UAB SCHOOL OF ENGINEERING

In-Service Evaluation of FHWA-Accepted Guardrail Terminals

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Abstract

Guardrail is installed along the length of a highway to shield motorists from life-threatening objects. However, these safety features are, in and of themselves, a hazard. The ends, in particular, can reap devastating consequences. Many different end treatments exist with almost as many different working concepts behind their designs. Due to this variability, it is possible that one or more systems may constitute an elevated level of risk to the public. Therefore, a statistical analysis was conducted to compare the distribution of end treatments involved in severe-injury or fatal crashes to an expected distribution, known as exposure. To date, Missouri and Ohio have been included, and in both states, it was found that the ET-PLUS placed motorists at a higher level of risk of both serious injury and fatality relative to its predecessor, the ET-2000.

Acknowledgments

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Chapter 1. Introduction

1.1. Problem Statement

Certain roadside hazards require shielding via longitudinal barriers, specifically when they cannot be moved outside of the clear zone, which is an unobstructed traversable area next to the roadside that can allow the driver to come to a safe stop [1]. This design practice is based on the assumption that the barrier represents a lower probability of injury to the occupants of an errant vehicle compared to the probability of injury associated with the shielded hazard. While this is true for most scenarios, it does not mean that longitudinal barriers are without risk.

In the family of longitudinal barriers, W-beam guardrail is the most prevalent [2]. These barriers are considered semi-rigid, providing resistance against lateral deflection while mitigating accelerations experienced by the occupant.

When these systems were first instituted, their ends were not considered dangerous and were often left exposed. This practice soon became obsolete due to high vehicle penetration rates. Instead, the ends of guardrails became turned down or treated with a shoe or fish tail shaped cap. For turn downs, a ramp was created and rollovers became prevalent. For shoes or fish tails, penetrations were still too common. Therefore, end treatments continued to evolve until the present day, where the most readily-accepted device (called a “guardrail terminal” for the duration of this report) has the ability to absorb energy by deforming the rail in some manner and/or has been crash tested to at least the National Cooperative Highway Research Program (NCHRP) Report No. 350 guidelines. For almost all common energy-absorbing guardrail terminals, this deformation occurs in response to compressive loading applied to the rail element. As such, there is an inherent risk of compressive buckling in the rail. When this buckling occurs early in the impact event, the errant vehicle has enough energy to cause impalement with the newly formed elbow in the rail. Other risk factors may develop as well, including, but not limited to, high deceleration rates, vehicle instability, and redirection into traffic. Each of these outcomes can lead to increased probability of serious injury and fatal crashes.

The nomenclature of injury severity used throughout this report is based on the KABCO scale. This scale categorizes injuries from fatal (“K”) down to property damage only (PDO or “O”). Severe and/or incapacitating injuries were considered “A” and the combination of severe injury and fatal crashes was called “A+K.” Continuing, “B” and “C” crashes typically result in moderate, non-incapacitating injuries or minor injuries, respectively.

As previously noted, energy absorbing guardrail terminals deform the rail in different ways. Some flatten the rail, some cut the rail, and some kink the rail. The mechanism of energy management controls the forces transmitted to the vehicle, and therefore the rail. This in turn influences the mode of failure, if there is one, in the rail element itself ahead of the end terminal. Regardless of these various design approaches, if they performed as intended, they would all have a similar success rate in mitigating fatalities and/or serious injuries (henceforth known as

“K” and/or “A+K” crashes). In order for States to proactively reduce the frequency of K and A+K crashes involving end treatments, they should expect all of their qualified products to perform at a relatively high level. Each successive generation of terminal design should improve safety performance.

1.2. Objective

The objective of this study was to evaluate the safety performance of NCHRP Report No. 350-approved guardrail terminals. This information should prove valuable to highway agencies attempting to determine which guardrail terminals provide a higher level of safety on their highways.

1.3. Scope

Data was originally collected from the States of Ohio and Missouri. Therefore, the statistical study was designed according to available data from these states. However, the required data is not unique to these states, and as such, the process documented herein can be applied to any state where the data is made available.

