The Operational and Safety Impacts of Run-Off-Road Crashes in Wisconsin: Object Hits and Ramp Terminals

Turn Down Guardrail End Hits in Run-Off-Road Crashes in the State of Wisconsin

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16. Abstract

Several publications, including the National Cooperative Highway Research Program (NCHRP) 500 series, have reported that turned down guardrail ends are not as safe as more current guardrail end treatments. Moreover, in June of 1990, the director of the Federal Highway Administration (FHWA) sent a memorandum to the Regional Federal Highway Administrators indicating that turned down guardrail ends should not be installed on new construction of federal aid projects, and should be replaced on high speed roadways with safety and rehabilitation improvements. Nonetheless, the Wisconsin Department of Transportation (WisDOT) still has many turned down guardrail ends installed throughout the state. This study explores the safety effects of turned down guardrail end hits in run-off-road crashes in the state of Wisconsin by analyzing the vehicle crash data of the past three years (2003 - 2005).

The results of this research were clear in finding that turn down guardrail ends provide the least effective safety record of all guardrail end treatments currently used in Wisconsin. Therefore, it is recommended that turn down guardrail ends are removed and replaced with energy absorbing-type guardrail ends with future rehabilitation, reconstruction, and safety improvement projects.

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DISCLAIMER

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CHAPTER I - INTRODUCTION

Over the five year period from 2001 to 2005, 214,364 people lost their lives on America's roadways (*1*). In 2005 alone, 43,443 people were killed in transportation-related crashes. Over 16,000 of these fatalities were a result of travel lane departures. Lane departure or run-off-road (ROR) crashes are associated with vehicles that leave the travel lane, encroach onto the shoulder and beyond, and hit one or more of any number of objects including opposing vehicles, bridge walls, poles, embankments, guardrails, parked vehicles, or trees (*2*). ROR crashes commonly involve only a single vehicle, and consist of a vehicle encroaching onto the right shoulder and roadside, on the median side where the highway is separated, or on the opposite side when the vehicle crosses the opposing lanes of a highway. In recent years, approximately 55 percent of traffic fatalities were a result of ROR type crashes (*3*). Approximately 40 percent of fatal crashes were single-vehicle ROR crashes.

Over that same five-year period, 3,990 people were killed in traffic crashes on Wisconsin's roadways, representing approximately 1.9 percent of the nation's total (*4*). In 2005 alone, Wisconsin experienced 801 fatalities in 700 fatal crashes. Wisconsin is also no exception to the high number of ROR crashes experienced nationally. A recent study found that approximately 54 percent of all non-intersection crashes on undivided roadways in Wisconsin were ROR type crashes (*5*). This percentage is likely to be higher on the divided roadway system.

One of the primary techniques in reducing the severity of run-off-road crashes is to clear the roadside of objects (i.e., trees, poles, other immovable objects). When removing objects is not possible, the object(s) can be protected by using some form of barrier system, most often guardrail. Guardrail can be very effective at keeping an errant vehicle on the roadway and preventing it from hitting one or more of the fixed objects it is protecting. Yet a guardrail is a fixed object itself. In an effort to reduce the negative impact of a vehicle encountering a guardrail, guardrail terminals or end treatments are placed at the beginning or end of a guardrail. End treatments are designed to reduce the severity of a crash when a vehicle impacts one of the guardrail ends. Between 1994 and 2004, approximately 3,700 guardrail end crashes were identified as the first or most harmful event in Wisconsin reported crashes (*5*).

Research Objectives

The objective of this research was to determine the frequency and safety impacts of crashes involving guardrail end hits. A focus was on turned down guardrail ends, in which Wisconsin still has many, as well as the other types of guardrail ends that exist. The goal of this research was to develop quantifiable evidence on the safety effects of the existing guardrail end treatments.

This research will also update the inventory of guardrails and related roadside hardware on selected state highways in the state of Wisconsin. The goal of this inventory is to make it accessible in tabular and spatial formats using a geographic information system (GIS) application.

Organization of Report

As presented in Figure 1, this report will consist of five sections. First, a literature review covers previous research conducted on in-service evaluations of guardrail end treatments in various states over the past 30 years. The study design defines the objectives, variables, area characteristics, and other aspects of the methods used to perform this study. While the results display injury severities, vehicle types, costs and other characteristics associated with crashes involving each of the end treatment types used in the state of Wisconsin along with some of the statistical analysis. Finally, the conclusion gives a summary, the recommendations for Wisconsin Department of Transportation (WisDOT), and suggestions for future research on the subject of guardrail end treatments.

