curves and on tangent sections cannot be specified. In like fashion, the increase in benefit gained from clearing roadsides to a 30-ft width versus the benefit gained from clearing roadsides to only 20 ft (a much less expensive treatment) cannot be specified.

This latter type of information, incremental effectiveness for specific locations and vehicles, is now needed in the decision-making process. Policy makers face continually increasing needs coupled with increased treatment costs. This results in heavy reliance on economic analyses for all highway programs, including safety. These economic analyses usually involve some method for comparing the predicted benefits of a given treatment to its cost and then comparing this benefit-to-cost index for one treatment to other alternatives that could be funded. Such an approach is obviously necessary and justified.

During the last 5 years, significant emphasis has been placed on improving economic methodologies used in carrying out such analyses, but in almost every case, the accuracy of the economic methodology far exceeds the accuracy of the critical input variable--predicted level of effectiveness of the countermeasure. Without accurate inputs of predicted benefits, the outputs are often worthless.

WHAT IS KNOWN

Insufficient knowledge exists to predict with absolute certainty the benefits of all safety features. However, there is ample knowledge to make rational decisions in selecting safety features. It is the latter definition that is used in this section.

Roadside Hardware

It is perhaps easiest to determine the effectiveness of roadside hardware because these devices are designed to reduce accident severity. However, in most cases the initial effectiveness assessment of these devices is not the result of evaluation of full-scale implementation, but rather an assessment of crash test results. Therefore, devices are accepted for implementation before true effectiveness measurements.

J.A. Cirillo, Federal Highway Administration, 6300 Georgetown Pike, McLean, Va. 22101. F.M. Council, University of North Carolina, Chapel Hill, N.C. 27514.

Crash Cushions

By far, one of the most effective devices to date has been the crash cushion. Studies have shown that crash cushions reduce fatalities and serious injuries by 75 percent (2). This device, which comes in a variety of designs, has been shown to be extremely effective in reducing fatalities at locations where object removal has been impossible (e.g., elevated bridge gores). The following designs are commonly used throughout the United States:

Steel Drum:	with cable guides; with or without side panels
Hi-Dro System:	with or without cable guides; with or without side panels
Hi-Dri System:	with cable guides and side panels
G-R-E-A-T Inertial System:	with or without side panels; with or without cable guides

Sign and Luminaire Supports

The next most effective device is the breakaway sign and luminaire support. Developed in the late 1960s, these devices have recently been studied for their effectiveness relative to very small passenger cars:

1. Shoe mount (no yielding)
2. Cast aluminum transformer base
3. Slip base
4. Frangible couplings
5. Shearbase

Results indicate a 30 percent reduction in injuries when breakaway supports are used. The effectiveness of breakaway luminaires is more dependent on impact speed than on vehicle weight (i.e., the higher the impact speed, the more effective the device regardless of vehicle weight), thus breakaway luminaires will not be effective when operating speeds are low (30 to 35 mph) (3).

Longitudinal Barriers

Research on longitudinal barriers has met with somewhat less success. In the early 1970s, the concrete safety shape was developed, tested, and redesigned. Since then it has become one of the most effective and widely used barriers in the United States. It is almost 100 percent effective in reducing barrier penetration/vaulting head-on accidents. Thus the severity of accidents has been reduced at locations where this barrier replaced other barriers. However, as is the case with most barriers, the number of accidents will increase if the barrier is installed where no barrier previously existed. Moreover, recent accident information indicated that longitudinal barriers may be a problem for very small vehicles (1,800 lb), causing them to roll over. This phenomenon is currently under study.

Other longitudinal barriers that have been successfully tested include the modified thrie beam (see Figure 1), which eliminates snagging for small vehicles, and the self-restoring guardrail (SERB), which can contain the entire range of vehicles (1,800-lb passenger car to 80,000-lb tractor-trailer). The longitudinal barrier also has a restoring action to reduce maintenance costs and to keep the barrier functional (Figure 2). This particular design has a high initial cost but has been shown to be most effective at high-accident locations. At four locations where the barrier is currently being evaluated, serious accidents have been eliminated. At least 60 impacts with the barriers have been observed with only 4 reported accidents and practically no maintenance.

