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REPORT 490

In-Service Performance of Traffic Barriers

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In-Service Performance of Traffic Barriers

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Charles Niessner
Staff Officer
Transportation Research Board

This report presents the findings of a research project to develop a practical procedures manual for conducting in-service performance evaluations of roadside barriers. The report will be of particular interest to safety practitioners with responsibility for roadside safety improvements.

Significant improvements in highway safety have been achieved through a multitude of actions over the past three decades, but one area where serious problems still exist is the highway roadside. Crash data indicate that more than 40% of highway fatalities involve vehicles hitting objects on the roadside, including barriers. Highway designers attempt to address these roadside safety problems by minimizing the number of objects, providing adequate clear zones, or using barriers to shield the vehicles from the hazard. Several generations of barriers have been developed to improve safety, but the effectiveness of these barriers in the field is not fully understood. While crashworthiness criteria have been established in *NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features,* the tests are based on idealized installations of barriers. In field installations, the barrier may be located on a slope, struck at different angles, subjected to the effects of settlement, and may be installed and maintained inconsistently. In addition, crashes not reported to the police confound attempts to determine the true in-service performance of barriers. Further, when assessing barrier performance factors such as injury risk, it is necessary to consider the changing characteristics of the vehicle fleet (e.g., airbags). These and other factors can influence in-service performance of barriers, but there has been only limited effort to investigate their effects.

Transportation agencies need guidance on the in-service performance of traffic barriers to make effective decisions on their use under specific conditions. The American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide* (RDG) provides general guidelines to assist design personnel in determining when safety treatments may be needed. The RDG presents these guidelines in terms of roadside terrain, traffic volumes, design speed, crash probability, and environmental conditions. This guidance is limited to general references to applicability under specific roadside conditions because in-service performance data are inadequate. Thus, needs exist for (1) in-service performance data for roadside barriers; (2) a procedure(s) to efficiently gather these data on a regular basis; and (3) a process to compile, maintain, and share these data in efforts to improve roadside safety.

Under NCHRP Projects 22-13 and 22-13(2), "In-Service Performance of Traffic Barriers" and "Expansion and Analysis of In-Service Barrier Performance Data and Planning for Establishment of a Database," respectively, Worcester Polytechnic Institute developed a procedures manual for conducting in-service performance evaluations.

The research team reviewed the literature to identify past and current in-service evaluation studies and determined what methods had been previously effective. An in-service evaluation was planned and performed in portions of the states of Connecticut, Iowa, and North Carolina. The in-service performance of common barriers and terminals was examined by collecting crash, maintenance, and inventory information in the three data collection areas. The information was supplemented with visits to the crash sites to make measurements of the damaged barrier and document the collision scene using photographs. A procedures manual for planning and conducting in-service evaluations of roadside hardware was developed based on the methods used and the lessons learned in the evaluation study. The manual was subsequently used as a guide for an in-service evaluation project performed in Washington State by a different research team and modified based on their experiences and recommendations.

The procedures can be used as a general framework for developing and performing an in-service performance evaluation of a roadside feature. They are based on techniques that have been used in other in-service performance evaluations as well as other collision data studies. The procedures are intended to be used by design and maintenance engineers and do not require that the collisions be reconstructed. The procedures can be implemented into the routine operations of many roadway maintenance organizations and used as an ongoing management tool.

The pilot studies have demonstrated that in-service performance evaluations can yield useful information about the field performance of roadside features. The researchers concluded that in-service performance evaluations should be integrated more fully into the overall cycle of design, test, and evaluation of roadside hardware. The results of such evaluations will allow state DOTs to develop policy and maintenance procedures based on observable field phenomena rather than speculation and conjecture.

CONTENTS

CHAPTER **1**

INTRODUCTION

ROADSIDE FEATURE DESIGN PROCESS

The process used to design roadside safety hardware has evolved over the past half century. Full-scale crash testing dominated the roadside hardware development process in the past because until recently there were no sophisticated analysis tools, little experience with collecting and analyzing real-world crash data, and no standard procedures for field monitoring of roadside features. Today there are a variety of sophisticated analysis tools and the response of materials and structures to impact loadings is better understood. Collecting and analyzing crash data, has also become a sophisticated enterprise that takes advantage of advances in statistical analysis techniques. Field monitoring of roadside features, however, has lagged behind these other techniques. As a result, critical information about the field performance of roadside features is being lost.

By the late 1970s, the roadside hardware design process had evolved into the conceptual framework illustrated in Figure 1 (*1*). Preliminary designs are formulated and then examined using a variety of analysis techniques. These analysis techniques are sometimes simple "back of the envelope calculations" and at other time can be sophisticated finite element or vehicle dynamics simulations. Once designers have some confidence in a concept, the design is evaluated in full-scale crash tests. If the full-scale crash test results are satisfactory, they are carefully reviewed by the FHWA, state DOTs, and local agencies and then implemented by installing the roadside hardware on the highway system. The last step in the process is to monitor the in-service performance of the roadside feature to ensure that it meets the original expectations of the designers. If problems are observed in the field, the whole process can begin again with the formulation of new or improved designs. With this process, roadside features can be continuously improved as each iteration results in more effective roadside hardware.

Unfortunately, the ideal process illustrated in Figure 1 has seldom been realized in practice. Typically, roadside hardware is designed, analyzed, and tested but there have been relatively few attempts to monitor the performance of the hardware once it has been installed in the field. The in-service performance evaluations that have been performed in the past have varied considerably in scope and quality. The cycle illustrated in Figure 1, therefore, is broken and opportunities for making further improvements to roadside safety hardware are being lost because of a lack of understanding about the field performance of roadside features.

PURPOSE OF IN-SERVICE EVALUATIONS

The purpose of in-service evaluations of roadside features is to determine how such devices perform under field conditions. Performance, in this context, includes knowing the number, severity, and proportion of people injured in collisions involving the roadside feature; installation and maintenance problems; and the collision, installation, and repair costs associated with the feature. If these performance measures are known, designers and policy makers can optimize the safety benefit obtained by installing the most appropriate roadside features in the most hazardous locations. In-service performance evaluations are the best source of information about injury severity and installation, maintenance, and repair costs. Without good in-service performance information, it is difficult to perform meaningful cost-benefit analyses.

Another purpose of in-service performance evaluation is to assess the relevance of full-scale crash test procedures. If the test conditions recommended in documents like *NCHRP Report 350* are not relevant to the way collisions occur in field service conditions, then improved crash test performance may not translate into fewer injuries and fatalities in the field (*2*). Likewise, roadside feature policies that are based solely on crash test results may not reflect actual conditions in the field. In-service evaluations can provide an independent check on test and evaluation procedures to ensure that crash test research efforts are solving appropriate real-world problems.

While careful design, testing, and evaluation of a roadside safety feature is critical, it is not a guarantee that the feature will perform as intended once it is installed along the roadside. In-service performance evaluation is the process of examining how well a roadside feature functions in actual service conditions and determining if its performance is consistent with its design. Conceptually, in-service performance evaluation is similar to experimental drug trials in the pharmaceuticals industries: After a particular drug is designed and tested in a clinical setting, the effect of the drug on the general population must be assessed before it is released for widespread use. This is done by tracking the health of a control group of human

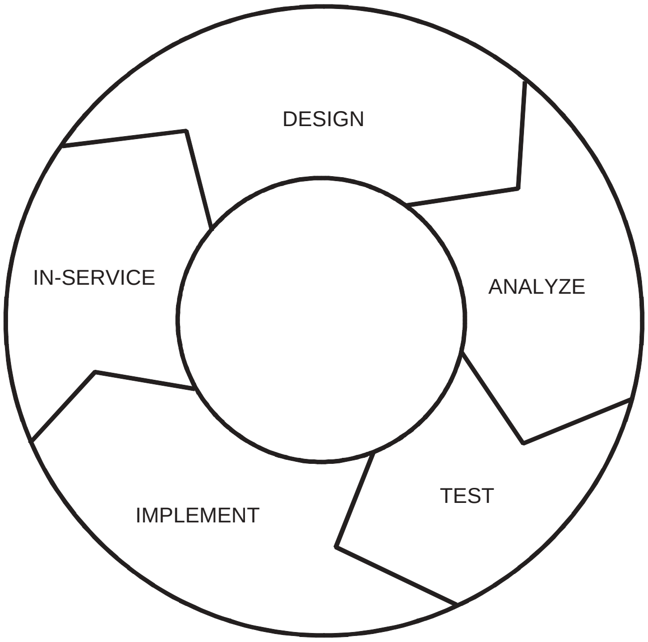


Figure 1. The roadside safety hardware development process (1).

subjects for a period of time and comparing the health of the group using the new drug to a similar group that is not being treated. Even after the drug is released to the general population, governmental agencies continue to track patient experience with the drug to determine if it is effective and to ensure there are no unanticipated side affects in the general population. Even with careful design and testing, unexpected situations and conditions could put some people at significant risk so the medication must be evaluated in the general population. Similarly, even if roadside features are carefully designed and tested, the only way to determine if they are functioning consistently and correctly is to observe the field performance.

In-service evaluations should attempt to answer four general questions:

1. Do roadside features perform as intended in typical real-world collisions?
2. Are roadside features installed correctly and does improper installation cause any particular performance problems?
3. Is the performance of the roadside feature degraded by weather, age, climate, or other environmental conditions?
4. What are the costs to install, repair, and maintain the roadside feature?

In the context of this report, in-service evaluation implies that actual sites were visited and examined within a few days of a collision occurring. Sometimes reviews of collision and maintenance records have been referred to in the literature as in-service evaluations. In such cases, however, it is not always possible to directly observe the site and the device. For example, it is often very difficult to determine exactly what was struck if the only information available is the police collision report. The device may not have been installed correctly, it may have been damaged by a prior collision, or it may be an obsolete barrier the DOT no longer uses. Studies retroactively examining collision and maintenance records are referred to herein as "collision studies" to differentiate them from "in-service evaluations" that involved site visits. Visiting the collision scene is an important feature of in-service performance evaluations.

IN-SERVICE EVALUATION RECOMMENDATIONS

The importance of in-service evaluations has been widely recognized by the roadside safety community for nearly three decades. As early as 1971, in-service evaluation was recommended as an essential part of the roadside safety research and development cycle. *NCHRP Report 118* recommended that "after the system has been carefully monitored and evaluated in service and its effectiveness has been established, the system is judged to be operational (*3*)." One of the earliest attempts to implement this recommendation and examine the real-world performance of traffic barriers was a study in the state of New York in the middle 1970s (*4*).

NCHRP Report 230, published in 1981, recommended that formal in-service evaluations be routinely performed and more than a decade later *NCHRP Report 350* re-emphasized the importance of in-service evaluation (*5*, *2*). *NCHRP Reports 230* and *350* suggested that without effective in-service evaluations, it was impossible to determine if barriers developed and tested under laboratory conditions performed as expected in the field. While *NCHRP Report 230* endorsed the concept of in-service evaluation, the inconsistent quality and scope of in-service evaluations performed up to that time was also noted. *NCHRP Report 230* listed six objectives for an in-service evaluation (*5*):

1. Actual field performance of the appurtenance,
2. Unreported accidents,
3. Susceptibility to vandalism,
4. Effect of environmental factors,
5. Influence of traffic conditions, and
6. Routine maintenance and repair costs.

A decade later, *NCHRP Report 350* reiterated these same six areas of concern, and lists seven other important issues and recommendations that should be addressed in developing an in-service evaluation project (*2*):

1. A minimum study period of 2 years,
2. Sufficient number of installations to result in a useful collection of cases,
3. Frequent site visits,
4. Before and after accident studies,

5. A method for observing unreported accidents,
6. Maintenance and repair cost information, and
7. Preparation and distribution of final report summarizing the in-service evaluation.

Through most of the 1980s, the FHWA encouraged states to perform in-service evaluations by classifying roadside hardware as either "experimental" or "operational" (*6*). When a device passed all the recommended full-scale crash tests, the FHWA was typically asked to approve the device for use on federal-aid projects. Normally, the FHWA granted "experimental" status to a device with the recommendation that an in-service evaluation be performed and submitted to FHWA to document the field experience with the system. In principle, the FHWA could then examine the in-service performance of the device to determine if it was functioning as intended and ensure that no unexpected problems were occurring in the field. If the field experience observed with the roadside feature was satisfactory, the FHWA would upgrade the feature to "operational" status. A few states responded to this request but most did not. There are several likely reasons why more states did not perform in-service performance evaluations:

1. There was no formal process to use so each state had to develop its own procedures,
2. Collecting and analyzing the data was labor intensive, and
3. Agencies did not perceive a benefit from performing in-service evaluations.

By November 12, 1993, the FHWA dropped the "experimental" status altogether. Today, there are no requirements that in-service evaluations be performed and, as a result, relatively few are being performed (*6*).

In the early days of crash test research, there were no standard methods for performing or evaluating crash tests. The result was that every testing agency used different methods and criteria. This situation changed in 1962 when *HRB Circular 482* was published (*7*). HRB 482 provided recommendations for performing full-scale crash tests. The field of crash testing has grown increasingly standardized with a succession of test recommendations, *NCHRP Report 350* being the most recent (*2*). A similar process must occur for in-service performance evaluations. To date the procedures and methods used for in-service evaluations have been *ad hoc* and the results have varied. A conceptual framework for performing in-service evaluations is necessary in order to evaluate the performance of roadside hardware.

COMPARISON OF CRASH TESTS AND IN-SERVICE EVALUATIONS

Full-scale crash testing and in-service performance evaluation are two distinctly different techniques, each with its particular advantages and disadvantages as shown in Table 1. Crash tests provide relatively unambiguous observable results. The performance can be quantified and judged to be either acceptable or not acceptable. Tests can be performed at well-known prespecified impact conditions and the characteristics of the vehicle and hardware can be measured before during and after the test. The impact conditions used in most full-scale crash tests are intended to represent a reasonable worst-case impact scenario in actual service conditions. Unfortunately, establishing how extreme the test conditions are with respect to typical impact conditions is very difficult. The relevance of crash test results to field conditions must always be questioned and the choice of impact conditions must always be justified. Standard crash test conditions may represent impact scenarios that are only rarely observed in the field, as illustrated by Figure 2. Increasingly demanding crash test procedures may result in roadside features that perform well in extreme crash tests although the performance in typical real-world collisions is unaffected. Relying on crash tests alone may tend to improve the crash test performance of hardware in the laboratory beyond a point of diminishing economic returns in the field.

The linkage between the performance of a roadside feature in a full-scale crash test and the risk to occupants of vehicles in real-world collisions is not well understood. For example,

TABLE 1 Comparison of full-scale crash testing and in-service performance evaluation

In-Service Evaluations	Crash Tests
Advantages	*Advantages*
Observed typical conditions	Expected worst-case conditions
Known injury results	Known impact conditions
Known costs	Known vehicle types
Actual service conditions	Observable behavior
Disadvantages	*Disadvantages*
Unknown impact conditions	Unknown injury severity
Unobservable behavior	Unknown costs
Unknown vehicle types	Unknown factors of safety

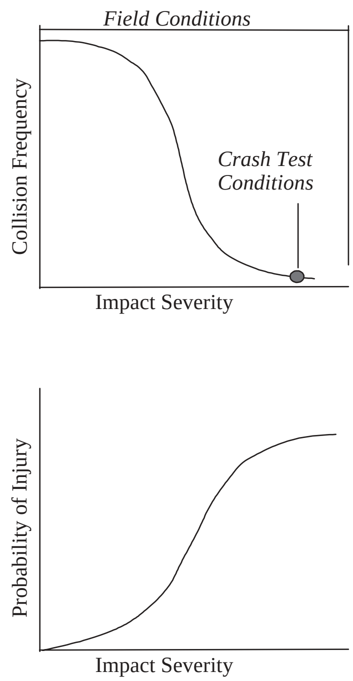


Figure 2. Relationship among collision frequency, impact severity, and occupant injury.

assume one guardrail crash test results in a lateral occupant risk value that is barely acceptable and a test of another system results in an occupant impact velocity half of the first. How much better is the former than the latter? How many fewer injuries and fatalities can reasonably be expected in the field on the system with the lower observed occupant impact velocity? It is not known how incremental improvements in hardware performance are translated into injury and property damage reductions. Finite element simulations have emerged in recent years as a way to perform simulated crash tests. While a broad range of impact conditions can be examined, simulation techniques share many of the same strengths and limitations of crash testing: the impact conditions are known but the field relevance must be inferred. The specific relationships among impact severity, collision frequency, and occupant injury for each type of roadside hardware can only be investigated through in-service performance evaluations.

On the other hand, in-service performance evaluations explicitly measure the amount of injury and property damage resulting from collisions with a roadside feature. Unlike full-scale crash tests, in-service evaluations are by definition relevant to the field. If an in-service performance evaluation of one guardrail finds that 10 severe and fatal injuries (A+K) occur per million vehicle-kilometers traveled and an evaluation of another guardrail finds that five A+K injuries occur per million vehicle-kilometers traveled, the guardrail with the lower rate is clearly the guardrail with superior performance, presuming the studies use comparable data collection and analysis techniques and the site conditions (e.g., speed, volume and geometry) were similar. In-service evaluations measure the typical or average performance of the system because a wide range of vehicles may strike the hardware at a wide range of impact conditions. Benefit-cost analysis can be directly related to the results of an in-service evaluation because collision rates, injury distributions, accident costs, and installation and repair costs are explicitly measured.

In-service evaluations, however, also have weaknesses. The precise impact conditions that occur in the field cannot be measured. Statistical methods like in-service evaluations are sensitive to sample size, so quick answers are difficult to obtain. Also, in-service techniques will generally miss the rare but catastrophic impacts with high societal costs.

In summary, in-service evaluations measure the *observed typical performance* of a roadside feature whereas crash tests measure the *expected practical worst-case performance.* Both measures are valuable. Relying only on crash tests will result in continued improvement for the worst-case scenarios with steadily decreasing benefits for typical collisions. Relying only on in-service performance evaluation results in maximized benefit for most typical collisions but exposure to occasional high-cost catastrophic collisions. The two techniques should be used together to develop safe and effective roadside features that maximize the societal benefit of installing the features on the roadway. The idealized development process shown in Figure 1 is probably the best means of exploiting the strengths of the two techniques.

BENEFITS OF IN-SERVICE EVALUATIONS

In-service performance evaluation of roadside features could be a very useful management tool. The performance of roadside features should be monitored to determine if the features are performing as intended. All roadside features, regardless of how carefully they were designed or tested, will result in some level of occupant injury and property loss since it is not feasible to build or to maintain a highway system with no risk to users. The objective of managing the roadside is to maximize the level of safety while minimizing the cost of providing that level of safety.

If the societal cost of roadside collisions observed during the monitoring period is acceptably small, no changes need be made. If, however, the amount of injury and property loss is unacceptably high, corrective actions must be taken. There are many types of corrective actions that could be used to reduce the societal cost including developing improved roadside hardware, changing policy about when to maintain or upgrade hardware, or revising the criteria used to select and locate hardware. Once an approach for reducing the loss has been identified, the improvements can be implemented and the monitoring process resumed. The result of the process, illustrated in Figure 3, would be a management and policy environment that continually responds to safety problems on the highway system as they are identified.

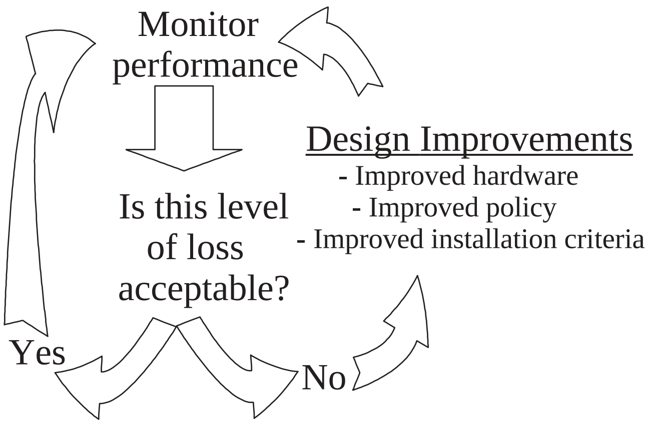


Figure 3. The in-service performance evaluation process.

This type of process could become a part of a state's Safety Management System since it is focused on quantifiable results that can be optimized. Safety management stresses the need for defining observable quantifiable performance measures. If safety is quantified, the degree of safety made available to the driving public with the resources available can be maximized. In-service performance evaluations are, in fact, a type of roadside safety management system that can help an agency identify problems, evaluate solutions, and wisely allocate public resources.

Unlike full-scale crash tests, in-service evaluations can provide dependable information about collision frequency, collision severity, installation cost, repair cost, and societal loss associated with roadside feature collisions. This type of information can be incorporated directly into common benefit-cost programs like Roadside or Roadside Safety Analysis Program (RSAP) (*8, 9*). Benefit-cost methods have great potential as management tools for roadside features but currently much of the data required are overly general, poorly documented, or based on intuition and out-dated data. Data obtained from in-service performance evaluations could provide information that is based on observable quantifiable conditions in a specific geographical area on specific roadways.

Figure 4 shows an improved process for developing and maintaining roadside features. If in-service evaluations are more effectively incorporated into the design process shown earlier in Figure 1, roadside designers could learn a great deal about how features actually perform in collisions under road service conditions. This part of the process is shown on the right side of Figure 4.

In-service evaluation, however, is not just a tool for designing better roadside features. Monitoring the field performance of roadside features can also provide better information for formulating policies about the installation, maintenance and repair of roadside features. This part of the cycle is shown on the left in Figure 4. The results of in-service evaluations can show which policy actions are effective and which are not. Policy about where to place specific roadside features can be assessed and if necessary changed. In-service performance data would also allow policy makers to evaluate the economic impact of changing specific roadside feature policies and benefit-cost methods could be more effectively used to maximize the safety benefit of allocating scarce roadside safety resources. Benefit-cost methods would then allow roadside designers to make better informed and more appropriate choices in deciding what features should be installed along the roadside. Finally, the effectiveness of policy decisions can be monitored to ensure that the desired results are achieved.

Today, roadside features are approved for use on the National Highway System (NHS) by demonstrating their crash test performance according to the guidelines contained in *NCHRP Report 350* (*2*). In recent years, several common guardrail systems have performed poorly in *NCHRP Report 350* crash tests. Some of these systems have been in use in some states for decades, and the level of loss associated with them has presumably been acceptable. Many states are now confronted with the need to spend millions of dollars to upgrade roadside hardware to *NCHRP Report 350* standards with no clear indication of the benefits that can be expected. In-service evaluation could provide a means of balancing the need to develop improved hardware for severe worst-case impact scenarios with the costs associated with installing improved hardware on the highway system. Presently, these important and costly decisions must be made without a full understanding of the economic benefits and costs.

SCOPE OF THIS STUDY

In-service performance evaluations of roadside features need to become an integral part of the roadside feature development and safety management processes. This approach has great potential for maximizing the safety impact that can be produced with limited resources. By combining in-service performance evaluation and benefit-cost (B/C) methods, states can ensure that they obtain the largest possible safety benefit

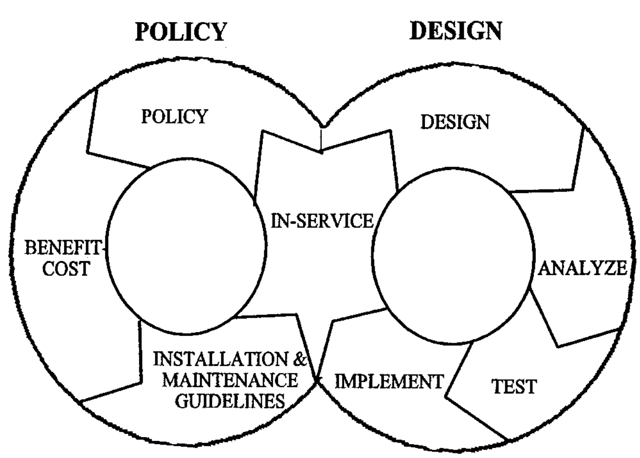


Figure 4. An improved roadside feature development process.

from the resources available. In-service evaluation has the potential to become a vitally important means of increasing the driving public's safety while at the same time effectively stewarding the public's resources.

The purpose of this report is to present results of a research project on in-service performance evaluation of common traffic barriers. A survey and literature review were first performed to identify past and current in-service evaluation studies and determine what methods had been effective previously. Then, an in-service evaluation was planned and performed in portions of the states of Connecticut, Iowa, and North Carolina. The in-service performance of common barriers and terminals was examined by collecting crash, maintenance, and inventory information in the three data collection areas. These official sources of information were supplemented with visits to the collision sites, generally within a day or two of the collision, to make measurements of the damaged barrier and document the collision scene using photographs. A procedures manual for planning and performing in-service evaluations of roadside hardware was then developed based on the methods used and lessons learned in the evaluation study. This manual was used as a guide for an in-service evaluation project performed in Washington State by a different research team and modified based on their experiences and recommendations.

One of the most persistent problems with performing in-service performance evaluations of traffic barriers and analyzing the results is chronically small sample size. Quick studies in small geographical areas may produce unreliable results based on a small number of cases that may be used to develop equally unreliable public policy. On the other hand, geographically widespread evaluations with very long multiyear study periods may produce large collections of data and definitive results with little practical value because decision makers could not wait for the results. A balance must be found between collecting sufficient cases for statistical significance and producing answers quickly enough to address pressing policy and design concerns.

The following chapters describe the survey and literature review, the procedures manual for in-service evaluations, the three data collection areas where the initial study was performed, and a variety of specific analyses that serve as examples of the types of studies that can be performed once detailed in-service performance information has been collected in the field.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

While agreement is almost universal on the importance of in-service evaluation for roadside safety appurtenances, the process that should be used has never been formalized. One goal of this project was to recommend an in-service evaluation process that could be used to evaluate the performance of a roadside safety appurtenance. This process was developed largely by examining prior in-service evaluations and identifying features and techniques that either did or did not result in a meaningful examination of the appurtenance's performance.

"In-service evaluation" here implies that actual sites were visited and examined shortly after a collision occurred. Studies retroactively examining accident and maintenance records are referred to as "historical studies" in this report. In other cases, data collection was performed concurrently with the study period by police or maintenance personnel, but no site visits occurred. Without examining the site of a collision, the data can be difficult to interpret. Such studies are referred to as "collision studies" to differentiate them from "in-service evaluations," which involved site visits.

A literature review was performed to identify prior in-service evaluation efforts. Materials were identified in three ways:

1. A TRIS search (*10*);
2. A review of FHWA reports, NCHRP reports, TRB papers, and other roadside safety literature; and
3. A survey of roadside safety professionals.

From these sources, 57 reports were obtained that described some type of roadside feature evaluation. The survey was sent to approximately 240 people in state DOTs, FHWA division offices, and FHWA regional offices; roadside hardware manufacturers; and other roadside safety professionals. Ninety-five people responded to the survey, representing a total of 45 states. Table 2 summarizes the survey results. Nineteen of the 45 states responding had performed some type of in-service evaluation in the past. Only 18 of the states had some type of roadside hardware inventory, a few of which were outdated according to the survey.

Table 3 summarizes the data sources used by respondents to perform roadside hardware evaluations in their states: police reports, hardware inventory, maintenance reports, or on-site investigations. Most of the respondents named police or maintenance reports as data sources with 21 and 20 responses, respectively. On-site investigations were used by 16 of the respondents and inventory reports by 5 of the respondents.

Table 4 presents a summary of the roadside devices identified by the respondents. Devices studied included various types of end treatments, guardrails, median barriers, and impact attenuators.

HISTORICAL STUDIES

A historical study in this review indicates a study that retroactively examines collision and/or maintenance records. The data collection is performed some time after the collisions occurred, and there is no investigation of the site.