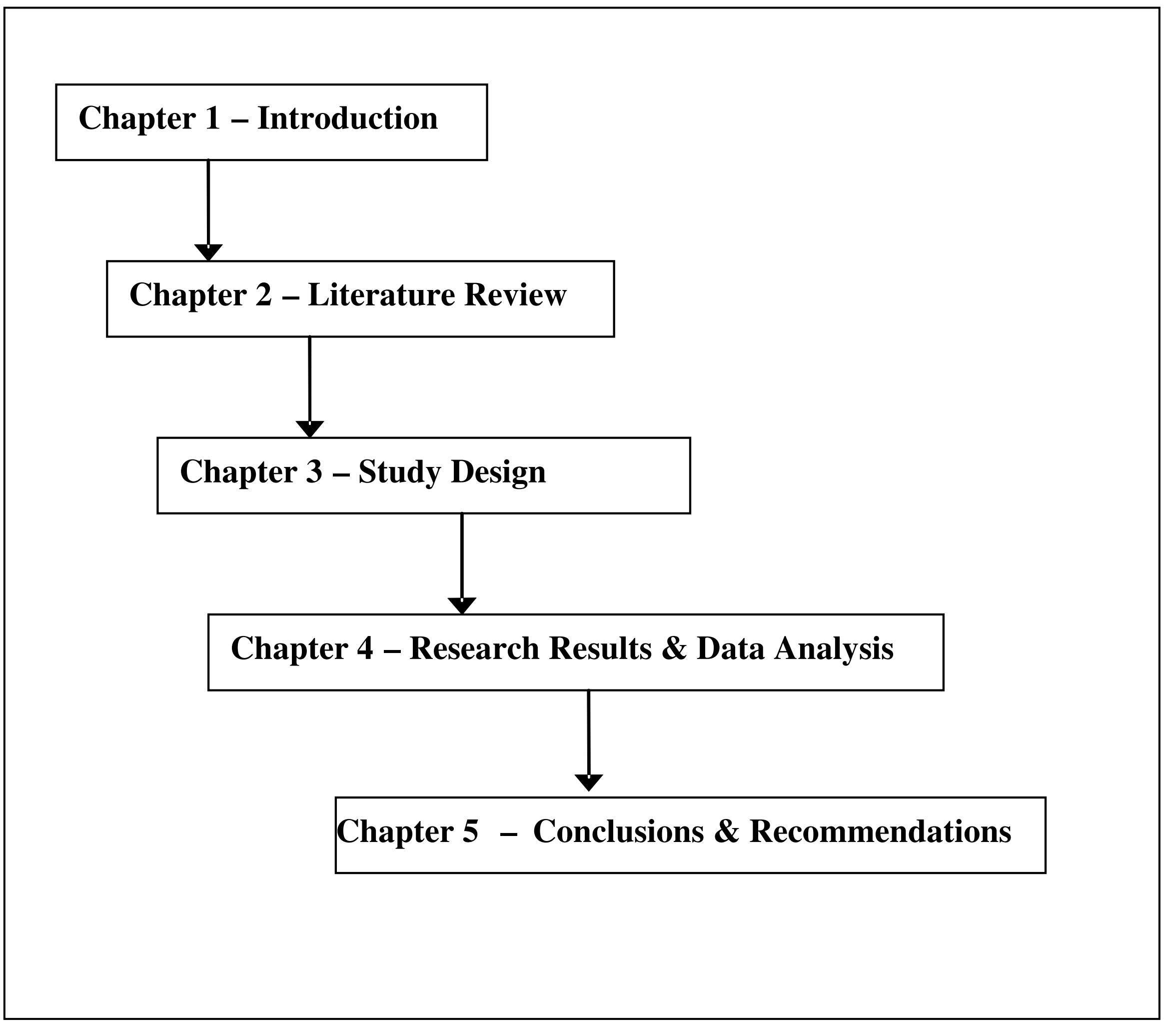

Figure 1 Organization of Report

CHAPTER II - LITERATURE REVIEW

One of the primary objectives of any successful road design is to minimize the safety impact to vehicles encroaching onto the roadside. Despite this design ideal, roadside encroachments do and will continue to happen. Factors such as the use of alcohol, drugs, excessive speed, and sleepy drivers can increase the chances of a vehicle encroaching onto the roadside thus increasing injuries and fatalities on our roadways (*2*). Run-off-road (ROR) crashes are defined in the AASHTO Strategic Highway Safety Plan (*7*) as crashes that involve vehicles that leave their travel lane, encroach onto the shoulder and beyond, and as a result, impact natural or artificial objects. Those objects can include bridge walls, poles, trees, embankments, parked vehicles, and guardrails. From an engineering point of view, once a vehicle encroaches onto the roadside, there are three main safety goals:

- Reduce the probability of overturning;
- Reduce the probability of impacting a fixed object; and
- Reduce the severity of the crash.

Each is part of "minimizing the consequences of leaving the road" and was adopted as one of the goals of the AASHTO Strategic Highway Safety Plan.