1.4. Organization

This report has been organized such that results for any state can be easily added to this report in the future. In general, the process of collecting data and the process of conducting statistical analyses on that data are described. Each state that has contributed data to this effort is studied while following the outline described in the general overview. A summary of any deviation from the general research approach, a summary of the collected data, a detailed presentation of the statistical analyses, and a discussion of the results of the analyses are given in a separate chapter for each state. Finally, a concluding chapter is provided to summarize the conclusions made for each state and comment on possible regional differences and trends.

Chapter 2. Research Approach

A sortable, tabulated crash database was compiled for each State. Each entry included data for the date, location, injury level, number of involved vehicles, and the events of the impact. This latter inclusion typically consisted of one to four events, and the most harmful event (MHE) was identified from this event field. This data was filtered to include only single-vehicle ran-off-road (SVROR) crashes where a guardrail end was identified as the MHE. A request for the police crash report was submitted for each identified crash.

Once the crash reports were received, they were screened according to the information contained in the report. Only crashes where the upstream end terminal was involved were included. Examples of crashes that were excluded are concrete barrier ends, downstream impacts with guardrail terminals, very low-volume roads (such as unpaved roads), and extreme vehicle types (e.g., tractor-trailers, single-unit trucks, and motorcycles). For this document, downstream refers to the end of the barrier system on the opposite side of the direction of travel.

For the remaining crashes in the database, the scene photos provided by the State, if available, were used to identify the end treatment via inspection according to the experience of the research staff. In addition to scene photos, state photologs and street images were investigated to approximately determine the type of end treatment located at the scene of the crash. Regardless of the method used for determining the end treatment involved in the crash, the date that the image was taken was recorded. The archived photolog or street images with the closest date prior to the crash were used as long as the photo predated the crash. Otherwise, the crash was filtered out of the database.

Next, exposure data was collected. Traditionally, the measure of effectiveness of a roadside safety device is the percent of A+K or K crashes relative to the total number of crashes, which would include less severe injuries and property damage only (PDO) crashes. A review of crash reports demonstrated that it was often impossible to determine the impact conditions of the crash. It was very likely that many of the crashes involved downstream impacts with the end terminal or side impacts with the upstream terminal. Most crash reports of minor injuries of PDO crashes excluded scene diagrams and almost never included photos or reconstruction reports. Therefore, only severe injury and fatal crashes could be used, wherein the crash reports were more fully documented and often accompanied with scene photos.

It was assumed that the occupants of the vehicle would have driven 10 miles on the highway prior to the crash. Therefore, exposure was defined as the number and distribution of end treatments observed in those 10 miles.

Assuming that the exposure data reflects the expected crash frequency for all injury levels, a comparison was made between the observed number of crashes and the expected number of crashes for each identified crashworthy end treatment. Here, “crashworthy” indicates that the system was crashed tested to at least NCHRP Report No. 350 test standards and was approved for use on the National Highway System by the Federal Highway Administration (FHWA) [3]. Only roadside barrier end treatments were analyzed. This effectively eliminated median treatments because the design constraints were so different that a fair comparison could not be made.

The significance of the difference between observed and expected frequencies was determined by statistical analyses, specifically referencing the P-value (such as from Fisher's exact test) and the odds ratio (from a logistic regression).

Chapter 3. Guardrail Terminal Identification

In general, each state determines what guardrail terminals can be used on their highways, and contractors pick from that list. Often times, the contractor has an affiliation with a manufacturer and will use guardrail terminals exclusively from that manufacturer's product line. Other times, the contractor will simply choose the least expensive option. However, guardrail terminals are not always called for by the state department of transportation. On low-speed, low-volume roads, end treatments that do not absorb energy might be more efficacious. Lastly, some of these end treatments are as old as the guardrail itself. These systems are often left in place because of budgetary considerations, since there are possibly thousands of these locations statewide, or because the relative risk for that section of roadway is low enough not to warrant an upgrade to a higher performing end treatment. Owing to these complexities, the number of end treatments was reduced by controlling the end treatment type. The end treatments had to be considered a crashworthy device for a roadside longitudinal W-beam guardrail such that it was approved by the FHWA for use on the National Highway System following compliance testing with at least NCHRP Report No. 350. This list also excluded median treatments, concrete blunt ends, cable end treatments, and crash cushions. Listed alphabetically, the five crashworthy guardrail terminals in the following sections were studied.