Kentucky, 1975—Bridges (*11*)

In 1975, Agent reported on an investigation of collisions associated with highway bridges and overpasses in the state of Kentucky. This investigation was performed to satisfy the FHWA's request that data be collected as part of routine bridge inspection. The objective of the study was to "identify those principal features of bridges and appurtenances which may be related to collision frequency and severity and to provide some further insights into highway safety."

Most of the study data were collected from police reports of collisions that occurred between 1972 and 1973. Non-fatal collision data were collected for 1972 only. Each type of device was assigned a severity index (SI) based on the severity of the injuries associated with the collision. The smallest value for the SI was 1.00 for property damage collisions. The highest value possible was 9.50 for a device that resulted in fatality or severe injury in all collision cases. If more than one fatality or severe injury occurred within a single event, this was noted but did not affect the SI.

Collisions with bridge piers, gaps between bridge openings, entrance posts and wing walls, bridge railing or curb, bridge railing and guardrail, and approach guardrail were investigated, where each type of object was categorized as a different device. In addition, impacts with another vehicle on the bridge and those due to bridge geometry were examined.

Although the specific results of the report are beyond the scope of this synopsis, it appears that the most common cause

TABLE 2 Inventory and evaluation data

	Yes Responses	No. of States
Evaluations?	25	19
Inventories?	20	18

of collisions associated with bridges and overpasses was icy or inclement weather conditions. The researchers also investigated whether there was a correlation between warning and flashing "ice on bridge" signs and a reduction in collisions. In general, investigation results showed a reduction in the number of collisions at high-incident locations.

The data presented in this report are based on a large sample base and consequently have statistical merit. The size of the database was sufficient for an investigation of the statistical significance of some of the factors, such as icy conditions, but such analyses were not performed. Correlating the type of device struck with the severity indices could have been investigated but was not.

Iowa, 1979—Cable Guardrail (*12*)

In 1979, Schneider reported the results of a study of cable guardrail collisions in the state of Iowa. The purpose of the study was to determine the performance of the light post cable guardrail within the state using collision statistics.

Data collection for the evaluation consisted of an examination of existing collision data sources such as the state maintenance property damage reports, the Accident Location and Analysis System (ALAS), and the police reports of motor vehicle accidents. Two years of collision data were used in the study.

Once the data were collected, the performance of the guardrail was categorized according to whether the guardrail redirected the vehicle, kept the vehicle from entering the hazardous area, and if the barrier was economical to construct and maintain.

Sixty maintenance reports were examined from the 2-year study period. Of these, 31 were matched with a corresponding police crash report from the ALAS database. Results showed that the average property damage and collision severity were lower for the cable guardrail than for all guardrail collisions in the state during the study period. Approximately 32 percent of the vehicles impacting the cable barrier penetrated it, and one fatality was recorded. Average costs for the installation, maintenance, and repair of the guardrail were also computed.

TABLE 3 Data sources for evaluations

	Yes Responses	Percent of Total Evaluations
Police	21	84%
Maintenance	20	80%
On-site	16	64%
Inventory	5	20%

Although the author states that time was limited for the completion of the study, a more thorough evaluation would have been obtained had data been collected concurrently with the collisions themselves. This would have allowed on-site investigations of the collisions and periodic examinations to determine unreported incidences, which could have changed report results and increased the number of documented collisions from which the conclusions were drawn.

New York, 1983—Turned-down Guardrail End Treatment (*13*)

In 1983, Fortuniewicz, Bryden, Hahn, and Phillips described crash testing and a subsequent collision and site study performed on a turned-down guardrail end treatment for heavy-post, blocked-out W-beam median barriers. The purpose of the evaluation was to determine the field collision performance and maintenance requirements of the end treatment.

Most of the data were collected retroactively by examining computerized collision files and maintenance records. The remainder of the data were collected during site examinations to find indications of unreported impacts. These unreported events were compared to reported collisions occurring at or near the end treatments involving guardrail or median barriers. Sites were classified as having sustained either minor or severe damage. Minor damage consisted of small dents, scratches, and paint marks. Severe damage included bent or misaligned posts and rail sections.

When the collision study and field investigations were performed in 1981, 62 turned-down end treatments for heavy-post median barriers existed in the state of New York. Police crash reports were difficult to obtain and only one was found in the files. A vehicle rollover occurred but no injuries were reported. All sites were examined once during the field investigation. Sixty-one impacts were documented; 53 were classified as minor and eight as severe. The authors noted that it was difficult to differentiate between multiple- and single-event impacts at any given location. Additionally, no maintenance activities had occurred at these sites since the first installations in the mid 1970s.

This study provided useful information for the implementation of the ramped end treatment for heavy-post guardrail in the state of New York. The criteria by which the impact with the turned-down treatment were evaluated included misaligned posts. Poor installation or soil settlement could account for misaligned or non-vertical posts. The study illustrates the difficulty of obtaining an adequate number of cases with a small installed inventory and a relatively short data collection period.

Iowa, 1989—Bridges (*14*)

In 1989, Schwall reported on a study of collisions occurring at or near bridges in the state of Iowa. The purpose of

TABLE 4 Roadside devices studied

Devices Studied	Report	No Report	Planned	Total
End Treatments				
BCT	6	1	0	7
ET-2000	2	2	2	6
Bluntend/Turndown	4	1	0	5
SENTRE	2	1	0	3
TREND	2	0	0	2
VAT	1	0	0	1
CAT	8	1	2	11
MELT	1	0	1	2
CO 3F	1	0	0	1
SRT	0	0	3	3
Brakemaster	4	0	0	4
Guardrail and Median Barrier				
W-beam GR	4	2	2	8
Cable GR	5	1	0	6
Box-Beam GR	3	1	0	4
WY-Box Beam	0	0	1	1
Mod. Thrie-Beam	2	0	0	2
Quick-Change	1	0	1	2
SERB	2	1	0	3
IBC Mark VII	2	0	0	2
Impact Attenuators				
Frangible Tube	1	0	0	1
CIAS	1	0	0	1
NCIAS	1	0	0	1
Tire-Sand Bar.	1	0	0	1
GREAT	1	0	1	2
CTMA	1	0	0	1
Triton Water	1	0	1	2
Modular CC	1	0	1	2
Hi-Dro Cell	1	0	0	1
Hex-Foam	1	0	0	1
Tor-Shok	1	0	0	1
LMA	0	0	1	1
REACT	0	0	2	2
Quadguard	0	0	1	1
ADIEM II	0	2	2	4

the study was to examine the collision data at bridges on Iowa's primary system and the cost-effectiveness of installing approach guardrail. This information was used to justify a program to upgrade approach guardrail at primary road bridges in Iowa.

The majority of the data came from a previous study's report, "Iowa Fixed Object Accident Analysis," by Dominic Vi-Minh Hoang of the Iowa Division of the FHWA. Police crash reports were collected for all fatal collisions at bridges and culverts in Iowa since 1981.

Sixty-one of the 90 fatal bridge collisions involved impacts with unprotected bridge ends. The study also identified the percentage or length of approach guardrail that was below current standards for W-beam approach guardrail.

Installation of approach guardrail was determined to cost on average $7,000. The average maintenance cost of these systems was also determined. In this assessment, only the cost to repair the guardrail after an impact was considered.

To determine the feasibility of upgrading unprotected and substandard guardrail on bridge ends, a benefit-cost (B/C) analysis was performed. The societal cost for each type of injury was assigned based on the Iowa value loss index. The average cost of a collision for an unprotected bridge end was then computed. It was then assumed that the use of approach guardrail would reduce the cost of an collision (based solely on severity) by 24 percent. Average maintenance costs were then added to the cost of the guardrail based on the average daily traffic (ADT) of the road where each bridge was located, and a B/C analysis was performed. An alternative was considered feasible if the B/C ratio was 1.2 or higher. Based on the analysis, installing approach guardrail on bridges with an ADT of 1,700 vehicles per with a 610 mm offset would result in a

B/C ratio of 1.2. All bridges on roads with an ADT of at least 2,700 vehicles per day had a B/C ratio of 1.2 for approach guardrail with a 3-m offset.

This study provides useful information for the upgrade of approach guardrail associated with bridges in the state of Iowa. To this end, the report did fulfill its purpose of examining collisions involving bridges and justifying a program to upgrade approach guardrail on primary road bridges. However, the methods of data collection and analysis could have been improved: (1) Mention was made of the reduction in the number and severity of collisions involving bridge ends, but it appears these factors were not incorporated into the final analysis. (2) Costs for routine maintenance such as replacing rotted posts, corroded guardrail, vandalized devices, etc. were neglected. Unfortunately, these repairs can be relatively costly and should have been included. The study was focused solely on fatal collisions. While fatal collisions have the highest societal cost, including other injury collisions may have changed the results.

New York, 1989—Cable Median Guardrail (*15*)

In 1989, Tyrell and Bryden described a study of the cable median barrier in the state of New York. The purpose of the evaluation was to determine the field performance of cable guardrail used as a median barrier.

Data collection for this report relied solely on police-reported collisions involving the 15 sites under investigation. Photologs were examined to verify that the collisions involved one of the cable barriers. Collisions were then classified according to the most severe injury in the event, the occurrence of a secondary collision, and how the vehicle interacted with the barrier (i.e., contained, penetrated, snagged, etc.). No attempt was made to determine the number of unreported collisions. It is important to note that only passenger vehicles are allowed on the parkway.

According to the collision data, 99 collisions occurred with the barriers during the 3-year evaluation period. Personal injury was reported in 24 incidents. In six cases, only a single vehicle was involved and no personal injury was recorded. There were, however, four cases where the impacting vehicle was not contained by the barrier. Two of these were attributed to the height of the barrier. The guardrail in the study was constructed before the standard height of cable barriers was lowered. In the other two cases, the vehicle impacted a tree. It is uncertain in the latter cases whether the vehicles penetrated the barrier or if the barrier deflected enough to allow the vehicles to strike the trees. Performance data and the costs associated with the use of the system determined that the cable median barrier's performance was satisfactory in this study.

This study presents useful information on the implementation of the cable barrier system when used as a median barrier. However, the exclusion of certain information from the study lowered the quality of the evaluation's findings: (1) As stated above, no attempt was made to determine the number of unreported collisions. This lowered the number of successful re-directions. (2) No attempt was made to determine possible problems with the installation or use of the systems. Interviews with maintenance personnel could have helped.

California, 1991—Median Barriers (*16*)

In 1991, Seamons and Smith of the California Department of Transportation (CalTrans) published a study of past and current median barrier practices in California. The report contained a collision study relating to the assumptions made when identifying and recommending a site for median barrier placement. The purpose of this study was to verify the accepted values for the increase of the collision rate after the placement of a median barrier at a particular location.

Collision data were acquired from California's Traffic Accident Surveillance and Analysis System (TASAS), which is "the computerized record system of traffic accidents and highway features for the (California) state highway system (*16*)." TASAS was used to identify sites where median barriers were the primary item on a contract and had been completed 5 to 6 years prior to the study to allow before-and-after study. Twenty-four freeway sites and five non-freeway sites were used in the collision study.

Installation of a median barrier greatly reduces the frequency of cross-median collisions but increases the total frequency of collisions. From previous studies cited within the report, the expected increase in the collision rate after placement of a median barrier was 20 to 30 percent. The results of the new study, however, indicated an increase of 10 to 20 percent on freeways and 50 percent on non-freeways was more likely. As a result of the collision analysis, it was recommended that the new percentages be used to determine the cost-effectiveness for the placement of median barriers within the state of California.

Texas, 1991—Turned-down Guardrail End Treatment (*17*)

In 1991, Griffin reported on the performance of turned-down guardrail terminals in the state of Texas. In 1990, a FHWA memorandum was issued stating turned-down terminals were to be replaced on high-volume and high-speed roadways and were not to be used in new installations. Since the turned-down end terminal was effectively the only end treatment used in Texas at the time, the Texas State Department of Highways and Public Transportation asked the Texas Transportation Institute to investigate the number of collisions involving guardrails, the severity of these collisions, the number of vehicles overturning on turned-down treatments each year, the type of highway and traffic volumes where the collisions occur, and other variables contributing to these collisions. The objective of the study was to examine the frequency of vehicle overturn and accidental death or injury associated with turned-down end treatments in order to assess the cost-effectiveness of replacing them with different end treatments.

Data for this study came from the Texas traffic accident database and police crash reports. In 1989, there were 190,512 police-reported collisions on state-maintained highways in Texas, including 4,047 that reportedly involved guardrails. From these 4,047 collisions, all collisions that resulted in fatalities were extracted. Next, every fourth non-fatal collision (based on accident number) was extracted, resulting in a 25 percent sample of the non-fatal data set.

The author reviewed the fatal and non-fatal collision reports and coded them based on two supplemental variables: the point of impact on the guardrail (turned-down end, not end, unknown, not guardrail) and whether the impacting vehicle rolled over. Of the 987 non-fatal collisions, 152 involved turned-down ends, 604 occurred at other known parts of the rail, 115 occurred at undetermined parts of the guardrail, and 116 collisions were actually non-guardrail collisions (e.g., they were mis-coded). Of the 100 fatal collisions, 32 occurred at a turned-down end, 46 occurred at other known points of the rail, nine occurred at undetermined points on the rail, and 13 were non-guardrail collisions. The resulting data were analyzed using standard crash report variables.

While the analysis of the data in this study is very thorough, the author is careful to mention possible uncertainties in the data collection method: (1) Determination of guardrail/non-guardrail collisions and other classifications was based largely on the narratives contained within the police reports. The author pointed out that the narratives in many cases were vague, so collision classification was subject to misinterpretation. (2) Data collection in this study was retroactive in nature. Report findings were based on interpretations of the reporting officers at the site as recorded in the police report. (3) Unreported collisions were ignored. The author hypothesized this would create a lopsided view of the end-hit to not-end-hit ratio because of the presumed higher rate of collision severity associated with end terminals.

North Carolina, 1993—Across-Median Collisions (*18*)

In 1993, Lynch, Crowe, and Rosendahl prepared a report on a collision study involving across-median collisions in the state of North Carolina. The objectives of the study were to

- Use collision histories to identify interstate locations that had an unusually high number of across-median collisions;
- Determine what safety improvements could be made;
- Develop a priority listing of the high incident locations; and
- Develop a model that will help identify potentially dangerous locations on North Carolina Interstates based on relevant variables such as median width, traffic volume, and other geometric and operational characteristics.

Data for the study were collected from police reports on file for the period of April 1, 1988, through October 31, 1991. During this period, the North Carolina reporting form did not indicate median involvement. Collisions involving medians were, therefore, identified as follows:

3,121 collisions listing “run off the road left,” “head on,” “sideswipe opposite direction,” “hit fixed object,” or “hit other object” as the first harmful event were extracted from all the collisions during the study period. These collisions were then more thoroughly examined. Construction zone collisions, reports of vehicles entering the median and recovering without incident, and non-reportable collisions (no personal injury and less than $500 property damage) were eliminated from the data. This resulted in 2,922 collisions that were eligible for the study.

Reports for the 2,922 collisions were copied and sent to the NC DOT Area Traffic Engineers. Each collision and location was investigated. Roadway characteristics and conditions for each location were collected using standard data collection forms developed by the researchers. The resulting data were entered into a computer database. The researchers then screened the data and extracted cases where a vehicle crossed a median and encroached on oncoming traffic. The final number of collisions used in the study was 751.

Seventy-one of the 751 across-median collisions resulted in at least one fatality. This represents 32.2 percent of all fatalities occurring on North Carolina interstates. Twenty-four high-collision locations were identified for potential installation of median barriers. A B/C analysis was used to rank the sites. The study was very concise and well organized. The use of computer forms to standardize the data collected was an excellent addition to the study. The use of area engineers to determine site characteristics illustrates the importance of site visits for in-service evaluations. Without the site data, it would have been difficult to make useful conclusions about potentially high-accident locations.

Oklahoma, 1993—Guardrail End Treatments (*19*)

In 1993, Gattis, Varghese, and Toothaker published a paper in *Transportation Research Record 1419* describing an evaluation performed on exposed, turned-down, and flared-end treatments in the state of Oklahoma. The purpose of the 3-year study was to determine whether there were differences among the three devices based on vehicle vaulting, vehicle overturning, and accidental death or injury.

Data for the study were collected from police collision records on interstate, U.S., and state highways; accident reports; and video logs of the collision sites. In the case of the video logs, it was assumed that the collision site had not changed since the time of the collision (e.g., repairs were performed on a replacement in-kind basis). Collisions were classified as approach or trailing end and by whether the collision was a presumed end hit, presumed-but-questionable end hit, or not an end hit based on the description in the police report. For the purposes of the study, only presumed and presumed-but-questionable end hits occurring at the approach end of the guardrail were used to determine the general performance of the end treatments. Because of the low number of collisions involving flared-end treatments, these collisions were eliminated from the data set.

After the collisions were classified, the significance in the difference between the different end treatments was determined based on the Games-Howell multiple comparison statistic. The statistical data indicated there was no significant difference between the exposed and turned-down ends in terms of the proportion of severe (A+K) injury collisions to the total number of collisions, or in terms of injuries from rollover/vaulting of the vehicles for the two devices.

Other observations were also noted within the report. Approximately 53 percent of the collisions occurred on the 10 percent of the roadway system with higher ADTs. The severity associated with rollover/vault collisions was significantly higher than non-rollover/vault incidents.

This article provides valuable insight into the correlation of collision severity with the performance of the vehicle during a collision. It also shows that a majority of collisions can occur on a limited segment of high-volume roads and compares the vaulting/rolling incidences between the exposed and turned-down end treatments. However, changes in data collection and comparison could have greatly enhanced the quality of the study. Spearing incidences should have also been considered due to the inclusion of the exposed end treatments in the study. This was the original reason for the development of the turned-down end and therefore should not be absent from the study. Data should have been collected in a way to allow on-site investigations of the sites. As stated in the report, the video logs did not prove to be useful and in some instances lowered the quality of the data collected. It was often unclear from the video log whether a blunt end, breakaway cable terminal (BCT), or trailing anchor was involved. The conclusions, therefore, cannot be accepted with much confidence since there was so much uncertainty about the types of devices struck.

South Carolina, 1994—Brakemaster and Crash Cushion Attenuating Terminal (*20*)

In 1994, the South Carolina DOT prepared a report describing an evaluation of the Brakemaster and crash cushion attenuating terminal (CAT) used in the state. The purpose of this study was to examine the effectiveness of using these systems to protect median bridge piers.

This study was more of a pre-evaluation of the CAT and Brakemaster systems since no actual collisions involving the CAT or Brakemaster were documented. Instead, collisions involving median guardrails were analyzed over a 2-year period. Fatalities, incapacitating injuries and property damage collisions were assigned societal costs based on the 1992 National Safety Council Formula (*21*). These costs were compared with the average installation costs of the CAT and Brakemaster during the same time period with the presumption that the injuries would have been prevented if these devices had been used at the site.

In addition to the comparison described above, a review of other in-service evaluations involving the CAT and Brakemaster was performed in order to evaluate how the CAT and Brakemaster were used in other states.

COLLISION STUDIES

In a collision study, police and maintenance records are collected concurrently with the study period. This type of evaluation does not include investigation of collision sites.

Connecticut, 1977—Tire-Sand Inertial Barrier System (*22*)

In 1977, Button described an in-service evaluation of the tire-sand inertial barrier system in the state of Connecticut. Two sites were used for the 2-year evaluation to obtain data concerning the performance and cost of the system.

It is unclear how the data for this study were obtained, but photographs of the systems were taken prior to and after impacts to the device. Also, photographs of one of the vehicles were taken after a collision, indicating that perhaps both the police and DOT were involved with the study. It is assumed that the cost data were obtained from maintenance records.

Four minor and two major hits were recorded on the system during the 2-year examination period. No injuries or fatalities were recorded for the six impacts. One impact caused a substantial amount of debris to be scattered on the roadway.

Cost comparisons of the system showed the initial cost of the system to be six times lower than comparable systems. The evaluation showed the average cost per collision to be the highest of the three systems used for comparison (e.g., $195 more than the Fitch Barrel system). Repair estimates were based on one impact with the system, but not all impacts would be as severe so the average repair cost may have been overstated. Cost data should have been collected for the minor and unreported collisions to the system for a fairer comparison. A B/C analysis could have been performed to provide a more precise comparison among the barrier system alternatives.

New York, 1977—Guardrail, Sign and Luminaire Supports, Impact Attenuators (*23*)

In 1977, Carlson, Allison, and Bryden reported on a collision study in the state of New York involving lightweight-post guardrail, slip-base sign posts, frangible luminaire supports, and impact attenuation devices such as sand-filled plastic barriers, water-filled cell sandwich units, water-filled cluster units, and empty steel drums. The purpose of the evaluation was to document field performance of the lightweight-post barriers at New York's newer mounting height and to investigate the field performance of the slip-base sign posts, frangible luminaire supports, and impact attenuation devices.

Data collection for the study varied by the type of device being investigated. For the light-post barriers, data were collected over a 4-year period between 1971 and 1975 for all barriers constructed between 1969 and 1971 on state roads. It was assumed that these barriers would have the newer New York standard height of 661.5 mm to the center of the rail. Data were also collected for light-post barriers on the New York State Thruway during a 6-month period in 1973. The report did not say why the data collected from the Thruway only lasted 6 months or why this area was included in the study.

At the beginning of the study, 47 selected breakaway sign supports and frangible-base luminaire supports were monitored. Few impacts occurred at these 47 sites. Therefore, the frangible-base luminaire supports and breakaway sign supports along the New York State Thruway were added to the observation. The sites along the Thruway were then monitored for the 6-month period during which the guardrails were under observation. In addition to the Thruway, a 20.12-km section of I-90 containing 392 frangible-base luminaire supports was also added to the data collection.

All impact attenuation devices on state roads were monitored during 1971–75. It is unknown how many impact attenuation devices were initially under observation, but by the end of the study, 70 devices were being monitored.

Most of the data were collected using three separate forms developed by the researchers. One form was created for guardrail, luminaire, and sign support collisions occurring on state roads; one form for these same devices on the New York State Thruway; and the third form collected collision information for impact attenuation devices. All the latter were located either on state highways, in New York City, or under the jurisdiction of the Port Authority of New York and New Jersey. All these agencies used the same form for describing collisions involving impact attenuation devices.

The two forms involving state-maintained roadways were provided to the NY-DOT Highway Maintenance Subdivision. All information except repair data was provided by the foreman assigned to the site being repaired for the guardrail, sign, and luminaire support collisions occurring on state roads. The repair data, (e.g., amount of device reused, cost data, etc.) for these devices were provided by the Resident Maintenance Engineer. For collisions involving impact attenuation devices occurring on state roads, the Resident Maintenance Engineer filled out the entire form. When an impact attenuation device collision occurred in New York City or in the areas maintained by the New York and New Jersey Port Authorities, the same form was used but filled in by different personnel within these agencies. In all cases involving guardrail, frangible-base luminaire supports, slip-base sign supports, and impact attenuation devices, an attempt was made to obtain a police accident report for the crash being investigated. This information, once collected, was then forwarded to the NY-DOT Engineering and Research Development Bureau.

The form for collisions occurring on the New York State Thruway was handled by the Thruway Authority's Traffic and Safety Engineer. A form was given to the state police officer reporting the collision, who filled in information about the type of barrier hit, the actions of the vehicle, etc., attached a copy of the police accident report, and forwarded this information to the Traffic and Safety Engineer. A form was also given to the maintenance supervisors in charge of the repair of the damaged devices. The maintenance supervisors filled in the same areas of the form as the police officers and also provided information on the repair materials needed for the device. The Traffic and Safety Engineer provided repair cost information, which was obtained from the Bureau of Accounting. After all of the information had been compiled, the data were forwarded to the NY-DOT Engineering and Research Bureau.

Collisions involving the luminaire supports on I-90 were obtained from the utility company. This information was then used to obtain police accident reports for these impacts, if available. Cost information for these collisions was not recorded due to the nature of the utility company's records.

The performance criteria for the devices were based on the severity of injury experienced in the impact, the vehicle reaction, and the maintenance requirements needed to repair the device. It is important to note that unreported collisions were not included as a part of this study. Severity of injury was classified as none, minor, severe, or fatal. Minor injuries included cuts, scrapes, and non-specific complaints of neck or back pain. Injuries were only classified as severe if hospital admission was required.

Vehicle reaction described whether the device performed as intended. Impact attenuators should gently decelerate a vehicle to a stop or redirect the vehicle. Sign and luminaire supports should easily release without excessive deceleration. Barriers were evaluated based on whether penetration had occurred. Post-impact vehicle trajectories were also noted for all the devices.

Maintenance requirements included collision damage repairs and routine maintenance costs. Collision damage repairs included costs for equipment, materials, and labor. Routine maintenance was recorded such as winterizing the attenuators. Maintenance for the sign and luminaire supports was considered negligible and was not included in the study.

A total of 392 collisions occurred involving roadside and median barriers. Minor and severe injuries were combined for each of the barrier types. The chi-square test was used to access differences among the barrier types at the 95 percent confidence level, both in terms of severity of injury and cost of maintenance and repair. Specifically, the box beam guardrail experienced lower injury severity but higher maintenance cost than the W-beam guardrail. For the barriers, only the difference between the W-beam and box beam median barriers was statistically significant. In general, the low number of serious injuries and the complete absence of fatalities indicated good performance for the barriers.

Penetration rates were also examined for the roadside and median barriers. Although the reporting forms developed by the researchers contained three methods of penetration (over, under, or through), the collisions were classified only by whether or not penetration had occurred. Except for cable guiderail, penetration rates were relatively low. However, there were few mid-section hits for the cable guiderail. Of the 29 collisions involving all types of end sections, most impacts were unreported, indicating good performance of the barriers.

Collision damage and repair costs were examined for the barrier impacts. The length of rail damaged tended to decrease as the stiffness of the rail increased. Therefore, cable guiderail had the highest average length of barrier damaged in an impact. However, the difference in repair costs among the different rails was very minor.

Ten hits were recorded involving slip-base sign supports. Three impacts resulted in injuries with two minor and one serious. The base appeared to have performed properly in all 10 collisions. Due to the high incidence of secondary collisions associated with this device, pole repair data were combined with repair costs of other roadside features. Therefore, no cost data were available for the sign supports.

Seventy-eight collisions were recorded involving frangible-base luminaire supports. Fifty-nine of these were investigated by the police and 19 incidents were unreported. A total of 15 incidents resulted in injury with 12 minor and 3 severe injuries. Eleven of the 15 injury collisions involved secondary collisions. The base also failed to release in a few instances. However, this was attributed to the low-impact speeds of the vehicles in these cases. Few repair data were available for the same reasons as the slip-base sign posts. In those instances where repair data were available, the cost to reuse the same pole averaged $362 while the total cost to install a new one averaged $715. The utility company made the repairs on I-90 so cost data for this area were unavailable.

A total of 393 collisions involving impact attenuators were recorded during the evaluation period (1971–76). The 35 sand barrel installations were impacted 242 times, the 21 Hi-Dro cell sandwich installations were impacted 63 times, 84 impacts occurred at the 11 water-filled cluster installations, and four impacts were recorded at the three steel barrel installations.

Four of the impacts with sand barrels resulted in injuries (three minor and one severe). Four impacts with the Hi-Dro sandwich units resulted in injury (three severe and one fatal). The fatality in this case was attributed to an older Hi-Dro design and poor installation practices at that location. Fifteen impacts with the water-filled clusters resulted in injury (14 minor and one severe). No injuries were recorded at the empty steel drum sites.

Maintenance costs were also considered for the attenuators. Attenuators repair costs ranged from $18 to $2,718. In general, the Hi-Dro cell sandwich units were the least expensive to repair, while the sand barrel systems were the most expensive to maintain.