Providing a roadside with recoverable slopes and free of fixed objects increases the probability of a safe outcome with roadway departures. When slopes and fixed objects cannot be avoided, the use of roadside protection, most often guardrail, provides a safety measure to prevent vehicles from encountering these obstacles. However, a guardrail is a fixed object in itself. Discussion of the performance of guardrails is well documented in NCHRP Report 490 (*14*).

Before understanding the guardrail end crashes in Wisconsin, it is important to review what research has already been performed and what those researchers found out. The first part of this literature review examines that evaluation of the various guardrail end types. Such questions as when and why were various guardrail ends invented are addressed. Subsequently, a survey of various state evaluations of guardrail end crashes is presented. The methodology and results are shown.

Evolution of Guardrail End Treatments

Although the intention of guardrails is to increase safety, one of the concerns of ROR crashes are vehicles that impact guardrail ends. Initially, guardrail ends were not treated and were simply constructed as blunt exposed ends; however, it was recognized in the mid-1960s that these unmodified ends were potentially lethal roadside hazards (*2*). Figure 2 depicts a blunt exposed guardrail end. The exposed ends would often impale vehicles and presented a serious safety concern for the vehicle's occupants. On the other hand, if a vehicle impacts a guardrail that has an adequate end treatment (i.e., the end has been designed to attenuate the impact of a vehicle) then the consequences of the crash can be reduced. With this idea, future generations of guardrail ends were created.

Figure 2 Blunt End Guardrail (*8*)

To remedy this problem, the highway community moved toward what appeared to be a safe and inexpensive alternative, the turned down guardrail end as shown in Figure 3. Instead of leaving the end exposed, a turned down guardrail end is a guardrail with the end twisted and anchored into the ground to keep from spearing vehicles involved in head on collisions with the guardrail. Unfortunately by the 1970s, it was realized that turned down ends can cause ramping and overturning of vehicles thus creating another safety hazard. In addition to this, the effectiveness of the turned down guardrail has not been aided by a changing vehicle fleet that is moving towards lightweight vehicles. These lightweight vehicles have shown a greater propensity to flip when striking a turned down guardrail end (*1*). The problems associated with this type of end treatment motivated research that resulted in other guardrail improvements.

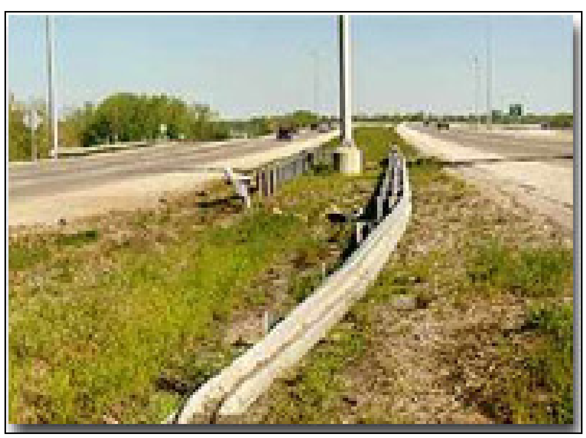

Figure 3 Turned Down Guardrail End (*8*)

The next generation in guardrail ends implemented in some states was the Breakaway Cable Terminal (BCT). The BCT was designed to prevent vehicle spearing, redirect errant vehicles without ramping, and minimize the hazard to the vehicle occupants on impact. The BCT design consists of a rail placed in a 37.5-foot parabola with the end post offset four feet away from the back of the rail for the straight section as shown by the plan in Figure 4. The first two posts are of breakaway design which means that they are designed to break, tear, or come apart easily. The BCT showed great promise in early tests, and as the first real alternative to turned down guardrail ends, the BCT enjoyed wide acceptance. However, in the early 1980s, the traffic safety community recognized that there were two problems with the BCT. First, the BCT was often installed incorrectly by states using inadequate distances for the offset and parabolic flare, and vehicles were not impacting the end treatment in the same manner the tests were completed (*2*). Once again, more research was done to create a better terminal.