3.1. ET-2000

The ET-2000 is an early-generation, energy absorbing end terminal. It is produced by Trinity Highway Products, LLC. Its main distinguishing feature is the device placed on the end of the guardrail, which is called a head. The guardrail is slid into the feeder chute of the head, and upon impact, the guardrail is extruded through the head to flatten the rail and kick it out to the non-traffic side of the road. This extrusion is facilitated by steel plates oriented in a way that causes the rail element to deform (in this case, flatten). An example of the ET-2000 found in the photologs of Ohio is shown in Figure 1.

Figure 1. ET-2000 on Interstate 90 in Ashtabula County

3.2. ET-PLUS

The ET-PLUS is a later generation of the ET-2000 and relies on the same basic principles. It is produced by Trinity Highway Products, LLC. It was redesigned to remove approximately 100 pounds of steel [4]. Visually, it can be distinguished by its rectangular face, whereas the ET-2000 used a square face. Additionally, there is no steel plate behind the face on the traffic side. An example of the ET-PLUS found in the photologs of Ohio is shown in Figure 2.

Figure 2. ET-PLUS on State Route 322 in Ashtabula County

3.3. Flared Energy Absorbing Terminal (FLEAT)

The Flared Energy Absorbing Terminal (FLEAT) was designed to be added to the end of a flared guardrail system. It is produced by Road Systems, Inc. Upon impact, the guardrail is forced through the head and sequentially kinked to dissipate energy. An example of the FLEAT found in the photologs of Ohio is shown in Figure 3.

Figure 3. FLEAT on Interstate 77 in Guernsey County

3.4. Sequential Kinking Terminal (SKT)

The Sequential Kinking Terminal (SKT) is an energy-absorbing end terminal produced by Road Systems, Inc. Upon impact, the guardrail is forced through the head and sequentially kinked to dissipate energy. Unlike the FLEAT, the SKT is designed to attach to a tangent section of guardrail. An example of the SKT found in the photologs of Ohio is shown in Figure 4.

Figure 4. SKT on Interstate 77 in Guernsey County

3.5. Slotted Rail Terminal (SRT)

The Slotted Rail Terminal (SRT) has strategically placed slots in the rail to reduce the rail's stiffness in the event of a head-on impact. It is produced by Trinity Highway Products, LLC. It utilizes a slight flare to reduce its footprint and crash frequency. An example of the SRT found in the photologs of Ohio is shown in Figure 5.

Figure 5. SRT on Interstate 77 in Guernsey County

3.6. Summary of EA Tangent Terminals

Energy absorbing (EA) terminals on tangent sections of highway included the ET-2000, multiple versions of the ET-PLUS, and the SKT. These systems are common in many states across the nation, and as such, a brief summary of the dimensions are given below. The FLEAT and SRT were not included. The flared nature of the FLEAT makes it perform substantially different from a kinematic point of view, and as such, its weight, length, and width are less critical. The SRT is not an EA terminal, and so it was not included. The summary of the weight, length of the feeder chute, and the width of the face plate for EA tangent terminals are shown in Table 1.

Table 1. Summary of Dimensions of Tangent EA Terminals

	ET-2000	ET-PLUS (1999)	ET-PLUS (2012)	SKT
Total Length (in.)	57.25	56.75	55.75	83.125
Feeder Chute (in.)	37	37	36	61
Impact Face Width (in.)	20	15	15	20
Weight (lb)	268	175	165	170

Chapter 4. Data Collection

4.1. Sources

Two prevailing types of data were collected: crash location data and exposure data. Crash data relied primarily upon available information collected at the scene of the crash and included scene photos and police crash reports. Occasionally, the end treatment involved in the crash could not be determined from the scene photos, so photologs or street images were used to supplement the crash location data. On the other hand, exposure data was collected exclusively using the photologs that were recorded by the State. The following sections provide a detailed description of scene data, photologs, and street images.

4.2. Crash Data

4.2.1. Scene Data

A request was submitted to the State Department of Transportation (DOT) for tabulated crash data, which they maintain and populated with a plethora of variables including number of vehicles, on or off the road, date, traffic volume, objects struck, and injury levels. The data was filtered to include only single-vehicle ran-off-road (SVROR) crashes where a guardrail end was coded in the events, and a request for crash reports and scene photos was made for those crashes. From the crash reports, vehicle type could be determined, and some crashes were eliminated because the vehicle was either very large (e.g., tractor-trailer) or very small (e.g., motorcycle). An example of a crash scene photo for which the end treatment is identifiable is shown in Figure 6.