The study provides extensive information about the devices under observation. The following modifications to the study would have enabled the information to be presented in a more concise manner:

- Narrowing the data collection to one area would have reduced the coordination required to obtain data from the different agencies. The inclusion of the I-90 data effectively eliminated repair data for all the luminaire supports and increased the number of agencies involved (i.e., the utility company).
- A uniform data collection period is needed for the devices being studied. The inclusion of the Thruway may have improved the data if the data collection period had been the same as the rest of the areas. The short data collection period of this area did not take into account variances in weather, change in vehicle fleet, etc.
- An explanation of why the Thruway was incorporated into the study would have been helpful. It is unclear why this area was included in the study. The short collection period of this area made the data obtained irrelevant.

Kentucky, 1984—Breakaway Cable Terminal and Median BCT (*24*)

In 1984, Pigman, Agent, and Creasey reported on the in-service performance evaluation of the breakaway cable terminals (BCTs) and median breakaway cable terminals (MBCTs) in Kentucky. Kentucky began using the BCT and MBCT in 1974. When the study was performed in 1983, there were 3,633 BCTs installed on Kentucky roadways with an average installation cost of $515. In addition to the BCTs, there were 573 MBCT installations with an average installation cost of $627. The purpose of the in-service evaluation was to determine if the BCT and MBCT were performing as expected in real-world collisions.

The number and location of BCT and MBCT collisions in 1980–1982 were identified using Kentucky's crash-reporting system. An inventory of BCT and MBCT installations was apparently developed using the accident database. This inventory was used to select routes that had a history of BCT and MBCT collisions. The study team then contacted maintenance engineers in the districts containing the selected routes (Kentucky DOT Districts 5, 6, and 7) and established a notification procedure. Whenever the maintenance engineer became aware of a collision involving a BCT or MBCT, the study team was contacted. The report is unclear whether the data collection was performed by the study team or whether the data were collected by the maintenance staff and forwarded to the study team. The study team also obtained information from the district operations managers on prior (i.e., before 1984) BCT and MBCT collisions. This involved searching the maintenance files for police reports, repair reports, and photographs of damaged installations.

The study group also collected some data serendipitously. When they observed damaged BCT or MBCT installations while driving around the state, the research team took photographs and searched the police crash reports for a case that matched the location. In some instances they were able to match the damaged BCT or MBCT to a police report, while in other cases no record of a collision at that location could be found. In general, it appears most of the data were collected "after the fact" by searching through DOT maintenance records.

Data collected were of three types: police crash reports, maintenance reports, and photographs. The police reports seemed to provide the most detailed information. It is unclear what specific information was contained within the maintenance reports although the authors reported repair costs ranging from $730 to $920. Interestingly, there were many cases where barrier repair cost exceeded the average initial cost of the barrier installation. This suggests that the repair cost may include guardrail repairs outside the terminal area. Photographic data were also limited. Generally, no photographs of collisions were found in maintenance files and repairs were often made before a study team member could photograph the damaged installations.

Fifty BCT and 19 MBCT collisions were identified using this procedure. Of the 69 total collisions, police crash reports were obtained in 50 cases, repair forms in 33 cases, and photographs in 33 cases. A complete set of data (i.e., police report, maintenance report, and photographs) was found for only six of the 69 collisions.

The purpose of the study was to assess performance of the BCT and MBCT barriers. To do this, the study team constructed criteria for defining proper performance. Proper performance was defined by whether the first breakaway post failed and no spearing of the vehicle occurred. Using these criteria, the performance was judged to be "proper" in 75 percent of the BCT cases and in 50 percent of the MBCT cases. Seventy-six percent of the BCT cases and 75 percent of the MBCT cases resulted in a serious or fatal occupant injury. It is interesting that in many cases where the barrier performance was classified as "proper," the collision was classified as "severe."

While the Kentucky study helps provide some much-needed information about BCT and MBCT collisions, the sampling technique and type of data collected limit the information that can be extracted from the data. For example

- The data sampling method was not rigorous. It is not clear how thoroughly or systematically maintenance records were searched.
- Cases were collected sporadically from different years, some as early as 1977 and some as late as 1983. If the study team came across a BCT or MBCT collision they included it regardless of when or where the collision occurred. Adding serendipitous information polluted the statistical validity of the data set.
- The inventory was based on collision data, so there was no real assessment of how many devices were actually covered by the study, and no systematic method to check the accuracy of the "collision-based" inventory.
- No attempt was made to assess whether the BCT or MBCT was installed or located consistent with the Kentucky State Standards. Several cases were noted where no BCT flare or an incorrect offset occurred and it seems likely that many other subtle installation deficiencies were present but not recorded. Without knowing which devices were correctly installed and which were not, it is difficult to compare the performance of the BCT specified in the state's standards.

Since the data sampling technique was not systematic, the percentages of "properly" and "improperly" performing devices and the percentages of "severe" and "un-severe" collisions were not reliable.

North Carolina, 1988—Self-Restoring Barrier Rail (*25*)

In 1988, Strong prepared a report describing an in-service evaluation of the self-restoring barrier rail (SERB) in the state of North Carolina. The project was initiated as a part of FHWA's Demonstration Project Number 64, "Traffic Barrier Systems." The purpose of the project was to evaluate the SERB under real-world conditions.

It is unclear how the data were collected for the project, but it is assumed the collision data relied solely on police and maintenance-reported incidents. Maintenance personnel were interviewed to determine how the device was installed and to estimate the expenses required to repair the device during its 2-year evaluation period.

Field investigations were made of the site before and after the installation of the SERB. Collision data were collected from the period of January 1977 to June 1988. During the period prior to the SERB's installation, eight reported collisions occurred at this location. During the study, three collisions were reported and numerous unreported collisions were noted from the field investigation performed at the close of the project.

Repair costs from the previous device were noted for comparison with the SERB's repair costs. However, upon interviewing the maintenance engineer, it was found that minimal repairs were needed to the SERB. The field inspection later revealed an impact which damaged the SERB to the point of repair, possibly from an unreported incident.

Strong's report on the evaluation of the SERB in the state of North Carolina was relevant and informative. This study, coupled with other studies involving the device, gives valuable insight into the utilization of the SERB in real-life applications. However, this study alone could have been more comprehensive with a few inclusions and changes to the evaluation:

- The only field evaluation, which was performed at the end of the evaluation period, revealed evidence of numerous unreported incidents. Periodic site investigations could have produced a more accurate picture of the total number of impacts with the device during the study.
- More SERBs could have been installed and evaluated at different sites to increase the number of impacts and more accurately determine the SERB's performance under in-service conditions.
- No indication was given of the condition of the occupants of the vehicle in the impacts with the SERB. Types and severity of injuries incurred can be indicators of the performance of the device being evaluated.

The inclusion of these suggestions could have altered the data in the study and given broader insight into the field performance of the self-restoring barrier rail.

Colorado, 1989—IBC Mark VII Barrier System (*26*)

In 1989, Woodham prepared a report describing an in-service evaluation performed on the IBC Mark VII barrier system in the state of Colorado. The purpose of this evaluation was to determine the performance of the barrier under field conditions and evaluate the costs associated with the use of the barrier.

Data for this study were collected from police crash reports and maintenance records. Sample police reports were included in the final report, along with a breakdown of the costs incurred from the use of the barrier during the 3-year evaluation period.

Nine known collisions occurred with the barrier during this time period, two of which required repairs to the barrier. Costs to repair the barrier in these two instances proved to be relatively high compared to the New Jersey concrete safety shape. In addition, the initial costs to install the barrier were twice that of the pre-cast concrete barriers.

North Carolina, 1989—GREAT (*27*)

In 1989, Stanley and Strong reported on an evaluation of the in-service performance of the GREAT system in North Carolina. The purpose of the study was to determine the performance of the device in field situations and the cost-effectiveness of the device from an initial cost, maintenance, and repair standpoint. The performance of the GREAT system was then to be compared to other devices used within the state.

Collision data for the study came mainly from police crash reports. The maintenance personnel were interviewed to determine the number of unreported incidents and the costs associated with installation, maintenance, and repair of the devices. The results of these interviews were summarized on a one-page report sheet.

Nineteen collisions occurred with GREATs during the October 1984 to early 1989 evaluation period. Although the GREAT system comprised 80 percent of the installed devices used in the state and in the study, no reported impacts occurred with the device. Instead, most impacts occurred with one of the devices intended to be compared to the GREAT system. One unreported impact did occur with the GREAT system, and it performed satisfactorily. Due to this unexpected result, the report then focused on the performance of the device most often struck (15 hits in all), the Hi-Dro Sandwich system.

Arizona, 1990—TREND and SENTRE (*28*)

In 1990, Lattin reported the results of an in-service evaluation of the TRansition END treatment (TREND) and the Safety barrier ENd TREatment (SENTRE) in Arizona. When the evaluation began, only two terminal designs were specified by the Arizona DOT (AZ-DOT). These were the standard BCT and Arizona's standard attenuator assembly. At the time of their installation, the SENTRE and TREND systems were classified as experimental under the old FHWA classification system. The purpose of the project was to determine the in-service performance of these two systems.

Only one site was used for each of the two systems. At both sites, attenuators were installed on both the upstream and the downstream ends of a bridge. Therefore, there were four installations of each barrier for a total of eight.

Prior to the installation of the systems, each site was investigated for previous collision history using information from the AZ-DOT Traffic Studies Branch. Collision totals were obtained from the period of 1973-88. For the TREND site, there were three collisions during this period. For the SENTRE installation site, 55 collisions were reported.

When Lattin's report was prepared, there had been only four collisions at the sites. These collisions all involved heavy construction vehicles from surrounding projects and the author did not feel these events were typical for what the attenuators would normally experience. No conclusions could be made about the in-service performance of either system in more typical situations.

Installation costs were totaled and compared with the AZ-DOT's estimates for other systems such as the BCT and the standard AZ-DOT attenuator. A BCT (including guardrail) at one site was estimated at $4,019. The cost for an AZ-DOT attenuator was estimated at $3,558. These costs were significantly lower than the installation costs of the SENTRE and TREND at $7,421 and $8,600 respectively. However, it was reported that the performance of the standard barriers was not equivalent to the SENTRE and TREND systems, making direct cost comparisons questionable. It was suggested that a system of weighting factors be assigned to each design objective to differentiate the importance of each in the cost comparison and the overall evaluation of the systems.

This evaluation does a good job of including site-specific concerns in cost comparison. Sites with a higher incidence of impacts should have been chosen for an in-service evaluation. In this case, the TREND site had experienced only three collisions in a 15-year period. It was highly probable that no impacts would occur with this system during the 2-year evaluation period; therefore, no concrete conclusions could be made about this system based on this study.

Site selection in this study seems to have negatively affected the ability to collect data. For the purposes of an in-service evaluation, a site with a high likelihood of impacts should be selected. More impacts would therefore most likely occur and reasonable estimates could be made regarding the performance and maintenance costs of the systems.

Iowa, 1990—IBC Mark VII Median Barrier (*29*)

In 1990, Marks described an in-service evaluation of the International Barrier Corporation's Mark VII median barrier (IBC Mark VII) in Iowa. The purpose of the evaluation was to determine the cost and performance of the barrier in the field and compare them with those of the New Jersey concrete safety shape.

Data collection methods were not documented in the report other than the mention of an annual field inspection. It is assumed from the contents of the report, however, that maintenance personnel were interviewed during the course of the study. Data from only one site were used for the study.

During the 4-year evaluation of the barrier, no severe impacts occurred. Upon performing the yearly inspection of the barrier, evidence of four minor impacts where the barrier was scraped or dented were found. Due to the minor nature of the impacts encountered during the evaluation period, no maintenance was necessary during the study. The relatively high initial cost of the barrier was noted, however.

This study presents important information pertaining to the installation of the IBC Mark VII and its performance with minor impacts. Due to the limited number of impacts experienced and the relatively long evaluation period performed in this case, there is evidence that the study methodology could have been improved: (1) No indication of a preliminary study for site selection was given in the report. A more suitable site, with a higher impact probability, should have been used if available. (2) If economically possible, more sites with high-impact probabilities could have also been used to help increase the chances of more severe impacts with the barrier. These types of impacts would provide more insight into the performance of the barrier and give some indication of the repair costs associated with the use of the IBC Mark VII.

Alaska, 1991—Side Slopes (*30*)

In 1991, Botha described a study performed to determine cost-effective side-slope safety countermeasures for Alaska's highways. The purpose of the study was to determine the relationship between slope steepness, embankment height, and other factors relevant to side-slope design and collision severity.

Data collection utilized existing police-reported collision data. Initially, collisions were examined for the years 1985 and 1986 and restricted to roads in northern Alaska. Later, more funds became available and the data collection period and area were expanded. This new data included the initial region along with data from the Parks Highway in central Alaska for the years 1984 to 1987.

The objective of the collision search was to identify collisions in which a side slope had been involved. This task used the Alaska DOT computerized police crash database. Initially, very broad categories were used to narrow the number of collisions to 1,077 records. Records were then extracted based on whether a guardrail was present, the vehicle hit a fixed object, damage occurred prior to the vehicle leaving the roadway, the collision occurred at an intersection, and other vehicles were involved. After this process, 538 sites remained for further investigation. Each of these sites was investigated to determine the height and slope of the side slope involved in the collision. During the course of this process, some sites were eliminated due to the presence of guardrail and other objects. A total of 330 sites was left for analysis.

The data were used to perform a site cost analysis to determine if a correlation existed between the cost of a collision and the side slope. Collision cost was determined by injury severity. These costs were analyzed using an extensive procedure described in the literature, and a correlation coefficient was determined to relate side slope to cost of collision (i.e., collision severity). A correlation coefficient of 0.33 was obtained from the data. However, in some instances, a negative correlation coefficient was determined, indicating that the cost of the collision decreased as the slope associated with it increased. These results were attributed to the high cost associated with fatalities (700 times greater than property damage only [PDO] collisions). Despite this, the correlation between side slope and collision cost or severity was determined to be relatively low. Further studies were recommended to develop a more reliable relationship between side slope and collision severity.

Indiana, 1992—Vehicle Attenuating Terminal and Crash-Cushion Attenuating Terminal (*31*)

In 1992, Gendron prepared a report on the in-service evaluation of the vehicle attenuating terminal (VAT) and the crash-cushion attenuating terminal (CAT) in the state of Indiana. In 1988, it had been decided that the VAT was to be used and evaluated in the state. To create a reliable sample base, a large number of VATs were installed within Indiana. Later, when the CATs were installed within the state, they were added to the study. The purpose of the study was to collect data on the ease and cost of installation, maintenance, and repair and collision performance.

Data collection for the study was obtained primarily from on-site investigators, although it is assumed some communication with local law enforcement agencies occurred because information typically provided on police crash reports was included in the data. In addition to the reports by the site investigators, photographs were also taken.

During the 3-year study period, 21 impacts were investigated and reported. Some of the collision summaries in the report were incomplete because of removal of evidence prior to the investigator's arrival on the scene.

The report includes many field problems experienced with the installation of the CAT and VAT such as splicing difficulties between the 10-gauge and 12-gauge guardrail sections. The report also mentions possible problems with the design that were associated with the one fatal collision in the study. In addition, collision summaries included detailed installation discrepancies experienced in the impacted devices.

New York, 1992—Light-Post Barriers (*32*)

In 1992, Hiss and Bryden reported on a collision study of light-post barriers in the state of New York. The purpose of this investigation was to perform an evaluation of these devices and to relate collision severity to mounting height of the barriers.

Data for this study were collected over a 1-year period from July 1, 1982, to June 30, 1983. Accident reports were the primary data source. On-site investigations were used to determine highway and barrier characteristics at the impact sites. Unfortunately, these measurements were typically made 1 to 2 years after the impact and repair of the barrier so it is questionable whether the measurements reflected the state of the system at the time of the collision. A total of 1,726 collisions involving light-post barriers were identified during the evaluation period.

Six types of barriers were examined in the study. Cable, W-beam, and box beam guardrails were investigated along with cable, W-beam, and box beam median barriers. These devices were rated according to occupant injuries, post-impact vehicle trajectory, and secondary collisions. These factors were then subdivided based on barrier height.

The box beam guardrail experienced 623 collisions and the median barrier experienced 308 impacts that were investigated in the evaluation. Collision severity did not vary significantly over the range of the barrier heights (i.e., 533 to 838 mm). Containment of the vehicles for the box beam system was high with a containment percentage exceeding 90 percent in nearly all the height categories. This device also performed similarly for a number of secondary events with a 4.3 percent overturn rate and a 16.7 percent fixed-object hit rate. Similar observations were made for the box beam median barrier.

Weak-post W-beam barriers were also evaluated based on 306 guardrail and 46 median barrier collisions occurring during the study period. Injury rates increased when the height of the barrier was below 762 mm. Redirection rates were high for barrier heights above 584.2 mm. The chance of a secondary event occurring was higher when the barrier height was below 685.8 mm. The relatively small sample size for the weak-post W-beam median barriers prevented the researchers from properly evaluating the performance of this device.

Based on the 427 cable guardrail and 16 median barrier collisions, it was determined that injury rates were relatively unaffected by barrier heights over 588 mm. Vehicle trajectory and the incidences of secondary collisions were lowest in the 588 to 710.5 mm height range. However, when the barrier height exceeded 710.5 mm, an increase of adverse vehicle trajectories was noted. The relatively small sample size for the cable median barriers prevented the researchers from evaluating the performance of this device. A recommendation was made to set the standard center of weak-post barrier rail heights to 588 mm based on the results of this evaluation.

Colorado, 1993—Brakemaster, CAT, and 10-gauge Guardrail (*33*)

In 1993, Outcalt reported on an in-service evaluation of the Brakemaster, crash cushion attenuating terminal (CAT), and 10-gauge guardrail systems. The objectives of the study were to evaluate the devices under field conditions and to determine the installation, maintenance, and repair costs associated with the use of the devices.

Data collection for the Brakemaster and CAT systems involved communication with maintenance personnel. Also, because of the descriptive nature of the collisions mentioned in the report, it is assumed that police reports were used in the study. For the 10-gauge guardrail evaluation, only data from the maintenance forces were used to determine the guardrail performance.

During the course of the evaluation, three impacts were recorded involving the Brakemaster systems. One injury and no fatalities resulted from the impacts, and one vehicle was able to drive away after colliding with the terminal. In addition to these collisions, one instance was documented where a Brakemaster was damaged from an impact with a boulder.

Only one site was used for the evaluation of the CAT. No collisions were documented during the 2-year evaluation period.

Two types of 10-gauge guardrail, galvanized and corrosion resistant railing, were examined in the evaluation. Corrosion resistant rail is used in Colorado for its aesthetic appearance. The main objective of the 10-gauge rail evaluation was to determine if the use of the thicker railing would be advantageous at sites that frequently need repair. Based on the interviews with maintenance personnel, the railing is as easy to work with as 12-gauge rails and does not require as much maintenance as the thinner 12-gauge railing.

Michigan, 1994—Breakaway Cable Terminal (*34*)

In 1994, Morena and Schroeder reported the results of an in-service evaluation on breakaway cable terminals (BCTs) in the state of Michigan. Since the late 1970s, the BCT had been the standard guardrail end treatment in Michigan. When the study began, there were over 14,000 BCTs in the state. At the time of the BCT's acceptance as a standard in Michigan (i.e., 1970s), the BCT's poor performance with the 820 kg test vehicle was considered moot since a more suitable end treatment was not available. By the early 1980s, however, more expensive end-treatment alternatives had been developed that provided better performance. The purpose of this study was to examine the in-service performance of BCTs in Michigan and to provide a basis for a subsequent cost-versus-performance comparison.

Data were collected during calendar years 1984–86 and 1988–90. The first data collection period relied initially on information obtained from maintenance records. The study group then developed a one-page reporting form for maintenance personnel to fill out each time a BCT was repaired. The forms were collected and cross-referenced with matching police crash records. During the matching phase of this process, additional collisions involving BCTs were discovered in the police crash reports and added to the data.

Most of the data came from police crash records. The maintenance reports appear to have been used primarily in the first data collection period to gather information regarding installation procedures and costs. Installation details were not checked in the second data set, and it is uncertain whether any maintenance records were used as data sources in the second phase of the study. It is also difficult to ascertain what information was available from the accident reports and maintenance forms because no sample forms were included in the final project report. No site visits were made during the course of this study.

Fifty collisions were observed in the 1984–86 period and 83 were observed in the 1988–90 period. Of the 50 collisions in the 1984-86 data set, 24 were matched to police accident reports. A majority of these collisions (42) happened on freeways while the remaining occurred on non-freeways zoned for 55 mph. All 83 impact events in the 1988–90 data occurred on two segments of interstate highways. These two segments were upgraded to BCTs in the mid-and late-1980s so the guardrail terminals better reflected then-current MI-DOT policy.

Once a collision was identified, five steps were required to collect the data:

1. The end treatment struck was first verified from MDOT's inventory.
2. Verification of an end hit was made based upon the description in the accident report.
3. Collisions where a secondary hit was involved were eliminated.
4. Car size was determined along with vehicle impact point, spin prior to, and roll after the impact.
5. The degree of injury and seat-belt usage were determined.

A higher percentage of drivers were injured (60 percent) in the 1984–86 data than in the 1988–90 data (35 percent). Changes in the vehicle fleet, seat-belt usage, number of nonfreeway collisions, and improved BCT design and installation were identified as possible reasons for the improved performance observed in the 1988–90 data. Examination of 1984–1990 general collision data showed similar trends during this time period.

The reduction in driver injury and fatality percentages between the two data sets may have been due to passage of a mandatory seat-belt law in 1985, and improved BCT design and construction techniques. The authors used these factors to justify elimination of the first data set; therefore, the study's findings and conclusions were based primarily on belted drivers impacting BCTs between 1988 and 1990 (i.e., the second data set). The first data set was used, however, to explore the advantage of the flared BCT over an earlier tangent design. Based on the data, occupants impacting a tangent BCT design were two to three times more likely to be injured than those impacting a flared design.

Further examination showed the percentage of occupants involved in a collision and reported wearing seat-belts was much higher (nearly 3 to 2) than known percentages in the overall vehicle fleet. Fines for not wearing safety belts may have caused occupants to report having seat-belts engaged during a collision when, in fact, they were not. The study group thus concluded that the belt-use data may have been contaminated.

The study team compared driver injury to BCT impact, type of vehicle, point of impact, right/left side placement of the guardrail, and spin/roll of the vehicle. The following conclusions were made based on the results of these comparisons:

1. Vehicles impacting a BCT were more likely to result in passenger injury than vehicles impacting a guardrail (8 : 5),
2. BCT performance improves as vehicle weight increases, especially for vehicles greater than 1,020 kg,
3. Left-side impacts with BCTs are more likely to result in driver injury than impacts involving other regions of the vehicle,
4. Vehicles spinning prior to impacting a BCT did not have a higher risk of driver injury,
5. Ten collisions were observed where the vehicle rolled over after an impact,
6. 67 percent of drivers purportedly wearing safety belts still received moderate to severe injuries, and

7. Impacts involving BCTs located on the right side of the road resulted in more moderate or severe injuries (27 percent) than those located on the left side (7 percent). It was hypothesized that better grading in the median areas resulted in more consistent application of flared BCTs than on the shoulder.

New Hampshire, 1994—Modified Eccentric Loader Terminal (*35*)

In 1994, McDevitt summarized an evaluation of the Modified Eccentric Loader Terminal (MELT) in the state of New Hampshire. The MELT was used to replace the outdated turned-down ends used prior to this study. The degree to which the various agencies were involved in the report was not specified. However, it is known that on-site photographs were taken and police accident reports were collected. Maintenance personnel were also used in the study, although it is not known how.

The period of the data collection was not specified in the report, although the report includes police crash reports from 1991 to 1993, a 3-year time span. During this time, approximately 25 collisions occurred involving the MELT. No fatalities or major injuries were reported in any of the documented collisions. In addition, no spearing, vaulting, or other negative vehicle behavior was reported.

Most of the MELT units which were struck during this period went unreported because the impacts were minor. Consequently, valid cost information for the repair of the terminals was unavailable. However, it was reported that the cost of a new MELT was $1,200. This was considerably less than the other terminals such as the ET-2000, SENTRE, and the Brakemaster under consideration by New Hampshire for replacement of the turned-down ends.

Problems occurred with the device when snow plows hit the terminal, knocking the rail off the shelf clip. To remedy this problem, more shelf clips were added to the device. More careful construction of the device was also recommended.

IN-SERVICE EVALUATIONS

In this report, an "in-service evaluation" includes examination of the collision sites shortly after a collision occurs. These studies also usually use police crash records and maintenance records as data sources.

Connecticut, 1977—Frangible-Tube Bridge Barrier System (*36*)

In 1977, Lane reported on an evaluation of the Frangible-Tube Bridge Barrier System used in the state of Connecticut. This system was based on an idea originating from NASA and applied to the area of roadside safety. The purpose of the 2.5-year evaluation was to observe the construction and monitor the performance of the barrier system.

Data were collected for a 3-year period prior to the system's installation (i.e., September 1971 to September 1974) to provide the basis for a before-after study. These data were obtained from the state's police department and the traffic engineering services section within the state. Although not directly stated, it is assumed no effort was made to determine the number of unreported collisions during this period.

Data were collected from multiple sources. Reported collisions were obtained from police data. Field inspections were performed at regular intervals to help determine the number of unreported collisions. The effects of winter maintenance, the change in skid numbers for the period, and initial installation and repair costs for the system were also noted.

Data for the evaluation of the frangible tube system were collected over a period of 2.5 years from July 1974 to February 1977. All data obtained for the study were acquired from one site. During this period, nine collisions involving ten vehicles were documented. Two of the vehicles were driven away, two minor injuries were reported, and a drop in the total number of reported collisions for this site was noted, even though the AADT increased during this period.

New York, 1977—Guardrail Systems (*4*)

In 1977, Van Zweden and Bryden reported on an in-service evaluation of the light and heavy-post guardrail systems used in the state of New York. The heavy post barriers consisted mainly of W-beam guardrail while the light-post barriers included cable, W-beam, and box beam systems. The purpose of the study was to determine the performance of the then newer light-post and older heavy-post barriers based on actual collision experience in New York. The secondary objective of the evaluation was to expose problems associated with the field use of the light-post barriers.

Data were collected over a 2-year period for each of the barrier systems but was not concurrent. Collisions on the entire state highway system, which involved all barrier types, were evaluated during the period of 1967–69. Data on median barrier collisions on the New York State Thruway were also collected during the same period. Collision data along the Taconic State Parkway were collected for a period between September 1968 and December 1970.

Multiple data sources were used for this study. Maintenance foremen completed a "barrier accident reporting form" for all barrier collisions occurring on state highways and the Taconic State Parkway during the study periods, which included basic data such as barrier type, length of rail damage, and rail penetration. They also provided information on repair costs. Police officers investigating collisions on the Taconic State Parkway were asked to fill out a one-page supplemental form in addition to the usual collision report.

Occupant injury was used as the primary means of characterizing the barrier performance. Collisions were classified based on the most severe injury occurring within the event. Initially, injuries were classified into the five categories of fatal, hospitalization required, minor, none, and unknown. As the study progressed, however, the researchers noted that many injuries were being classified as unknown, which suggested more minor injuries. The classification was revised into three categories where "minor," "none," and "unknown" were combined into "other."

Vehicle characteristics and behavior were also used to evaluate the performance of a particular system. Vehicles were classified by whether they penetrated the barrier, where the impact occurred on the system (within 15.2 m of end or in the middle), and the weight of the vehicle. The weight classification was intended to differentiate passenger car impacts from truck and service vehicle impacts.

The barrier type was also recorded. In reviewing standards for the heavy-post barriers, the researchers discovered that a minimum of 22 different combinations of rails, posts, and blockouts were used. Therefore, the heavy-post barriers were classified only by the rail type used and the placement of the barrier (i.e., normal or median). Most of these types of heavy-post barriers are now considered obsolete.

Three types of data were collected to determine the maintenance performance of the barriers: the number of posts reset and replaced, rail length re-erected or replaced, and the length of barrier damaged per collision. Additionally, repair costs for some collisions were also recorded to determine average repair costs for each barrier type.

