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Title: SAFETY EFFECTIVENESS OF UPGRADING GUARDRAIL TERMINALS TO REPORT 350 STANDARDS

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ABSTRACT

Developing safe and effective guardrail terminals has been a high priority for roadside safety researchers for several decades. Numerous full-scale crash tests have been performed and many types of new terminals have been developed . In recent years the Federal Highway Administration formalized the evaluation and certification process for roadside safety hardware with the net result that all guardrail terminals to be used on the National Highway System must now satisfy the full-scale crash test and evaluation requirements of National Cooperative Highway Research Program Report 350. While there is no doubt that newer guardrail terminals are characterized by better full-scale crash test performance, it is less clear how relevant such improvement is to a reduction in serious and fatal injuries in real-world guardrail terminal collisions. The purpose of this paper is to examine several in-service performance evaluations of guardrail terminals and determine if upgrading guardrail terminals to NCHRP Report 350 standards can be expected to result in a reduction in serious and fatal injury accidents.

KEYWORD

Roadside safety, in-service performance evaluation, guardrail terminals, Report 350.

INTRODUCTION

In 1991 the United States Congress passed the Intermodal Surface Transportation and Efficiency Act (ISTEA).*(1)* In Section 1073 of the ISTEA legislation the Federal Highway Administration (FHWA) was directed by Congress to "establish standards for installation" of a variety of roadside safety features including guardrail terminals.*(4)* The ISTEA legislation also specifically referred to the crash testing recommendations of NCHRP Report 230, the predecessor of Report 350, and required that FHWA develop design and installation standards to accommodate other types of vehicles like vans, minivans, pickup trucks and sport utility vehicles .*(2)* The FHWA responded to this legislative mandate by publishing a rule that required that all roadside hardware should meet the full-scale crash testing requirements of Report 350 by the end of fiscal year 1998.*(3)* The FHWA clarified the rule, made some minor changes and established an implementation time table in several subsequent memoranda.*(4)(5)* When the various state DOTs began to assess the affect of the legislation and rules they realized that implementing the requirements would pose a variety of significant challenges. The American Association of State Highway and Transportation Officials (AASHTO) formed a task force to investigate the FHWA time-table and in collaboration with the FHWA developed a modified time table for implementing the Report 350 requirements.*(6)* The net result with respect to guardrail terminals was that State Departments of Transportation (DOT) were directed to:

> "... implement NCHRP Report 350 safety standards for ... W-beam guardrail terminals on new construction effective October 1, 1998. However, upgrading of existing safety hardware that meets NCHRP Report 230 criteria to Report 350 guidelines would not be required on 3R or other resurfacing or rehabilitation projects, except for terminal end sections."*(7)*

State DOTs must, therefore, install guardrail terminals that have passed the required Report 350 tests whenever a guardrail terminal is installed in new construction or on any resurfacing or rehabilitation project. This requirement could have a significant economic impact on the DOTs. Albin, for example, has estimated that the cost to upgrade guardrail terminals from the BCT to a Report 350 terminal on state maintained roadways in the State of Washington will cost approximately $3 million in the 1999 construction year alone.*(8)* Since the BCT has been used in Washington for decades, this multi-million dollar cost would recur for a number of years before all the existing BCTs are upgraded.

The adoption of NCHRP Report 350 in 1993 introduced full-scale crash tests using a 2000-kg pickup truck rather than the more stable but now obsolete 2000-kg full-size passenger car. Several guardrail terminals that were acceptable using older crash testing guidelines no longer passed the required crash tests. Among these terminals was the BCT which was tested according to Report 153 and the MELT which was tested according to Report 230.*(9)(10)(11)* It has been estimated that more than 40 states use the BCT and hundreds of thousands of BCTs have been installed since the early 1970's.*(12)* Based on an inventory of three Counties in Iowa, there are probably nearly 20,000 BCTs and 3500 MELTs in Iowa alone. The requirement to satisfy the testing requirements of Report 350, therefore, resulted in the elimination of some of the most widely used guardrail terminals in the United States.

Satisfying the requirements of more demanding test and evaluation criteria would be beneficial if doing so results in safer roadside hardware and fewer serious and fatal injuries. Undoubtedly, hardware developed according to Report 350 is safer in the sense that it addresses a wider range of vehicle types and inherently requires more stable collision performance. The incremental improvement in safety, however, may or may not be significant, depending on how relevant the crash testing conditions are to real world field conditions.