Figure 6. Identification of an End Treatment from Scene Photos

4.2.2. Photologs

Occasionally, the scene photos were inconclusive. For these, and for crashes without scene photos, two alternative sources were used. This section describes the photologs. A vehicle equipped with photography equipment drove on the entire state highway network capturing photos at regular intervals. Each image was tagged with a date, county, route number, mile post, and geographical coordinates. The latitude and longitude provided in the crash reports were used to pinpoint the location of the crash, and when possible, nearby landmarks from the scene photos were used to ensure accuracy in the site location. The photolog with the closest year to the crash date was chosen, but the photolog had to predate the crash. If the oldest photolog was more recent than the crash, then the crash was not included in the database.

4.2.3. Street Images

This was the second alternative source for end treatment identification when scene photos were inconclusive or non-existent. In conjunction with the photologs, street images were identified by first estimating the location based on coordinates. Then, when possible, landmarks from the scene photos or photologs were used to precisely determine the location. Using archived street photos, the closest year to the crash date was chosen, but the street image had to predate the crash. If the oldest archived street image was newer than the crash date, the crash was not included in the database.

4.3. Exposure Data

For this study, exposure was defined as the number of end treatments that a driver would encounter in a 10-mile segment of the highway immediately prior to the crash location. Here, “crash location” is a reference to the location of SVROR crashes with a guardrail end impact coded as the MHE. To gather this exposure data, the state photologs were used. In these photologs, the current segment could end when a county line is passed. In this event, the analyst would have to manually reselect the highway on the opposite side of the county line and continue gathering data until the 10-mile requirement was met. On very rare occasions, the road would pass into another state. Since this study was pertinent to each state individually, and because the photologs end at state lines, these segments were shorter than 10 miles.

Additional rules for gathering exposure data are listed as follows:

- Only upstream ends were included.
- For divided highways, only the direction of travel was considered.
- Work zones were not excluded.
- Urban areas were not excluded.

Chapter 5. Statistical Analyses

The software package NCSS 9 was used to determine the statistical significance of the differences in distributions for each NCHRP Report No. 350-compliant end treatment. Also, it was used to estimate the odds ratio of an A+K or K crash for each system relative to the ET-2000, which represents the baseline system because it was the first energy-absorbing system approved under NCHRP Report No. 350.

5.1. Probability and Odds Ratio

For each system, the number of crashes was divided by the number of those systems in the exposure data. This quotient represented the probability of a system being involved in a crash. Then, the odds ratio was calculated from these probabilities. First, the ET-2000 was chosen as the baseline system. Then, the probability of each of the other systems was divided by the probability of the ET-2000 to calculate the odds ratio between the ET-2000 and each of the other guardrail terminals. In essence, this approach would estimate the likelihood that the system was involved in the crash relative to the ET-2000. The probability and odds ratio equations are shown below.

$$P_{System\ X} = \frac{No.of\ Crashes}{Exposure}$$

$$OR = \frac{P_{System\ X}}{P_{ET-2000}}$$

5.2. Statistical Significance Test

Fisher's exact test for statistical significance is applicable regardless of sample size and is commonly used when sample sizes are small. It can only be used for 2x2 tables, where two end treatments can be compared for differences. For example, the A+K crash rate and exposure data can be compared for the ET-2000 and ET-PLUS to determine if they are statistically different (P-value less than 0.1). The calculation of Fisher's exact P-value can be calculated using Table 2 and the equation below. The calculations were performed with the software package NCSS 9.

$$P = \frac{n_1!\,n_2!\,m_1!\,m_2!}{N!\,x_{11}!\,x_{12}!\,x_{21}!\,x_{22}!}$$

Table 2. Parameter Definitions for Fisher's Exact Test

	Exposure	Injury	Total
Group 1	x_{11}	x_{12}	n_1
Group 2	x_{21}	x_{22}	n_2
Total	m_1	m_2	N

Because the ET-2000 was the first crashworthy energy-absorbing end terminal, it was used as a baseline for comparison to analyze the other systems. Essentially, this notion follows the principle that all subsequent systems should perform at least as well as the first system.