Additional factors affecting barrier performance like the impact angle of the vehicle, braking prior to impact, vehicle type, and roadway geometry were also considered. Due to the difficulty in coding these items, however, they were excluded from the data collection.

During the 2-year collection period, 4,213 collisions involving guardrails were reported, including 717 light-post crashes and 3,496 heavy-post impacts. Comparisons were made between the various barrier types and differences between barrier types were analyzed using the Chi-square contingency test. Specific results are beyond the scope of this synopsis; however, general results are as follows:

- Fatality and serious injury rates were lower for light-post barriers, but rates for median barriers of both types were nearly identical.
- End-section impacts resulted in higher injury rates than mid-section impacts.
- In general, light-post barriers were penetrated less frequently than the heavy-post barriers. There was also a positive correlation between penetration and the severity of a collision.
- Field investigations made during the course of the study showed that the low mounting height of the light-post barriers could have contributed to vehicle penetration.

The New York study was very thorough and well organized, especially considering its early date, 1977. A large sample and statistical analysis helped provide a degree of confidence in the results. A few more minor revisions to the methods of the data collection could have improved the evaluation:

- Data for the different barrier types should have been collected concurrently. This would not have been as important if the types of barriers being examined were thoroughly mixed within the study areas. However, since the Taconic Parkway study involved primarily the box-beam median barrier, comparisons with other systems may not be valid due to unconsidered factors that change over time.
- Comparisons between the systems may also not be valid due to differences in installation details and location. The light-post barriers were generally installed on newer roadways while the heavy-post systems were normally installed on older highways and involved a variety of obsolete designs. Care should be taken to ensure valid comparisons are made between different types of barriers installed at different locations.

Connecticut, 1980—Connecticut Crash Cushion (*37*)

In 1980, Carney and Larson reported on an in-service investigation of the Connecticut Crash Cushion truck-mounted attenuator in the state of Connecticut. This portable device is mounted on the rear of vehicles protecting minor maintenance activities. Prior to 1977, Hydrocell units served this purpose, but they were heavy and did not perform adequately in field tests. The purpose of the evaluation was to investigate the ease of installation, removal, and replacement; the cost of construction and repair; and the level of acceptance by the maintenance personnel.

At the onset of the 3-year study, three devices were in use, increasing to eight by the end of the evaluation. All existing devices were observed for impacts during the course of the evaluation.

Data for the study were mainly collected from maintenance personnel already on site when the impacts occurred. Data were also gathered from accident reports filed by the maintenance personnel after the impacts. Photographs and schematics of the collisions were included to help illustrate device performance.

Three impacts occurred during the evaluation period. Information about the first impact was not available, so descriptions and conclusions were based on the two later collisions. No major injuries and no damage to the maintenance vehicles were reported for these impacts. The repair cost estimate for the unit in the third impact, based on 1980 data, was $1,323. The original cost of the device in 1977 was $2,000.

Indiana, 1980—Breakaway Cable Terminal (*38*)

In 1979, the state of Indiana was concerned about the effectiveness of the breakaway cable terminal (BCT) because of a large number of serious collisions involving BCTs. An in-service evaluation was performed to determine if the BCT was performing as expected. The study had three objectives:

1. Determine if the barriers were being installed properly,
2. Observe the field performance of the terminal, and
3. Identify possible design and installation procedure changes that might improve BCT performance.

Data were collected primarily by highway maintenance personnel. Once a collision location was identified, a field inspection was performed at each site, the damaged BCT was photographed, police crash reports were obtained, and police photographs of the damaged vehicles were collected. All pertinent information from these sources was then condensed into a one-page report form developed for the study. Witnesses and occupants of the vehicles were not interviewed.

This procedure initially provided 21 impacts for examination over a 1-year period. Two collisions were eliminated because they involved tractor-trailer impacts for which the BCT was not designed. Nine of the remaining 19 collisions were eliminated because the collision date was not known. Without the date, it was difficult to obtain the accident report. Photographs of 10 collisions were identified for further study. Six of the 10 collisions (60 percent) involved fatalities. Five of these fatal collisions involved the guardrail penetrating into the vehicle's passenger compartment. Based on these data, the author proposed changes to the design of the BCT including the diaphragmed end.

New Jersey, 1980—Breakaway Cable Terminal (*39*)

In 1980, Baker reported on a breakaway cable terminal (BCT) in-service evaluation in the state of New Jersey. When the BCTs were first installed there in 1976, the FHWA requested that an in-service examination of the device be performed. The New Jersey DOT performed a 2-year study of the BCTs in the state to collect field performance data for the BCT and compare these impacts with experimental crash tests.

Fifty BCT sites were initially selected for study. Organizational difficulties with this number of sites necessitated reducing the number of sites to four. The small number of collisions observed at these sites prompted the researchers to ask NJ-DOT maintenance personnel to keep track of all BCT sites in one of New Jersey's maintenance districts. Thirteen major collisions and six minor collisions were examined.

Types of data included on-site investigation of all collision sites, accident reports involving impacts on or near a BCT, and photographs of the damaged BCT and the collision site. These data were condensed to a one-page collision summary form developed specifically for this study.

While some cases exhibited performance similar to crash tests, many of the impacts involved spearing, rebounding, displaced footings, and ramping of the vehicle. The displaced footings were attributed to poor installation practice, and the rebound phenomenon was thought to be due to the corrective actions of the driver. The remaining factors, however, were attributed to site problems or poor BCT design.

The study provided useful information on the field performance of the BCT including: (1) a correlation between unflared BCTs and spearing and (2) a correlation between BCTs placed near curbs and vaulting of the vehicle. The sampling method used seems to have resulted in a bias toward more severe crashes. Different maintenance garages may have interpreted the study objectives differently resulting in an ad hoc sample. There were also many cases where incorrectly installed BCTs were observed but the data was not segregated by proper or improper installation.

Colorado, 1988—Type 3F End Treatment, Self-Restoring Barrier, and Modified Thrie Beam Guardrail (*40*)

In 1988, a report was prepared describing an in-service evaluation performed on three devices in the state of Colorado. These devices were the Colorado Type 3F end treatment, the self-restoring barrier (SERB), and the modified thrie beam guardrail. The purpose of this project was to determine the performance of the systems under operating conditions as well as noting the damage repair costs due to field impacts.

Data for this project were collected from September 1983 to January 1988. Data sources included police reports and, in the case of the SERB and Modified Thrie Beam devices, site visits. One SERB, three Modified Thrie Beam installations, and over 200 Colorado Type 3F end-treatment sites were analyzed.

Collisions were documented for all the devices in the study. Four impacts occurred with the SERB. No fatalities were recorded, and no repair was necessary for three of the impacts. Six impacts were reported at the Modified Thrie beam sites. Again, no fatalities were recorded for these collisions and the system required only minimal repair in most cases. However, there were two collisions involving the SERB and the Modified Thrie Beam guardrail where the vehicles penetrated the railing. Both incidences involved heavy vehicles for which the devices are not designed (two military transports and a semi tractor-trailer). These incidents involved occupants being ejected from the vehicles after penetration. Six impacts were documented with the Colorado Type 3F end treatments during this time. One incident involved skeletal injury to a person who was not wearing a seat-belt, and minor injuries were recorded in the rest of the cases.

Maintenance for the SERB and the Modified Thrie Beam system was, in most cases, relatively minor. However, the cost to repair the Colorado Type 3F end treatment nearly matched the initial cost of installation. Modifications were suggested for all three devices to reduce maintenance.

Connecticut, 1988—Connecticut Impact-Attenuation System (*41*)

In 1988, Lohrey prepared a report describing an in-service evaluation of the Connecticut impact-attenuation system (CIAS). The systems were first installed in Connecticut in 1984 under the joint cooperation of the Connecticut DOT (Conn-DOT) and the FHWA. The purpose of the 3-year study was to determine the field performance of the CIAS and examine the maintenance requirements and other problems associated with field use.

Although the author never explicitly states where the information for this study was obtained, police reports and maintenance personnel were apparently used as data sources. Also, judging from the included pictures of the impact events, site visits were probably performed.

This study did not quantify collision severity except to state that no major injuries were sustained to the vehicle occupants in any of the impact events. Barring this information, the report seemed to focus more on the maintenance requirements and minor problems with the design of the system.

Site visits involved measuring of system displacements and stating which cylinders needed replacement. The researchers also noted problems with the cover of the system, which is intended to keep debris and snow out of the crash cylinders. The design of the cover was not adequate to withstand the wind loading from passing heavy trucks on the freeway. The fastening system was redesigned and tested in the field.

The study also examined the maintenance requirements of the system. If the cylinders needed to be reshaped, they needed to be transported to a garage and reshaped by maintenance personnel. The study did examine on-site refurbishment possibilities, but these proved to be too time-consuming and inadequate for reassembly.

Indiana, 1988—SENTRE (*42*)

In 1988, Noureldin prepared a report describing an in-service evaluation of a SENTRE end treatment in the state of Indiana, including the methods used in the evaluation. The report also includes data collection forms from the study. The objectives of the study were to evaluate the field performance of the SENTRE system and analyze the cost effectiveness of the barrier. The 2-year study involved four agencies. The Indiana Division of Design, maintenance personnel, the Division of Research, and the contractor all inspected the sites after a collision and had input into the project.

Post-collision investigation was to include an overall performance of the barrier during the collision, the reusability of its components, the estimated cost of repair, photographs of the damage, and police reports relating to the collision.

An initial cost of the SENTRE (i.e., $5,747) was determined based on the average cost of the four systems involved in the study. This cost was much more than the possible alternatives such as the BCT (i.e., $1,200/unit) and the conventional buried end (i.e., $479/unit).

During the course of the evaluation, only one impact was observed and investigated. A police report, ambulance report, barrier report form, and cost estimate report were all obtained after the collision and used to draw the conclusions made in the study. From these reports, it was estimated that the terminal would cost $1,194 to repair or approximately 20 percent of the initial cost and, more important, the vehicle was not speared and did not overturn during the collision.

North Carolina, 1990—SENTRE (*43*)

In 1990, Stanley prepared a report describing a field evaluation of the SENTRE guardrail anchor system in the state of North Carolina. Six units were installed and observed in the study. The purpose of the project was to evaluate the vehicular impact performance of the SENTRE and determine the costs associated with repair. The units were installed during the fall of 1987, with the final two devices being completed in December of that year. Data were then collected over a 2-year period.

Data collection involved biannual site investigations and relied primarily on police crash reports. Information was also obtained from maintenance personnel regarding device and cost history, as well as interviews with police officers. The average installation cost of the devices was $5,000.

No reported collisions occurred during the course of the study. The researchers stated the sites did not have a high AADT and that many impacts were not expected. Also, it was observed from the site investigations that no hit-and-run or unreported collisions had occurred. Minor vandalism of the devices was observed, however.

Kentucky, 1991—BCT, MBCT, CAT, Brakemaster, and Turned-down End (*44, 45, 46*)

Pigman, Agent, and Creasey prepared several reports between 1991 and 1993 describing an in-service evaluation performed on the breakaway cable terminal (BCT), Kentucky’s version of the median breakaway cable terminal (MBCT), the crash cushion attenuating terminal (CAT), the Brakemaster system, and the Type 7 weakened turned-down end treatment in the state of Kentucky. The purpose of this study was to determine whether these devices were performing as designed in the field.

Data for the evaluation were obtained from police crash reports, maintenance personnel, on-site visits, and observations while traveling through the state. The data were then sorted according to the performance of the device. A device was considered “proper” if it performed as designed when impacted. Data involving impact severity, including vehicle and property damage and injury severity, were not used as criteria to judge the performance of the device. A previous study was supplemented with an additional 2 years of data for the final analysis.

A total of 5,706 sites were used for the BCT evaluation. From these sites, 232 impacts were found. Since some collisions lacked data, BCT performance was rated for only 158 of the 232 recorded collisions. These 158 collisions were then categorized by their geometry as straight, simple curve, and parabolic flare. From this investigation, it was determined that the curvature, and especially the parabolic flare, improved the performance rating of the BCT. At the time of the report there were 848 sites using the MBCT and 66 impacts involving the MBCT. The performance of the MBCT was determined in only 33 of the cases because some collisions lacked important information. Performance was judged to be proper in 64 percent of the 33 impacts. Three collisions involving the MBCT resulted in fatalities. Spearing of the vehicle occurred in two of the cases and the third resulted in a vehicle rollover. The MBCT was recommended to be redesigned or eliminated from Kentucky standards, following evaluation of the data.

The criteria used to determine "proper" CAT performance was based on the intended design of the device. This included the release of the breakaway posts during an impact event. Factors such as guardrail damage, vehicle damage, and injury severity incurred in a collision were not used as criteria to determine the performance of the device. During the 4-year evaluation period, 34 collisions involving the CAT were documented. Accident reports were available for 23 of the incidents, and repair forms obtained from maintenance forces identified the remaining 11 impacts. The performance of the CAT was judged to be "proper" in 28 of the 34 impacts. Improper performance of the CAT was attributed to improper rail height and the raised medians in which the devices were installed. Based on these data, researchers recommended further use of the device within the state.

Twenty Brakemaster sites existed in Kentucky during the course of this evaluation. From these, two collisions were recorded during the evaluation. One collision was judged to be severe although the device performed "properly" in this case. Due to the small number of collisions, further evaluation was recommended before the performance of this device could be completely assessed.

A total of 3,781 installations of the Type 7 weakened turned-down end treatment existed in Kentucky during the period of this study. At these, 67 collisions were documented during the evaluation. Due to the lack of information for some of the impacts, the performance of the device was determined in only 61 of the cases. Based on this data, performance was judged to be "proper" in 51 of the 61 collisions. All the improper collisions involved vehicle rollover. Two fatalities were recorded, both involving rollover of a small automobile and ejection of the occupant from the vehicle.

While the study illustrates the hazardous nature of rollover collisions, an evaluation of performance should also involve recording the collision severity. A collision that resulted in serious injuries should not be classified as performing properly simply because the vehicle did not roll over or penetrate the barrier. Collision severity should have been used in defining the performance criteria. The ultimate goal of roadside hardware is to reduce fatalities and serious injuries. Proper determination is not possible when this type of data is excluded from an evaluation.

North Carolina, 1993—TREND and CAT (*47*)

In 1993, Stanley described an in-service evaluation of the TREND and CAT devices in the state of North Carolina. The purpose of this study was to determine the impact performance of the devices, and to identify any problems associated with the installation and maintenance of the hardware.

As of the writing of the final report, six CAT and two TREND devices had been installed and were under observation by the study group. The period of observation for the devices was 3 years, although four CAT terminals had been installed after the initiation of the collision data collection.

Data collection for the study involved gathering police crash reports, interviews with maintenance personnel for information on upkeep, and periodic site visits to help identify unreported collisions. The final report indicated no impacts had occurred with any of the eight devices in the study area.

North Carolina, 1993—Quick-Change Movable Concrete Median Barrier (*48*)

In 1993, Stanley produced an interim report describing an ongoing in-service evaluation of the quick-change movable concrete median barrier (MCB) in the state of North Carolina. The purpose of this study was to determine the ease of use of the device in the field, its vehicle redirection characteristics, and problems associated with its use.

Data for this study included collisions occurring at the construction sites during the use of the MCB and information provided by the maintenance staff. Due to the nature of the device, this study had continuous on-site monitoring. This provided researchers with daily inspections of the device for incidental impacts occurring during the off-hours of the construction and maintenance crews.

At the time of the second interim report, three construction sites had been used to evaluate the device, with four more sites proposed and one other approved for future use of the device. As of the second interim report, a total of 77 recorded collisions had occurred at the construction sites. However, not all these collisions involved the MCB; a few of the impacts involved either the Vehicle Mounted Impact Attenuator (VMIA) or both the VMIA and the MCB. Although the exact number of collisions involving the MCB is not given in the report, it is stated that over three out of four of the 77 collisions involved the MCB system. Of the reported incidents involving the MCB, only one collision resulted in an incapacitating injury; the rest of the reported injuries were minor.

Problems associated with the use of the device were also noted. In four of the collisions, the MCB may have contributed to trapping water on the roadway causing the vehicles to hydroplane and lose control. Chipping and spalling of the corners of the barrier sections was also observed.

Connecticut, 1994—Narrow Connecticut Impact-Attenuation System (*49*)

In 1994, Lohrey described an in-service evaluation of the narrow Connecticut impact attenuation system (NCIAS). The NCIAS was installed at five high-hazard locations within the state of Connecticut in 1991 and evaluated for a period of 3 years. The purpose of this study was to evaluate the in-field performance of the NCIAS by examining occupant injury and comparing repair costs of the system to similar devices used on Connecticut roadways.

Data collection for this study involved three major sources: official police crash reports, site visits, and state property damage reports. The police crash reports, when available, along with the on-site measurements and photographs, provided the researchers with information necessary to evaluate the barrier's safety performance. The state property damage reports were used to determine costs of repair of the barrier, including parts, labor, and equipment. In addition to these data, damage reports for similar devices were obtained for a cost-effectiveness comparison to other attenuators.

The five evaluation sites that were used in the study were chosen based on four major factors: size of the hazard to be shielded, available space for the cushion, need for an upgraded safety device, and impact frequency.

Although more collisions were expected based on historical data, only one reported collision occurred at the sites during the course of the 3-year period. The researchers suggested the increased visibility of the system may have played a role. However, this may have also been attributed to an increase in safety performance associated with the new barrier. In the only reported collision, the occupant was treated and released for a head injury the same day as the collision.

Although the number of reported collisions was very low, cost estimates for the repair of the system could be made in the other impact events from the state property damage reports. However, five of the six hit-and-run collisions were not significant enough to require cost reports. Therefore, the repair cost estimates for the NCIAS in this study are based on two impact events.

Virginia, 1994—Quick-Change Movable Concrete Barrier System (*50*)

Cottrell reported in 1994 on an in-service evaluation of the quick-change movable concrete barrier system in Virginia. The barrier system was used on two concurrent projects during the period of February 1991 to April 1993. The main goal of the evaluation was to develop guidelines for use and evaluate the system's effectiveness in the field. More specifically, its performance during setting, resetting, and during a collision were of concern, as well as the costs, advantages, and disadvantages of the system.

Data were collected from maintenance personnel and police crash reports. In addition, photographs of the incidents were taken. The conditions of the road, time of day of the collision, number of vehicles involved, as well as injury data, were collected. The data collection took place between May 1991 and August 1992.

Forty-two collisions occurred involving the barrier system during the evaluation period. No collisions resulted in a fatality and 33 percent of the impacts resulted in an injury. In one case involving a tractor-trailer, the vehicle broke through the barrier. In general, most incidents were brush hits and resulted in little or no damage to the barrier system.

The initial costs of the system included the cost for the vehicle to move the barriers and the actual barriers themselves. The cost of purchasing the vehicle was $246,000 in project one and $275,000 in project two. The cost per meter of the barrier was $312 and $241 for project one and project two, respectively. In-place costs were also determined. These included minor maintenance to the placement vehicle and the system. Estimates per meter were $13 for project one and $14 for project two. The total cost for the systems was $2.1 million for project one and $1.4 million for project two.

Pennsylvania, 1995—Brakemaster and Crash Cushion Attenuating Terminal (*51*)

Snyder describes a 1995 in-service evaluation of the crash cushion attenuating terminal (CAT) and the Brakemaster systems in the state of Pennsylvania. The purpose of the 32-month evaluation was to explore the feasibility of using the CAT and the Brakemaster Systems as an alternative to the GREAT system for concrete barrier end terminals in narrow median width (1200 mm) applications.

Four different sites were used for the evaluation of the Brakemaster and CAT. The contractor chose which barrier was to be installed at each site. Between the four projects, a total of 22 CAT and two Brakemaster devices were evaluated for costs and collision experience.

The sites were generally inspected after a collision, however, one collision that occurred after the end of the official evaluation period did not include a site visit. Maintenance forces were interviewed to determine installation and maintenance costs for the devices. The average installation costs for the CAT and Brakemaster systems were $8,570 and $7,700, respectively. Attempts were made to obtain police reports corresponding to each collision.

Only one collision involving a Brakemaster system occurred during the study period. No police crash report was filed for the collision. The site was visited the day after the collision and photographs were taken of the damaged device. The device performed as designed, but the panels designed to flare outward upon impact protruded into the roadway travel lane. When personnel from the manufacturer were later questioned, they recommended a minimum median width of three meters for placement of the Brakemaster. The cost to repair the device was $4,305.83.

One collision involving a CAT system occurred shortly after the end of the study period and was also described in the report. A police crash report was obtained from a Pennsylvania Engineering District office. No photographs of the scene or site visits were made by the researchers for this incident. The sole occupant (driver) sustained minor injuries that did not require medical attention. Extraction of the wooden posts from the galvanized sleeves was very difficult. The cost to repair the device was $3,257.27.

Although both devices performed as designed and were less expensive to install and repair than the GREAT system, the CAT and Brakemaster systems were not recommended as alternatives to the GREAT system for narrow median applications. This was because the Brakemaster's flaring panels protruded into the traveled way, and the CAT was classified as a "gating" device. Based on NCHRP Report 350, "gating" devices should have a recovery area 6 m behind the rail and 23 m along the length of the rail and are not appropriate in narrow median applications.

This report provides valuable information for the use of the Brakemaster and CAT systems in narrow median applications. The study also reasserts the need to carefully consider all site characteristics when selecting an impact attenuation device. Not nearly enough collisions were observed during the course of the study to make accurate determinations for the typical repair costs or device performance. Perhaps the selection of more collision-prone sites could have increased the number of impacts encountered. Two Brakemaster units are not sufficient to make a reasonable determination of the costs and performance of the device. More of these devices should have been installed.

Ohio, 1996—ET-2000 Guardrail Terminal (*52*)

In 1996, the Ohio DOT reported on an in-service performance evaluation of the ET-2000. The ET-2000 is a proprietary guardrail terminal that has been permitted by Ohio DOT since 1992. This device was used where grading requirements limit the use of the MELT. Between February 1992 and December 1995, 6,421 ET-2000s were installed in Ohio at an average cost of $2,205. Also during this period, 214 ET-2000s were rebuilt with an average cost of reconstruction of $1,640. The purpose of this in-service evaluation was to examine the safety performance of the ET-2000.

Information on the average installation costs of the new guardrail terminals was obtained from the Ohio DOT records following the study. During the 40-month data collection period, 306 collisions involving ET-2000s were reported and investigated. The data were collected by DOT district staff who visited the collision site prior to repairs, took photographs, and filled out a one-page collision summary.

The ET-2000 terminal performed very well according to the study. Only 39 of the 306 collisions (12.8 percent) involved occupant injuries. Of these 39 collisions, only five injuries (1.6 percent) were moderate or serious. Most of the collisions that resulted in an injury involved impact speeds of 88 km per hour or more (82 percent). The average cost to repair the ET-2000 was relatively high at $1,640, or 74 percent of the original installation cost.

The data collection was one of the most systematic and complete in-service performance evaluations found in the literature. Site visits were performed by maintenance personnel, guaranteeing evaluation prior to the terminal's repair. A one-page reporting form was developed for maintenance personnel, which probably simplified the data collection and limited the data collected to only those areas which were part of the study.

Certain data sources and data types excluded from the study may have provided better insight into the performance of the ET-2000. It was unclear what was included in the on-site estimate of the repair costs for the ET-2000. Some of the estimates possibly included labor costs, while others did not. This would have an impact on the average estimate for repair of the terminal. The installation cost for the ET-2000 was compared with the average installation cost of the MELT. The cost of installing the MELT, however, did not include the cost of providing proper grading around the terminal. The difference between the installation costs for the ET-2000 and the MELT is probably less than what is reported.

Texas, 1996—ET-2000 Guardrail Terminal (*53, 54*)

A presentation and report in 1996 described an in-service performance evaluation of the ET 2000 guardrail end treatment in the state of Texas. The objective of this study was to determine the field performance of the ET-2000 and to refine the design to improve its safety and ease of installation.

Data collection for this study consisted of interviews with district design personnel, area engineers, project inspectors, maintenance and warehouse personnel, examination of police accident reports, the witnessing of an installation of a GET by a contractor, and the review of several of the impact sites.

When the data had been collected, a task force consisting of the original designers, the manufacturer, researchers, and FHWA was formed to examine the performance, installation characteristics, and repair issues in order to improve the device. This group suggested many changes that were implemented in later designs of the system. Among these design changes were the removal of legs and rubber bumpers which were deemed unnecessary, a change in the universal posts to simplify construction, changing the attachment bracket from a one-hole to three-hole system to allow for minor changes in post placement, and the addition of delineators for visibility.

Although it is unclear when the collision data collection ceased, the results of the Texas study are based on a period in 1993 and 1994. During this period, 37 collisions involving the ET-2000 were investigated. Of these 37 collisions, 92 percent resulted in no injuries or only minor injuries to the occupants. Three crashes resulted in incapacitating injuries to at least one of the occupants of the impacting vehicle. These collisions included a side impact, an unrestrained occupant in the bed of a pickup truck, and a possible misreported injury. No fatalities were recorded. Because of the limited number of collisions recorded, no attempt was made to analyze the data statistically.

In addition to collision severity data, undesirable performance characteristics of the device were also identified. In some cases, the extruder head was pushed into a traveled lane of traffic and remained there, blocking the roadway. Concern was also expressed that the extruded rail might encroach on lanes of traffic if installed in medians less than 7.6 m wide. Perhaps the most important observation was that of a rail becoming sheared prior to being extruded in the GET, which resulted in the rail spearing the vehicle.

PROCEDURAL STUDIES

A procedural study is an evaluation or discussion of data collection procedures.

Connecticut, 1975—Photographic Surveillance (*55, 56*)

In 1973 and 1975, Bowers prepared two reports summarizing experience with photographic surveillance of roadside devices in the state of Connecticut. The purpose of the reports was to describe the problems encountered with the installation and use of the system.

A Rich Hy-Dro Cell sandwich unit and a Fitch Inertial Sand Barrier were observed at sites with a relatively high frequency of impact. Ease of camera and surveillance system mounting was considered in selecting sites. One system was located in an overhead sign bridge and the other was located on a wooden pole at an I-95 off-ramp.

The surveillance systems consisted of high-speed waterproof cameras encased in wooden housings and mounted strategically at the site. The detection system consisted of 50-mm diameter by 50-mm deep magnetic sensors mounted in the concrete gore area upstream of the attenuation device. These sensors, when tripped, sent a signal to the camera. To minimize the time lapse between the signal and the first exposure, the camera motor ran continuously. An estimated 38 impacts and false alarms could be recorded before film replacement was necessary.

These systems were plagued with many problems. The author noted at least two instances per system where camera motor gears had to be replaced due to continual use. There was a high instance of false alarms. In the initial debugging stage, site counters recorded 100 false alarms per day at one site and an average of 300 per day at the other site. Many explanations were given for the high number of false alarms, including rush hour traffic, gore area crossovers, near misses, and thrill-seeking motorists. To remedy both problems, the systems were shut off during peak traffic hours. The systems were also disengaged during nighttime hours due to lighting constraints. The rate of false alarms, however, still exceeded 40 per day and cameras still required daily film replacement. The systems were prematurely removed and the project ended because of high false alarm rate and infrequency of impacts at either site.

These reports illustrate the many potential problems that must be considered when considering photographic surveillance techniques. The author suggested ways to improve similar studies in the future, including:

- Site selection should consider collision experience and potential false alarm rates,
- Still frame cameras should (as of 1975) have their motors running continuously to reduce lag time between system activation and film exposure, and
- Using continuously erasing video tape systems should be considered to prevent running out of film and therefore eliminate the false alarm concern. The author also suggested that the system shut down after an impact had occurred.