This paper will attempt to answer the following question with a specific example: Is the accident reduction that can be expected from upgrading from a BCT to an ET-2000 sufficient to warrant the policy agreed to by AASHTO and FHWA (e.g., Report 350 terminals on all new construction and rehabilitation projects)? These two particular guardrail terminals were selected because the BCT is one of the most commonly used pre-Report 350 guardrail terminals in the nation, the ET-2000 satisfies the Report 350 requirements and good in-service evaluations are available for both systems. The availability of the in-service evaluations allows for the comparison of injury rates in actual service conditions and so they provide a good measure of the effectiveness of each type of terminal in real-world field conditions.

PRIOR IN-SERVICE EVALUATIONS

The design of safe guardrail terminals has been a concern in the roadside safety community for many decades so it is not surprising that there have been more in-service performance evaluations performed on guardrail terminals than any other type of roadside hardware.*(13)* The BCT in particular has been studied in at least five states over the past 20 years. The occupant injury severities from these studies are summarized in Table 1 along with the results of an in-service performance evaluations performed in Iowa and North Carolina in 1997-98.*(14)* The severe and fatal injury rates (A+K) vary dramatically between the different studies. The Iowa and North Carolina in-service evaluation of the BCT indicated A+K rates of less than five percent while the first BCT study, performed in Indiana in 1980, indicated a rate of 60 percent. Clearly an explanation for these conflicting results is required.

The following sections will briefly describe these earlier studies. The discussions are presented in chronological order with the oldest studies appearing first and the most recent appearing last. Much more information on each individual study can be found in the reports cited in the following paragraphs. There are two characteristics of the BCT which appear repeatedly throughout all the previous studies; namely, flare and offset. For the purposes of this discussion offset refers to the distance perpendicular to the roadway from a tangent to the main guardrail to the traffic face of the first post of the BCT. Flare refers to the shape of the curve along the 11.43-m long BCT installation. A straight flare is one where the rail is straight between the first and last post of the BCT. A parabolically flared design, (i.e., the crash tested version of the design), is one where the rail has a specific parabolic shape. The flare and offset were frequently not installed correct, especially in the 1970's when the BCT was just beginning to be installed in the field.

Indiana

Indiana began using the BCT in 1977 on all new construction projects. In 1979 there were several dramatic BCT collisions that resulted in severe occupant injuries so the Indiana DOT decided to investigate the performance of the BCT.*(15)* The BCT detail used in Indiana at the time was a steel-slipbase post version of the BCT. Although the State design standards recommended a 1220-mm offset for the first post (i.e., the crash tested design), first post offsets as small as 300 mm were allowed by the same standards at the time the study was performed. The data was collected by instructing DOT workers in the maintenance garages to contact the study team whenever a BCT collision occurred. Twenty one impacts were reported; two were discarded because they involved tractor-trailer trucks, nine were eliminated because no accident report could be located leaving a study sample of 10 cases. It is interesting to note that nearly half of the cases (e.g., 9 of 21) were apparently unreported collisions as shown in Table 2. Six of the remaining ten study cases involved fatal accidents yielding a surprisingly high A+K rate of 60 percent. Examination of the cases documented in the report indicates that at least half of the study cases involved side impacts with BCTs with very little or no first post offset. The occupant compartment was severely penetrated in many of these cases resulting in traumatic occupant injury. Although the researchers did not measure the offset of the first post in all cases, a review of the photographs, sketches and comments in the report show that at least seven of the ten cases involved BCTs with almost no flare (e.g., 300 mm or less). The occupant severity values for the Indiana study shown in Table 1 are not representative of properly installed BCTs because the majority of cases involved improperly installed BCTs (e.g., no flare) that were significantly different than the crash tested design.

New Jersey

New Jersey began installing BCTs in 1976 and at the same time initiated an in-service monitoring project at the request of the FHWA. *(16)* The BCT design used in New Jersey used wood breakaway posts mounted in concrete. The standard New Jersey design at the time used a straight 15:1 flare rather than the crash-tested parabolic flare and some installations were installed without any first-post offset (e.g., no flare at all). The performance of BCTs in a portion of New Jersey were monitored over a two-year period. Maintenance garage personnel were provided with a form to fill out whenever a BCT was repaired. There were 33 maintenance-reported BCT collisions but only 13 could be matched to police reports so the study sample consisted of the 13 police reported cases as shown in Table 2. This indicates that 60 percent of the BCT collisions that required repairs by maintenance workers were never reported to the police. While this study also resulted in much useful information at the time, the occupant injury values are not representative of properly installed BCTs because the majority of the installations did not correspond to the crash tested design.