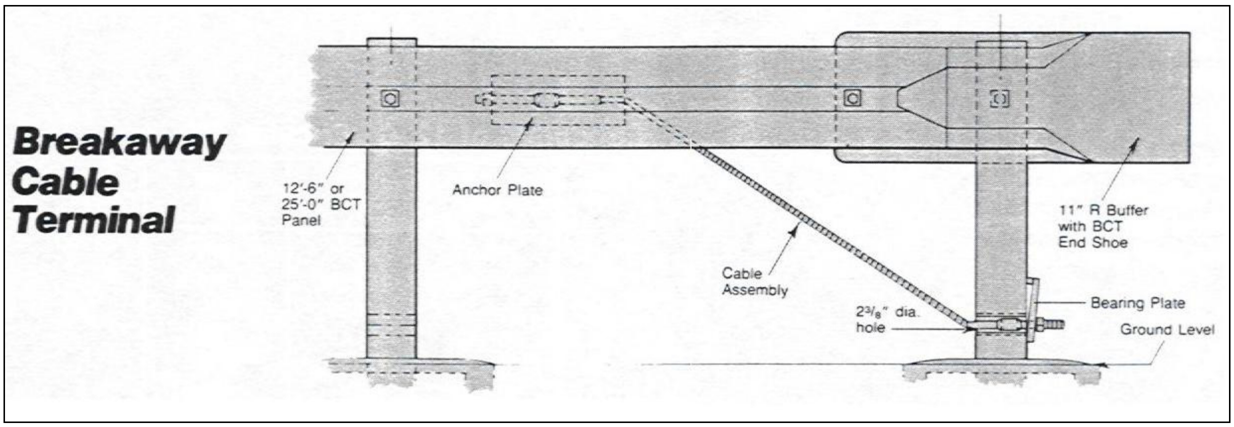

Figure 4 Breakaway Cable Terminal (*9*)

The next terminal type which is depicted in Figure 5 is an evolution of the BCT named the Modified Eccentric Loader Terminal (MELT). The MELT had similar offsets and flares to the BCT but performed better in crash tests. In 1994, the MELT met the NCHRP Report 230 requirements and was adopted by the Federal Highway Administration (FHWA) as an alternative to the BCT (*2*). Nonetheless, there are still safety concerns with the MELT that in a head-on collision, the vehicle sustains severe damage similar to the BCT. The MELT has been found to be a less expensive option than its immediate predecessor the Eccentric Loader Terminal (ELT) (*2*).

Figure 5 Modified Eccentric Loader Terminal (*8*)

Another development of guardrail end treatment technology, intended to replace the BCT and MELT designs, was the Slotted Rail Terminal (SRT) which is shown in Figure 6. The SRT is similar to the BCT and MELT designs except that it involves cutting longitudinal slots to reduce the buckling strength while maintaining tensile capacity. The reduced buckling strength allows for controlled buckling of the rail, which greatly reduces the yaw rate of the impacting vehicle. This minimizes the potential for the buckled rail to penetrate the occupant compartment (*2*).

Figure 6 Slotted Rail Terminal (*8*)

The preferred type of guardrail end treatment used by most states today is the Energy Absorbing Terminal (EAT). The two proprietary designs of the EAT suggested in the Wisconsin Facilities Development Manual are the ET-2000 and the SKT-350 (*19*). These two types of attenuating terminals have been shown to be very effective at reducing crash severity. An impact head at the end of the terminals absorbs vehicle energy in collisions. During a collision, the impact head bends the W-beam rail 90 degrees, flattens it, and directs the rail away from the car and its occupants as the terminal is pushed downstream (*2*).

Figure 7 ET-2000 Terminal (*8*)

Other designs of guardrail end treatments, in addition to those previously mentioned have been implemented over the years. Some notable systems include the Safety Barrier End Treatment, the Transition End treatment, the Crash-Cushion Attenuating Terminal and the Vehicle Attenuating Terminal.

Most research studies of the safety effects of the different guardrail ends completed in several states have considered the turned down end, BCT, MELT, SRT, and ET-2000 end treatments. In general, the research results have shown little differences in their safety performance. The lack of statistically significant results has contributed in part to the slow adoption, by states, of guardrail end treatments. Moreover, states are often required to perform studies on their own highways before decision-makers are compelled to change the end treatments used in the state. The following section summarizes state-specific research of guardrail end crashes.

Previous In-Service Evaluations

Indiana

In 1977, Indiana began using the BCT on all new construction projects. After an apparently large number of serious accidents involving BCTs, the state began an in-service evaluation of the guardrail ends in 1979 (*10*). Data collected by maintenance personnel initially provided reports on 21 crashes. However, two crashes were discarded because they involved tractor trailers for which the BCT was not designed. Another nine were discarded because their corresponding police reports were not found. Of the remaining 10 crashes, six involved fatalities. At least half of these fatal crashes involved side impacts with BCTs with little or no side offset and the guardrail penetrated the passenger compartment of the vehicle. Although the design standards recommended a 1.22 meter offset, the study found that BCTs were allowed to have offsets as little as 0.3 meters. Due to the small sample size and lack of properly installed BCTs, the occupant severity rates found in this study cannot be used to represent the performance of properly installed BCTs.

New Jersey

As a recommendation and request from the FHWA, the New Jersey Department of Transportation (NJDOT) began installing the BCT as a guardrail end treatment in 1976 and began a two-year monitoring period to study the in-service performance of the end treatment (*11*). The BCT design installed by the NJDOT used wood breakaway posts mounted in concrete and a straight 15:1 flare. Of the 33 BCT collisions reported by the maintenance department, only 13 had corresponding police reports. Small car spearing was found to occur with head-on collisions with non-flared terminals. The authors suggested that BCT should be redesigned for straight (non-flared) applications as well (*11*). This study provided useful information, but due to the limited number of crashes evaluated, the occupant injury rates were not statistically significant.

Kentucky

Kentucky began installing BCTs in 1974 and has conducted four in-service performance evaluations of its guardrail end treatments over the years. The first study, completed in 1984, collected crash data from three different sources: police crash reports, repair reports, and photographs of damaged installations (*12*). The study, which identified 69 crashes, was originally intended to cover crashes that occurred between the years 1980 and 1982 only. However, the final sample included cases collected from 1977 to 1983. A follow-up study was completed in 1991 which included the crash data between the years 1980 and 1987 and some select cases from 1988 to 1990 (*12*). The report studied the performance of the BCT, the Median Breakaway Cable Terminal, CAT, BRAKEMASTER, and the Type 7 weakened turned down end treatment.

One of the many improvements made by the researchers to reduce bias from the previous study was the determination of whether each BCT installation had a parabolic flare (e.g., similar to crash tested design), simple curve flare, or straight (very little or no offset). Performance was rated for 158 out of the 232 cases recorded. It was found that the BCTs with a simple curve flare had a higher fatality/incapacitating injury rate (38 percent) than the BCTs with a parabolic flare (25 percent). Instead of using injury severity as a method to evaluate the performance of the end treatments, performance was classified as either proper or improper. For instance, proper performance of the BCT resulted when the end treatment performed as intended, with wooden posts breaking away or the guardrail redirecting the vehicle. Using this method, the difference in performance between the BCTs with parabolic flare (80 percent) and BCTs with simple curve flare (71 percent) was less evident than by using the injury severity parameter. Because one third of the cases had an unknown BCT flare type, the results had limited value.

After a second follow-up study in 1992, the next major in-service evaluation of end treatments in Kentucky was not until 2004. This report included crash data from 1995 to 2003 and studied the performance of the ET-2000 only (*13*). A total of 135 crashes were identified during the evaluation period; however, only 80 cases with police reports were analyzed. There was no injury reported for half of the cases. Incapacitating injuries occurred in 12 cases and one fatal crash was reported. The performance of the ET-2000 was deemed proper in 88 percent of the crashes. The authors concluded that the end treatment reasonably performed as designed and warranted continued use. However, they cautioned that due to the high costs associated with the ET-2000 compared with other treatments, they could not justify widespread use on all types of roadways.

Michigan

A two-phase report on the in-service performance of BCTs in Michigan was published in 1994 (*14*). The first phase included crash data collected during the years 1984 through 1986 and the second included data from 1988 to 1990. Police crash reports and maintenance records were used as the sources of data. The Michigan Department of Transportation (MDOT) maintenance department filled out forms whenever a BCT was repaired. Those forms were then cross-referenced with police crash reports. This matching process allowed the identification of additional crashes for analysis. A total of 50 crashes were observed during the 1984 to 1986 period and 83 crashes during the 1988 to 1990 period. No field visits were performed to identify properly installed BCTs from the improperly installed ones.

For the second phase, the researchers assumed that there were more properly installed BCTs in the inventory, due to the fact that MDOT had upgraded its BCT design standards, and some of the major routes in the study area had been upgraded with the new BCTs. In comparing the two phases, the authors found that the property-damage-only crashes increased between the two periods from 40 percent to 65 percent. On the other hand, the proportion of injury crashes decreased. Nevertheless, the authors identified the increased seat belt usage of the passengers as the primary contributor to the decrease in occupant injuries with additional contribution from the improved BCT design and installation.

Oklahoma

A study of guardrail end treatments including crashes from 1988 through 1991 in Oklahoma was published in 1996 (*15*). The predominant two end treatments in use at the time were exposed, blunt ends and turned down ends. The state database contained 1,734 crash entries at that time. Crashes the researchers were fairly sure involved impacts with the guardrail end, were termed "presumed". If researchers were less certain, the crashes were termed "questionable." It was found that 453, approximately 25 percent, of the crashes were presumed. For the guardrail end types, 17 percent of the crashes resulted in fatal or incapacitating injuries, 31 percent resulted in minor or possible injuries, and 52 percent were property damage only. The vehicles involved in the crashes were aggregated into three weight groups: 1,750-2,750 lbs, 3,250 lbs, and 3,750-4,750 lbs.

It was found that turned down guardrail ends were more likely to produce roll/vault of the vehicle than other guardrail ends. As expected, the lightest vehicle weight group was most likely to roll/vault. Not expected was the finding that crashes involving exposed blunt ends were more likely to result in minor or possible injuries, but less likely than turned down ends to result in fatal or incapacitating injuries. Considering the occupant severity rates and the proportion of vehicles that roll/vault for each treatment, it was concluded that the turned down ends do not experience less crash severity than the exposed, blunt ends that they replaced. However, the authors caution that before replacing end treatments, decision makers must consider the cost of more expensive end treatment options in relation to crash severity reductions.