NHTSA, 1982—Longitudinal Barrier Special Study (*57, 58*)

The National Accident Sampling System (NASS) was established to aid the National Highway Traffic Safety Administration (NHTSA) in the reduction of the number of fatalities, injuries, and economic losses resulting from motor vehicle crashes on the nation's highway. The Longitudinal Barrier Special Study (LBSS) was one of three studies initiated to provide more in-depth information on particular types of collisions. The LBSS addressed collisions involving longitudinal barriers, both guardrails and median barriers, but not bridge rails.

The LBSS data were collected using a stratification sampling based on area type (rural, urban), highway type (freeway, non-freeway), vehicle size (small # 1,134 kg, large >1,134 kg), and longitudinal barrier types (G1, GR1, G2, G3, G4(1W), G4(2W), G4(1S), G4(2S), G9, W-beam, Blocked-out W-beam, Concrete safety shape, MB1, MB2, MB3, MB4W, MB4S, MB5, MB7, MB8, MB9, and MB10). A sample size of 82 was requested in each stratum. Priority for sampling was given to all collisions involving end treatment type BCT and guardrail/bridge rail transition.

Data collectors visited police agencies weekly, biweekly, or monthly and identified collisions that met the study criteria. All collisions in the Special Study had at least one impact involving a guardrail or median barrier, and the collision was reported by police at the scene with all involved vehicles and drivers present. Note that this excluded unreported collisions. All vehicle types were included with the exception of motorcycles when their involvement in the collision was hitting the barriers. If motorcycles were involved in collisions where the other vehicle hit the barrier, the crash was included.

Data collectors then investigated selected collisions in further detail. Documentation of barrier damage including photography and field measurements, impact and trajectory data, and vehicle damage data sufficient to obtain the Collision Deformation Classification (CDC) had to be present to include the collision in the LBSS. Extensive photographs were taken at the scene with the scale identified. The basic requested photographs included: general photographs along the path of the vehicle starting from 3 m behind the tire marks, with multiple “path pictures” if the path was over 15 m long; photographs of the point of impact and vehicle rest positions; photographs of the road and terrain in the direction of travel beginning 305 m upstream with photographs at 60-m increments and 30-m increments after the vehicle left the roadway; at least two general photographs of each impact taken in the direction of travel at different distances; at least two general photographs of each impact taken opposite the direction of travel at different distances; one or more photographs along the paths between impacts; a general photograph of each roadside structure/object struck; and at least one close-up photograph displaying the damage at each roadside structure/object struck.

Data collection was organized into the following four categories: header information, location identification, impact sequence, and longitudinal barrier information. The header category identified the Primary Sampling Unit (PSU), the investigator that completed the form, and general information required for data processing. The location identification category identified the location of the collision. The impact sequence category identified the impact sequence in the collision for each impact by the object contacted and its lateral offset. The longitudinal barrier category described the characteristics of the struck barrier, the roadside cross-section, the extent of damage to the barrier, the vehicle dynamics and trajectory during impact, and the barrier performance.

The data collection requirements, coding instructions, and field procedures used in the study were detailed in the Coding/Editing and Field Procedures Manual. The manual was intended for use by PSU investigators for data collection and Zone Center (ZC) personnel in their review process. The manual provided an introductory page for each category that identified the name of the category, the applicable variable numbers, a description of the data category, and references used in formulating the definitions and coding instructions for the variables. For each variable or group of variables, the variable number, variable name, format, beginning column, element value (range and individual codes or responses), the source, any remarks (level of data collection, descriptions and definitions, coding instructions, and illustrations), field procedures, and related variables were provided. The manual also contained a section that identified editing and consistency checks to aid PSU investigators and ZC personnel when they reviewed the special study forms.

Erinle et al. discussed an analysis of the LBSS data in a 1994 report (*59*). Some of the results included the following:

- Weak-post barriers were less associated with driver injury than strong-post and fixed barriers.
- Drivers were more often injured when their vehicles returned to or crossed the roadway than when their vehicles remained on top of, penetrated, or overrode the barriers.
- The subsequent impact that most often resulted in driver injury was rollover. Rollover was also associated with higher serious injury (A+K) rates.
- Serious driver injuries were more often associated with blunt and turndown ends than with the length-of-need section of guardrails.
- In many cases of barrier failure, the impact conditions were “unusual,” i.e., they differed significantly from the crash test impact conditions.

DISCUSSION AND CONCLUSIONS

In-service evaluations provide a means to test assumptions and conclusions resulting from crash testing roadside appurtenances. Typically, these devices are designed and tested based on worst-case scenario crash test conditions. Since worst-case conditions represent a small percentage of actual crash occurrences, it could be concluded that most in-service collisions will simply give better performance results than crash testing. During most crash tests, however, these devices are installed and tested under ideal conditions and do not take into account variations in weather, unusually high corrosion due to the use of de-icing salts, driver behavior due to the installation of the device, and other factors not under the control of the test facility. In short, the real world presents substantially more variables than can be completely accounted for under laboratory conditions, making in-service evaluations a necessary and vital tool for the development of roadside devices.

The rationale for observing real-world performance of a roadside device is well founded. Historical studies, considered a predecessor to in-service evaluations, are documented as far back as the early 1970s. These studies use primarily police crash reports to examine the performance of existing devices. For example, an early Iowa study focused on collisions with light post cable guardrail systems retroactively using state data sources (*3*).

Although historical studies are valuable in evaluating existing devices, states often require data on the performance and cost-effectiveness of newer devices. DOTs have conducted various types of collision studies since at least the late 1970s. A collision study usually involves performing data collection as collisions occur, rather than searching records retroactively. Maintenance personnel as well as police officers generally are involved in the data collection, and costs associated with the installation and maintenance of the devices are recorded to some degree. New York DOT, for example, conducted several studies on the performance of guardrails and other roadside appurtenances that relied heavily on maintenance personnel for data collection (*4, 23*).

Based on such collision studies, a number of improved methodologies have been developed and implemented to improve data collection and analysis. In-service performance evaluations represent a more exhaustive study of collisions. This method of data collection is performed concurrently with the time period for which the data are being collected. This simultaneous data collection enables individuals involved to make personal visits to the collision sites and collect all the necessary information for the performance evaluation of the devices. Unfortunately, many times the individual responsible for data collection lacks proper training, which may lead to incomplete data. To remedy this, an in-service evaluation will typically require the development of a comprehensive, standardized reporting form to be used by those collecting information from site visits. These forms can then be distributed as supplementary documentation to the individual responsible for filing accident reports, usually the police officer at the scene.

A few studies have examined methods of data collection and how they could be improved. One Connecticut study documented an attempt to obtain data from cameras mounted along selected highways (*55, 56*). Although this early study failed to achieve its objectives, it was valuable in stressing the importance of accurate data collection from on-site observation. More recently, the “Coding/Editing and Field Procedures Manual” for the NASS Longitudinal Barrier Special Study outlined methods for collecting, recording, and verifying data for use in in-service evaluations (*57*).

Collision characterization and evaluation are typically governed by the number of devices available for observation. When only a few devices or installations are investigated, field evaluations are relatively easy to perform. However, as noted in many of the reviewed reports, this may lead to insufficient sampling of collisions. Conversely, when more devices are examined in an evaluation, more collisions are typically experienced, but the ability of the study team to perform on-site investigations is impaired. In addition, in-service evaluations often target devices under development, which do not already exist within the geographical area of study. This generally has a crippling effect on the number of sites available for study. New devices, however, typically exhibit high installation costs compared to those already existing within an area. In general, if a device must be installed prior to its evaluation, not many are constructed. Therefore, in most of the evaluations reviewed, the number of devices studied was not sufficient for researchers to make valid determinations regarding the performance of the device.

Uncertainties associated with new devices and their high installation costs typically contributed to the sparse number of devices available for study. This, in turn, has limited the number of observation sites. For example, many reports noted that bid estimates to install new devices varied greatly and tended to be substantially higher in comparison to the actual cost of installation. In many cases, contractors who lacked experience installing new devices would leave a monetary buffer for possible unforeseen installation costs. When only a small number of devices can be constructed, sites should be selected which are appropriate for the device and facilitate collision experience with the appurtenance. In contrast in the literature review, a few studies occurred where some sites did not experience a single hit over a 2-year period. In some other studies, while the sites selected were appropriate for the function of the hardware, often they were not chosen to encourage collision experience with the devices. In the most successful studies, site selection involved researching the potential sites and determining which ones had the highest collision probability. These sites were then typically chosen as construction and observation sites. In this manner, all but one study reported reasonable collision experience given the number of devices under observation. As devices become more widely used and contractors more experienced in installing them, costs will naturally decrease, and opportunities for in-service evaluation will increase.

The lack of collision experience with devices under observation limits the validity of any conclusions drawn from a particular study. Ideally, the quantity of data collected should be sufficient for statistical analyses, but cost constraints limit the number of observation sites and therefore collision experience. With limited collision experience, many of the reports were primarily anecdotal in nature with perhaps an average cost of installation or percent injured by class noted. Statistical evaluation was mostly confined to the larger historical and collision studies, although a few in-service evaluations used statistical methods to analyze their data.

Despite the absence of statistical analyses in most of the in-service evaluations, valuable information can still be obtained. The inclusion of a collision report form filled out by the police or the investigators can improve the quality of the data collected by targeting only those data that are relevant to the study. Reports that were based solely on police accident reports and accident databases were not as flexible as studies that included the use of some sort of data collection form. Data collected in this manner were also available from a centralized data repository. In many instances, however, if necessary data were not available from the accident database, the source police crash report had to be obtained, which frequently did not produce the desired information. On several occasions, the police crash report itself could not be found, thus reducing the data pool even further. Maintenance information for these events was often even more difficult to obtain.

Simultaneous data collection did have some drawbacks, however. Cases were noted where the researchers experienced difficulties in obtaining information from the data collectors. Good communication among all individuals and agencies involved is, therefore, critical. This type of data collection also requires that data be obtained simultaneously with the evaluation period. That is, the study period must be the present. Data must be collected for a period of time before any conclusions can be drawn about the performance of a device.

Many other problems were experienced during the course of the in-service evaluations. Often, especially under circumstances associated with "new" devices, the hardware was not installed properly as determined by the researchers or other DOT personnel. These cases reinforced the importance of inspection of the devices to ensure correct installation.

Perhaps the most difficult problem resulted from unreported incidents. Although occupant injury and vehicle and device damage were typically minor in these instances, these types of collisions are still important because the device apparently performed correctly and had no serious consequences. Routine inspections of the devices were the primary method used to document these events. Unless these inspections were performed regularly, however, many unreported collisions could occur between inspections, making it difficult to determine the actual number of unreported collisions. Even when these events were documented, details of the collisions were impossible to determine. If unreported collisions were documented in a report, injuries were usually classified as PDO and the devices were generally judged to have performed "properly."

Fifty-seven reports on collision studies and in-service evaluations were reviewed in the literature survey, most typically performed by state DOTs. Two particularly good studies are an evaluation of the MCB system in Virginia and an evaluation of the ET-2000 in Ohio (*50, 52*).

In-service evaluations have been recognized as an important part of the development of roadside devices (*5*)(*2*). Full-scale crash testing can only provide information about the performance of a device under ideal installation conditions and prescribed impact conditions. The basis of evaluation is of utmost importance to a collision study or in-service evaluation. Factors such as difficulty in installation, poor application, and environmental factors can decrease the performance of a device and should therefore be included.

CHAPTER 3

DATA COLLECTION AREAS

This chapter describes the characteristics of three data collection areas where in-service evaluation data was collected beginning in July 1997, including the types of hardware on the road system, the historical collision data, police procedures, and maintenance procedures. Data collectors were informed about possible cases by police and maintenance agencies in each area. The collision site was visited generally within a day of the impact so that the damaged system could be measured and photographed. After documenting the scene, data collectors obtained official sources of information from police and maintenance reports where available. The following sections describe features of the Connecticut, Iowa, and North Carolina data collection areas, the sources of official documentation available in each data collection area, the types and quantity of roadside hardware in the three data collection areas, and the number of collisions observed involving various roadside features during the data collection period.

CONNECTICUT DATA COLLECTION AREA

General Characteristics

The data collection area in Connecticut was composed of the interstate network in the northern half of Connecticut DOT District 1 as shown in Figure 5. The data collection area crosses several city, town, and county boundaries because maintenance areas are defined by snow routes rather than political boundaries. The data collection area contains the Hartford metropolitan area (including Bradley Airport) several smaller municipalities, and four interstate highways.

The information in this section deals only with state-maintained roadways rather than roadways maintained by all the local governments in the data collection region. Counties in Connecticut do not have police agencies or roadway maintenance agencies, so all roads are maintained either by the state or local towns and cities. The state maintains all interstates, U.S. highways, and state routes, while the towns and cities maintain the local roads and streets.

Highways in the Hartford area experience particularly high traffic volumes. A review of the collision history in the data collection region demonstrated that roadside hardware collisions are clustered along the routes with the highest volumes. This is not surprising since there are more opportunities for vehicles to strike barriers on higher-volume, high-speed roads. The majority of barrier-related collisions should be found by concentrating on the state-maintained roadway system (the interstates and state routes). Although the interstate highways in the data collection area account for only 15 percent of the roadways by length, they account for over one-half the vehicle kilometers traveled, as shown in Table 5. The study was limited to the 117 km of interstate highways in the northern half of Connecticut DOT District 1.

Police Reports

On average there are nearly 800 barrier-related collisions on state-maintained roadways in the Connecticut data collection area each year, as shown in Table 6. The table shows that 528 of the 769 yearly barrier collisions (70 percent) occur on the interstate system although the interstate highways only account for 15 percent of the State-maintained roadway mileage and 54 percent of the vehicle miles traveled, as shown in Table 5. Although interstate highways are built and maintained with the highest roadside safety standards, the large traffic volume and high speeds result in the majority of collisions occurring on the interstate highways.

Based on the historical data shown in Table 6, 1 percent of the collisions on the interstate highways can be expected to result in severe injuries (A+K) and 70 percent can be expected to involve property damage alone. The historical collision data from Connecticut does not distinguish between different types of barriers, so it is impossible to relate the information in Table 6 to the performance of any particular barrier system. Table 6 does, however, provide a good estimate of the overall number of collisions that might be expected in a 12-month period.

Connecticut uses a uniform collision reporting form for all law enforcement agencies including the State Police, city, and town police departments. The use of this standard form simplified coordinating information on the collision reports between law enforcement agencies. In Connecticut, police collision reports are not considered public documents until the file has been officially closed by the police department, and this can take up to 3 months. The DOT, and by extension, the data collection team, are considered members of the public, so it was not possible to rely on the police for notification

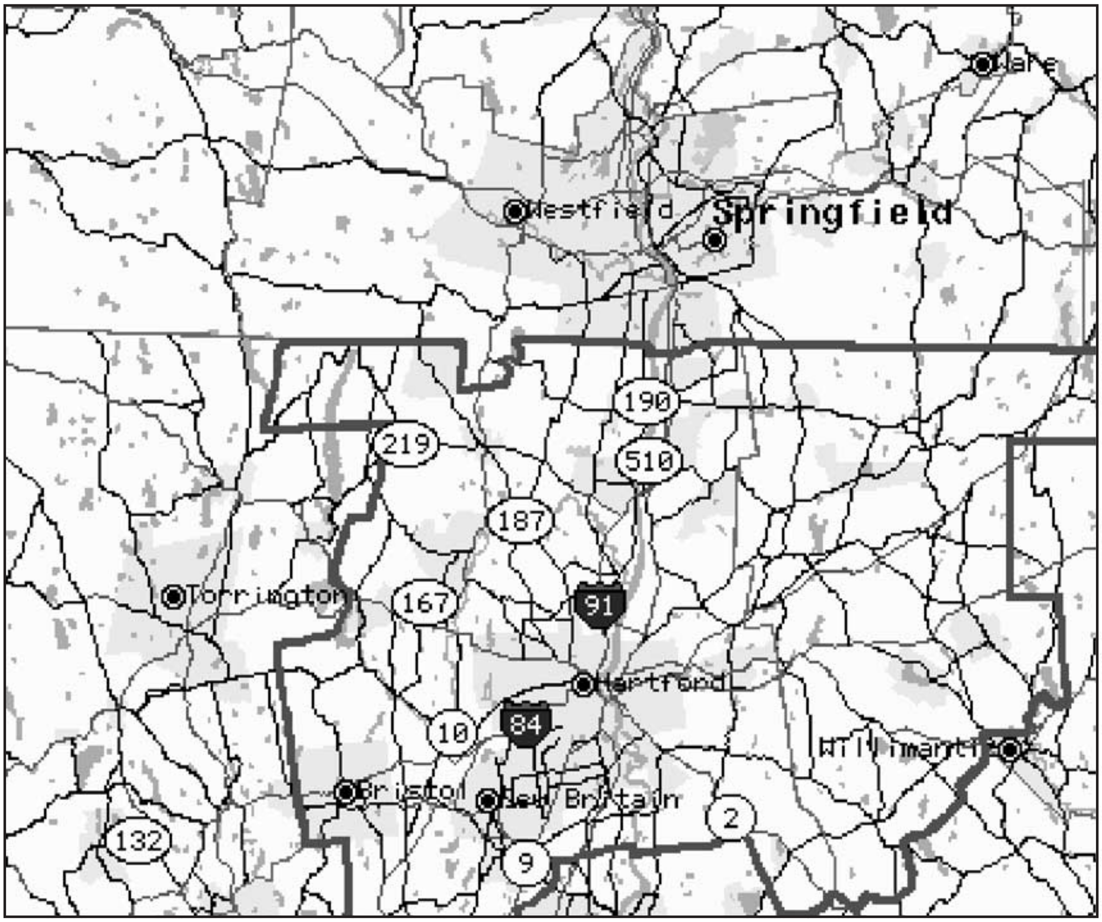


Figure 5. Connecticut data collection area.

about collisions. Police collision reports were obtained as soon as they were released, but since this could be as much as 3 months after the collision, it was often difficult to match police reports with specific damaged installations.

Police reports in Connecticut, like in many states, indicate the location of collision sites using major landmarks like overpasses, intersecting streets, and exits. Even the interstate highways have very few mileposts, so it was often difficult to match a police report to a specific damaged barrier, especially if the damage was old. Some types of barriers, like the concrete median barrier, rarely are damaged, and locating a specific collision site on this type of barrier can be very challenging.

Maintenance Reports

The Connecticut DOT attempts to recover the cost of barrier repairs from motorists who damage roadside hardware in a collision. Police agencies normally notify the Connecticut DOT Collision Records Section by forwarding a copy of the police report after the police report is classified as a public document. Unfortunately, the period between when the collision occurs and when the report is delivered to the DOT can be as much as 3 months. To help alleviate this problem, officers are supposed to leave a sticker on any damaged State property including guardrails. When the maintenance crew

TABLE 5 Kilometers of state-maintained roadway and ADT in the Connecticut data collection area

Roadway Type	Length in Study Area		ADT	Vehicle-km Traveled	
	km	%	veh/day	10^9 veh/yr	%
Interstate	117	15	69,595	2.97	54
US Highway	64	8	15,904	0.37	7
State Highway	595	77	10,191	2.21	39
Total	776	100		5.55	100

TABLE 6 Average number of barrier collisions on state-maintained roads in the Connecticut data collection area (1994–1995)

Severity	Interstate		US		State		Total	
	No.	%	No.	%	No.	%	No.	%
A+K	4	1	4	24	8	4	16	2
B+C	157	29	5	29	52	23	214	28
PDO	367	70	8	47	164	73	539	70
Total	528	100	17	100	224	100	769	100

repairs the barrier, the reference number on the sticker can be used to identify the responsible party.

DOT maintenance supervisors routinely monitor the roadside hardware in their areas of responsibility. When a damaged barrier is noticed by maintenance personnel or reported to maintenance by the police or public, the maintenance supervisor schedules the repair. Repairs are usually performed by DOT personnel. When the repair is complete, a "Report of Property Damaged by Collision" form is completed by the maintenance supervisor with an itemized list of the material, labor, and equipment cost required to repair the barrier. If a sticker is found at the site, the reference number is attached to the report so that the appropriate motorist can be charged with the expense of repairing the barrier. The primary purpose of this form is to allow the state to claim the repair cost from the motorist's insurance company, but since it includes cost information it is also useful in the context of an in-service performance evaluation.

The DOT maintenance garages were the primary means of notification for the data collection team in Connecticut.

Inventory Data

The Connecticut DOT does not have an inventory of roadside safety hardware. Connecticut does have videologs of all state-maintained roadways and is in the process of developing a method for creating statewide inventories, including roadside hardware, based on the videologs. Fortunately, the DOT inventoried roadside hardware on a portion of the roadways in District 1 early in 1997 to determine the number and type of guardrail terminals. Table 7 shows the results of the spot inventory of District 1 extrapolated to the entire Connecticut data collection area.

Although G3 box beam guardrails are included in the standards, the most commonly used flexible guardrail is the weak-post W-beam guardrail (G2) as shown in Table 7. The G2 guardrail is shown in drawing SGR02 of the AASHTO-ARTBA-AGC "Guide to Standardized Barrier Hardware" (Hardware Guide) (*60*). The most common terminal is the weak-post turned-down end, used to terminate and anchor the G2 guardrail. The next most common flexible guardrail is the G1 weak-post three-cable guardrail, shown in the Hardware Guide as SGR01a (*60*). Essentially no BCT or MELT terminals are used in Connecticut because of the predominance of the weak-post W-beam guardrail. Crash cushions are frequently used for the ends of concrete median barriers (CMBs) and in gore areas rather than guardrail terminals. There are also many kilometers of permanently installed CMBs on the high-volume high-speed interstates routes like Interstates 91 and 84 through Hartford.

TABLE 7 Estimated quantity of barriers and terminals in the Connecticut data collection area based on a spot survey of selected routes in 1997 in CT District 1

Barrier Type	Interstate	US	State	Total
Roadside barriers (m)				
G1	12,500	900	10,000	23,400
G2	67,000	26,000	10,000	103,000
G3	0	0	0	0
G4(1S)	5,000	1,600	60,000	66,600
Concrete roadside barrier	4,000	700	0	4,700
Non-standard	0	0	135,000	135,000
TOTAL	88,500	29,200	215,000	332,700
Median barriers (m)				
M2	6,000	0	0	6,000
M4	5,000	21,000	0	26,000
Concrete median barrier (CMB)	184,000	15,000	0	199,000
TOTAL	195,000	36,000	0	231,000
Terminals (installations)				
Cable anchor	50	10	20	80
Weak-post turndown	300	40	0	340
Box-beam turndown	0	0	0	0
Strong-post turndown	0	300	2,000	2,300
Buried-in-backslope	30	10	50	90
W-beam anchor	60	30	0	90
TOTAL	440	390	2,070	2,900

As shown by the inventory results in Table 7, the most common longitudinal barrier systems used in the Connecticut data collection area are the CMB, the G2 weak-post W-beam guardrail, and the G1 weak-post cable guardrail. These three systems were chosen for the study since they were expected to result in the largest number of collisions during the study period.

Results

Table 8 shows the number of collisions observed and expected in the Connecticut data collection area based on the historical number of collisions (Table 6) and the estimated amounts of barrier (Table 7). The estimates of the number of collisions were obtained by taking the number of barrier-related collisions that historically occurred on each type of road (e.g., interstate, U.S., state) and assigning the number of collisions to specific types of hardware based on the amount of hardware installed in the data collection area. Based on the data from North Carolina shown later in this section, 80 percent of the collisions were expected to involve barriers and 20 percent would involve guardrail terminals. The number of cases was then apportioned among the different types of

TABLE 8 Number of barrier collisions expected and observed on interstates in the Connecticut data collection area

Barrier Type	Observed Severity A+K		Observed Severity B+C		Observed Severity PDO		Total Police Reported		Only Maintenance Reported§	Total Observed	Number Expected	Error‡
No.	No.	%	No.	%	No.	%	No.	%	No.	No.	No.	%
G1	0	0	3	21	11	79	14	100	7	21	20	+5
G2	1	1	14	15	77	84	92	100	23	115	110	+5
Concrete	2	1	37	31	81	68	120	100	2	122	280	56
Total	3	1	54	24	169	75	226	100	32	258	410	37

§ Collisions that were not reported to the police but were repaired by the maintenance agency are shown as “only maintenance reported” collisions. The severity percentages are calculated based only on the police reported collisions.

‡ The error is defined as the number of cases observed minus the number of cases expected divided by the number of cases expected. The value is expressed as a percent.

barriers and terminals in each data collection area based on the quantities indicated by the inventory on each type of roadway.

As shown in Table 6, 528 barrier-related collisions can be expected each year on interstates in the Connecticut data collection area. If 80 percent are assumed to involve the length-of-need portion of the barrier, then 422 non-terminal-related collisions can be expected. As shown in Table 7, there are 188 km of concrete median and roadside barriers. This represents 66 percent of the length of barriers, so it is reasonable to assume that 66 percent of the 422 non-terminal collisions will involve concrete median or roadside barriers. Approximately 280 collisions can therefore be expected that involve impacts with concrete median and roadside barriers (e.g., $528 * 0.80 * 0.66 = 278$). The other estimates in Table 8 were calculated in a similar manner. The total number of barrier collisions expected does not equal 422 in Table 8 because some of the installations involve systems there were not studied (i.e., strong post W-beam median barriers).

During the 12-month data collection period in Connecticut, data about 258 collisions were collected, or approximately two-thirds of the expected number of collisions. The severe injury rate for all three barriers was 1 percent or less, even though the G1 guardrail is among the most flexible of barriers and the concrete median barrier is among the most rigid. Only property damage resulted from approximately 80 percent of the flexible guardrail (e.g., the G1 and G2) collisions, whereas rigid CMB collisions resulted in only property damage just under 70 percent of the time. The difference between the property-damage-only rate for the CMB and G2 guardrails is statistically significant at the 90 percent confidence level. The more flexible barrier, therefore, results in a higher proportion of property-damage collisions and a lower proportion of injury collisions based on the police-reported data.

The observed number of flexible guardrail collisions was greater than the expected number as shown in Table 8, but the observed number of rigid barrier collisions was significantly less than expected. Flexible barriers like the G1 and G2 guardrails usually must be repaired after an impact, whereas a rigid barrier is seldom damaged. One possible reason for the smaller number of rigid barrier collisions is that the data collection team received notification of collisions primarily from the maintenance organization and few CMBs require repair after a collision.

Discussion

The data collection in Connecticut illustrates several important points about performing in-service performance evaluations. First, highways with large traffic volumes can be expected to experience a large number of collisions. The quickest way to perform an in-service evaluation is to find a high-volume roadway with a large installed inventory of the roadside hardware of interest. Second, there were significant notification problems that resulted from the legislative environment in place in Connecticut. It was not possible to obtain police reports quickly and therefore many cases could not be located. This resulted in a loss of information about the damaged barrier systems. Third, the lack of a good linear referencing system on the highways compounded problems with matching police reports to sites with barrier damage. It was often very difficult to identify collision scenes with confidence.

Results of the Connecticut data collection are discussed further in Chapter Seven, “In-Service Performance Evaluation of Post-and-Beam Guardrails in Connecticut, Iowa, and North Carolina,” not published herein.

IOWA DATA COLLECTION AREA

General Characteristics

The in-service performance data for a variety of common traffic barriers was collected in portions of Iowa between 1 July 1997 and 30 June 1999. The strong-post W-beam guardrail and the weak-post three-cable guardrail were studied, as well as the breakaway cable terminal (BCT), the modified eccentric loader breakaway cable terminal (MELT), and bullnose median barriers.

The data collection area shown in Figure 6 was composed primarily of Cedar, Johnson, Linn, and Scott counties in southeastern Iowa. The data collection area contained three metropolitan areas (Cedar Rapids, Davenport and Iowa City), four interstate highways (74, 80, 380, 280, and 218), and roadways in a variety of functional classes. The area was selected based on Iowa DOT maintenance garage responsibility maps. The data collection area was chosen to coincide with the areas covered by each maintenance garage even when the coverage area crossed a political boundary. In addition to roadways in the four counties, several roadway segments were included in other counties to conform to the state DOT maintenance garage coverage areas. These additional routes included Route 30 and all state roadways south of Route 30 in Clinton county (added to Scott county) and Interstate 380 in Benton, Buchanan, and Blackhawk counties (added to Linn county). The average traffic volume on each type of roadway and the number of kilometers of roadway in each county are shown in Table 9.