5.3. Logistic Regression

A logistic regression was conducted in each state, using speed limit and the end treatment type as variables. From the data, speed limit was typically shown to be statistically insignificant, with P-values greater than 0.10, leaving only one variable in the logistic regression. Although this type of analysis can be a useful tool, it was not considered appropriate when only one variable remained in the model. Therefore, unless otherwise stated, only descriptive statistics, such as the odds ratio and Fisher's exact P-values, were used. In each state, the logistic regression will be described, and either the statements made in this paragraph will be echoed or a more in-depth analysis will be presented. A general description of a logistic regression follows.

Logistic regression studies the relationship between a dependent variable and a set of independent variables, and in this case, the dependent variable had only two categories (injury and exposure). A 1-way regression model was chosen, meaning that no interaction between end treatments was studied. This was done because the installation of a system is not necessarily a function of the installation of any other system. A general equation associated with the logistic regression is shown below:

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n$$

Where, p = proportion of observations
β_0 = intercept in the regression model
β_n = regression coefficient for the system n
X_n = independent variable from exposure for system n

This logistic regression was applied to each end treatment as the reference parameter. In other words, the performance of all other crashworthy systems was studied via independent logistic regression models. Independent variables included speed limit and end treatment type. If speed limit was removed from the model due to a large P-value, only one independent variable remained. This independent variable (end treatment involved in the crash) was modeled with the exposure data, where the ET-2000 was held as a reference parameter. In other words, the odds ratios from the separate models (one for each terminal in the crash database) were calculated relative to the ET-2000, similar to the descriptive statistics described in Section 5.1. An OR of 1.0 would indicate that the corresponding system had the same odds of causing an injury or fatality as the ET-2000. An OR larger than 1.0 indicated a higher risk of injury or fatality than the ET-2000.

Chapter 6. Missouri

6.1. Deviation from Research Approach

More than 700 crashes were investigated as part of the study. Most of those crashes were filtered out for basic reasons, such as the involvement of a semi tractor-trailer, or the upstream end of the guardrail was struck. However, many other crashes were also filtered out because of a lack of available data. They occurred predominantly on low-volume, low-speed roads where crashworthy terminals are unlikely to be installed. When the oldest available photolog was newer than the date of the crash, that crash was excluded from the analysis.

6.2. A+K Crash Data

In the State of Missouri, there were 207 A+K crashes involving a crashworthy end terminal between January 4th, 2005 and March 29th, 2014. Scene photos were used to identify the end treatment involved in the crash. When scene photos were not available, the online photologs were used. The ET-PLUS was involved in nearly two-thirds of the crashes. The crash distribution for the five crashworthy systems is shown in Table 3.

Table 3. Distribution of End Treatments in A+K Crashes

System	Total	Distribution
ET-2000	63	30.4%
ET-Plus	132	63.8%
FLEAT	0	0.0%
SKT	0	0.0%
SRT	12	5.8%
Total	207	100.0%

6.3. Fatal Crash Data

There were 25 fatal crashes in the data set. Almost three quarters of them involved an ET-PLUS. The distribution of the identified systems for fatal crashes is shown in Table 4.

Table 4. Distribution of End Treatments in Fatal Crashes

System	Total	Distribution
ET-2000	5	20.0%
ET-Plus	18	72.0%
FLEAT	0	0.0%
SKT	0	0.0%
SRT	2	8.0%
Total	25	100.0%

6.4. Exposure Data

The total exposure was approximately 1,500 miles and 3,437 end treatments. The most common system was the ET-PLUS at 54.3%. The entire distribution of observed systems is shown in Table 5.

Table 5. Exposure Data for Guardrail End Crash Locations

System	Total	Distribution
ET-2000	1,283	37.3%
ET-PLUS	1,865	54.3%
FLEAT	7	0.2%
SKT	39	1.1%
SRT	243	7.1%
Total	3,437	100.0%

6.5. Statistical Analysis

6.5.1. Simple Odds Ratio

The first and simplest analysis of the data compared the probability of a system being involved in a crash with the probability of a baseline system being involved in a crash. The probability was defined as the number of crashes divided by the exposure for each system, as described in Section 5.1. For example, the probability of the ET-2000 was 0.0491 for A+K crashes (63/1,283).

Next, an odds ratio was estimated for each system. Referencing the baseline, the odds ratio provides an estimate of how much more or less likely the end terminal is to be involved in a crash than the baseline terminal, which was the ET-2000. To calculate this odds ratio, the probability of the baseline system is divided by the system of interest. For example, the odds ratio of the ET-PLUS with respect to the ET-2000 was 1.44 for A+K crashes (0.0708/0.0491). In essence, this means that the ET-PLUS is 44% more likely to be involved in an A+K crash than the ET-2000. The number of crashes, total exposure, probability, and odds ratio for each system are shown in Table 6 for A+K and K crashes.

Table 6. Simple Probability and Odds Ratios

A+K Crashes				
System	Accidents	Exposure	Probability	Odds Ratio*
ET-2000	63	1283	0.0491	1.00
ET-PLUS	132	1865	0.0708	1.44
FLEAT	0	7	0.0000	0.00
SKT	0	39	0.0000	0.00
SRT	12	243	0.0494	1.01
K Crashes				
System	Accidents	Exposure	Probability	Odds Ratio*
ET-2000	5	1283	0.0039	1.00
ET-PLUS	18	1865	0.0097	2.48
FLEAT	0	7	0.0000	0.00
SKT	0	39	0.0000	0.00
SRT	2	243	0.0082	2.11

*Odds of System X being involved in the accident compared to ET-2000

6.5.2. Statistical Significance Tests

There were 207 A+K crashes to go with the total of 3,437 end treatments in the exposure data. To check if any one end treatment had a statistically significant contribution to this crash rate, Fisher's exact test was conducted for each treatment, comparing it to the ET-2000, which was the original energy absorbing end terminal. This was done because of the expectation that subsequent systems would show an improvement in safety performance. For example, there were 12 A+K crashes involving a SRT and 243 SRTs in the exposure data. By comparison, the ET-2000 had 63 crashes and 1,283 units of exposure. The resulting Fisher's exact value was 0.749, which would indicate that the difference in the two systems was not statistically significant. The Fisher's exact values for each system compared to the ET-2000 for both A+K and K crashes are shown in Table 7. The only statistical significance was in the A+K and K crashes when comparing the ET-PLUS to the ET-2000, indicating that the ET-PLUS was statistically different than the ET-2000.

Table 7. P-Values for Statistical Significance

Comparing to ET-2000		
System	Fisher Exact Values	
	A+K	K only
ET-PLUS	0.024	0.087
FLEAT	1.000	1.000
SKT	1.000	1.000
SRT	0.749	0.311

6.5.3. Logistic Regression

The exposure collected for each crash was included with the end treatment involved in the crash as one row in the data table used to conduct the logistic regression. Effectively, this meant the logistic regression was conditioned upon the exposure at each location independently. Doing so ensured that the probability of a system being involved in a crash was not masked by the overall average exposure. For example, if a crash involved an ET-PLUS, but 95% of the exposure in the 10-mile segment leading up to that crash consisted of ET-PLUS guardrail terminals, then the involvement of the ET-PLUS was not unexpected.

Speed limit from the crash reports was also used in the logistic regression as an independent variable. Along with the exposure for all 5 crashworthy systems, an initial model was developed. However, the speed limit and exposure of the FLEAT, and SKT were not statistically significant in the model or from Fisher's exact values (for the guardrail terminals only, excluding speed limit). Therefore, the final logistic regression model was conducted using only exposure data for the ET-PLUS, ET-2000, and SRT. Since speed limit was eliminated from the model, only the end treatment type remained as an independent variable. The logistic regression confirmed odds ratios above 1.0 for the ET-PLUS relative to the ET-2000. Since this analysis did not overturn the trends from the descriptive statistics, and because there was only one independent variable in the final model, it was not used to derive conclusions and recommendations. Instead, the descriptive statistics using odds ratios and Fisher's exact P-values were used.

6.6. Discussion and Recommendations

The probability of a guardrail terminal being involved in a crash was calculated using the crash site and exposure data for each of the 5 crashworthy guardrail terminals. Then, using the ET-2000 as a baseline, an odds ratio was calculated relative to the other systems (i.e., the odds of a terminal being involved versus an ET-2000). For Missouri, the odds ratios of the ET-PLUS were found to be 1.44 and 2.48 for A+K and K crashes, respectively, when compared to its predecessor, the ET-2000. According to the Fisher's exact P-values, each of these ratios was statistically significant at the $P = 0.10$ level. Further, in Missouri, only the ET-PLUS was found to be statistically different than the performance of the ET-2000.

Considering the small sample size for the FLEAT, SKT, and SRT, it is recommended that further research and crash data collection be undertaken in order to provide a more complete analysis of these additional guardrail terminal options.

Chapter 7. Ohio

7.1. Deviation from Research Approach

Ohio was the first state to contribute data to this project, and as such, most of the processes developed for studying these end treatments correlated to the available data in Ohio. However, the data set was considerably smaller than Missouri's data set, and as such, the statistical analysis was limited.

7.2. A+K Crash Data

Most crash scene photos were detailed enough to determine the end treatment involved in the crash, like the one shown in Figure 6. Of the 83 crashes with available scene photos, the end treatment could be identified in 74 of them. The data set was further reduced to include only crashworthy guardrail terminals, leaving 60 crashes. The crash distribution for these five systems is shown in Table 8.

Table 8. Supplemented End Treatment Distributions

End Treatment	Sum	Proportion
ET-2000	28	46.7%
ET-PLUS	26	43.3%
FLEAT	0	0.0%
SKT	0	0.0%
SRT	6	10.0%
Total	60	100.0%

7.3. Fatal Crash Data

The prior tables of crash data all pertain to A+K crashes. However, fatal crashes represent an especially severe category and warrant special consideration. The distribution of the identified systems for fatal cases is shown in Table 9.

Table 9. Distribution of End Treatments in Fatal Crashes

End Treatment	Sum	Proportion
ET-PLUS	4	80.0%
ET-2000	1	20.0%
FLEAT	0	0.0%
SKT	0	0.0%
SRT	0	0.0%
Total	5	100.0%

7.4. Exposure Data

Owing to the enormous time requirement to collect this data, only 44 crashes were used to gather this information. These crashes were the first 44 in numerical order according to their report numbers. Only one of these 10-mile segments was truncated due to crossing a state line, bringing the total exposure to 437.58 miles and 704 end treatments. The most common system was the ET-2000 at 50.9 percent. The entire distribution of observed systems is shown in Table 10.

Table 10. Exposure Data for Guardrail End Crash Locations

System	Total	Distribution
ET-2000	358	50.9%
ET-PLUS	236	33.5%
FLEAT	9	1.3%
SKT	6	0.9%
SRT	95	13.5%
Total	704	100.0%

7.5. Statistical Analysis

7.5.1. Simple Odds Ratio

The first and simplest analysis of the data compared the probability of a system being involved in a crash with the probability of a baseline system being involved in a crash. The probability was defined as the number of crashes divided by the exposure for each system, as described in Section 5.1. For example, the probability of the ET-2000 was 0.0782 for A+K crashes (28/358).

Next, an odds ratio was estimated for each system. Referencing the baseline (ET-2000), the odds ratio provides an estimate of how much more or less likely the end terminal is to be involved in a crash than the ET-2000. To calculate this odds ratio, the probability of the baseline system is divided by the system of interest. For example, the odds ratio of the ET-PLUS with respect to the ET-2000 was 1.41 for A+K crashes (0.1102/0.0782). In essence, this means that the ET-PLUS is 41% more likely to be involved in a crash than the ET-2000. The number of crashes, total exposure, probability, and odds ratio for each system are shown in Table 11 for A+K and K crashes.

Table 11. Simple Probability and Odds Ratios

A+K Crashes				
System	Accidents	Exposure	Probability	Odds Ratio*
ET-2000	28	358	0.0782	1.00
ET-PLUS	26	236	0.1102	1.41
FLEAT	0	9	0.0000	0.00
SKT	0	6	0.0000	0.00
SRT	6	95	0.0632	0.81
K Crashes				
System	Accidents	Exposure	Probability	Odds Ratio*
ET-2000	1	358	0.0028	1.00
ET-PLUS	4	236	0.0169	6.07
FLEAT	0	9	0.0000	0.00
SKT	0	6	0.0000	0.00
SRT	0	95	0.0000	0.00

*Odds of System X being involved in the accident compared to ET-2000

7.5.2. Statistical Significance Tests

There were 60 A+K crashes to go with the total of 704 end treatments in the exposure data. To check if any one end treatment had a statistically significant contribution to this crash rate, Fisher's exact test was conducted for each treatment, comparing it to the ET-2000, which was the original energy absorbing end terminal. This was done with the expectation that subsequent systems would show an improvement in safety performance. For example, there were 6 A+K crashes involving a SRT and 95 SRTs in the exposure data. By comparison, the ET-2000 had 28 crashes and 358 units of exposure. The resulting Fisher's exact value was 0.827, which would indicate that the difference in the two systems was not statistically significant. The Fisher's exact values for each system compared to the ET-2000 for both A+K and K crashes are shown in Table 12. The only statistical significance was in the fatal crashes when comparing the ET-PLUS to the ET-2000, indicating that the ET-PLUS was statistically different than the ET-2000 for this injury type.