Texas

In 1991, a study was conducted on all reported guardrail crashes in 1989 in the state of Texas. However, before the 1990s, the turned down guardrail end was effectively the only end treatment in use in the state (*6*). Thus, the study only made comparisons between crashes on the turned down guardrail ends and crashes on the rest of the guardrail. The author found that fatality rates were more than three times as great for crashes with the turned down end than with the rest of the guardrail. Turned down guardrails were regarded as a significant safety problem by the author. However, the extent to which vehicle overturns and driver/occupant fatalities could be reduced by replacing turned down guardrails with newer treatments was deemed unknown since the report did not study other end types.

By 1996, other types of end treatments had been installed in the state, and a study was published on the field performance of the ET-2000 in Texas (*6*). The evaluation involved the Texas Department of Transportation (TxDOT), the original designers, and the manufacturers of the end treatment. Although it is unclear which agencies were used to collect the data, it is assumed police reports, field visits, and discussions with maintenance personnel were used in the data collection process. During the collection period between April of 1993 and 1994, the researchers found 37 crashes with the ET-2000. Only three crashes (eight percent) resulted in incapacitating injuries to the occupants. These three crashes included a side impact, an unrestrained occupant in the bed of a pickup truck, and a possible misreported injury.

New Hampshire

In 1994, a report was published on the evaluation of in-service performance of MELTs in the state of New Hampshire (*16*). The study period of the data collection was from 1991 to December of 1993. Although the report states that there were 25 crashes occurring with MELTs during this period, only the cases from nine police reports were included in the study. No fatalities or major injuries were identified in any of the reported crashes; only two crashes involved minor injuries. Moreover, no spearing or vaulting/ramping was reported.

Ohio

In 1996, a report was published by the Ohio Department of Transportation (ODOT) on the ET-2000s installed in the state (*14*). The report collected data between 1992 and 1995, and is one of the largest, most comprehensive, and most carefully controlled studies conducted on end treatment in-service performance. In order to collect the data, ODOT maintenance personnel visited crash sites prior to a repair, took photographs, and completed a one page summary report. There were 306 crashes and 97 were reported to the police. The researchers found that the ET-2000 performed well and only 39 (13 percent) of the 306 crashes involved occupant injuries. Only five (1.6 percent) of the injuries were considered moderate or serious. Most crashes that involved injuries were the result of impact speeds of 55 mph or more.

Iowa and North Carolina

A study was conducted that examined the in-service performance of the BCT and the MELT in Iowa and North Carolina for a 24 month period between 1997 and 1999 (*17*). Data from 102 BCT and 42 MELT collisions were reported during the evaluation period. Three end-on impact scenarios were studied:

1. End on, redirect front;
2. End on, side impact; and
3. End on, redirected behind.

After collisions were reported, a visit to the crash site was completed immediately to evaluate if the guardrail end was installed properly. A grading criterion, ten being the highest and zero the lowest, was developed and each guardrail end treatment was given an installation quality score according to state standards. BCT scores ranged from zero to 6.25 with a mean of 3.40. MELT scores ranged from zero to 6.00 with a mean of 2.91. It was found that the event distributions for MELT and BCT collisions were not statistically significant at the 90 percent confidence level (*18*). Overall, the BCT and MELT performed well in both states and the proportion of properly installed terminals was very high. However, the authors cautioned that their conclusions are limited by the modest amount of cases, and states with a large number of improperly installed BCTs and MELTs cannot expect the same results found in Iowa and North Carolina.

Washington State

In 2004, a research study was published by St. Martin's College for the Washington State Department of Transportation. The study evaluated the in-service performance of the existing guardrail end treatments and unrestrained pre-cast concrete barriers in Washington State (*18*).

WSDOT maintenance personnel collected data on end terminal crash sites, including the installation characteristics, the extent of damage, and repair costs. This was done for a selected portion of highways between the years 2000 and 2003. Police crash reports, corresponding to the study area, were gathered during this collection period as well.

An inspection of end treatments after vehicle hits found that nearly all installation characteristics were within acceptable limits. Although the researchers studied all existing guardrail terminals installed in the study area, only the BCT and SRT had large enough samples to make meaningful comparisons. After creating 90 percent confidence intervals for occupant injury rates, it was concluded that there was no significant difference in the performances of the SRT and BCT in the study area. Thus, when installed correctly, it was found that the BCT is still a valid end treatment. Research was also conducted on unrestrained pre-cast concrete barriers (UPCCB). Often used outside work zones, the UPCCB were involved in 42 crashes. It was found that the roadside barrier demonstrated reduced severity rates in comparison to crashes with other concrete barriers in the state and approved the use of the UPCCB in appropriate applications.

Summary

Over the last thirty years, several research studies have done in-service performance evaluations of guardrail end treatments as presented in the previous sections. Table 1 presents a summary of these studies. Unfortunately, these studies have only included limited research on the turned down, BCT, MELT, SRT and ET-2000 terminals, and there has been little work done with the SKT-350. The latter is one of the prominent end treatments used in Wisconsin. In addition to this, there was no meaningful literature pertaining to research conducted on the performance of sloped concrete barriers, another roadside safety barrier used in Wisconsin.

Table 1: Aggregated injury severities of previous in-service evaluations

Treatment Type	State	Date	No. of Cases	A+K[a] No.	A+K[a] %	B+C[b] No.	B+C[b] %	PDO[c] No.	PDO[c] %
Turned Down	Oklahoma	1988-91	249	46	18	70	28	133	53
	Texas 1991[d]	1989	269	60	22	59	22	150	56
BCT	Indiana	c. 1980	10	6	60	1	10	3	30
	New Jersey	1976-79	13	6	46	3	23	4	31
	Kentucky 1984	1980-82	50	11	29	14	37	13	34
	Kentucky 1991	1980-87	52	13	25	22	42	17	33
	Michigan	1984-86	50	5	10	25	50	20	40
	Michigan	1988-90	83	10	12	18	22	55	66
	Iowa	1997-99	24	1	4	5	21	18	75
	North Carolina	1997-99	62	3	5	18	29	41	66
	Washington	2000-03	18	3	17	4	22	11	61
MELT	New Hampshire	1991-94	9	0	0	2	33	4	67
	Ohio	1992-95	17	1	16	1	16	4	67
	Iowa	1997-99	2	0	0	1	50	1	50
	North Carolina	1997-99	27	1	4	12	44	14	52
ET-2000	Ohio	1992-95	97	4	4	35	36	58	60
	Texas 1996	1993-94	37	3	8	10	27	8	22
	Kentucky 2004[e]	1995-2003	80	13	16	27	34	40	50
Concrete Barrier	Washington	2000-03	42	1	2	7	17	34	81

Notes

[a] Fatal and incapacitating injuries
[b] Non-capacitating and possible injuries
[c] Property damage only
[d] Number of persons injured by severity
[e] Estimates of B+C and PDO from text

CHAPTER III - STUDY DESIGN

Based on the findings of the literature review and the research objectives, the following hypothesis was developed:

- Turn down guardrail end impacts lead to more serious injury outcomes and are more unsafe than other guardrail ends.

To test this hypothesis, the research tasks described were developed.

Task 1: Literature Review

A literature review is required to explore the research completed in other states and the associated findings. Details on all guardrail end types were explored. All elements of the literature review were presented in Chapter 2.

Task 2: Guardrail End Crash Analysis

Guardrail end crashes on all state highways were considered. This includes all 72 counties in the five regions of the state (southeast, southwest, northeast, north central, and northwest). A map of the counties and regions is illustrated in Figure 8. The crashes studied occurred on the State Trunk Highway system (Interstate, US, and state highways) in Wisconsin. Both divided and undivided roadways were considered. Crashes occurring on country trunk highways, town roads, municipal roads and other local roads were not included. A breakdown of these route types are shown in Table 2.

The WisTransPortal Crash Database is a complete archive of the WisDOT Wisconsin Motor Vehicle Accident Report form (MV4000) Traffic Accident Extract data for 1994 through the current year. These data are provided to the TOPS Laboratory by the DMV-Traffic Accident Section of WisDOT. For this research, the WisTransPortal Crash Database was queried for the combined attributes of guardrail end and guardrail face crashes occurring over a five-year period between January 1, 2001 and December 31, 2005. Although the purpose of the study is determine the effects of guardrail end crashes, guardrail face crashes were queried as well due to high level (greater than 20 percent) of guardrail end crashes incorrectly classified as guardrail face crashes and vice versa. Overall, the query found 8,151 crash reports for the two crash types in the five year study period.

Figure 8: Regions and counties included in study

Table 2: Route type of highways included in study area

Route Type	Miles	% Miles	VMT (in millions)	% Veh-Miles
Interstate Highways	743	0.7%	10,359	17.3%
Other State Trunk Highways	11,040	9.7%	25,283	42.1%
State Trunk Highways Total	**11,783**	**10.3%**	**35,642**	**59.4%**
County Trunk Highways	19,769	17.3%	10,492	17.5%
Town Roads	61,921	54.2%	2,439	4.1%
Municipal Roads	18,836	16.5%	11,381	19.0%
Other Roads	1,833	1.6%	66	0.1%
Total	**114,141**	**100.0%**	**60,018**	**100.0%**

After identifying the correct subset of guardrail crashes, the researchers collected the MV4000 reports for each of the crashes identified. For crashes occurring before 2005, the authors looked at microfiche rolls and scanned the crash reports into TIF format. For crashes occurring in 2005 and later, the crashes were digitized and could be downloaded into TIF format.