The data collection area consisted of 981 km of state-maintained roadway with a total traffic demand of 4.21 billion vehicle-kilometers traveled per year. The interstate highways accounted for 30 percent of the highway length and almost 55 percent of the traffic demand as shown in Table 9.

Police Reports

The average severities of police-reported barrier collisions that occurred on state-maintained roadways in the Iowa data collection area between 1989 and 1993 are shown in Table 10. On average, nearly 100 barrier-related collisions occur each year in the four-county data collection area, almost 80 percent of them on the interstate system. Collisions on the interstate system resulted in property damage only (PDO) in nearly 70 percent of the collisions and severe injuries (A+K) in about 5 percent of the collisions.

All police agencies in Iowa use a uniform collision reporting form. The use of this standard form simplified coordinating information on the collision reports between law enforcement agencies. The State Police were regularly contacted by the data collection team to obtain police reports, since they responded to the majority of the collisions on the interstate system. Local police agencies were also surveyed periodically to ensure that all cases were identified. Reports were available from the police as soon as the investigating officer completed

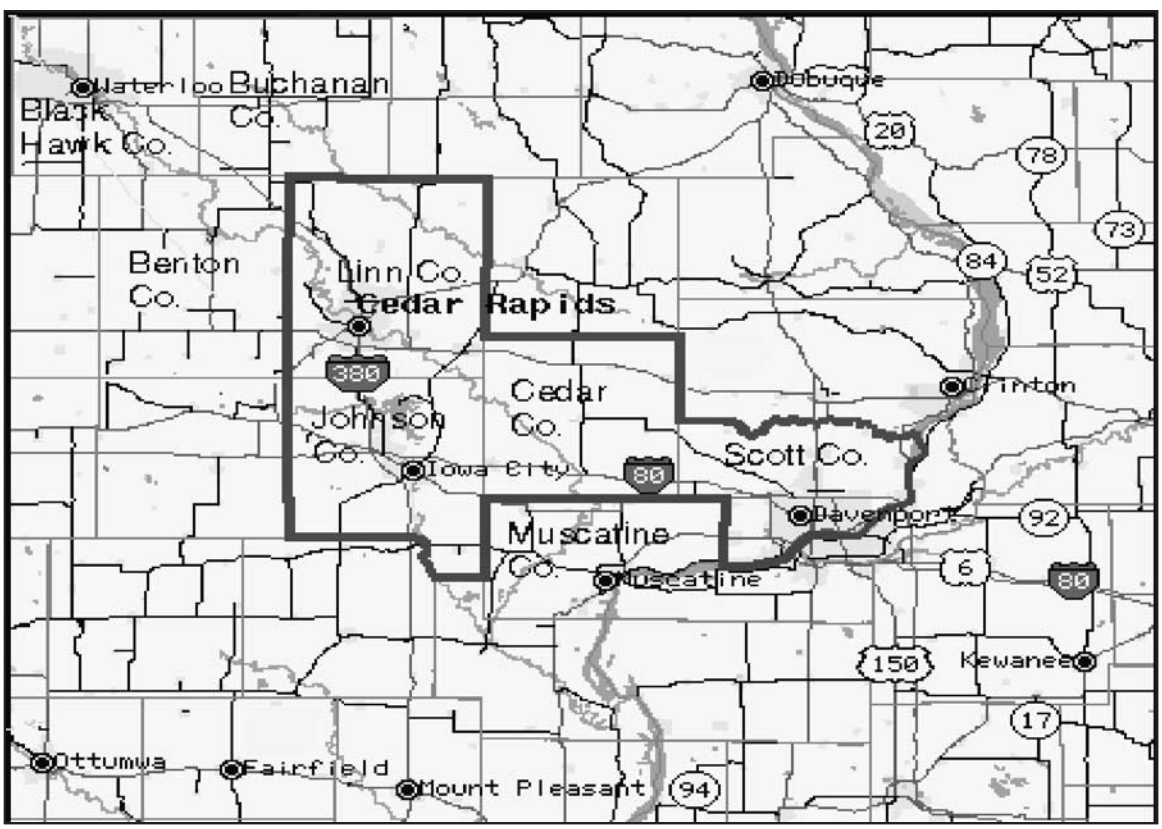


Figure 6. Iowa data collection area.

TABLE 9 Kilometers of state-maintained roadway and traffic volumes in the Iowa data collection area

Roadway Type	Kilometers of Roadway Cedar	Johnson	Linn	Scott	Total		Average ADT	Vehicle km Traveled	
	km	km	km	km	km	%	veh/day	10^9 veh-km	%
Interstate	43	56	124	67	290	30	21,542	2.28	54
US Highway	93	68	24	179	364	37	9,810	1.30	31
State Highway	50	100	97	80	327	33	5,245	0.63	15
Total	186	224	245	326	981	100		4.21	100

the paperwork. The State Police barracks were used as a secondary means of notification.

Maintenance Reports

Iowa DOT attempts to recover the cost of barrier repairs from the people who damaged the roadside hardware in a collision. For this reason, the DOT documents the materials, labor, and equipment required to repair any state-owned property including guardrails and guardrail terminals. The police agencies normally notify the appropriate DOT maintenance supervisor whenever a collision occurs that involves damage to roadside hardware. In the case of major damage, the maintenance supervisor is notified immediately, whereas for less severe collisions the maintenance supervisor is faxed a copy of the police report within a couple of days of the collision. Fortunately, there is excellent cooperation between the DOT maintenance garages and the local State Patrol. From the beginning, therefore, the collision damage is linked to the collision that caused the damage. DOT maintenance supervisors generally inspect each mile of roadway under their jurisdiction regularly, so damage that was not reported to the police is also identified.

Once the DOT has been notified about damaged roadside hardware, the maintenance supervisor schedules the repair of the hardware. When the repair is complete, a "Memorandum of Cost Report" is completed and submitted, which itemizes the materials, labor and equipment used to repair the damaged hardware. The Cost Memo is filled out whenever a roadside appurtenance is repaired as a result of a collision, even if the collision is not reported to the police. The Cost Memo is filed so that if a collision is subsequently linked to the damage or the responsible party is identified the cost can be documented. For example, a collision report may be lost or not delivered in a timely manner due to clerical errors. In such a case, the barrier may have already been repaired before the collision report is delivered to the DOT. Since the Cost Memo is always filled out, attaching a late or missing collision report is relatively easy. A cost report is <u>not</u> filled out for routine maintenance, however, which sometimes might include minor damage to a guardrail that was never reported, such as that shown in Figure 7.

The maintenance supervisors were the primary agents for notification during the study. They called the data collection team whenever they became aware of a barrier or terminal collision. The data collection team also made sure they contacted each maintenance supervisor at least once a week to be sure that all cases were sampled.

Inventory Data

Approximately 10 years ago, each Iowa DOT resident maintenance engineer (now area engineer) developed an inventory of barriers and terminals on state-maintained roads. There was, unfortunately, no standard format or content in these inventories, but some area engineers still use these inventories as

TABLE 10 Average annual barrier and terminal collisions on state-maintained roads in the Iowa data collection area (1989–1993)

Severity	Interstate No.	Interstate %	US/State No.	US/State %	Total No.	Total %
A+K	4	5	2	9	6	6
B+C	21	28	6	26	27	27
PDO	51	67	15	65	66	67
Total	76	100	23	100	99	100

Figure 7. An example of minor guardrail damage.

a means of managing their roadside hardware inventories and scheduling maintenance work. For example, the Scott county inventory is updated every year and is used as a management tool for identifying installations that need routine maintenance or repair. The Johnson and Cedar counties inventories for the interstate highways are still routinely used, although the other state-maintained roadway inventories have not been updated in a number of years. The Linn county inventory has not been updated in about 5 years. The inventory in Linn county was estimated by extrapolating the amount of hardware based on the number of kilometers of roadway and the ratios from the other counties. Table 11 shows the estimated quantity of each type of guardrail and terminal in the four-county data collection area based on the inventories.

The G1 cable guardrail and the G4(1W) strong-post W-beam guardrail are used in Iowa. The G4(1W) is a modified version of the Hardware Guide's SGR04b that uses 200×200 mm wood posts with wood blocks (*60*). Terminals used include the bullnose end for W-beam median barriers, W-beam anchor, and the BCT and MELT. The BCT used in Iowa is a wood-post system with a concrete foundation for the breakaway posts (post one and two). It is essentially the same device as is shown in drawing SEW03 of the Hardware Guide (*60*). The Iowa BCT uses the concrete foundation option (detail B) and 200×200 wood line posts rather than the more typical 150×200 posts (e.g., PDE05 rather than PDE02). The BCT has been the primary guardrail terminal used for W-beam guardrails in the state of Iowa for over 20 years. The long period of BCT use is reflected in the large number of BCTs in the inventory in Table 11. There are nearly 1,500 BCTs on state-maintained roadways in the four-county data collection area.

In 1994 the FHWA issued a memorandum indicating that the BCT would no longer be acceptable for new construction on high-speed high-volume roadways on the National Highway System (NHS) after 29 September 1995 (*61*). Many states, including Iowa, chose to begin using MELT terminals in situations where they would have previously used the BCT. Beginning in the spring of 1996 and continuing through the 1998 construction season, MELT terminals were used for new construction in Iowa, and by the beginning of the data collection period, there were 51 MELTs in the Iowa data collection area. The state of Iowa uses the details for the MELT shown in the Hardware Guide for terminal SEW05 (*60*). Beginning in the 1999 construction season, Iowa DOT began to install the FLEAT as the standard W-beam terminal.

TABLE 11 Estimated quantity of W-beam guardrails and terminals on state-maintained roads in the four-county data collection area

Element	Interstate	US/State	Total
Guardrail			
G1	9.8km	9.4km	19.2km
G4(1W)	12.9km	11.6km	24.5km
Total	22.7km	21.0km	43.7km
Terminals			
Bullnose end	158	115	273
BCT	510	942	1,452
W-Beam Anchor	48	190	238
MELT	51	0	51
Total	609	1,132	1,741

Results

Table 12 shows the number of collisions observed and expected in the Iowa data collection area based on the historical number of collisions (Table 10) and the estimated lengths of barrier and number of installations of terminals (Table 11). As in Connecticut, the estimates of the number of collisions were obtained by taking the number of barrier-related collisions that historically occurred on each type of road (e.g., interstate, US, State) and assigning the number of collisions to specific types of hardware based on the amount of hardware installed in the data collection area. Based on the data from North Carolina shown later in this section, 80 percent of the collisions were expected to involve barriers and 20 percent would involve terminals. The number of cases was then apportioned among the different types of barriers and terminals in each data collection area based on the quantities indicated by the inventory on each type of roadway.

During the 2-year data collection period in Iowa, data about 124 collisions were collected, or approximately two-thirds of the expected number of collisions. The severe injury rate was 10 to 14 percent for the guardrails, 18 percent for the bullnoses, and only 4 percent for the BCTs. Only property damage resulted from 70 to 79 percent of the guardrail and BCT collisions and about 50 percent of the bullnose collisions. There were not enough MELT collisions to draw conclusions about its performance.

The observed number of guardrail collisions was significantly less than the expected number as shown in Table 12, and the observed number of terminal collisions was significantly greater than expected. The difference is probably due to the high ratio of terminals to the length of guardrails installed in the state of Iowa.

Discussion

There were many advantages to performing an in-service evaluation in Iowa. First, the coordination and cooperation between the police agencies and the maintenance agencies are very good. This in turn makes it possible to receive notification from both the police and maintenance agencies, ensuring that cases were not missed. Iowa interstates have milepost markers every 80.5 m (0.05 mi), which makes it relatively easy to identify specific roadside hardware installations. This is exceptionally helpful for identifying minor collisions that

TABLE 12 Number of barrier and terminal collisions expected and observed in the Iowa data collection area

Hardware Type	A+K		Observed Severity B+C		PDO		Total Police Reported		Only Maintenance Reported§	Number Observed	Expected	Error‡
No.	No.	%	No.	%	No.	%	No.	%	No.	No.	No.	%
G1	2	14	1	7	11	79	14	74	5	19	69	67
G4(1W)	1	10	2	20	7	70	10	83	2	12	90	-84
Bullnose	5	18	10	36	13	46	28	67	14	42	7	+500
BCT	1	4	5	21	18	75	24	65	13	37	27	+37
MELT	0	0	1	50	1	50	2	14	12	14	2	+600
Total	9	12	19	24	50	64	78	63	46	124	195	-36

§Collisions that were not reported to the police but were repaired by the maintenance agency are shown as "only maintenance reported" collisions. The severity percentages are calculated based only on the police reported collisions.
‡The error is defined as the number of cases observed minus the number of cases expected divided by the number of cases expected. The value is expressed as a percent.

were reported to the police but resulted in little or no damage. The roadside hardware standards used in Iowa are highly standardized and have been stable for many years, so there tends to be a large quantity of one or two types of hardware. The quality of the installations also tended to be high for the same reason. Iowa is a particularly good place to study terminals, since the proportion of terminals to the length of guardrails installed is very high. This is because most guardrail terminals in Iowa are associated with bridge approaches.

There was, however, one disadvantage to performing an in-service evaluation in Iowa. Roadways in the state, even interstates, experience relatively light traffic volumes so the data collection area had to be quite large in order to sample a sufficient number of cases. The data collection area required to obtain 51 guardrail terminal collision cases in 24 months was very large and required nearly 2 hours to drive from one corner to the other.

Results of the Iowa data collection are discussed further in Chapter Five, "In-Service Performance Evaluation of the BCT and MELT Guardrail Terminals in Iowa and North Carolina"; Chapter Six, "In-Service Performance Evaluation of the Bullnose Median Barrier in the State of Iowa"; and Chapter Seven, "In-Service Performance Evaluation of Post-and-Beam Guardrails in Connecticut, Iowa and North Carolina," not published herein.

NORTH CAROLINA DATA COLLECTION AREA

General Characteristics

The data collection area in North Carolina, shown in Figure 8, is comprised of Durham, Orange, and Wake counties in the 5th and 7th Divisions of the North Carolina DOT (NCDOT). The data collection area is characterized by two major interstate routes (I-40, I-85 and I-440); two large cities (Durham and Raleigh); and three counties with a mixture of urban and rural land use. This three-county area includes approximately 5,600 km of roadway of all functional classes and a range of operating speeds and volumes. Table 13 shows the average traffic volume and number of kilometers of roadway by functional class in the three-county North Carolina study area.

Police Reports

There were 345 police-reported collisions involving barriers and terminals on state-maintained roadways in the North Carolina data collection area in 1995 as shown in Table 14. Like Iowa and Connecticut, over 60 percent of the police reported collisions occurred on the interstate highways even though those highways account for approximately 40 percent of the traffic demand.

Unlike Connecticut and Iowa, it is possible to distinguish between the ends and line-runs of barriers as well as shoulder versus median applications in the North Carolina police-reported data. Overall, 287 crashes involved barrier faces (83 percent) and about 58 involved ends (17 percent) as shown in Table 15. The ratio, however, is very sensitive to the characteristics of the area like land use, topography and design standards. As shown earlier for the Iowa data, it may not apply well in other parts of the country.

The police agencies, in particular the Highway Patrol, were the primary means of notification about barrier collisions. The data collection team regularly contacted every police agency in the data collection area to determine if any collisions had occurred in the study area.

North Carolina uses a standard collision reporting form for all law enforcement agencies in the state, which includes State Highway Patrol, local police, and sheriffs' departments. Unlike Iowa and Connecticut, the North Carolina data collection team received relatively more reports from local agencies since the proportion of interstate roadways was somewhat lower.

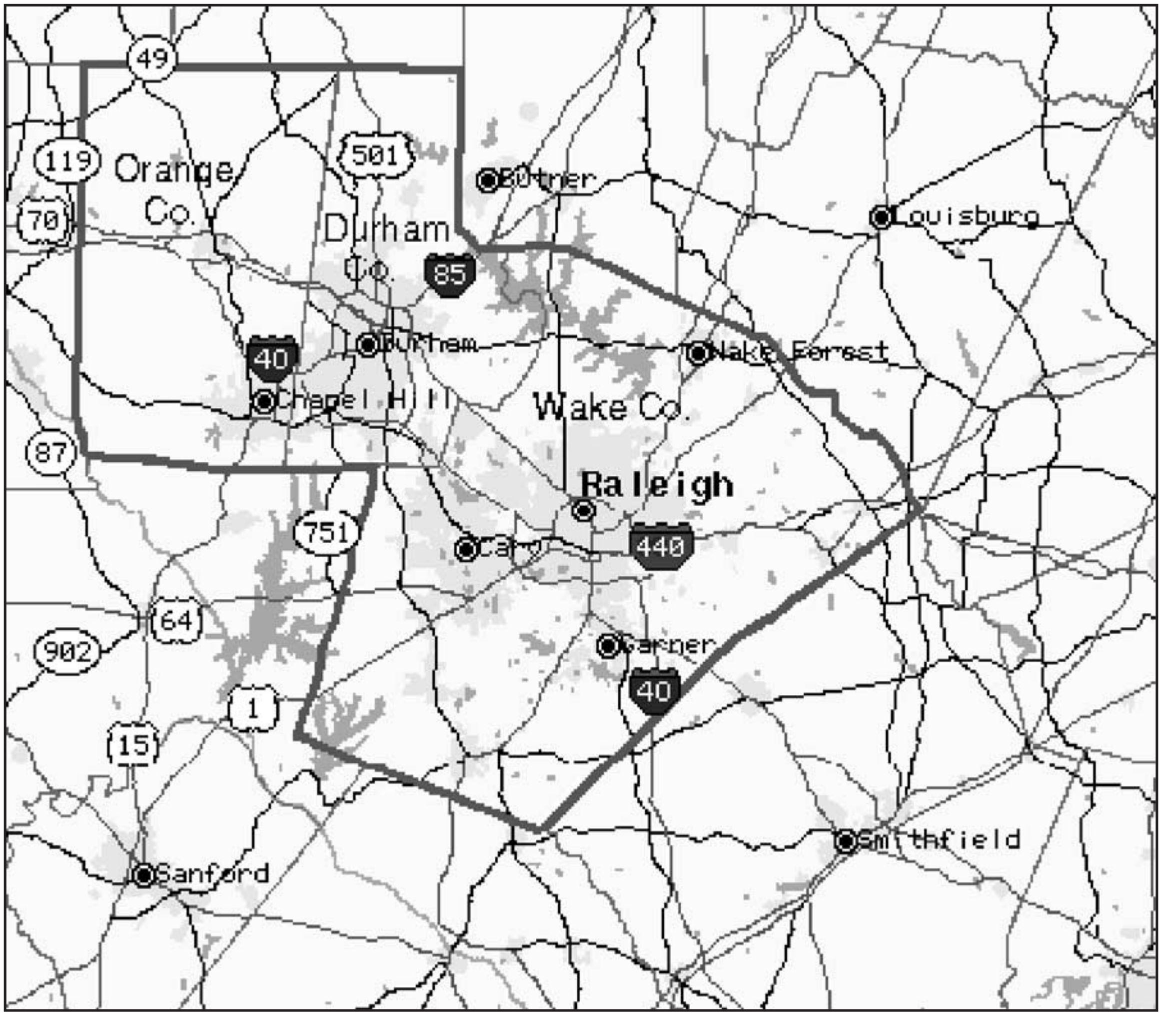


Figure 8. North Carolina data collection area.

Maintenance Reports

As in Iowa and Connecticut, the NC-DOT attempts to recover the cost of repair from motorists who damage guardrail and other pieces of hardware in collisions. Notification of a crash usually occurs from the investigating police agency and a copy of the crash form is sent to the appropriate DOT maintenance garage. If a collision report is available, costs are documented on a form that is sent to a fiscal unit at NC-DOT headquarters. This unit attempts to locate the responsible party. Sometimes private citizens report damages and in some cases maintenance personnel notice the damage in driving along the road. It appears that the cost form mentioned above is not routinely filled out unless there is a reasonable chance to locate the responsible party.

A maintenance supervisor schedules repair, which varies according to the object struck and amount of damage. Crashes on interstate and other primary routes get highest priority. In

TABLE 13 Kilometers of state-maintained roadway and traffic volumes in the North Carolina data collection area

Roadway Type	Kilometers of Roadway Durham	Orange	Wake	Total		Average ADT	Vehicle km Traveled	
	km	km	km	km	%	veh/day	10^9 veh/yr	%
Interstate	8.1	8.4	13.4	29.9	17	53,500	0.58	41
US Highway	14.4	9.8	43.8	67.2	39	21,260	0.52	36
State Highway	20.1	21.0	35.9	77.0	44	11,640	0.33	23
Total	42.6	39.2	93.1	174	100		1.43	100

TABLE 14 Average number and severity of barrier and terminal collisions on state-maintained roads in the North Carolina data collection area (1995)

Severity	Interstate		US		State		Total	
	No.	%	No.	%	No.	%	No.	%
A+K	6	3	4	7	0	0	10	3
B+C	49	22	17	29	20	30	86	25
PDO	165	75	38	64	46	70	249	72
Total	220	100	59	100	66	100	345	100

Division 7 some interstate barrier repair is being done by a private contractor and the division appears to be pleased with the turnaround time. Durham county currently has a contractor in place, and Wake and Orange counties expect to do the same within a few months. Orange County DOT repair crews perform their work. Personnel in both divisions indicated that end treatments are considered items that need timely repair. Barrels are placed at the scene until the repair can be performed. Since contractors are responsible for repair and maintenance, the maintenance supervisors were not as effective a source of notification as they were in Iowa.

Inventory Data

The NC-DOT does not maintain an inventory of roadside hardware. Videologs of state-maintained roadways were considered as a means of collecting inventory information but since the videologs were not up-to-date and it was difficult to recognize different types of hardware (e.g., a MELT versus a BCT), videologs were not used.

Information about the quantities of barrier in place in the North Carolina data collection area was obtained by sampling typical roadways in each functional class. The selected roadways were inventoried by driving the route and recording the types and quantities of hardware. All interstate, U.S., and state routes were driven in Orange county. One complete interstate, U.S., and NC route was driven and inventoried in both Durham and Wake counties. The quantities of W-beam guardrail and associated end treatments were estimated by extrapolating the spot survey data based on the number of kilometers of each functional class in each county.

Table 16 shows an estimate of the total length of barriers and the number of end treatments in place by route type. Overall there are approximately 280 km of W-beam guardrail (G4) in place on Interstate and primary routes. The vast majority is strong post W-beam guardrail with either steel or wood posts (G4(1S) or G4(1W)). The G4(1S) used in North Carolina is shown in the Hardware Guide as a SGR04a (*60*). Besides the strong-post W-beam guardrails, some concrete median and cable guardrail barrier is also present along with a limited amount of thrie beam guardrail (G9). The 12 km of cable guardrail are all on Interstate 40 in Wake county. The total amount of all types of barriers is estimated to be 308 km. Over 50 percent of the guardrail terminals are BCTs, with the majority of these being steel post BCTs. Non-breakaway flared anchors account for another 18 percent and buried-in-backslope terminals account for another 5 percent. There were very few MELTs in place since they were only installed over two construction seasons. The G1 weak-post cable guardrail, the G4(1S) strong-post W-beam guardrail, the BCT, and the MELT were chosen as study systems since they represented the majority of the installed inventory.

Results

The collisions expected and observed in the North Carolina data collection area are summarized in Table 17. The expected number of cases was estimated using the same techniques discussed for the Connecticut and Iowa data collection areas. There were 370 collisions observed during the 2-year data collection. This is about 23 percent fewer cases than were expected based on the historical collision data and the inventory.

TABLE 15 Average number and type of barrier and terminal collisions on state-maintained roads in the North Carolina data collection area (1995)

Barrier Type	Interstate		US		State		Total	
	No.	%	No.	%	No.	%	No.	%
Barrier Faces								
Shoulder guardrails	68	31	31	53	33	50	132	38
Median guardrails	49	22	4	7	5	8	58	17
Median barriers	65	30	9	15	6	9	80	23
Shoulder barriers	11	5	4	7	2	3	17	5
Total	193	88	48	82	46	70	287	83
Barrier ends and terminals								
Shoulder guardrails	15	6	8	14	16	24	39	11
Median guardrails	8	4	2	3	4	6	14	4
Median barriers	2	1	0	0	0	0	2	1
Non-guardrails	2	1	1	1	0	0	3	1
Total	27	12	11	18	20	30	58	17
Grand Total	220	100	59	100	66	100	345	100

TABLE 16 Estimated quantity of barriers and terminals on state-maintained roads in the North Carolina data collection area

Element	Interstate	US	State	Total
Barriers (m)				
G1	12,392	0	0	12,392
G4(1C)	9,249	1,374	610	11,233
G4(2W)	5,752	11,424	38,490	55,666
G4(1S)	94,121	44,490	73,717	212,328
G9	444	482	709	1,635
CMB	15,128	0	0	15,128
Total	137,086	57,770	113,526	308,382
Terminals (installations)				
BCT	386	470	867	1,723
MELT	1	5	8	14
Buried-in-backslope	66	21	77	163
Flared anchor	48	53	484	585
Straight anchor	367	227	115	709
Total	868	776	1,551	3,194

TABLE 17 Number of barrier and terminal collisions expected and observed in the North Carolina data collection area during the 2 years of data collection

Hardware Type	Observed Severity A+K		Observed Severity B+C		Observed Severity PDO		Total Police Reported		Only Maintenance Reported§	Total Observed	Number Expected	Error‡
No.	No.	%	No.	%	No.	%	No.	%	No.	No.	No.	%
G1	1	2	8	13	52	85	61	100	17	78	23	+239
G4(1S)	8	4	61	31	130	65	199	100	0	199	395	-50
BCT	3	5	18	29	41	66	62	100	3	65	63	+3
MELT	1	4	12	44	14	52	27	100	1	28	1	+270
Total	13	4	99	28	237	68	349	100	21	370	482	23

§ Collisions that were not reported to the police but were repaired by the maintenance agency are shown as "only maintenance reported" collisions. The severity percentages are calculated based only on the police reported collisions.

‡ The error is defined as the number of cases observed minus the number of cases expected divided by the number of cases expected. The value is expressed as a percent.

Discussion

The data collection in North Carolina depended primarily on police notification since most maintenance and repair is contracted out. As a result, the team was able to collect a large number of police-reported collisions but the number of maintenance-only reported collisions was very low. The high-traffic volumes experienced in the North Carolina data collection area make it a good place to collect collision data. A large number of cases were collected in a reasonably sized area. While there is not a good linear referencing system in place in North Carolina, the data collection team was able to locate more collisions by working closely with the police agencies.

Results of the North Carolina data collection are discussed further in Chapter Five, "In-Service Performance Evaluation of the BCT and MELT Guardrail Terminals in Iowa and North Carolina," and Chapter Seven, "In-Service Performance Evaluation of Post-and-Beam Guardrails in Connecticut, Iowa and North Carolina," not published herein.

CONCLUSIONS

The different regulatory environments in the three data collection areas created unique problems in obtaining data. In Connecticut, the long delay in obtaining police reports hampered the data collection team from being notified about numerous collisions. When the police report became available, it was often impossible to locate the scene of the collision either because the milepost information was very coarse or the damage was no longer obvious. Obtaining notification through the maintenance agencies was logistically easier but the maintenance agency experienced the same difficulty with long delays in obtaining police reports. In North Carolina, police reports were readily available but maintenance notification was not possible since most repair tasks are accomplished by contractors in North Carolina. This limited the data collection to police-reported collisions. The procedures and regulations in a potential data collection area will often affect the way data can be collected and may have subtle effects on the resulting data.