The effectiveness of several devices has been discussed under the following assumptions: (a) the device has been installed where it has been needed, and (b) the device has been installed properly. As will be discussed later in this section, the biggest problem in the area of roadside accidents is the development of criteria to determine where and what type of device is warranted.

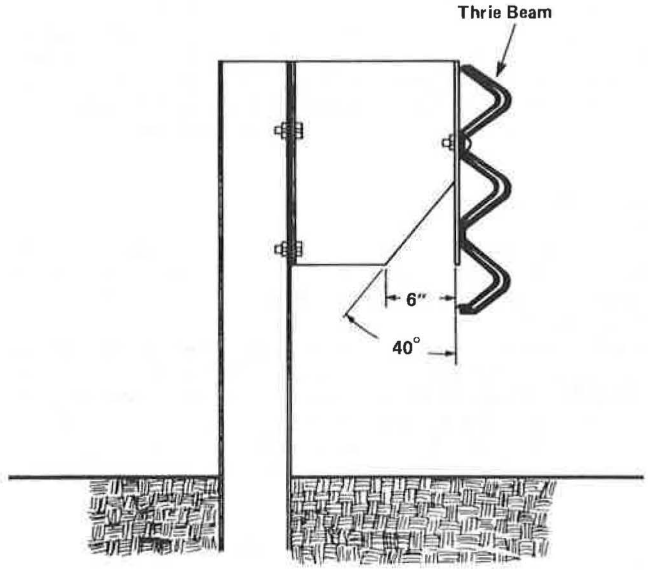

FIGURE 1 Modified thrie-beam guardrail.

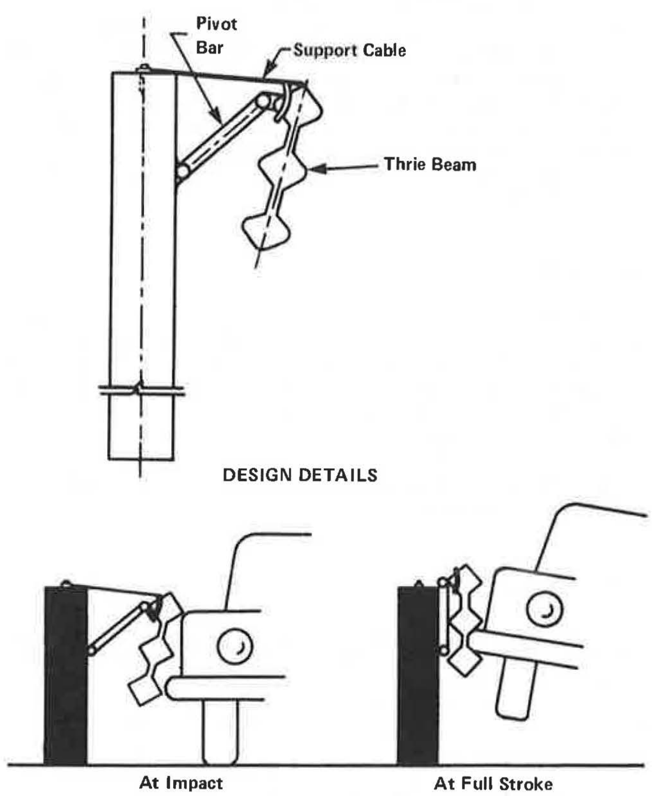

FIGURE 2 Self-restoring barrier (SERB) guardrail.

It appears to be much easier to determine the effectiveness of safety countermeasures whose objective is to ameliorate the effects of an accident rather than to prevent the accident from occurring. A discussion of the effectiveness of those items designed to reduce accident frequency follows.

Cross-Sectional Elements

During the past 10 years no group of items has received as much attention in the United States as cross-sectional elements (Figure 3). Considerable controversy has raged about the safety impacts of these items since the federal government agreed to participate in funding resurfacing, restoration, and rehabilitation (RRR) projects. The RRR program provided financial relief in the area of heavy maintenance. Before its institution, maintenance was strictly a state function with no federal funding.

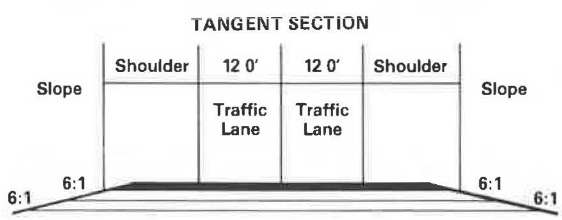

FIGURE 3 Cross-sectional elements.