Kentucky

Kentucky began installing BCTs in 1974, before the final crash tested version of the design was completed in 1978. *(17)* The Kentucky BCT is a wood breakaway post system mounted in concrete foundations. Like Indiana and New Jersey, many installations in Kentucky were characterized by both non-parabolic flares and small or nonexistent first post offsets. The data was collected retroactively by requesting information from maintenance garage records on BCT collisions. The final sample, however, included collisions that occurred outside the pre-defined sampling period and outside the pre-defined sampling area and the selection of cases depended on the ability of the data collectors to find information in the maintenance and accident files. This procedure was likely to introduce a bias toward collecting only the more severe collisions since these cases would more likely have repair records, photographs and other data whereas information on more minor collisions may not have been recorded and filed in the maintenance records. While photographs were not available for all cases, many of the cases shown in the report clearly involve BCTs with little or no offset and non-standard flares.

A follow-up study was performed in 1991 in order to compare the performance of a variety of guardrail terminals including the BCT.*(18)* The researchers made a number of improvements in the second study that reduced the sample bias and otherwise improved the quality of the data. Since the first study had shown that there were numerous non-standard installations in Kentucky, the study team assessed each accident site and characterized it as having either a parabolic flare (e.g., more or less the crash tested design), a simple curved flare, a straight flare or an unknown type of flare. A re-analysis of the data presented in the report was performed so that the injury severities in police reported collisions could be tabulated. This re-analysis is summarized in Table 3. The A+K injury rate for the simple curved flared BCT was 50 percent greater (38 percent versus 25 percent) than for the parabolically flared system, the one closest to the crash tested design. There were 89 cases collected for the parabolically flared BCT but only 52 were used in the study presumably because police reports could not be obtained for the other 37 cases (see Tables 1 and 3). Unfortunately, just over one third of the cases in the data set involved an unknown type of BCT flare. With this large number of unknown installation types the results may not be very reliable. Although the data collection method may still have included some bias toward more serious collisions, excluding installations that did not conform to the tested BCT design dramatically reduced the severe injury rate shown in Tables 1 and 3.

Michigan

A report on the in-service performance of the BCT in Michigan was published in 1994.*(19)* Michigan, like the states discussed above, had a long history of using the BCT. More than 14,000 BCTs had been installed in Michigan as of 1994. The study was performed in two phases; the first between 1984 and 1986 and the second between 1988 and 1990. A data collection form was developed and provided to the DOT maintenance garages in three districts in the state. Maintenance workers were instructed to fill out the form and send it to the study team whenever a BCT was repaired. The maintenance-generated forms were then matched with police accident records to form the study sample. The search of police reports also resulted in some additional cases where a BCT had been struck in the study area but no repairs had been performed; these cases were also added to the study set.   There was no attempt to verify that specific BCTs were properly installed and corresponded to the crash tested design.   The study team recognized that there were probably numerous non-standard BCT installations but there was no way to separate properly installed systems from improperly installed ones since there were no inspections of the collision sites.

A follow-up study was performed in 1988-1990 after the DOT had upgraded its BCT design standards. The authors presumed that a larger number of properly installed BCTs were in the inventory since some of the major routes in the study area had been upgraded with new BCT terminals.   As shown in Table 1, the proportion of property damage only accidents increased dramatically from 40 percent to 65 percent between the two study periods (e.g., conversely the proportion of injury accidents decreased). The authors explored a variety of reasons for why the injury severities were so different and concluded that one probable factor was the upgraded design standards and a higher proportion of correctly installed BCTs in the study area. Unfortunately there was no way to separate flared and unflared terminals, or terminals with proper or improper grading in the data set so the severity values shown in Table 1 are known to include both properly and improperly installed and maintained terminals.

New Hampshire

In 1994 a report summarizing an in-service performance evaluation of the MELT in New Hampshire was published.*(20)*   The author states that "since the first MELT was installed in 1991, approximately 25 have been impacted resulting in little or no injury to the driver or occupants."*(23)*   The report appears to only include details on the police reported collisions. The injury severity information shown in Table 1 was tabulated by examining the police reports included in the in-service evaluation report.   Only nine cases were reported and of these two involved possible minor injuries.

Ohio

Since guardrail terminals developed and tested according to Report 350 are relatively new there are very few in-service performance evaluations available. The ET-2000 was the first guardrail terminal to be judged satisfactory according to the Report 350 guidelines and it was quickly adopted as an alternative in a number of States. Ohio DOT began installing ET-2000 guardrail terminals in the 1992 construction season. Fortunately, Ohio DOT also immediately began to collect in-service performance data on collisions with the ET-2000. The ET-2000 in-service evaluation was performed between 1992 and 1996 and represents one of the largest most carefully controlled in-service evaluation project performed to date.*(21)* Maintenance workers filled out a one-page form and returned it to the study team whenever an ET-2000 was repaired. The MELT and several other terminals were included in the study although there were far more ET-2000 cases than any of the others. All together there were 302 collisions involving the ET-2000, 97 of which were reported to the police as shown in Table 2. While not documented in the report, there were also 15 MELT collisions in the Ohio data, six of which were reported to the police as shown in Table 2.

Texas

The ET-2000, earlier known as the Guardrail Extruder Terminal (GET), was also studied in Texas between 1990 and 1995.*(22)* The Texas DOT issued guidelines for the use of the ET-2000 in 1992 and simultaneously initiated an in-service performance evaluation of the system that involved both TX DOT personnel, the original developers and the manufacturer. The results of the study are summarized in Table 1.

Iowa and North Carolina

An in-service performance evaluation of a variety of guardrails and guardrail terminals was performed in portions of Iowa and North Carolina between July 1, 1997 and June 30, 1998.*(23)* The BCT and the MELT are both widely used in both Iowa and North Carolina and these system were included in the in-service performance evaluation.*(24)(17)* Both states have used the BCT for decades and prior to 1997 used BCTs almost exclusively for W-beam guardrail end treatments. The BCT used in Iowa uses all wood posts, the first two breakaway posts being mounted in a concrete foundation. Unlike most states, Iowa uses a 200x200 mm wood post rather than the more typical 150x200 mm post for the standard guardrail. These larger square posts are also used in the BCT for all posts except the two breakaway posts. In contrast, the primary guardrail used in North Carolina is a steel post design so the steel line-post BCT in used. The wood breakaway posts (i.e., posts one and two) are mounted in steel foundation tubes with soil plates in North Carolina. Beginning in the 1996 construction year both states switched from the BCT to the MELT as their primary guardrail terminal. Data was collected in both states on all BCT and MELT collisions that occurred within a pre-defined sampling area over a 12-month period spanning 1997 and 1998.

In addition to collecting police and maintenance reports, the study team also visited each site as soon as practical after each collision to document site characteristics and collision damage. The North Carolina and Iowa data sets therefore allow the analyst to determine if the BCT or MELT was installed according to the State standards. Ray and Hopp developed an installation quality score that combined measurements of characteristics like the rail height, offset at each post, and many other characteristics.*(27)(25)* The score measured how closely the specific installation conformed to the state standards with zero being a perfect system and 10 being a very poor system. There were no cases in the Iowa data collection area where a BCT or MELT installation had a first post offsets less than 300 mm or a non-parabolically flared guardrail. In North Carolina, 12 of the 58 BCT and MELT cases (e.g., about 20 percent) where characterized by installations with first-post offsets less than 300 mm or inadequate flares. Collision severity rates based on the Iowa and North Carolina study represent the performance of properly installed BCT and MELT terminals since 80 percent or more of the terminal installations in the data are similar to the design details used in the crash tests.

As shown in Table 2, 21 MELT and 62 BCT cases were collected in the two States; 13 police reported MELT cases and 53 police reported BCT cases. Since nearly all the previous studies were based on police reported collisions, only data derived from the police reported collisions are shown in Table 1. Also, since the studies listed in Table 1 did not eliminate cases based on the quality of the installation, no cases were eliminated from the Iowa or North Carolina data because of a poor quality of installation score. As shown in Table 1, since there was only one A+K injury in the 53 police reported BCT collisions and none for the MELT, the A+K rate for both systems would appear to be very small, probably less than five percent.

Washington

Most recently, the State of Washington has re-examined its accident data and construction project information to identify specific highway segments where BCTs were installed.*(11)* The accident data for these same highway segments were searched to identify "end collisions" during seven years between January 1990 and December 1996. A total of 37 police reported accidents were identified as shown in Table 1. Approximately eight percent involved A+K injuries.

COLLISION SEVERITY

For the reasons discussed above, the occupant injury rates reported in the Indiana, the first Kentucky study and the New Jersey studies do not represent the typical performance of properly installed, well maintained BCTs since each of these studies included unknown but probably significant numbers of non-standard BCT installations (e.g., inadequate flare or no first-post offset). Probably the best in-service evaluation of the BCT with the most reliable sampling procedures in the literature are the Michigan and Washington studies but it is not possible to distinguish between properly installed and maintained BCTs and those with known design defects such as insufficient first-post offset or a straight flare. While the second Kentucky study probably retained some sampling problems, the authors did make one critical improvement in the data set by recording the type of BCT (e.g., parabolic flare, circular flare or no flare).

The best estimates of the collision severity of the BCT, MELT and ET-2000 are considered to originate from the Iowa, North Carolina and Ohio studies. The severity distributions based on the number of collisions reported to both the police and maintenance agencies are shown in Table 4. These collisions required the maintenance personnel to repair the guardrail terminal but presumably resulted in no serious occupant injury or vehicle damage since the collision did not result in a police report. The values in Table 4 were calculated based on the assumption that collisions that required repair but for which there was no police report resulted in no more than property damage. Although there may be isolated incidences where this assumption is not correct, it is probably reasonable to assume that collisions not reported to the police resulted in little or no occupant injury or vehicle damage. As shown in Table 4, the observed A+K severity rates for all three guardrail terminals in all three states are very small, always less six percent of all police and maintenance reported collisions.

Table 5 shows the injury severity distribution for police reported collisions only. Since there are fewer non-injury cases than in Table 4, the percentage of A+K and B+C injuries is higher. In assessing injury rates like those shown in Table 1, it is important to account for the effect of different sample sizes. Studies with a large amount of data result in injury rates that are more accurate than studies with smaller sample sizes. The 90th percentile confidence range for the injury rate estimates were calculated for the best studies of the BCT, MELT and ET-2000 and are included in Tables 4 and 5. For example, the one BCT case with an A+K injury in the North Carolina study suggests that A+K cases represent three percent of all the police reported cases (see Table 5). Since there were only 40 police reported cases, however, the three percent estimate has a precision of only ± 4 percent. The probability that the true rate is between zero and seven is at least 90 percent. The Ohio study of the ET-2000 has an A+K injury rate precision of ±3 percent since there are more than twice as many cases in the Ohio study than in the North Carolina study. More than doubling the number of cases only improved the precision of the A+K rate estimate by about one percent. This shows that very large sample sizes would be needed to detect small statistically significant differences between the performance of two devices.

As shown in Table 5, the mean A+K rates for police reported BCT, MELT and ET-2000 collisions are all less than eight percent, and an A+K rate of five percent is probably a reasonable estimate for all three systems. The true A+K rate for the BCT based on the North Carolina study can be expected to between zero and eight percent while the true A+K rate for the ET-2000 based on the Ohio study can be expected to be between zero and seven percent. Since the two ranges overlap, the difference between the three percent rate for the BCT in North Carolina and the four percent rate for the ET-2000 in Ohio is not statistically significant at 90 percent confidence level. There is no reason to conclude that upgrading from a properly installed BCT or MELT guardrail terminal to the ET-2000 will result in a reduction in the number of severe and fatal injury collision based on the Iowa, North Carolina and Ohio data.There is also no statistically significant difference between the injury rate (i.e., K+A+B+C) or the property damage only rate for these three guardrail systems. In term of occupant injury, the ET-2000, BCT and MELT all result in essentially identical performance based on these 163 police reported collisions.

In a white paper providing background to the AASHTO ballot on Report 350 compliance dates it was estimated that the benefits from upgrading guardrail terminals to Report 350 would be “extremely high.”*(9)* In particular the white paper estimates an accident reduction benefit of $25 million nationwide using the AASHTO Roadside Design Guide estimates for accident costs.*(9)* The white paper used an estimate of an A+K rate of 14 percent for the BCT and 1.5 percent for the ET-2000.. The BCT rates were taken from a study performed in Oklahoma in the late 1980's.*(26)* Unfortunately, the Oklahoma study involved a comparison between turned-down ends and "exposed end" guardrail terminals. The authors of the Oklahoma study explain that "exposed end" terminals include trailing end anchors, blunt-end guardrails, non-standard BCTs as well as an unknown number of properly installed parabolically flared BCT terminals. Videologs were used to characterize guardrail terminals and it would be very difficult to distinguish between some types of end anchors and a properly installed BCT from a forward-mounted videolog. The authors go on to say that "it was not possible to differentiate breakaway cable terminals with rounded ends from "normal" rounded exposed ends; both were classified as rounded ends."*(29)* The Oklahoma study was an inappropriate basis for comparison since (1) the "exposed end" category includes a variety of "exposed end" terminal types in addition to the BCT and (2) the proportion of properly installed BCTs in the data set is presumed by the authors of the Oklahoma study to be small and the precise number is unknown.

The injury rates for the ET-2000 study are summarized in Table 1 for the 97 police reported accidents in the study.*(24)* The AASHTO white paper compares the 14 percent A+K rate for "exposed end" terminals in Oklahoma with a 1.5 percent A+K rate from Ohio. Unfortunately, the comparison is not appropriate for several reasons. First, the "BCT" value is not a valid representation of the A+K rate for BCTs since the Oklahoma study included a variety of "exposed end" terminals and BCTs were a relative small portion of the category. Second, Oklahoma "exposed end" terminal data includes only police reported collisions whereas the Ohio ET-2000 A+K rate of 1.5 percent can only be obtained by using collisions that were reported to the police and unreported collisions that were repaired by maintenance workers (see Table 4). If only police reported collisions are used, the ET-2000 data shown Table 1 will be obtained. The appropriate police reported A+K rate for the ET-2000 is four percent. The AASHTO White paper assertion that the benefits of upgrading to Report 350 guardrail terminals would be "extremely high" were, therefore, based on an erroneous assessment of the data.*(9)*

While it is not appropriate to compare the Ohio ET-2000 study to older BCT and MELT in-service evaluations, it is appropriate to compare it to the study performed in Iowa and North Carolina. Both the Ohio study and the Iowa and North Carolina studies used similar population-based sampling protocols and the BCT installations in Iowa and North Carolina were checked for conformity to the appropriate State design standards to assure that the systems were, in general, properly installed. Table 5 shows the police reported injury severities for the BCT, MELT and ET-2000 along with the ranges for the 90th percentile confidence range for each system. These in-service evaluations indicate that there is no statistically valid reason to presume that the use of the ET-2000 will result in a reduction of severe and fatal injury accidents (A+K) in comparison to using the BCT or MELT. By extension, Table 5 suggests that older properly installed terminals like the BCT and MELT will experience similar injury rates to newer guardrail terminals that satisfy the full-scale crash testing requirements of Report 350. It is unlikely that upgrading to Report 350 guardrail terminals will significantly affect the A+K injury rate observed on highways in States that have a history of using properly installed and maintained BCT and MELT terminals.

CONCLUSIONS

The occupant injury data collected in the Iowa and North Carolina in-service evaluations provide the first reliable assessment of injury rates for properly installed BCT and MELT guardrail terminals. The overall A+K injury rate for the BCT was three percent and no A+K collisions were observed for the MELT. Although these data are limited by a modest sample size, there is as yet no statistically valid reason to conclude that the MELT results in any fewer A+K injuries than the BCT.

More importantly, there is statistically no difference between the performance of the ET-2000, BCT and MELT in terms of occupant injury rates. Though they are characterized by very different crash test performance, the BCT, MELT and ET-2000 all have mean A+K rates below five percent. This suggests that while Report 350 terminals like the ET-2000 may be better systems as judged by full-scale crash tests, they may not result in a reduction in the injury rate when used in a particular state. The reason for this is probably that the severe worst-case impact scenarios used in full-scale crash tests are rare in real-world impacts. There may be good reasons to upgrade from the BCT to a Report 350 guardrail terminal but an expectation of a reduction in the number of severe guardrail terminal collisions should not necessarily be expected.

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Table 1. Police reported occupant injury in in-service performance evaluations of the BCT, MELT and ET-2000.

	Date	Cases	A+K		B+C		PDO	
	Date	No.	No.	%	No.	%	No.	%
BCT								
Indiana *(18)*	c. 1980	10	6	60	1	10	3	30
New Jersey *(19)*	1976-79	13	6	46	3	23	4	31
Kentucky 1984 *(20)*	1980-82	50	11	29	14	37	13	34
Kentucky 1991 *(21)*	1980-87	52	13	25	22	42	17	33
Michigan *(22)*	1984-86	50	5	10	25	50	20	40
Michigan *(22)*	1988-90	83	10	12	18	22	55	66
Iowa *(26)*	1997-98	13	0	0	2	15	11	85
North Carolina *(26)*	1997-98	40	1	3	19	35	25	62
Washington *(11)*	1990-96	37	3	8	16	43	18	49
MELT								
New Hampshire *(23)*	1991-94	9	0	0	2	33	4	67
Ohio *(24)*	1992-95	17	1	16	1	16	4	67
North Carolina *(26)*	1997-98	13	0	0	4	31	9	69
ET-2000								
Ohio *(24)*	1992-96	97	4	4	35	36	58	60
Texas *(25)*	c. 1996	37	3	8	10	27	8	22

Table 2. Reported and unreported collisions in guardrail terminal in-service evaluations.

		Police Collisions		Unreported[†] Collisions		Total
	Date	No.	%	No.	%	No.
BCT						
Indiana *(18)*	c. 1980	12	57	9	43	21
New Jersey *(19)*	1976-79	13	39	20	60	33
Kentucky 1991 *(21)*	1980-87	52	58	37	42	89
Iowa *(26)*	1997-98	13	68	6	32	19
North Carolina[¶] *(26)*	1997-98	40	93	3	7	43
MELT						
New Hampshire *(23)*	1991-94	6	24	19	76	25
Ohio *(24)*	1992-96	4	27	11	73	15
Iowa *(26)*	1997-98	0	0	10	100	10
North Carolina *(26)*	1997-98	10	91	1	9	11
ET-2000						
Ohio *(24)*	1992-96	97	32	209	69	302
Texas *(25)*	c. 1996	37	70	16	30	53

† Unreported collisions in this context are those that are repaired by maintenance personnel but could not be matched to a police report. It is presumed that such collisions are unreported.

¶ North Carolina primarily uses contracted maintenance contractors to repair barriers. The only maintenance reported collisions to the DOT, therefore, are collisions requiring immediate repair.

Table 3. Police reported occupant injury in a Kentucky in-service performance evaluations of the BCT. *(21)*

	A+K		B+C		PDO		Reported		Unreported	Total
Type of BCT Installation	No.	%	No.	%	No.	%	No.	%	No.	No.
Parabolic Flare	13	25	22	42	17	33	52	100	37	89
Simple Curve	17	38	17	38	11	24	45	100	21	66
Straight Installation	0	0	0	0	3	100	3	100	2	5
Unknown	3	14	9	43	9	43	21	100	50	71
Total	33	27	48	40	40	33	121	100	110	213

Table 4. Best estimates of police and maintenance reported injury severity for the BCT, MELT and ET-2000 with 90th percentile confidence ranges.

	A+K			B+C			PDO†			Cases
	No.	%	Range	No.	%	Range	No.	%	Range	No.
BCT										
Iowa *(26)*	0	0	--	2	10	0-21	17	90	79-99	19
North Carolina *(26)*	1	2	0-6	14	32	20-44	28	65	53-77	43
MELT										
Ohio *(24)*	1	6	0-16	2	12	0-25	14	82	66-98	17
North Carolina *(26)*	0	0	--	4	31	10-52	9	69	48-90	13
ET-2000										
Ohio *(24)*	4	1	0-2	35	12	9-15	263	87	84-90	302

† The number of PDO collisions was calculated based on the assumption that collisions that required maintenance repairs but were not matched to police accident reports resulted in no injury to the vehicle occupants.

Table 5. Best estimates of police reported injury severity for the BCT, MELT and ET-2000 with 90th percentile confidence ranges.

	A+K			B+C			PDO			Cases
	No.	%	Range	No.	%	Range	No.	%	Range	No.
BCT										
Iowa *(26)*	0	0	--	2	15	0-31	11	85	69-99	13
North Carolina *(26)*	1	3	0-8	14	35	23-47	25	62	49-75	40
MELT										
North Carolina *(26)*	0	0	--	4	31	10-52	9	69	48-90	13
ET-2000										
Ohio *(24)*	4	4	1-7	35	36	28-44	58	60	52-68	97