It is useful when planning an in-service evaluation to be able to estimate the number of collisions that can reasonably be expected in a particular period in a particular area. The method used in this study, proportioning the average number of barrier-related collisions based on the quantity of hardware in place, is probably the best method available but it is only a crude indicator of the number that will actually be sampled.

CHAPTER **4**

PROCEDURES

While there is almost universal agreement on the importance of in-service evaluation for roadside safety appurtenances, the process that should be used has never been formalized. The purpose of this chapter is to describe the procedures manual that was developed in this project and that is recommended for evaluating the performance of a roadside safety feature. The *Procedures Manual for In-Service Performance Evaluation of Roadside Hardware* is included as an appendix to this report.

DEVELOPMENT PROCESS

The procedures used to plan and carry out the Connecticut, Iowa, and North Carolina ISPE study (Phase One) were based on analysis of the studies discussed in the literature review (Chapter Two). They were developed largely by examining the prior in-service evaluations and identifying features and techniques that either did or did not result in a meaningful examination of the performance of an appurtenance. The data collection forms used in Phase One are shown in Figures 9 through 17.

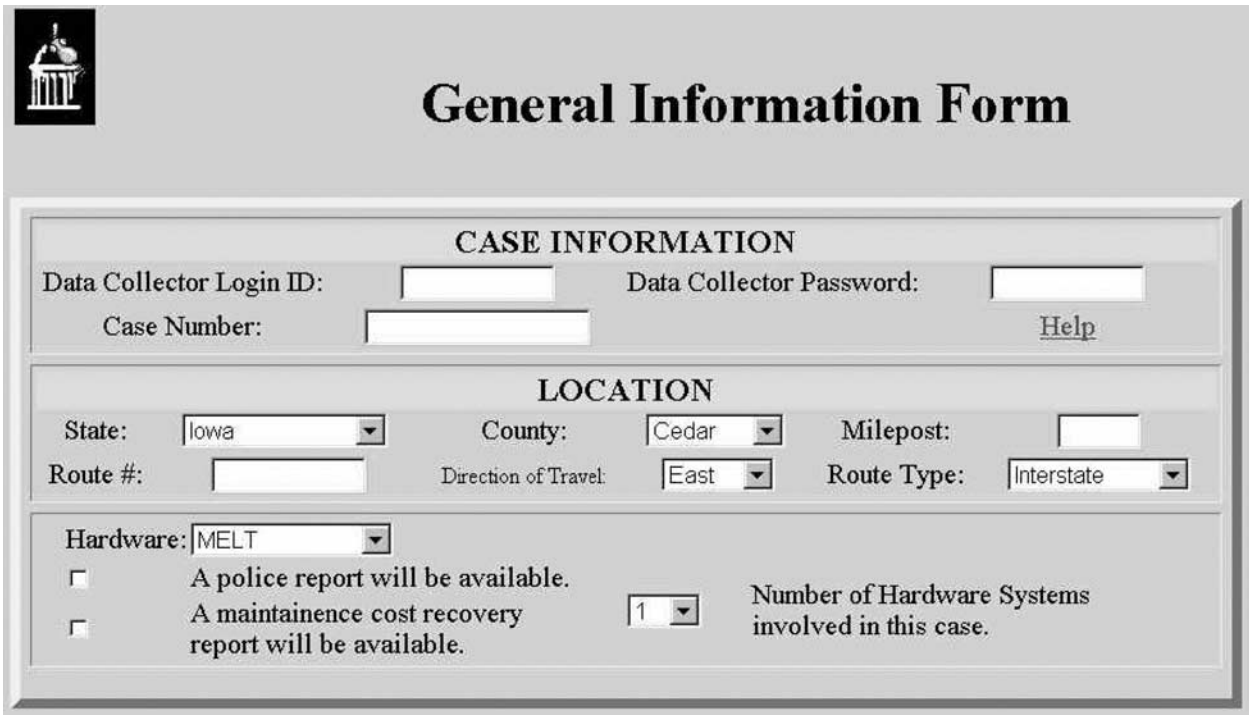
After the Phase One study was complete and the data were analyzed, a draft Procedures Manual was assembled to reflect the procedures and forms used in the Phase One study. These procedures and forms were then modified based on the experience gained from the study. Several iterations of revisions resulted in a “final” draft version of the manual.

In 2000, Saint Martins College began an in-service evaluation of terminals and unrestrained concrete barriers for the Washington State DOT. The Saint Martins project team planned the study and developed data collection forms for it with the assistance of the “final” draft Procedures Manual and the WPI research team. The data collection forms for this study are shown in Appendix B (not published herein). The Saint Martins team also used chapters from the Procedures Manual in training the data collectors, who were WSDOT maintenance personnel. Upon completion of data collection, the Saint Martins team analyzed the data to assess the performance of the hardware, using the Procedures Manual for guidance in their analyses. The principal investigator for the WSDOT study provided a brief critique of the Procedures Manual, included as Appendix C to this report (not published herein).

The Procedures Manual was revised again after receiving the recommendations of the Saint Martins team. The final version appears in Appendix D of this report.

SUMMARY

The recommended procedures in the manual can be used to perform a specific evaluation of a roadside feature or as a long-term part of a safety management system. They were developed with the assumption that in-service evaluations will normally be performed by maintenance workers, DOT engineers, university researchers, and consultants. These procedures are not intended to be in-depth collision reconstruction activities. They are instead intended to be straightforward, routine and therefore easily implementable by any highway professional with basic technical skills. The procedures are based on techniques that have been used effectively in in-service performance evaluations as well as other collision data studies, and they have been tested in the field and refined by the project team to address the needs and concerns of actual evaluation studies.


General Information Form

CASE INFORMATION

Data Collector Login ID: Data Collector Password:

Case Number: Help

LOCATION

State: Iowa County: Cedar Milepost:

Route #: Direction of Travel: East Route Type: Interstate

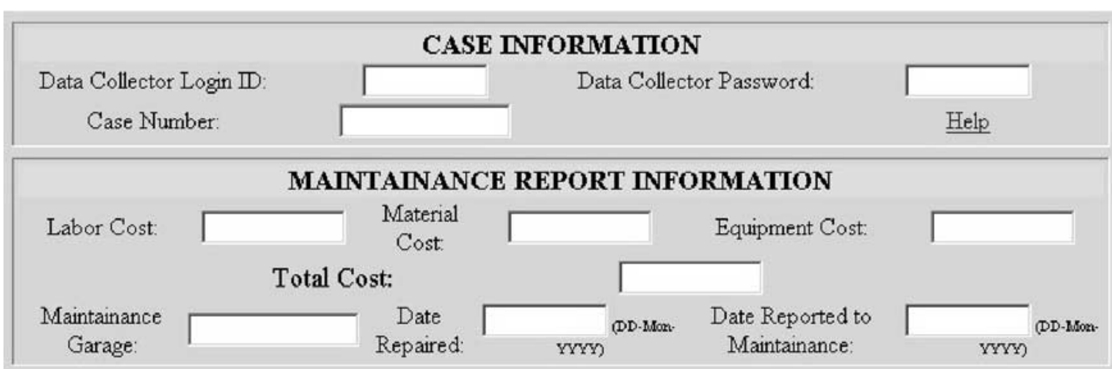
Hardware: MELT

A police report will be available.

A maintainence cost recovery report will be available.

1 Number of Hardware Systems involved in this case.

Figure 9. General Information form.


CASE INFORMATION

Data Collector Login ID: Data Collector Password:

Case Number: Help

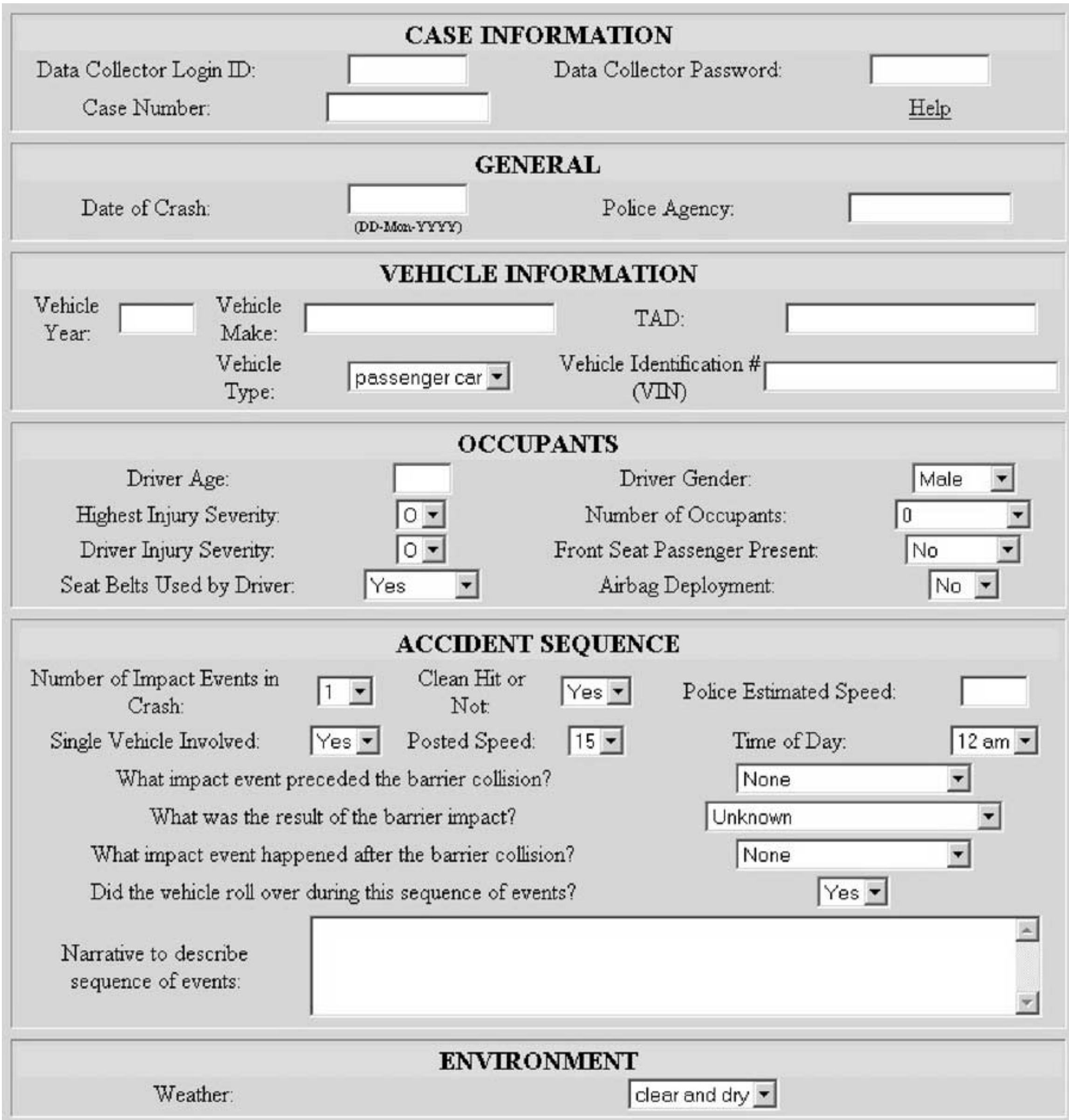
MAINTAINANCE REPORT INFORMATION

Labor Cost: Material Cost: Equipment Cost:

Total Cost:

Maintainance Garage: Date Repaired: (DD-Mon-YYYY) Date Reported to Maintainance: (DD-Mon-YYYY)

Figure 10. Maintenance Cost Report form.



CASE INFORMATION

Data Collector Login ID: Data Collector Password:

Case Number: Help

GENERAL

Date of Crash: (DD-Mon-YYYY) Police Agency:

VEHICLE INFORMATION

Vehicle Year: Vehicle Make: TAD:

Vehicle Type: passenger car Vehicle Identification # (VIN)

OCCUPANTS

Driver Age: Driver Gender: Male

Highest Injury Severity: O Number of Occupants: 0

Driver Injury Severity: O Front Seat Passenger Present: No

Seat Belts Used by Driver: Yes Airbag Deployment: No

ACCIDENT SEQUENCE

Number of Impact Events in Crash: 1 Clean Hit or Not: Yes Police Estimated Speed:

Single Vehicle Involved: Yes Posted Speed: 15 Time of Day: 12 am

What impact event preceded the barrier collision? None

What was the result of the barrier impact? Unknown

What impact event happened after the barrier collision? None

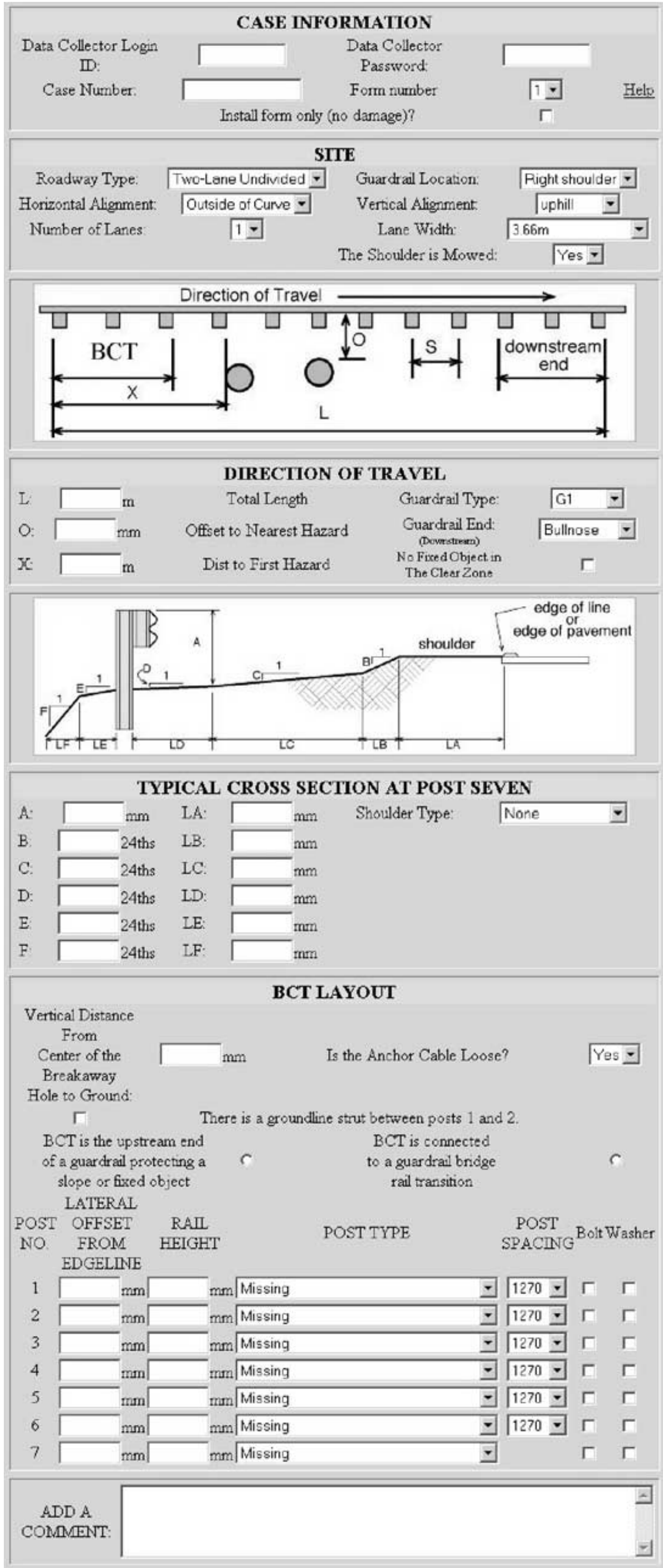
Did the vehicle roll over during this sequence of events? Yes

Narrative to describe sequence of events:

ENVIRONMENT

Weather: clear and dry

Figure 11. Police Report form.



CASE INFORMATION

Data Collector Login ID: | Data Collector Password:
Case Number: | Form number 1 | Help
Install form only (no damage)?

SITE

Roadway Type: Two-Lane Undivided | Guardrail Location: Right shoulder
Horizontal Alignment: Outside of Curve | Vertical Alignment: uphill
Number of Lanes: 1 | Lane Width: 3.66m
The Shoulder is Mowed: Yes

DIRECTION OF TRAVEL

L: m Total Length | Guardrail Type: G1
O: mm Offset to Nearest Hazard | Guardrail End: (Downstream) Bullnose
X: m Dist to First Hazard | No Fixed Object in The Clear Zone

TYPICAL CROSS SECTION AT POST SEVEN

A: mm | LA: mm | Shoulder Type: None
B: 24ths | LB: mm
C: 24ths | LC: mm
D: 24ths | LD: mm
E: 24ths | LE: mm
F: 24ths | LF: mm

BCT LAYOUT

Vertical Distance From Center of the Breakaway Hole to Ground: mm | Is the Anchor Cable Loose? Yes

There is a groundline strut between posts 1 and 2.

BCT is the upstream end of a guardrail protecting a slope or fixed object | BCT is connected to a guardrail bridge rail transition

POST NO.	LATERAL OFFSET FROM EDGELINE	RAIL HEIGHT	POST TYPE	POST SPACING	Bolt	Washer
1	mm	mm	Missing	1270		
2	mm	mm	Missing	1270		
3	mm	mm	Missing	1270		
4	mm	mm	Missing	1270		
5	mm	mm	Missing	1270		
6	mm	mm	Missing	1270		
7	mm	mm	Missing			

ADD A COMMENT:

Figure 12. BCT Installation form.

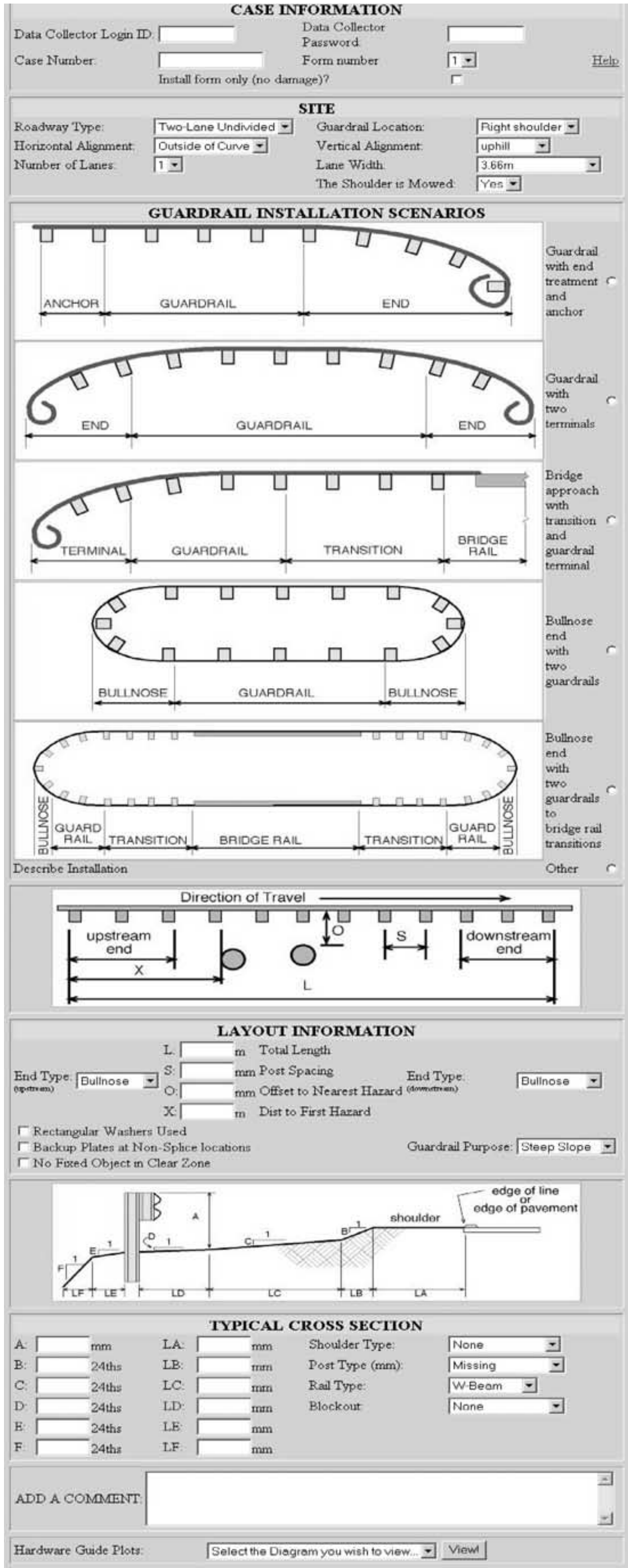


Figure 13. Guardrail Installation form.

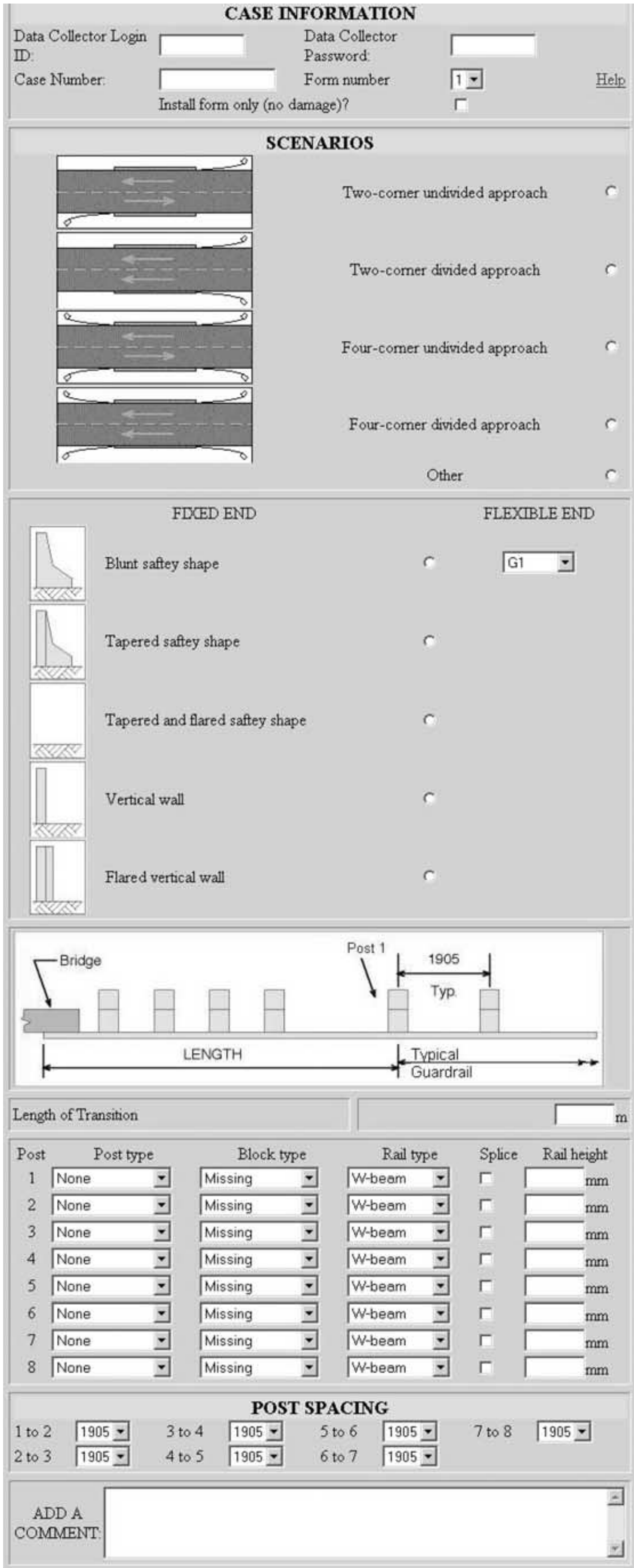
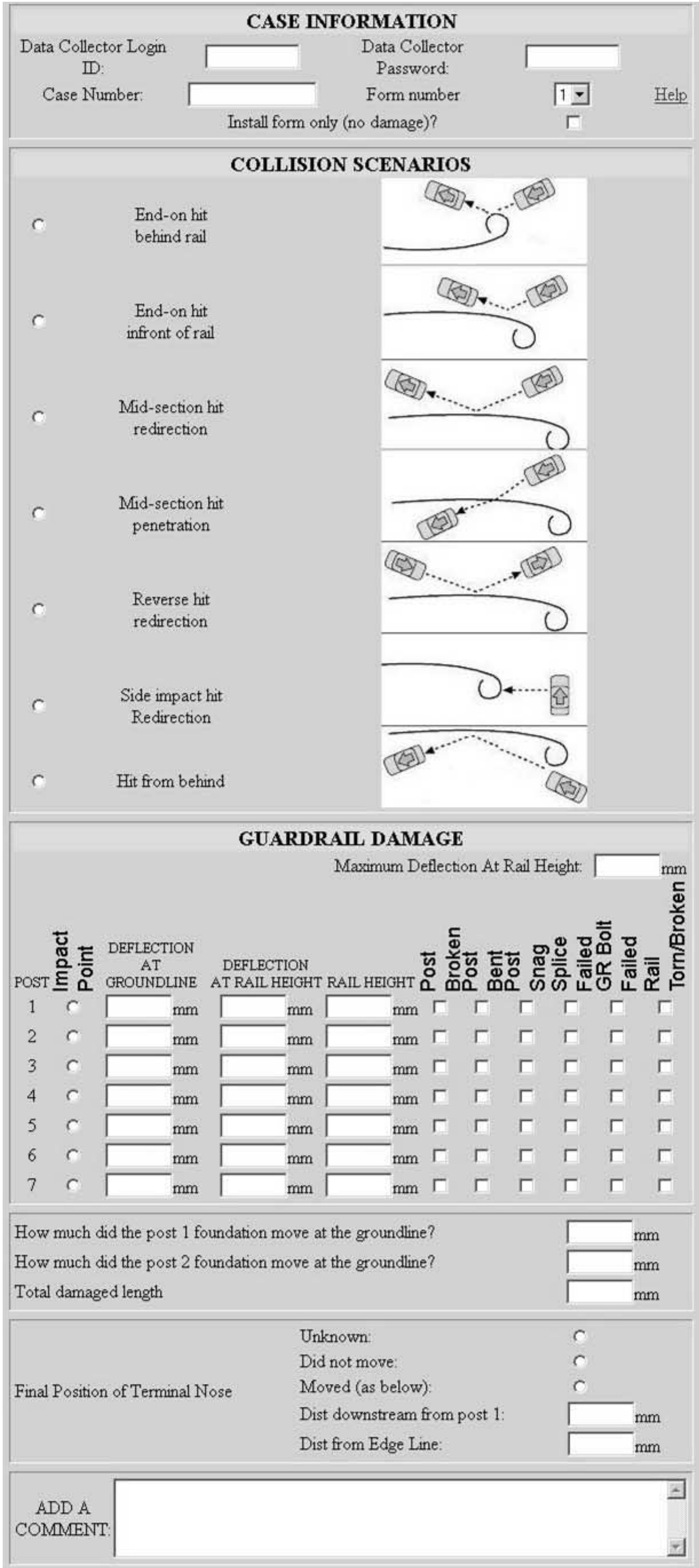


Figure 14. Transition Installation form.



CASE INFORMATION

Data Collector Login ID: | Data Collector Password: | Case Number: | Form number 1 | Help

Install form only (no damage)?