With the addition of RRR work, certain groups contended that all geometric elements should be constructed to new construction standards (12-ft lanes, 8-ft shoulders, etc.), regardless of the traffic volume or the roadways' functional class. Others in the highway community (mainly state and local officials) contended that requirements to reconstruct all facilities would result in an unreasonable financial burden and would thwart the intention of the RRR program--that of maintaining the highway infrastructure. Currently, the National Academy of Sciences, under the direction of the Congress, is attempting to resolve this controversy.

The following sections are an assessment of geometric elements.

Lane Width

In general, 11-ft lanes provide the most appropriate balance between safety and traffic flow. This is true for all classes of highways where the percent of truck traffic does not exceed 8 percent. For facilities with truck traffic in excess of 8 percent and operating speeds in excess of 40 mph, 12-ft lanes should be used. Figure 4 shows the relationship between lane width and accident rates for two-lane rural highways (4).

Shoulder Type

When shoulders exist, particularly on high volume freeways, they should be paved. Other than access control, no geometric element has shown a more consistent relationship to safety (i.e., reduced accidents) than shoulder type. Estimates of accident reduction due to paved shoulders range from 1.3 accidents per year per 10,000 average daily traffic (ADT) for freeway noninterchange sections to 4 accidents per year for loop ramps at interchanges (5).

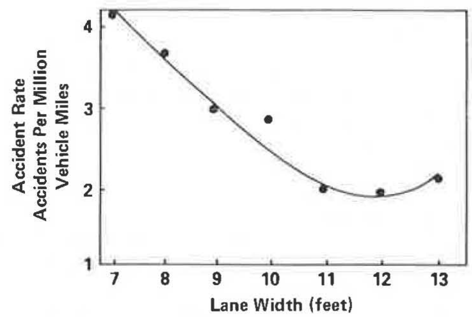

FIGURE 4 Relationship between lane width and accident rate on rural, two-lane roads.

Other Elements

Controversy still exists about shoulder width, sideslope, and horizontal and vertical curves. Most studies agree that shoulders up to 6 ft wide on facilities with greater than 1,000 ADT provide a safety benefit. The effect beyond 6 ft is not clear; existing studies conflict. Left shoulders on divided highways should not exceed 6 ft. Wider shoulders appear to encourage vehicle stopping on the left, which violates drivers' expectancy and causes safety problems.

Studies agree that slopes of 2:1 are dangerous and 10:1 are safe. Controversy still exists about slopes between 3:1 and 6:1. This area is particularly important when many miles of highways are being widened to improve safety. If insufficient information is available about slopes, the widening improvement may be causing safety problems because the existing slope will become steeper after the widening project.

The problems associated with horizontal and vertical curves are more complex. Studies agree that horizontal curves should be less than 3 degrees with vertical curves less than 6 percent. However, on low-volume, two-lane roadways, it is almost never cost-effective to redo highway alignment. The question then becomes "What is cost-effective to do?" It is the answer to this question that is being sought by the National Academy of Sciences.

TRAFFIC CONTROL DEVICES

By far, the least is known about traffic control devices and their effect on safety. For example, the traffic signal--installed to provide protected crossing maneuvers--invariably increases intersection accidents. However, it also eliminates the more serious angle and head-on accidents observed at uncontrolled intersections, and it smooths traffic flow--sometimes. Variations on traffic signal indications, timing, and phasing are more difficult to quantify because the changes are slight and the measure of effectiveness is sometimes too gross to detect change.

Traffic signs fall into the same class. Although some publications praise the cost-effectiveness of signs, there have been few evaluations of signs that have been properly documented. Thus, although it is intuitively believed that signs are effective, their specific effectiveness cannot always be demonstrated. Unfortunately, because misinformation on the effectiveness of signs has been widely distributed, and because signs are cheap and intuitively appealing, their use is widespread. In some cases signs are installed in lieu of other available, but perhaps more expensive, countermeasures.

The one type of traffic control device that has been adequately tested is pavement edge markings. In two studies reported in 1960 and 1961, both Ohio (6) and Kansas (7) demonstrated the effectiveness of pavement markings on two-lane rural highways. Both studies showed significant reductions in accidents (19 and 46 percent, respectively) at intersections when edge markings were used. Both studies were conducted with control sections.

Using comparison sections, additional studies have indicated significant benefit as a result of installation of centerline markings on low-volume, two-lane roadways (8).

WHAT IS UNKNOWN?

Illustrated in the previous section are some examples of what has been learned. Much remains to be learned and, in some cases, past knowledge has to be updated to reflect current trends, changes in technology, and improvements. For example, because of continuous changes in the motor vehicle population, engineers have had difficulty in specifying a design vehicle. Recently, the weight of new passenger cars has been decreasing with each model year, and today 25 percent of the vehicle population in the United States consists of vehicles less than 2,400 lb. Some of the other major gaps in knowledge include: roadside clear zones, guardrail location, guardrail end treatments, bridge rail design, luminaire/sign support design for small vehicles, breakaway utility poles, discontinuities at the edge of pavement (i.e., pavement edge-drop), and the general effectiveness of roadway signing, signalization, and illumination. As indicated earlier, geometric design countermeasures are currently undergoing review by the National Academy of Sciences. Until that review is completed, the authors are withholding judgment. Geometric issues of concern include horizontal curvature, sideslope design, bridge widths, and general intersection design.

Some explanation of these lists is certainly in order. At first glance, it is almost heresy for the authors to say that "we do not know the effects of roadway clear zones, guardrail location, or certain breakaway devices." The problem is that we know these countermeasures are effective, but we do not know how effective they are for specific situations. Roadway clear zones are unquestionably better than cluttered roadsides. As indicated earlier, for years roadside standards have cited the need for a 30-ft clear zone to allow errant vehicles to recover. There is little, if any, data on the differential effectiveness of the 30-ft clear zone over a 20- or 25-ft clear zone or for a 30-ft clear zone versus a partially clear roadside containing only small trees.

From the multitude of crash tests conducted, a tremendous amount of knowledge has been developed about the forces to the vehicles resulting from crashes into various guardrail designs, luminaire/sign support designs, bridge rail transition sections, guardrail terminals, and other hardware. Roadside hardware standards are continually enhanced and upgraded based on the results of such tests. Unfortunately, it is almost impossible to convert these g-force decreases to the vehicles to some meaningful measure of the decrease in predicted injury to the occupants. Little is known about what a decrease of five g's to the vehicle means in terms of the percent reduction in fatal injuries for a belted or unbelted occupant. Thus the determination of effectiveness still has to result from assessment following implementation.

Finally, where accident studies have been conducted, they are often conducted at high-accident locations. Bypassing the later discussed issue of the accuracy of effectiveness measured at such locations, there remains the troubling question of whether these results can be extrapolated or transferred to other situations. For example, reductions in the frequency or rates of fatalities or injuries derived from studies conducted in rural areas may or may not be transferable to urban areas where speeds are lower, driver behavior may be different, and accidents in general are less severe.

This issue of transferability of results is becoming more critical because of the shift in the vehicle fleet to much smaller passenger cars accompanied by a shift to larger and heavier cargo-carrying trucks. The overwhelming majority of crash tests and accident studies to date have been based on data sets from a fleet of larger (1,130 to 2,050 kg), more stable passenger cars and somewhat smaller and lighter trucks. Knowledge is just beginning to develop about which designs will not work with the smaller cars. For example, many of the guardrail terminal designs that appear to be quite adequate for larger passenger vehicles are now causing smaller passenger cars to ramp and roll over or to snag and be stopped violently.

It is thus apparent that (a) there are many areas in which adequate accident research has not been conducted to provide levels of effectiveness, and (b) there are certain countermeasures for which a way is yet to be found to convert information on changes in forces to the vehicle to meaningful measures of reducing the severity of injuries to occupants. In addition, even in areas where general effectiveness factors have been specified to some level of certainty, there remains the issue of transferability to other locations and to the smaller passenger vehicles.

WHY IT IS UNKNOWN

Gaps in knowledge concerning the effectiveness of countermeasures are the result of a number of different causes, most of which are under the control of the researcher and research administrator.

One of the basic causes of the lack of good effectiveness measures is the propensity on the part of roadway researchers to use less than adequate study design. Unfortunately, the study design that has been used most often in the past is also the design which, in many cases, provides either little or no sound information related to countermeasure effectiveness--the simple before-after design.

In this design, data are collected for a short period before the implementation of the countermeasure and are compared directly with data collected from a similar period following implementation of the countermeasure. This design is easy to implement, it requires little planning on the part of the researcher because it can be implemented at any time (even after the treatment has been implemented), it appears logical, and it has a long history of use in the field. Unfortunately, the design often produces results that have little relationship to reality. The problem is compounded when the design is used in evaluating a treatment that has been applied to a high-accident location.

The problems with the design have been discussed by many authors (9). Briefly, the major problems include the following:

1. Many other causes for a measured change often occur at the same time as the treatment, making it virtually impossible to ascertain the true cause of the change;
2. Underlying long-term trends in accident rates

can either disguise a true effect or produce a false effect; and

3. The ever-present threat of regression-to-the-mean in which high-accident locations, as defined by elevated accident rates during a short period, will usually improve, with or without treatment.

In contrast, little use has been made of stronger experimental designs that often require (a) planning before being implemented and (b) definition of control or comparison groups of sites where the treatment is withheld. A variety of reasons for not using these stronger designs are cited by researchers:

1. The need for short-term results (successes). A primary reason for using the simple before-after design is that it allows the researcher to use short periods of data collection to draw what appear to be accurate estimates of benefit. Because there is continual pressure on the research community to produce short-term results for policy makers, this design often appears to be the only answer. Realistically, what the policy maker is looking for are successes resulting from his or her decisions. And unfortunately, because of its nature, the before-after design often tends to produce a very optimistic picture of the benefits of a particular countermeasure, particularly if the countermeasure has been implemented at a high-accident location.

2. Quality of the data. Police accident reports are the usual source of accident data but often have inadequate information. Thus, many researchers argue that there is no need to use a strong design because the data are so poor. Unfortunately, the use of a weak design with poor data only compounds the problem.

3. Difficulties in establishing control groups. It is much more difficult to establish a nontreated control group ahead of time, or even to identify a good comparison group after the fact than it is to simply implement a treatment and look at the sites treated.

4. Legal/political reasons for the lack of control groups. Finally, the current climate in the United States toward increased litigation has affected roadway research by providing another reason for not using control groups. There is a cited fear among both state administrators and some researchers that if they were to withhold treatment from a control group and if the treatment ultimately proved to be a success, then those persons involved in accidents at control sites might well sue the implementing agency for its lack of implementation. Although no such case has yet entered the court system, this fear provides administrators a reason not to institute control groups for a treatment that they believe may have a beneficial effect.

The preceding impediments to the use of sound study designs are directly related to the nature of the designs themselves. Other factors also influence the design used.

The Congress requires a yearly report from the Secretary, U.S. Department of Transportation, on the progress of the states in implementing the hazard elimination and pavement marking program. The report must include ". . . number of projects . . means and methods used, and the previous and subsequent accident experience at improved locations" (10). To meet this requirement, each state is required to report the costs and safety benefits of their safety improvements. The states, because of limited available dollars to determine the effectiveness of improvements, have chosen to use the easiest possible design (before/after).

A movement is underway within FHWA to change this. During the past 2 years, some states have been allowed to trade off a large number of before-after studies for a limited number of in-depth studies. National coordination of this activity would make it possible to design evaluations with control or comparison sites. For example, each state could pick one countermeasure to evaluate for a specific time period, for example, 5 years. Studies would be carefully designed and countermeasure installation and data collection (specified in study design) would be done by states. Data from several states could be pooled and analyzed. States would no longer have to evaluate a large number of safety improvements, and the state of knowledge on countermeasure effectiveness would be significantly improved. For each 5-year period, approximately 10 countermeasures could be evaluated. Such a coordinated effort would significantly improve the state of knowledge in this area by permitting an accumulation of a listing of reduction factors and an updating of these reduction factors as new research is conducted.

Perhaps the major reason for poor safety research in the United States is the researchers themselves. For lack of a better definition, this could simply be characterized as a lack of peer pressure to conduct good research. For example, there have been numerous syntheses of research in certain areas. However, these syntheses tend only to repeat results presented by the original authors, with no judgment provided concerning the accuracy of the estimates. There have been few critical reviews of past studies, and even when critical reviews have been attempted, the findings have often conflicted. It appears that the problem is finding researchers who are knowledgeable about the area being researched, the proper use of research methods and statistics, and who have the status and the fortitude to criticize poor work done by their peers. Indeed, even the critical review procedures, established journals, and safety conferences are not very discriminating. Poor data, research designs, and interpretations are still presented at major national conferences and in engineering research journals.

It is encouraging to note that there are now attempts to rectify the situation. Approximately 20 individuals involved in highway research have petitioned the Transportation Research Board to remove the names of authors and organizations from papers submitted for review. It is believed that this change will provide a more objective review process. It is the authors' belief that the U.S. research community should encourage pointed and direct questioning and challenging of research studies. Pressure from peers can only tend to make a researcher more careful.

Finally, as noted earlier, at least one major cause exists for a lack of knowledge over which no group has control--the rapidly changing vehicle fleet. The effect of this change will continue to affect the benefits of highway countermeasures that were designed for larger passenger cars and smaller trucks. Here, the major gaps in knowledge are a result of an inability to keep pace with changes in the overall system so that the benefits of improvements can be accurately predicted.

CONCLUSIONS

In summary, through years of research efforts, the U.S. highway safety community has developed significant knowledge concerning certain countermeasures. Decisions concerning crash cushions, sign and luminaire supports, median barriers, lane widths, paved shoulders, pavement edge markings, and in some cases, intersections signalization can be made with some certainty. Much less is known about other countermeasures, particularly where the information needed is a specific level of effectiveness for use in economic analyses. There are gaps in our knowledge about the effectiveness of horizontal and vertical curvature, side slope design, pavement edge treatments, certain roadside clear-zone configurations, guardrails, guardrail end treatments, bridge widths and bridge rail designs, breakaway utility poles, and others. In addition, the shift to smaller passenger cars and larger trucks is resulting in new unknowns.

The highway field needs to utilize improved methods of evaluating safety features, provide continual review and updating of effectiveness factors, and increase "peer pressure" in the research community to upgrade research efforts.

The safety community must continually strive to overcome these problems by using the existing methodological knowledge, by building on what has been learned in the past, and, most important, by making poor research unacceptable.

REFERENCES

1. D. Solomon, S. Starr, and H. Weingarten. Quantitative Analysis of Safety Efforts of the Federal Highway Administration. FHWA, U.S. Department of Transportation, 1970.
2. J.G. Viner and G.M. Boyer. Accident Experience with Impact Attenuation Devices, FHWA, U.S. Department of Transportation, 1973.
3. L.R. Calcote, R.L. Mason, and J.P. Buckingham. Accident Analysis--Breakaway and Nonbreakaway Poles Including Sign and Light Standards Along Highways, Volume IV. NHTSA, U.S. Department of Transportation, 1984.
4. C.V. Zegeer, R.C. Deen, and J.G. Mayes. The Effect of Lane and Shoulder Widths on Accident Reductions on Rural, Two-Lane Roads, In Transportation Research Record 806, TRB, National Research Council, Washington, D.C., 1981, pp. 33-43.
5. J.A. Fee, S.K. Bietz, and R.L. Beatty. Analysis and modeling of Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System. FHWA, U.S. Department of Transportation, 1969.
6. J.V. Musick. Effect of Pavement Edge Marking on Two-Lane Rural State Highways in Ohio. In HRB Bull. 266, HRB, National Research Council, Washington, D.C., 1960, pp. 1-7.
7. A.J. Basile. Effect of Pavement Edge Markings or Traffic Accidents in Kansas. In HRB Bull. 308, HRB, National Research Council, Washington, D.C., 1962, pp. 80-86.
8. S. Bali, R. Potts, J.A. Fee, J.I. Taylor, and J. Glennon. Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments for Rural Two-Lane Highways. FHWA, U.S. Department of Transportation, 1978.
9. F.M. Council, D.W. Reinfurt, B.J. Campbell et al. Accident Research Manual. FHWA, U.S. Department of Transportation, 1980.

Publication of this paper sponsored by Committee on Methodology for Evaluating Highway Improvements.