Table 12. P-Values for Statistical Significance

Comparing to ET-2000		
System	Fisher Exact Values	
	A+K	K only
ET-PLUS	0.248	0.000
FLEAT	1.000	1.000
SKT	1.000	1.000
SRT	0.827	1.000

7.5.3. Logistic Regression

The data set in Ohio was small, and as such, an extensive conditional logistic regression could not be conducted. However, an unconditional logistic regression was attempted for the limited data set. Possibly due to the small sample size, no statistical significance was observed in the regression model. As such, it is recommended that more data be collected to conduct a conditional logistic regression.

7.6. Discussion and Recommendations

The probability of a guardrail terminal being involved in a crash was calculated using the crash site and exposure data for each of the 5 crashworthy guardrail terminals. Then, using the ET-2000 as a baseline, an odds ratio was calculated relative to the other systems (i.e., the odds of a terminal being involved versus an ET-2000). For Ohio, the odds ratio of the ET-PLUS for fatal crashes was found to be 6.07 when compared to its predecessor, the ET-2000. According to the Fisher’s exact P-values, the fatal odds ratio was statistically significant at the $P = 0.001$ level. Further, in Ohio, only the performance of the ET-PLUS was found to be statistically less safe than the ET-2000 when evaluated for the risk of fatal crashes.

Considering the small sample size for the FLEAT, SKT, and SRT, it is recommended that further research and crash data collection be undertaken in order to provide a more complete analysis of these additional guardrail terminal options.

Chapter 8. Overall Conclusions

Thus far, two states have contributed to the study by supplying crash data and access to archived photologs. These states are listed below:

- Missouri
- Ohio

Assuming the severity of the end treatments is not a function of the state or the region, the data for the participating states was combined, and a simple odds ratio was calculated for each system as compared to the ET-2000. The results of this analysis are shown in Table 13, with Fisher's exact P-values in Table 14.

Table 13. Combined Simple Probability and Odds Ratios

A+K Crashes				
System	Accidents	Exposure	Probability	Odds Ratio*
ET-2000	91	1641	0.0555	1.00
ET-PLUS	158	2101	0.0752	1.36
FLEAT	0	16	0.0000	0.00
SKT	0	45	0.0000	0.00
SRT	18	338	0.0533	0.96
K Crashes				
System	Accidents	Exposure	Probability	Odds Ratio*
ET-2000	6	1641	0.0037	1.00
ET-PLUS	22	2101	0.0105	2.86
FLEAT	0	16	0.0000	0.00
SKT	0	45	0.0000	0.00
SRT	2	338	0.0059	1.62

*Odds of System X being involved in the accident compared to ET-2000

Table 14. Fisher's Exact P-values for Combined Data

Comparing to ET-2000		
System	Fisher Exact Values	
	A+K	K only
ET-PLUS	0.025	0.020
FLEAT	1.000	1.000
SKT	1.000	1.000
SRT	1.000	0.632

The odds ratios for the ET-PLUS, compared to the ET-2000, for both A+K and K crashes were both statistically significant to the 0.03 confidence level. Therefore, the overall trend for all states included in the analysis shows that the ET-PLUS is 1.36 times more likely to be involved in a severe injury than the ET-2000. More poignantly however, the ET-PLUS is 2.86 times more likely to be involved in a fatal crash than the ET-2000.

The results and conclusions pertinent to one state are not necessarily pertinent to any other state. In general, trends and regional effects would be observed amongst neighboring states with similar populations and design standards.

Unfortunately, combining the two data sets still did not provide a large enough sample size for statistical evaluation of the safety performance of the FLEAT, SKT, and SRT. It is recommended that states with high exposure to these terminals should be added to this study in order to provide objective guidance for use of these terminals.

Chapter 9. References

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