COLLISION SCENARIOS

End-on hit behind rail

End-on hit infront of rail

Mid-section hit redirection

Mid-section hit penetration

Reverse hit redirection

Side impact hit Redirection

Hit from behind

GUARDRAIL DAMAGE

Maximum Deflection At Rail Height: mm

POST	Impact Point	DEFLECTION AT GROUNDLINE	DEFLECTION AT RAIL HEIGHT	RAIL HEIGHT	Post	Broken Post	Bent Post	Snag Splice	Failed GR Bolt	Failed Rail	Torn/Broken
1		mm	mm	mm							
2		mm	mm	mm							
3		mm	mm	mm							
4		mm	mm	mm							
5		mm	mm	mm							
6		mm	mm	mm							
7		mm	mm	mm							

How much did the post 1 foundation move at the groundline? mm

How much did the post 2 foundation move at the groundline? mm

Total damaged length mm

Final Position of Terminal Nose

Unknown:

Did not move:

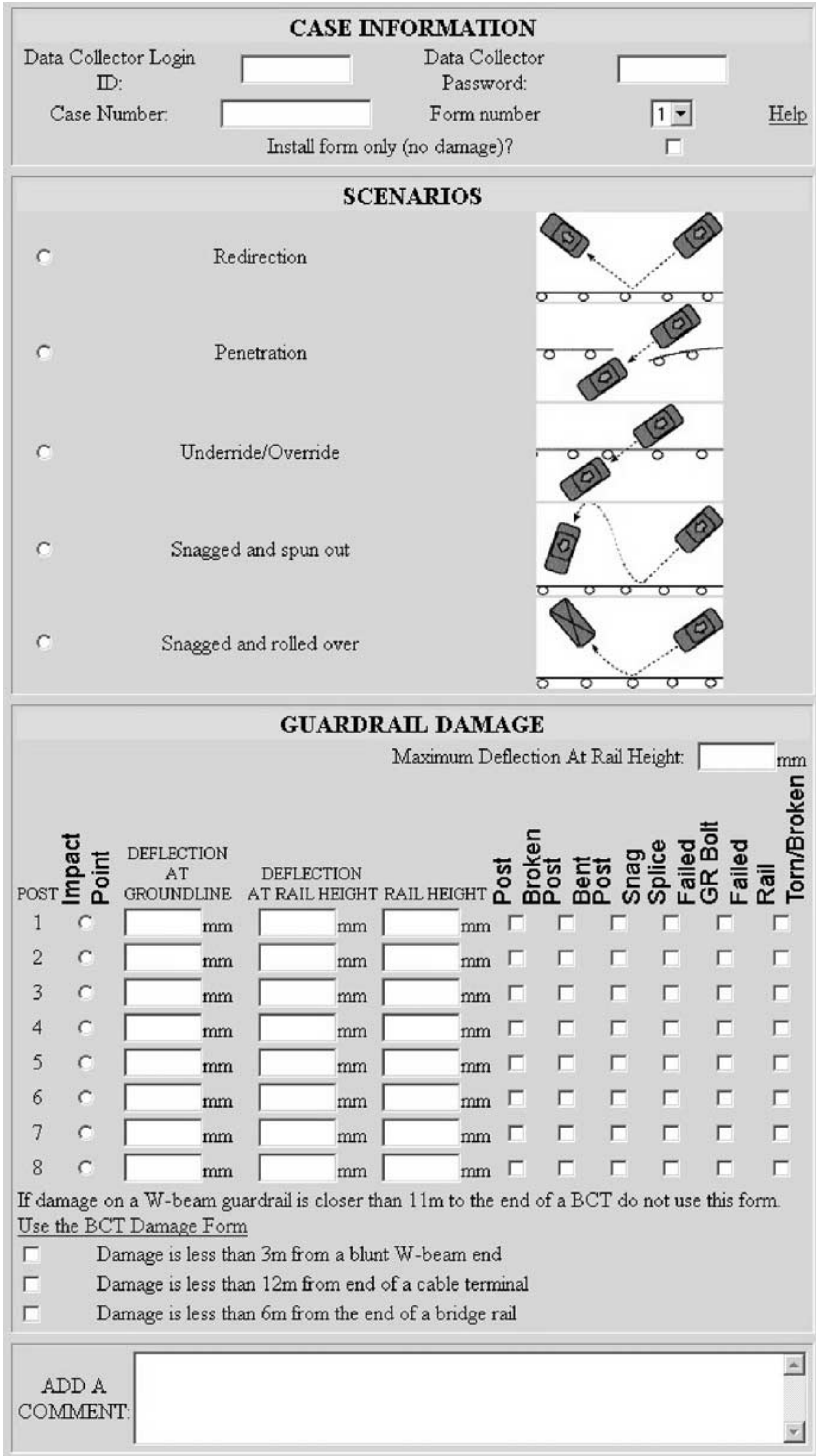
Moved (as below):

Dist downstream from post 1: mm

Dist from Edge Line: mm

ADD A COMMENT:

Figure 15. BCT Damage form.



CASE INFORMATION

Data Collector Login ID: | Data Collector Password:

Case Number: | Form number 1 | Help

Install form only (no damage)?

SCENARIOS

Redirection

Penetration

Underride/Override

Snagged and spun out

Snagged and rolled over

GUARDRAIL DAMAGE

Maximum Deflection At Rail Height: mm

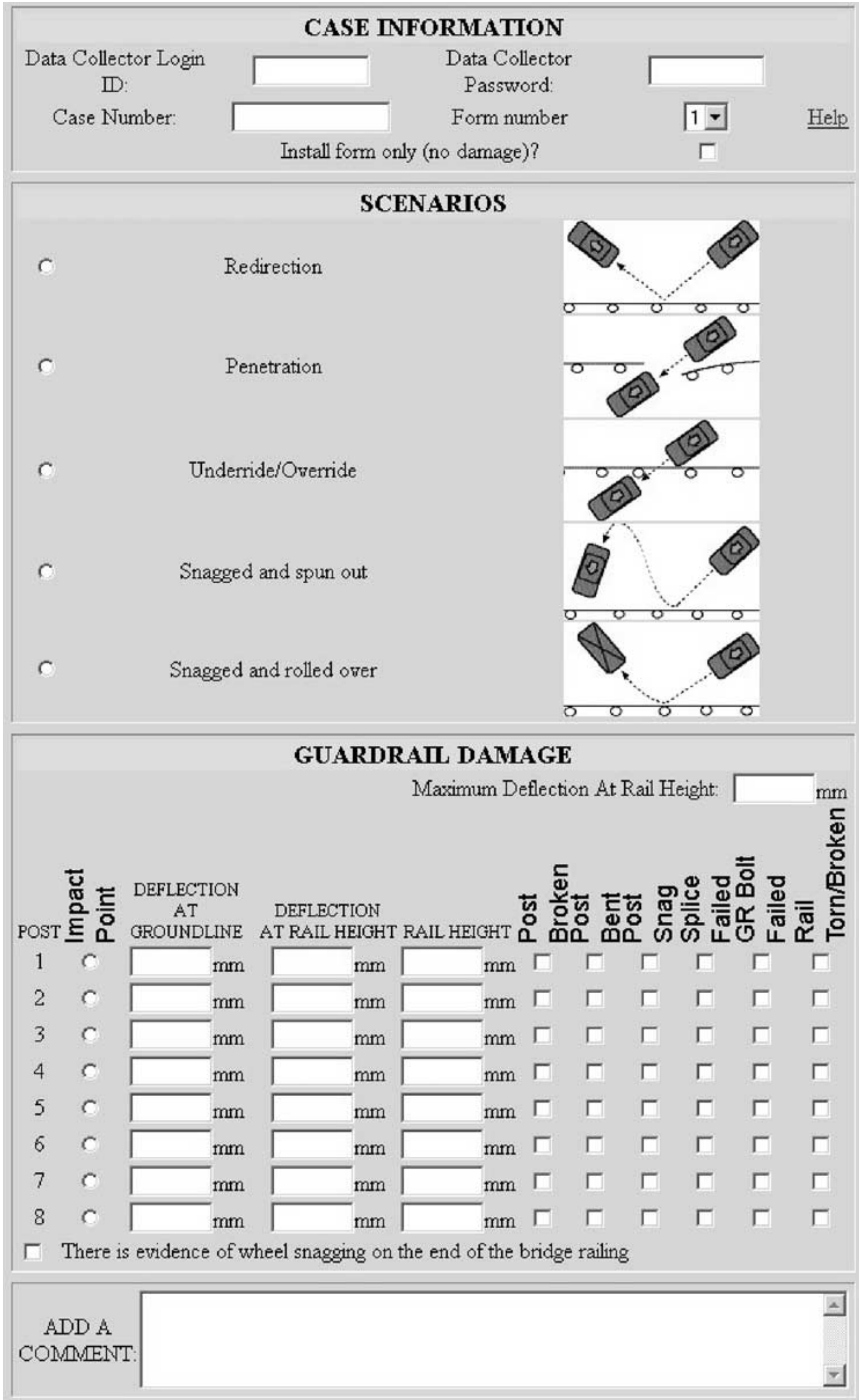
POST	Impact Point	DEFLECTION AT GROUNDLINE	DEFLECTION AT RAIL HEIGHT	RAIL HEIGHT	Post	Broken Post	Bent Post	Snag Splice	Failed GR Bolt	Failed Rail Torn/Broken
1		mm	mm	mm						
2		mm	mm	mm						
3		mm	mm	mm						
4		mm	mm	mm						
5		mm	mm	mm						
6		mm	mm	mm						
7		mm	mm	mm						
8		mm	mm	mm						

If damage on a W-beam guardrail is closer than 11m to the end of a BCT do not use this form. Use the BCT Damage Form

- Damage is less than 3m from a blunt W-beam end
- Damage is less than 12m from end of a cable terminal
- Damage is less than 6m from the end of a bridge rail

ADD A COMMENT:

Figure 16. Guardrail Damage form.



CASE INFORMATION

Data Collector Login ID: [ ] Data Collector Password: [ ]

Case Number: [ ] Form number 1 Help

Install form only (no damage)? ☐

SCENARIOS

- ○ Redirection
- ○ Penetration
- ○ Underride/Override
- ○ Snagged and spun out
- ○ Snagged and rolled over

GUARDRAIL DAMAGE

Maximum Deflection At Rail Height: [ ] mm

POST	Impact Point	DEFLECTION AT GROUNDLINE	DEFLECTION AT RAIL HEIGHT	RAIL HEIGHT	Post	Broken Post	Bent Post	Snag Splice	Failed GR Bolt	Failed Rail	Torn/Broken
1	○	mm	mm	mm	☐	☐	☐	☐	☐	☐	
2	○	mm	mm	mm	☐	☐	☐	☐	☐	☐	
3	○	mm	mm	mm	☐	☐	☐	☐	☐	☐	
4	○	mm	mm	mm	☐	☐	☐	☐	☐	☐	
5	○	mm	mm	mm	☐	☐	☐	☐	☐	☐	
6	○	mm	mm	mm	☐	☐	☐	☐	☐	☐	
7	○	mm	mm	mm	☐	☐	☐	☐	☐	☐	
8	○	mm	mm	mm	☐	☐	☐	☐	☐	☐	

☐ There is evidence of wheel snagging on the end of the bridge railing

ADD A COMMENT: [ ]

Figure 17. Transition Damage form.

CHAPTERS **5, 6, 7, and 8**

UNPUBLISHED MATERIAL

Chapter 5, “In-Service Performance Evaluation of the BCT and MELT Guardrail Terminals in Iowa and North Carolina”; Chapter 6, “In-Service Performance Evaluation of the Bullnose Median Barrier in the State of Iowa”; Chapter 7, “In-Service Performance Evaluation of Post-and-Beam Guardrails in Connecticut, Iowa, and North Carolina”; and Chapter 8, “Videolog Assessment of Vehicle Collision Frequency with Concrete Median Barriers on an Urban Highway in Connecticut” are not published herein. For a limited time, they are available for loan by the NCHRP.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The preceding chapters of this report have presented results of a research project on the in-service performance evaluation of common traffic barriers. The first chapter addressed the importance and utility of performing in-service performance evaluations as a normal part of the roadside feature development and assessment process. A survey and literature review were presented in the second chapter to assess methods and procedures used in other studies. The third chapter documented the data collection for an in-service evaluation performed in portions of the states of Connecticut, Iowa, and North Carolina. The fourth chapter outlined the recommended procedures based on what had been used successfully in earlier studies. The fifth, sixth, and seventh chapters presented the results of these data collection efforts by describing the performance of the BCT and MELT guardrail terminals, the bullnose median treatment, and post-and-beam guardrails, respectively. The in-service performance of these roadside features was examined by collecting collision, maintenance, and inventory information in the three data collection areas. These official sources of information were supplemented with visits to the collision sites, generally within a day or two of the collision, to make measurements of the damaged barrier and document the collision scene using photographs. This concluding chapter briefly summarizes the findings and recommendations of this research.

LITERATURE REVIEW

Historical studies, the predecessor to in-service evaluations, are documented in the literature as far back as the early 1970s. These studies usually use police crash reports to examine the performance of existing devices. Historical studies are valuable in evaluating existing devices, but since states often require data on the performance and cost-effectiveness of newer devices, DOTs have conducted various types of collision studies since at least the late 1970s. While a historical study is performed retroactively (e.g., looking through records of past collisions), a collision study is performed as collisions occur. Maintenance personnel as well as police officers are generally involved in the data collection, and costs associated with the installation and maintenance of the devices may be recorded by maintenance personnel. Ten historical studies and 14 collision studies were found in the literature. Some of the better studies include an examination of the turned-down end terminal in Texas and a study of weak-post guardrail, sign and luminaire supports, and impact attenuation devices in New York *(17, 23)*. The earliest study report was an investigation of collisions associated with highway bridges and overpasses in the state of Kentucky in 1975 (*11*).

Historical and collision studies are relatively easy to conduct but they have several inherent weaknesses. First, they are limited to police-reported collisions, so many less-severe collisions where the device performs correctly are not included. Relying on only police-reported collisions to judge the performance of a roadside feature biases the evaluation toward more severe collisions and collisions where the feature did not perform correctly. Second, the collision sites are usually not visited so it is often difficult or impossible to know exactly what type of device was struck and whether the device was properly installed. Third, traffic data are seldom included in a historical or collision study so the actual exposure to collision events is usually not known.

In-service performance evaluations evolved from collision studies as a means of correcting some of the shortcomings discussed above. Data are collected soon after a collision occurs and include visits to the collision sites to document the installation and site characteristics. Police- and maintenance-reported data typically used in a historical collision study are also usually collected in an in-service performance evaluation. An in-service evaluation typically requires the development of a comprehensive, standardized reporting form to be used by those collecting information from site visits. These forms contain information about the type of roadside feature, site characteristics, and collision results that are not normally included in a police or maintenance collision report. These forms are usually distributed to police, maintenance workers, or third-party contractors as supplementary documentation to those responsible for documenting collisions. Seventeen in-service evaluation studies were found in the literature. Some of the better studies include an examination of the ET-2000 in Ohio and a study of weak-post and strong-post guardrails in New York *(52, 4)*.

A variety of procedures and techniques have been used to perform historical and collision studies and in-service performance evaluations. One early Connecticut study attempted to use cameras mounted along selected highways to collect information about collisions *(55, 56)*. Although this early study failed to achieve its objectives, it was an interesting attempt to use an innovative method to observe collisions in the field. Most studies have relied on police-reported collision data and the field procedures used to collect such data. Perhaps the most sophisticated variations of such procedures are represented by the National Accident Sampling System procedures. These procedures have been used as a model for collecting many types of on-site data including the geometry of the site, the result of the collision, notification procedures and sampling techniques. The NASS Longitudinal Barrier Special Study (LBSS) is a particular example of detailed data collection activity focused on guardrails *(57)*.

The most common problem identified in earlier studies is small sample size. Collecting an adequate number of cases is difficult for several reasons. First, in-service evaluations require personnel and funding resources and often the resources allocated for examining the field performance of roadside hardware are not adequate. Second, an in-service evaluation requires closely monitoring an often large geographic area for a substantial amount of time. Sometimes organizations have failed to follow a study through to the end due to the logistic difficulties entailed and the time required. Third, many in-service evaluations have been attempted with an inadequate amount of hardware installed in the field. The small number of devices installed can greatly limit the number of possible cases that can be collected.

Another frequently observed problem with prior studies was an imprecise sampling plan. In order to preserve the statistical validity of the sample, the data collection needs to be associated with a well-defined geographic area and a clearly defined period of time. Sampling plans that are ad hoc or serendipitous result in data that cannot be used to make statistical inferences. A consistent method for notification about collisions in a specific area during a specific period of time is one of the key components to developing a successful in-service performance evaluation study.

Documenting the characteristics of the roadside features involved in a collision is another, often neglected aspect of performing an in-service evaluation. Studies have often been performed where critical features of the barrier system had to be assumed based on what should have been built according to design standards or bid documents. Unfortunately, hardware is not always installed according to the appropriate design standards, sometimes systems are not well maintained or repaired, and sometimes changes are made in the field that are not noted in the documents filed at headquarters. It is, therefore, a poor practice to assume the characteristics of roadside hardware based on design standards and maintenance procedures. In many states, it is difficult to even determine what type of barrier was struck from the police or maintenance data. Visits to the collision sites are the only means of determining if the hardware was correctly installed and maintained.

When data are collected based on police-reported collisions, information about the many unreported events is lost. If a roadside object performs correctly, the accident is not severe and no one is seriously injured. Such collisions are often not reported. The performance of a roadside feature cannot be adequately addressed without accounting in some way for unreported collisions. Unfortunately, documenting such collisions is very time-consuming and inexact.

Lastly, the issue of collision exposure has been a serious shortcoming of most in-service performance evaluations performed in the past. One method for indirectly accounting for unreported events is to base collision rates on the exposure to traffic. If, for example, the number of injury collisions per million vehicle-km traveled past a barrier is calculated, the unreported events are at least indirectly included in the overall exposure to collision events. This requires that basic traffic data be collected as well as police-reported collision data and on-site data.

In-service evaluations have been recognized as an important part of the development of roadside devices but finding a way to successfully integrate in-service evaluation into the process has been difficult. Full-scale crash testing can only provide information about the performance of a device under ideal installation conditions and prescribed impact conditions, whereas an in-service evaluation can provide essential information about how roadside features perform under actual field conditions.

DATA COLLECTION AREAS

Three pilot in-service evaluation projects were performed in portions of Connecticut, Iowa, and North Carolina. The different regulatory environments in the three data collection areas created unique problems and opportunities in obtaining data. In Connecticut, the long delay in obtaining police reports hampered the data collection team from being notified about numerous collisions. When the police report became available, it was often impossible to locate the scene of the collision either because the milepost information was very coarse or the damage was no longer obvious. On the other hand, there was a great deal of hardware installed on high-volume roadways such that many cases could be collected. Obtaining notification through the maintenance agencies was logistically easier but the maintenance agency experienced the same difficulty with long delays in obtaining police reports. In North Carolina, police reports were readily available but maintenance notification was not possible since most repair tasks are accomplished by contractors in North Carolina. This limited the data collection to police-reported collisions. The police and maintenance agencies in Iowa were very cooperative and helpful but the rural nature of the area resulted in a large data collection area with relatively modest traffic volume which limited the number of cases that could be collected. The procedures and regulations in a potential data collection area will often affect the way data can be collected and may have subtle effects on the resulting data.

It is useful when planning an in-service evaluation to be able to estimate the number of collisions that can reasonably be expected in a particular period in a particular area. The method used in this study, proportioning the average number of guardrail-related collisions based on the quantity of hardware in place, is probably the best method available but, as experienced in these three pilot studies, it is only a crude indicator of the number that will actually be sampled.

PROCEDURES

While there is almost universal agreement on the importance of in-service evaluation for roadside safety appurtenances, the process that should be used has never been formalized. Chapter Four describes the process that was used in this study and that is recommended for evaluating the performance of a roadside safety feature. These recommendations have been developed largely by examining prior in-service evaluations and identifying features and techniques that either did or did not result in a meaningful examination of the performance of an appurtenance.

The procedures described in Chapter Four can be used as a general framework for developing and performing an in-service performance evaluation of a roadside feature. They are based on techniques that have been used in other in-service performance evaluations as well as other collision data studies. Many specific procedures were borrowed from the NASS General Estimates Systems as well as the Longitudinal Barrier Special Studies. The procedures are intended to be used by design and maintenance engineers and do not require that the collisions be reconstructed. The procedures could be implemented into the routine operations of many roadway maintenance organizations and used as an on-going management tool.

Most in-service evaluations will require specific procedures for the following:

- Being notified when crashes occur,
- Collecting on-site data,
- Obtaining police crash report information,
- Obtaining traffic data,
- Obtaining maintenance and repair information, and
- Performing analysis of the data.

The procedures provided in Chapter Four should provide a good basis for developing the specific procedures needed to perform an in-service evaluation study.

BCT AND MELT TERMINALS

Chapter Five examined the in-service installation and performance of BCT and MELT terminals in the Iowa and North Carolina data collection areas, based on data collected between July of 1997 and June of 1999. There were approximately 600 BCTs and 50 MELTS on state-maintained roads in the Iowa study area and a similar number in the North Carolina study area. During the study period, all police-reported and maintenance-reported collisions in the study areas that involved either type of guardrail terminal were investigated. Along with collision data, information regarding the pre-impact characteristics of the systems was collected to determine how closely the terminals in the field corresponded to the crash-tested designs. Installation information was also collected for all BCT installations along a 35.8-km long section of the eastbound lanes of I-80 in Johnson County. During the 24-month data collection period, a total of 169 MELT and BCT cases, including 144 collision cases, were collected.

Past in-service performance evaluations of the BCT and MELT terminals have revealed that the terminals were often not installed and maintained in a manner consistent with the crash-tested designs. Terminals in place may not perform as designed due to inadequate offsets, incorrect flare, and other installation flaws. Performance data reported in the literature is, therefore, not necessarily representative of the crash-tested designs unless quality of installation is taken into account. To address this need, one of the sections of this chapter presented a method for quantifying the quality of BCT and MELT installation. The data collected showed that the proportion of properly installed terminals in the study areas was very high, and it was determined that good or excellent installations can routinely be achieved if the DOT is proactive in ensuring that BCT and MELTs are carefully constructed. The installation quality score can be used to identify poorly installed or maintained installations that should be upgraded, or as an acceptance criterion to ensure that installation and repair contractors perform quality work.

The in-service collision performance data for the BCT and MELT guardrail terminals in the study areas indicate that in general, these terminals are performing reasonably well. Over 60 percent of the 115 police-reported MELT and BCT collisions resulted in only property damage, and only five involved severe occupant injuries. The analysis showed that when side impacts occur in the field, they tend to result in very serious occupant injury. Another problem is the unexpectedly large number of cases with some evidence of guardrail tearing, which may indicate that standard 12-gauge guardrail splice is performing at its limit in the field.

Finally, it was shown that about 90 percent of collisions with BCT terminals are minor collisions that result in little property damage, no occupant injury and are not reported to the police. Although one collision event occurs for every four million vehicles that pass a BCT terminal, collisions serious enough to be reported to the police occur on average only once for every 68 million vehicles passing the installations.

The data analyses indicated that the BCT and MELT terminals are performing reasonably well in Iowa and North Carolina. These analyses, however, are limited by a modest number of cases and the conclusions may require revision as more data are collected. Both Iowa and North Carolina have many years of experience in using these terminals and the proportion of properly installed terminals was very high. A state with a larger number of poorly installed and maintained BCT and MELT terminals cannot expect to replicate these results, since poorly installed systems have been shown to result in unsatisfactory performance *(38, 39, 44).*

BULLNOSE MEDIAN BARRIERS

The in-service performance evaluation of bullnose median treatments in a portion of Iowa involved collecting information about bullnose collisions from field investigations, police reports, and maintenance records. These sources of information indicated that the bullnose installations in the data collection area were usually installed consistent with Iowa DOT policy and represented good quality installations. While the dataset for this study was small (42 police and maintenance-reported cases and 38 unreported events), an examination of the characteristics of the collisions suggests that impacts at and near the nose often result in unacceptable penetrations or overrides. Collisions at the nose resulted in serious or fatal injuries in one-third of the cases. While the bullnose does not appear to be particularly effective in nose and near-nose collisions it is unclear whether any other median treatment would result in better performance. These data suggest that there is a need to develop median treatments that prevent vehicles from penetrating the system and contributing to injuries of vehicle occupants. One collision event occurs for every 0.13 vehicle-kilometers traveled past a bullnose median barrier, and collisions serious enough to be reported to the police occur on average once for every 5.18 million vehicle-km traveled past the installations.

GUARDRAILS

Chapter Seven described a preliminary analysis of the data collected in an in-service performance evaluation of the G1, G2, G4(1W), and G4(1S) guardrails in Connecticut, Iowa, and North Carolina. Passenger cars dominated the in-service collision data, and there were significant differences between the data collection areas with respect to the percentage of large trucks involved in collisions.

Past studies have indicated some concern about the ability of the G2 guardrail to safely contain and redirect large vehicles *(62)*. Of the 15 cases included in this evaluation in which a pickup, SUV, or tractor-trailer impacted a G2 guardrail, there was one override and one penetration, neither resulting in occupant injuries. Overall, the G2 performed well.

Almost 75 percent of the police-reported guardrail collisions resulted in only property damage. Thirteen of the 400 police-reported collisions involved severe occupant injuries or fatalities. Within the limits of the data collected to date, there was no statistically significant difference between the performance of the guardrails in the three states, and there was no difference between the performance of the G1 and G2 or the G1 and G4(1W). However, occupant injuries were less common in collisions with a G1 guardrail than in collisions with the G4(1S) or both G4 types combined. Damage to the guardrail was also generally less severe in G1 collisions than in G4 collisions.

Past studies have also indicated a concern about the effects of rail height on barrier performance. This study confirmed that rail height is an important factor in the collision performance of G1 and G4(1S) guardrails.

On average, collision events occur once for every 5.4 vehicle-kilometers traveled past a G1 guardrail, once for every 11.1 vehicle-kilometers traveled past a G2 guardrail, and once for every 1.2 vehicle-kilometers traveled past a G4 guardrail. Collisions serious enough to be reported to the police occur on average once for every 10 million vehicle-km traveled past the G1 installations, once for every 13.7 million vehicle-km traveled past the G2 installations, and once for every 15.6 million vehicle-km traveled past the G4 installations. In general, collision events with guardrails occur once for every 6.7 million vehicle-km traveled past a guardrail and police-reported collisions occur once for every 13 million vehicle-km traveled past the installations**.**

RECOMMENDATION

The pilot studies discussed in this report have demonstrated that in-service performance evaluations can yield useful information about the field performance of roadside features. This performance data can be used to assess how effectively roadside safety resources are being used. If such information were available, decisions on upgrading roadside hardware, changing design standards or developing new hardware could be based on observations made in the field rather than on intuition and judgement. The procedures and pilot studies discussed in this report also show that it is possible to obtain useful data using relatively simple procedures and maintenance personnel. While intensive studies based on collision reconstructions might be useful tools, they would be too costly and labor-intensive for most typical state DOTs.

In-service performance evaluations should be integrated more fully into the overall cycle of design, test and evaluation of roadside hardware. The procedures discussed and demonstrated in this report can be used by states as a basis for performing an in-service performance evaluation. The results of such evaluations will allow state DOTs to develop policy and maintenance procedures based on observable field phenomena rather than speculation and conjecture.

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APPENDIX A

BIBLIOGRAPHY

INTRODUCTION

The following pages contain a list of reports and papers concerning in-service performance evaluations of roadside safety features. The reports are arranged first by the general type of feature discussed in the report (e.g., bridge railings, guardrails, guardrail terminals, median widths, etc.). Reports addressing specific systems are listed chronologically within each general barrier category. If several devices are addressed in one report, the report is listed several times, once for each type of device. In addition to reports of specific in-service evaluations, reports and papers providing recommendations for performing in-service evaluations are included in the "Procedures and Recommendations" section.

BRIDGE RAILS

Frangible-Tube Bridge Railing

K.R. Lane, "An Energy Absorbing Frangible-Tube Bridge Barrier System - FINAL REPORT," Report No. 361-F-77-2, Connecticut DOT, Wethersfield, Connecticut, April 1977.

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CRASH CUSHIONS

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation