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The Cost Effectiveness of Updating Guardrail End Treatments

Prepared by

Brian Bowman, Ph.D., P.E.
Douglas Peterson

Department of Civil Engineering
Auburn University

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EXECUTIVE SUMMARY

Beginning October 1, 1998, the Federal Highway Administration (FHWA) required that all new and replacement safety features installed on National Highway System (NHS) routes must be in compliance with guidelines set forth in National Cooperative Research Program (NCHRP) Report 350. This directive specifically included new installations and the hundreds of thousands of existing guardrail end terminals on highways across the United States. Some end terminals, such as the turned-down end or the spade end, clearly pose a substantial hazard when impacted by any type of vehicle. Others, such as the Breakaway Cable Terminal (BCT) or Modified Eccentric Loader Terminal (MELT), are not so obvious since in majority of cases they tested as in compliance with previously applicable testing standards such as NCHRP 230. Currently only the much more expensive proprietary end terminals are in compliance the currently applicable testing standards of NCHRP 350. The purpose of this research is to attempt to answer the question, What is an unsafe end terminal from a cost-effective analysis of impact severity?

A number of States have been studying the in-service performance of guardrail end terminals such as the BCT, MELT, and proprietary extruding types for more than twenty years. This research effort, summarized in this report, analyzed the results of these studies to determine if any statistical a significant differences could be found between the distribution of injury severity resulting from impacts with different terminal types.

The following summary of conclusions and recommendations result from the analysis efforts and the literature review.

- One such study administered through the auspices of the NCHRP program of the Transportation Research Board (Project 22-13) is a large multi State effort. This study attempts to ascertain if BCT and MELT end treatments were properly installed. Only those installations where correct installation can be established are included in the analysis. Preliminary conclusions of the NCHRP project 22-13 study, (hence referred to as Project 22-13), indicate that there is no significant difference in the crash severity categories between BCT/MELT and NCHRP 350 end treatments.
- Assuming that BCT/MELT installations are equally probable to be installed in every State resulted in a decision to increase the data base by including data not used in Project 22-13. The reasoning behind this decision is that correct/incorrect installations are not only difficult to determine but is an inherent problem with the BCT/MELT systems. Knowing proper/improper installation after impact is even more difficult. Errant vehicles, leaving the roadway are and not impacting only the proper installations and replacing BCT/MELT systems with NCHRP 350 devices may have a significant impact in overall safety. Analysis on the expanded data base determined that fatalities and A injury crashes would be significantly reduced by the installation of NCHRP 350 end terminals.

- The installation of NCHRP 350 end terminals would reduce K+A severity by 15.5% and B+C injuries by 17.2%, while increasing PDO crashes by 32.7%. Placing the 32.7% reduction into perspective, however, indicates that K+A severity would have been reduced by 9 crashes (15.5% of 57 BCT/MELT K+A crashes) and B+C severity would have been reduced by 17 crashes (17.2% of 98 BCT/MELT B+C crashes).
- The results of Project 22-13 and the practical consideration of this study indicate that it is not cost effective to change BCT/MELT to NCHRP 350 end terminals unless the BCT/MELT's are replaced due to destruction by impact. For example, the reduction of a total 26 crashes from personal injury categories to PDO crashes was determined by analyzing 23 years of data from 7 States. Consideration to the number of end treatments present and the volume of traffic present during the analysis period fosters the conclusion that the probability of impact is very small.
- Quantitatively answering the question of whether it is cost effective to replace BCT/MELT installations with NCHRP 350 devices requires additional data to estimate the probability of end treatment impact. Data collection forms and procedures have been developed to assist in this endeavor. Obtaining such data is outside the scope of this current project.

TABLE OF CONTENTS

LIST OF TABLES

GLOSSARY OF TERMS

BCT - Breakaway cable terminal.

B-E-S-T - Beam eating steel terminal.

ET2000 - Extruder terminal.

ET2000-LET - 37.5 ft. ET2000

FLEAT 350 - Flared energy absorbing terminal.

KABCO Scale - Injury classification system (Alabama definition) as follows:

- K - Killed
- A - Visible injury or carried from scene
- B - Bruise/ abrasion/ swelling
- C - Not visible - has pain/faint
- O - Property damage only

MELT - Modified eccentric loader terminal.

PDO - Property damage only.

REGENT - Redirective gating end terminal.

SKT 350 - Sequential kinking terminal.

SRT 350 - Slotted rail terminal

1. INTRODUCTION

In 1966, more than 50,000 people were killed in traffic crashes in the United States, resulting in a fatality rate of 5.5 deaths per 100 million vehicle miles traveled [1]. Efforts by the Federal Highway Administration (FHWA), the American Association of State and Highway Transportation Officials (AASHTO), the Transportation Research Board (TRB), and State and local highway agencies to improve roadside safety dramatically reduced the number of people killed in traffic crashes in the United States each year. From 1966 until 1994, the total number of fatalities dropped each year to a point that in 1994 just over 40,000 people were killed in traffic accidents, a fatality rate of 1.7 deaths per 100 million vehicle miles traveled [2]. Motor vehicle deaths increased for a few years after this point, but in 1999 motor vehicle deaths had decreased for the third consecutive year to 41,300 deaths and a fatality rate of 1.54 deaths per 100 million vehicle miles traveled. The lowest rate on record. As if this dramatic decrease in fatality rate is not remarkable enough on its own merit, it occurred while vehicle miles traveled increased almost 2.5 times that of the 1966 total [3]. However, motor vehicle crashes accounted for more than 2.2 million disabling injuries with a societal cost of $181.5 billion in 1999 [4].

Improved roadway design and the application of the "forgiving roadside" concept were the means by which Highway agencies attempted to ensure that vehicles remained on the roadway; and in event of an automobile leaving the roadway, would have the opportunity to recover without in a serious incident. Roadside safety and the "forgiving roadside" concept have been enhanced over the years by improved geometric design, development of crashworthy guardrail barriers and end terminals, crashworthy sign and luminary supports, and improved guidelines for design, selection and maintenance of safety features.

When a vehicle leaves the roadway, the probability of a crash, and the crash severity is dependent upon the roadside environment, vehicle speed, and vehicle trajectory. The roadside environment is the primary area where highway engineers can influence the frequency, type, and severity of ran-off-the-road crashes. In order to reduce, in the best possible way, the losses from these crashes, it is necessary to identify the frequency or rate of impacts with fixed objects. This knowledge enables emphasis on which implementation and research activities are necessary to further increase roadside safety.

Run-off-the-road crashes can typically be classified as rollover, on slopes or ditches, or fixed object impacts that may or may not involve rollover. Additional insight into the fixed object crashes such as what is being struck, how often it is being struck, and under what conditions the striking is occurring were provided in a study performed by Hunter and Council [5]. Hunter and Council analyzed five years of fixed object collisions, from six States, and determined that impacts involving embankments, ditches and other roadside terrain features is the leading category in terms of overall frequency. The second leading category is trees, with guardrail, guard posts, and median barriers constituting a major category of impacted objects. In North Carolina, where the total five years data on guardrail crashes were available, 24 percent of the reported guardrail impacts occurred on the end. This represents a disproportionate risk of crash involvement compared to the total length of an installed guardrail. The severity of crashes with most installed end types are higher than crashes with the barrier itself.

Knowledge of the types of crashes and the fixed objects impacted provides information on what needs to be treated to improve roadside safety. How to treat the physical roadside features and fixed objects to achieve a cost effective improvement in roadside safety is dependent upon available technology, characteristics of the vehicle fleet, and the results of crash tests. As expected, effective safety treatments will vary with changes in vehicle fleet and technology . The current procedure for approving roadside safety hardware is contained in National Cooperative Highway Research Program (NCHRP) Report 350. This document, prepared by contract under the supervision of a NCHRP committe, supercedes NCHRP Report 230. NCHRP Report 350 describes the evaluations of the safety performance of roadside hardware based upon crash tests, including the vehicles to be used in the testing, the test conditions, and the instrumentation that will be used to test the hardware.

NCHRP Report 350 was developed to address the changing roadway vehicle fleet and to incorporate the changes in safety hardware and testing experience gained since the adoption of NCHRP Report 230. The major changes incorporated into NCHRP Report 350 include: a) changes to the test vehicles including the use of a pickup truck (2000P), b) changes to the number and impact conditions of the test matrices, c) adoption of the concept of "test levels" as opposed to "service levels", d) changes to the evaluation criteria, e) inclusion of test guidelines for additional features, and f) adoption of the metric system.

The "basic" vehicles under NCHRP 350 are the 820C and the 2000P. The 820C is a small car with a mass of 820 kg, (1800 lbs) which is essentially the same small car test vehicle used in NCHRP Report 230. The adoption of the 2000P, which is a "3/4-ton" pickup truck with a mass of approximately 2000 kg, (4,400 lbs) represents a major change in testing criteria. The 2000P was chosen as a test vehicle primarily because it is believed to be a reasonable representative of the increasing light-truck population making up today's passenger vehicle fleet. The assumption was backed up by a report by Ross that found light truck sales accounting for approximately 40 percent of all vehicle sales in 1994 [7].

Beginning October 1, 1998 all new and replacement safety features installed on National Highway System (NHS) routes must be in compliance with NCHRP Report 350. This directive includes the hundreds of thousands of guardrail end terminals installed on roadways across the United States. Some end terminals, such as the turned-down end or the spade end, clearly pose a substantial hazard when impacted by any type of vehicle. Others, such as the BCT or MELT end terminals, are not so obviously deficient. These terminals passed guidelines set forth by NCHRP Report 230 (predecessor to NCHRP 350), while the spade and turned-down ends did not. In fact, the FHWA went as far as sending out design specifications on the generic MELT terminal to all FHWA regions indicating that it would pass the NCHRP 350 guidelines. As a result, many States began replacing substandard terminals with the MELT end terminal; a device which could not pass NCHRP 350 guidelines and be considered as crash worthy. Currently only proprietary end terminals are in compliance with NCHRP 350 guidelines. One issue that needs to be resolved is if it is cost effective to replace previously acceptable end treatments because they cannot qualify under the test criteria of NCHRP 350. If it is not cost effective then the funds being expended on replacing the BCT/MELT end treatments would provide a greater increase in safety by being invested elsewhere.

This is the issue that the research effort, summarized in this report, was designed to address. It must be realized however, that the funds and level of effort available for this study do not permit the collection of end treatment and crash data. What this study does do is critically critique existing data bases; providing an alternative, and more realistic, data analysis. Data collection forms and procedures, that are designed for Alabama Department of Transportation data availability and organizational structure were also developed as part of this project.

2. LITERATURE REVIEW

At least eight states have performed some type of in-service performance evaluation of the BCT, MELT, or NCHRP 350 guardrail end terminals. The following sections review these studies.

Indiana

In 1979, officials with the Indiana State Highway Commission (ISHC) expressed concern that vehicle impacts with BCT end terminals resulted in some accidents with severe injuries to vehicle occupants [8]. As a result, the Federal Highway Administration (FHWA) decided to conduct an in-service evaluation of BCTs performance installed on the State highway system.

A total of 21 impacted BCT's were identified through the review and monitoring effort. Two of these were eliminated from analysis because of involvement with tractor-trailers and nine others had incomplete accident information, resulting in the analysis of ten accidents.

Six of the ten impacts involved a fatality. In four of the six impacts that resulted in fatalities, the vehicle had left the roadway, and was attempting to return, when the side of the vehicle struck the BCT end. Three of the six fatal impacts that, including two in which the vehicle struck the BCT end head on, the occupant that died was thrown from the vehicle. Table 1, summarizes the severity of impacts with BCTs in Indiana.

Table 1 - Crash Severity of Impacts with BCT End Terminals in Indiana.

	Crash Severity					
Terminal Type	K	A	B	C	PDO	Total
BCT	6	0	1	0	3	10

Iowa and North Carolina

In January 2000, at the Annual Meeting of the Transportation Research Board (TRB), Malcolm Ray presented a paper on his ongoing research of the in-service performance evaluation of the BCT and MELT guardrail terminals in North Carolina and Iowa [9].

Data for this study was collected in a four county area in Iowa and a three county area in North Carolina from July 1, 1997 until June 30, 1999. The data collection teams were notified by police or highway maintenance agencies when an impact had occurred. Police accident reports and maintenance cost-recovery reports were obtained for each accident when available. The accident sites were also visited by the data collection team to inspect the guardrail terminal damage and take photographs. Data was collected for a total of 102 BCT impacts and 42 MELT impacts, of which, 115 impacts were matched with police accident reports. Performance of the guardrail end terminal was evaluated with respect to collision characteristics, occupant injury, and barrier damage. Table 2, presents the crash severity related to the type of guardrail end terminal type for both Iowa and North Carolina.

Table 2 - Crash Severity in 115 Police-Reported BCT and MELT Collisions in Iowa and North Carolina.

Terminal Type	A+K	B+C	PDO	Total
	Iowa			
	Crash Severity			
BCT	1	5	18	24
MELT	0	1	1	2
	North Carolina			
BCT	3	18	41	62
MELT	1	12	14	27

Kentucky

The State of Kentucky has a long history of in-service performance evaluations (ISPE). In 1980, Kentucky began collecting data on guardrail end terminals, primarily the BCT. The data collection effort on the BCT continued until 1991, with reports being released in 1984, 1987, and 1991 [10,11,12]. An NCHRP 350 qualified device, the ET2000 was evaluated also, with data released in a 1997 report [13]. The Kentucky is presented as Table 3 , shows the crash severity by type of guardrail end terminal. It should be noted that the Kentucky contains information BCT data on parabolic flare, simple curve, and straight installation configurations. No straight installation configurations were included in our data analysis. The BCT was crash tested under NCHRP 230 guidelines using a 37.5 ft parabolic flare and a 4 ft offset. Other configurations using offsets of approximately 5 ft. were also common.

Table 3 - Crash Severity Related to Guardrail End Terminal Type in Kentucky.

	Crash Severity						
Terminal Type	**K**	**A**	**B**	**C**	**PDO**	**Unknown**	**Total**
BCT (parabolic)	2	11	21	1	17	37	89
BCT (simple)	6	11	10	7	11	20	65
ET2000	0	4	4	6	11	9	34

The in-service performance of the BCT and ET2000 reveals that they usually performed as designed and the results warrant continued use. However, it is the authors' recommendation that the BCT be installed where a 4 ft. offset can be obtained at the end of a 37.5 ft. parabolic flare with a 10:1 slope in advance of the terminal and sufficient recovery area, not exceeding a 3:1 slope, behind. The ET2000, was not considered as cost effective on all types of highways.

The State of Kentucky was one of the first States to install breakaway cable terminals (BCT), with the first installation made in 1974. Through 1990, approximately 5,700 installations had been made. The weighted average installation cost for each BCT installation was $499, as compared to repair costs of approximately $700 in 1984, $644 in 1987, and $783 in 1991. Limited data was available for repair costs, but repair costs were higher than original installation costs for each collection period.

Michigan

Michigan's standard guardrail end terminal since the late 1970's has been the breakaway cable terminal (BCT), with the State installing more than 14,000 of these terminals [14]. By 1991, new end terminal designs had been developed that performed better in crash tests, including those involving subcompact size cars which the BCT had failed to pass. The purpose of this study was to evaluate the performance of Michigan's BCTs and to provide a factual basis for the cost/performance trade-offs to be considered in the future.

Data was collected for this study during two time periods: 1984 - 1986 and 1988 - 1990. The BCT impacts were mainly on freeways in the southern half of the State that were under Michigan Department of Transportation (MDOT) jurisdiction. Because of the abnormalities in the first data set and the assumption that end terminals monitored in the second data set more closely followed DOT installation specifications as compared to the first data set, only the second data set included in this literature review. Table 4, presents the results of the ISPE of Michigan BCT guardrail end terminals for injury severity.

Table 4 - Crash Severity of BCT Impacts in Michigan.

	Injury Severity					
Terminal Type	**K**	**A**	**B**	**C**	**PDO**	**Total**
BCT	0	10	12	7	54	83

New Hampshire

Prior to 1991, New Hampshire's primary end terminal was the turned-down end terminal [15]. When the FHWA recommended that turned-down end terminals not be used on high speed, high volume roadways, the New Hampshire Department of Transportation (NHDOT) was concerned about replacing the units in an orderly and timely manner. Acceptable end terminals included two NHDOT terminal unit designs, the BCT, ET2000, SENTRE, and the Breakmaster. Analysis of these end terminals led the NHDOT to conclude that the BCT offered the most benefits for inclusion as the NHDOT standard end terminal. However, before any BCTs were constructed on New Hampshire roadways, information was received on a revised design called the Eccentric Loader BCT (ELBCT) that simplified design, used standard hardware, and reduced cost per unit. The NHDOT moved to adopt this revised design as its standard, which was later slightly modified and renamed the Modified Eccentric Loader BCT (MELBCT). This design was adopted as the NHDOT standard and the name was simplified to the Modified Eccentric Loader Terminal (MELT). The NHDOT was the first state in the nation to install the MELT on its roadways. The cost of the MELT is approximately $1,200 if purchased through a vendor.

During the period that the MELT was first installed in 1991 until this report was released in 1994, approximately 25 MELT end terminals had been impacted with little or no injury to the driver or occupants. The in-service performance of the MELT in New Hampshire has been exceptional from glancing blows to full end-on impacts. No spearing, vaulting or other negative results have been reported.

New Jersey

In 1976, on the recommendation of the FHWA, New Jersey began installing BCTs as guardrail end treatments [16]. Since this was a new end treatment in New Jersey, the Department of Transportation agreed to participate in the FHWA's national monitoring effort of the BCT's performance. Under the monitoring program, all accident sites were to undergo a field inspection, with pictures of the vehicles and the sites, and accident reports for every reported impact with each BCT, or with connected guardrail within 75 feet of a BCT.

Data was collected for this program for a period of two years. During that time thirty-three impacts with BCTs were identified and investigated by the Division of Research & Development. Of the thirty-three that were identified, thirteen impacts are discussed in this report. The remaining twenty impacts were eliminated due to insufficient accident information. This was primarily caused by the unknown date of impact. Without the date, it was impossible to obtain the accident report and inspect the vehicle. In some instances the BCT was repaired before a field inspection could be made. Table 5, below, shows the crash severity of impacts with BCT guardrail end terminals in New Jersey. This report only characterized injuries as serious, moderate, or none so A+K and B+C have been combined accordingly.

Table 5 - Crash Severity of Impacts with BCT Guardrail End Terminals in New Jersey.

	Crash Severity			
Terminal Type	**A+K**	**B+C**	**PDO**	**Total**
BCT	6	3	4	13

Ohio

After increasing evidence of poor performance of turned down guardrail end treatments, the FHWA encouraged the removal of these devices from high speed, high volume roadways [17]. In 1991, the Ohio Department of Transportation (ODOT) proposed a new policy on guardrail end terminals that included provisions to use either the Type B Modified Eccentric Loader Terminal (MELT) or the Type E (Guardrail Extruding Terminal, i.e. ET2000) on high speed, high volume roadways instead of the Type A (turned-down) anchor assembly. The MELT terminal was chosen because it was an existing standard in Ohio. However, this anchor assembly requires extensive grading and is difficult to use in some areas. The ET2000 was chosen as a design alternative.

The FHWA requested annual performance review of the ET2000 and the ODOT developed an in-service performance evaluation program accordingly. The program entailed District staff performing field investigations of any new treatments that were impacted. The investigator photographed the scene and completed a one-page impact report form

A total of 306 impacts involving the Type E (ET2000) assemblies were reported during the data collection period of October 1992 through February 1996. In addition to assessing the occupant's injuries, the investigators were asked to measure the length of extruded guardrail to provide an indication of the severity of impact severity. Severity was classified as unknown, none, minor, moderate, or serious. The "unknown" classifications resulted from accidents in which the vehicle either left or was removed from the scene and no accident report was filed. The severity resulting from impacts with the ET2000 guardrail end terminal in Ohio is summarized in Table 6.

Table 6 - Severity of ET2000 Impacts in Ohio.

	Crash Severity						
Terminal Type	**K**	**A**	**B**	**C**	**PDO**	**Unknown**	**Total**
ET2000	0	4	1	34	58	209	306

Summary of In-Service Performance Evaluations Review

Prior research, in the form of in-service performance evaluations, was determined to have occurred in at least eight States. The type of end terminal studied in each State is summarized in table 7.

Table 7 - Summary of End Terminal In-Service Evaluations by State.

State	BCT	MELT	ET2000
Kentucky	X		X
Indiana	X		
Iowa and North Carolina	X	X	
Ohio		X	X
Michigan	X		
New Jersey	X		
New Hampshire		X	

Table 8 summarizes the occupant injury rates for the various in-service performance evaluations for the BCT, MELT, and ET2000.

Table 8 - Summary of Crash Severity for In-Service Performance Evaluations.

Terminal/State	No. Cases	A+K No.	A+K %	B+C No.	B+C %	PDO No.	PDO %
BCT							
Indiana	10	6	60	1	10	3	30
Iowa	24	1	4	5	21	18	75
North Carolina	62	3	5	18	29	41	66
Kentucky (parabolic)	52	13	25	22	42	17	33
Kentucky (simple)	45	17	37.8	17	37.8	11	24.4
Michigan	83	10	12	19	23	54	65
New Jersey	13	6	46	3	23	4	31
Totals	**289**	**56**	**19.4**	**85**	**29.4**	**148**	**51.2**
MELT							
Iowa	2	0	0	1	50	1	50
North Carolina	27	1	4	12	44	14	52
Totals	**29**	**1**	**3.4**	**13**	**44.9**	**15**	**51.7**
ET2000							
Kentucky	25	4	16	10	40	11	44
Ohio	306	4	1	35	11	267	88
Totals	**331**	**8**	**2.4**	**45**	**13.6**	**278**	**84.0**

3. STATISTICAL ANALYSIS

NCHRP Project 22-13 that analyzed the safety effectiveness of updating guardrail end terminals to NCHRP 350 by to only including properly installed and maintained BCT and MELT end treatments. For example, in-service evaluations of end terminals in Michigan, Washington, Kentucky, and New Jersey were ignored due to unknown information on installation configuration (parabolic flare, circular flare, no flare, first post offset, or straight installation). While these installation issues are directly related to performance, they are issues that pertain to every installation. If it is acknowledged that BCT and MELT installations can be incorrect in one State it is safe to assume that they can be incorrectly installed in every State. This acknowledgment inherently supports the need for BCT/MELT replacement.

The severity of impacts with BCT/MELT end terminals is, therefore, considered as valid data regardless of proper or improper installation. In addition, since MELT installations were considered operationally adequate for a relatively small period of time, and was never qualified under NCHRP 350, their performance can be considered as analogous to the BCT. Consequently, the crash experience of the BCT and MELT were combined and the data from Michigan, Kentucky, Indiana, Iowa, North Carolina and Ohio were used.

Analyses were performed on the severity distribution of impacts between the BCT/MELT and NCHRP 350 end terminals. The data, presented as both a proportion and frequency ( ) in table 9 indicates that there were over 2.5 times as many impacts with BCT/MELT installations than there were with NCHRP 350 devices. This is the result of a greater number of BCT/MELT installations, and therefore, a greater opportunity of impact. Since the purpose of this analysis is to determine the statistical significance of the distribution of impact severity after an impact had occurred. The analyses were performed by analyzing the proportional distribution.

Table 9 - Proportion of Crash Severity Related to Terminal Type.

	Crash Severity (number of impacts in parentheses)			
Terminal Type	**(A+K)**	**(B+C)**	**PDO**	**Total**
BCT+MELT	.179 (57)	.308 (98)	.513 (163)	318
NCHRP 350	.024 (8)	.136 (45)	.840 (278)	331
Totals	**.100 (65)**	**.220 (143)**	**.680 (441)**	**649**

The 95% level was chosen to agree with, and serve as a check on, the analyses performed by NCHRP Project 22-13 [18]. This study performed analysis by constructing a symmetrical (two tailed) 90% confidence interval, for each end treatment and severity category. If these confidence intervals overlapped then it was assumed that there was no significant difference. A one-tailed 95% test is comparable to the two-tailed 90% test used by Ray. Statistical analyses for the study of this report was conducted between the sample proportions as a 95% level of confidence, one tailed test, using the statistic shown below [19].

$$z = \frac{p_1 - p_2}{\left[\hat{p}\hat{q}\left(\frac{1}{m} + \frac{1}{n}\right)\right]^{1/2}} \quad (1)$$

where :

$$\hat{p} = \frac{x + y}{m + n} \quad (2)$$

$$p_1 = \frac{x}{m} \quad (3)$$

$$p_2 = \frac{y}{n} \quad (4)$$

The results of the statistical analysis are summarized in table 10. The NCHRP 350 end terminals have a statistically lower evidence of K+A and B+C, and significantly higher PDO, crashes. This indicates that the reductions in the K+A and B+C crashes are being distributed into the PDO category.

Table 10 - Summary of Statistical Analysis Between Severity of BCT/MELT and NCHRP 350 End Terminals.

	Value of Calculated Statistic[1]		
	K+A	**B+C**	**PDO**
Statistic Value	6.58	5.29	8.93
Signif./Not Signif.	**Significant**	**Significant**	**Significant**

[1]Critical $Z_{.05}$ = 1.645

These results differ from the conclusions of NCHRP Project 22-13 which determined that there was no statistical difference between the different end terminals for any severity categories. [18] By combining the different States and recognizing that BCT/MELT installations can be improper leads to the conclusion that K+A severities can be reduced by 15.5% and B+C severities by 17.2% if an NCHPR 350 end treatment is present when an end impact occurs.

This conclusion cannot, however, be directly converted to a monetary amount. The reduction is only realized after an impact has occurred; not for every BCT/MELT installation that is replaced with a NCHRP 350 device. The probability of impact is dependent upon the ADT, type of installation (flared or straight), distance from traveled way, facility speed, and presence of horizontal curves.

To quantitatively answer the question of whether it is cost effective to replace BCT/MELT installations with NCHRP 350 devices requires additional data. Data collection forms and procedures have been developed to assist in this endeavor, and are discussed in the next section.

4. DATA COLLECTION PLAN

There were 1,148 persons killed in traffic crashes in Alabama in 1999, an increase of 7% over 1998 figures [20]. The motor vehicle death rate was 26 per 100,000 people, which is tied with New Mexico for the fourth highest motor vehicle death rate in the country. Hitting a fixed or other object and overturning accounted for 12.3% of all crashes and 32.5% of all fatalities during 1999. Crashes occurring on interstates, federal routes, and state routes accounted for 48.2% of all crashes and 59.8% of all fatalities. While the statistics don't expressly segregate crashes with guardrail end terminals, data analyzed by Hunter/Council from six States, over 5 years, reveals that impacts with guardrail is the second most impacted type of roadside hardware and the fourth most impacted fixed-object type. In the North Carolina data, which segregates guardrail or guardpost from guardrail end, 24% of the impacts occur on the guardrail end. It is the purpose of this data collection plan to focus on crashes with guardrail end terminals on interstates, federal routes, and state routes.

The data collection plan has been designed to be implemented by ALDOT maintenance forces and to collect a minimal amount of data on the in-service performance of guardrail end terminals. A relatively simple, two-page form (see Appendix A) has been developed to facilitate the data collection effort. The data collection will focus on obtaining data from impacts with guardrail end terminals that are currently installed on Alabama highways. The end terminals to be targeted in this data collection effort are those that have passed NCHRP 350 guidelines. In particular, the BCT and MELT, which have not passed NCHRP 350 or those which have not, but are commonly found on Alabama highways, will be targeted, as well as, the SRT 350, FLEAT 350, REGENT 350, ET2000, family, SKT 350, ET2000-LET, and the BREAKMASTER, which have passed NCHRP 350 guidelines. Table 11 shows the ALDOT designation for these end terminal types.

Table 11 - Summary of ALDOT End Terminal Designation.

Type 10	Type 10A	Series 10	Series 20	Type 21
BCT	MELT	SRT 350	ET2000	Breakmaster
		FLEAT 350	B-E-S-T	
		REGENT	SKT 350	
			ET2000-LET	

The data collection area will be focused on guardrail end terminals located on interstate highways, Federal routes and State routes that are being maintained by ALDOT maintenance forces. The literature shows that the majority of impacts with guardrail end terminals occurs on roadways with high ADT, therefore, these types of roadways should produce the majority of impacts while still maintaining statistical validity for all functional classifications. Also, by focusing on to high speed, high volume State roadways, will mitigate that some of the problems associated with proper grading and installation.

The data collection area can be designed to encompass the entire State or selected ALDOT divisions as needed. The data collection could be set up as a pilot program for a limited collection area and then expanded.

The data collection effort is essentially two-fold: 1) After the maintenance crew has been notified of an end terminal impact, the site is visited and the data collection form is filled out, and 2) The police accident report, if available, is obtained for the impact. An arrangement with the Department of Public Safety to notify the maintenance crews when a guardrail end terminal has been impacted would significantly improve the chance of obtaining the police accident report and therefore the quality of the data for the study. The following information is vital to tracking down the accident report if it cannot be obtained directly from the police agency: date of the crash, route number, location (mile post), and driver's name. A checklist for important data items to be recorded from the police accident report has been developed (see Appendix A). The information from the data collection form and the items from the police accident report should be entered into a database or spreadsheet to await analysis and the hard copies should be filed for future reference.

Few states have roadside hardware inventory information, however, an estimate of the quantity of traffic barriers is often important in understanding the injury severity rate calculated for all reported collisions. The number of opportunities for a collision is a function of the amount of roadside hardware in place and the traffic volume passing the hardware. To estimate the inventory of a particular piece of hardware, an actual drive-by inventory can be performed prior to the start of data collection (see Appendix A for sample form [21]). A sample of typical roadways of each functional classification can be inventoried to estimate the quantities of traffic barriers in the data collection area. After the inventory has been collected, the number of guardrail end terminals per mile of roadway can be calculated and then extrapolated to give an estimate for each functional class in the data collection area. This estimated inventory can then be combined with the ADT for each particular route to establish an exposure rate.

Once there is a sufficient sample of impacts (at least 100) with a particular guardrail end terminal, the data can be analyzed to get an indication of the injury severity being sustained by drivers and occupants of vehicles impacting guardrail end terminals and the costs that are associated with those impacts.

5. CONCLUSIONS AND RECOMMENDATIONS

The following summary of conclusions and recommendations result from the analysis efforts and the literature review.

- One such study administered through the auspices of the NCHRP program of the Transportation Research Board (Project 22-13) is a large multi State effort. This study attempts to ascertain if BCT and MELT end treatments were properly installed. Only those installations where correct installation can be established are included in the analysis. Preliminary conclusions of the NCHRP project 22-13 study, (hence referred to as Project 22-13), indicate that there is no significant difference in the crash severity categories between BCT/MELT and NCHRP 350 end treatments.
- Assuming that BCT/MELT installations are equally probable to be installed in every State resulted in a decision to increase the data base by including data not used in Project 22-13. The reasoning behind this decision is that correct/incorrect installations are not only difficult to determine but is an inherent problem with the BCT/MELT systems. Knowing proper/improper installation after impact is even more difficult. Errant vehicles, leaving the roadway are and not impacting only the proper installations and replacing BCT/MELT systems with NCHRP 350 devices may have a significant impact in overall safety. Analysis on the expanded data base determined that fatalities and A injury crashes would be significantly reduced by the installation of NCHRP 350 end terminals.

- The installation of NCHRP 350 end terminals would reduce K+A severity by 15.5% and B+C injuries by 17.2%, while increasing PDO crashes by 32.7%. Placing the 32.7% reduction into perspective, however, indicates that K+A severity would have been reduced by 9 crashes (15.5% of 57 BCT/MELT K+A crashes) and B+C severity would have been reduced by 17 crashes (17.2% of 98 BCT/MELT B+C crashes).
- The results of Project 22-13 and the practical consideration of this study indicate that it is not cost effective to change BCT/MELT to NCHRP 350 end terminals unless the BCT/MELT's are replaced due to destruction by impact. For example, the reduction of a total 26 crashes from personal injury categories to PDO crashes was determined by analyzing 23 years of data from 7 States. Consideration to the number of end treatments present and the volume of traffic present during the analysis period fosters the conclusion that the probability of impact is very small.
- Quantitatively answering the question of whether it is cost effective to replace BCT/MELT installations with NCHRP 350 devices requires additional data to estimate the probability of end treatment impact. Data collection forms and procedures have been developed to assist in this endeavor. Obtaining such data is outside the scope of this current project.

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APPENDIX A - ALABAMA MAINTENANCE FORM

DEPARTMENT OF TRANSPORTATION

Guardrail End Terminal
Maintenance Crash Report and Evaluation Form
Alabama Department of Transportation

Date of Crash ____________ ALDOT Division ___________ ALDOT District ____________

Location

County ____________ Route ____________ Milepost ____________

Direction (Circle) NB SB EB WB

Side (Circle) Left Right Ramp Other ____________________________________

Guardrail End Terminal Information

Type (Circle) BCT MELT SRT-350 FLEAT-350 REGENT-350

ET2000 B-E-S-T SKT-350 ET2000-LET Breakmaster

Location of Impact (Circle) End-on Downstream of Post 2

Within guardrail LON Other ______________________

Impact Result (Circle) Vehicle Redirected Vehicle Penetrated/Gated

Vehicle Stopped in Contact

If Extruder Type; Length of Extruded Guardrail ____________

Crash Location Information

# of Lanes _____ Lane Width _____ Shoulder Width _____

Distance of Guardrail Face from Traveled Way _____

Horizontal Curve Present (Circle) Yes No

Vertical Curve Present (Circle) Yes No

Other Roadway or Geometric Contributing Factors ________________________________

Description of Damage to Guardrail

APPENDIX A (CONT.)

Description of Crash

Sketch Crash Location

Show a plan view of lanes, guardrail end terminal, vehicle path, impact point, and final vehicle location.

Estimate of Repair Cost

Material Cost: ______________________

Labor Cost: ______________________

Equipment Cost: ______________________

Include photographs of crash or end terminal damage.

Return to: ALDOT Division Maintenance Engineer

Reported By: ______________________ Date: __________

Title: ______________________

APPENDIX A (CONT.) - ALABAMA POLICE DATA CHECKLIST

DEPARTMENT OF TRANSPORTATION

Police Data Ckecklist
Alabama Department of Transportation

The following items will be needed for data collection and analysis from the police accident report form.

_____ Reporting Police Agency

_____ Location of collision

_____ Direction of travel

_____ Route number and type

_____ Month, year, and time of day of the collision

_____ Number of vehicles involved

_____ Posted speed

_____ Weather conditions

_____ Roadway conditions

_____ Vehicle type, year, and VIN

_____ Number of occupants and whether a front seat passenger was present

_____ Safety devices used by the driver

_____ Severity of injuries to the driver and the highest injury severity of any occupant

_____ Vehicle speed

_____ Impact angle

_____ Vehicle trajectory

_____ Vehicle reaction after impact (redirected, penetrated, vaulted, overturned)

_____ First harmful event

_____ Most harmful event

_____ Officer's account of the crash

APPENDIX D (CONT.)
SAMPLE "DRIVE-BY" INVENTORY FORM [21]

Project # Project:	Hardware Inventory Date:

County/ District	Route #	Hardware Type	Side of Road	Length	1-way ADT (vpd)	Date of Survey