Due to the large volume of crash reports needed to be scanned from microfiche film, the data set was reduced to crashes occurring during a three year period between January 1, 2003 and December 31, 2005. The number of guardrail crashes identified for this three year period was 5,138. After retrieving the reports for guardrail crashes, the researchers determined the crash type (guardrail end or guardrail face) by viewing the sketch and narrative provided by the reporting officer in the crash report. After removing the guardrail face and any miscoded crash reports, 1,049 guardrail end crashes were identified in Wisconsin over the three year period.

The WisDOT Photolog was used to identify the specific guardrail end terminal types involved in each crash. The WisDOT Photolog is a log of photos of the roadway and roadside captured every 0.01 mile, or approximately every 50 feet of the State Trunk Highways in the state of Wisconsin. Due to the fact that the WisDOT Photolog only includes roadway mainline of the State Trunk Highway system, guardrail on ramps could not be seen and hence crashes occurring on ramps were not included in this study. Other crash reports not included in this study involved guardrail end terminals that were special/unknown, only used during roadway construction, or were unable to be found using the WisDOT Photolog.

Task 3: Data Analysis

Several important variables were compiled in the study of this data set. Crashes possessing particular variable values were removed in an effort to create a uniform data set.

Guardrail End Hits – The number of end hits for each guardrail end terminal type, including turned down and sloped concrete ends, were included in this variable. There were 627 usable guardrail end hits on the State Trunk Highway system over the three year study period. Table 3 shows the data reduction for the usable guardrail end hits.

Table 3: Summary of Guardrail End Crash Total Calculations

Initial Selected Guardrail End Crashes for the Five Year Period	**8,151**
Crashes from 2001 through 2002	-3,013
Crashes that did not include guardrail ends or did not correspond to the Photolog	-4,089
Crashes that were with guardrails that were for roadway construction or on ramps	-417
Crashes that occurred with special or unknown guardrail ends	-5
Final Selected Guardrail End Crashes	**627**

Collision Severity – The collision severity variable was reported for each crash and it gives a quantifiable estimate of passenger injuries sustained during collisions with the guardrail end treatments. There are various scales used to grade collision severity, but the KABCO scale was used in this research. In the KABCO system, each letter represents the extent of the occupant injury and ranges from death to property damage only:

- K: Fatal
- A: Incapacitating Injury
- B: Non-Incapacitating Injury
- C: Possible Injury
- O: Property Damage Only

Traffic Volume – The traffic volumes used for these crashes were the Average Annual Daily Traffic (AADT) counts reported. AADT counts ranged from 390 to 167,900 vehicles per day. Care was taken to identify traffic counts obtained during the same year as the crash occurred.

Vehicle Type – There were four vehicle types found in these crashes: passenger car, utility truck, straight truck (insert truck), and truck tractor (semi attached). Due to the low occurrence of the straight truck and truck tractor crashes – about five percent combined – and the fact that guardrail end terminals were not designed for impacts with these vehicle types, these crashes were removed.

Posted Speed Limit – The posted speed limits involved in these crashes ranged from 25 to 65 mph. However, more than 90 percent of the crashes occurred on highways with posted speed limits of 55 mph or greater.

Crash Impact Type – There were four crash impact types involved with the guardrail end terminals: head on, midsection, rear end, and trailer. Trailer collisions occurred when the trailer being towed hit a guardrail end, but the vehicle towing the trailer did not. Due to their relative infrequency – about five percent combined – rear-end and trailer impacts were removed.

End Terminal Location – The end terminal locations in this research were designated as either approach or departure. Guardrail ends locations designated as approach were impacted by vehicles before the vehicles passed the object the guardrail was protecting in the direction of travel. Conversely, guardrail end locations designated as departure were impacted by vehicles after the vehicles passed the object the guardrail was protecting in the direction of travel. Due to their relative infrequency – less than five percent – departure crashes were removed.

The guardrail crash data are recorded in the first harmful event category of the MV4000 report. Guardrail is not included in the most harmful event section. Similarly, the crash reports do not include information on the location of the guardrail (i.e., offset) related to the travel lane. Therefore, this information was not available for each crash location.

Data were compiled and then analyzed using several different statistical software packages. The results of the analysis are reported in the following chapter.

CHAPTER IV - RESEARCH RESULTS

After the data reduction discussed in Chapter 3, this chapter focuses on analysis of the crash data associated with guardrail ends. Chapter 4 focuses on comparison of the various guardrail ends; an aggregate analysis that compares crash severity distributions of different end treatments and the impact of various variables on crash severity; and a separate analysis of crashes on divided and undivided highways.

Researchers found 14 different guardrail end terminal types in the 627 crashes identified in the previous chapter. Table 4 shows the crash severity distribution versus the guardrail end types.

Table 4: Injury severities by guardrail end type

Guardrail End Type	Injury Severity					Total
	K	A	B	C	O	
BCT	3	8	17	15	67	110
Blunt Concrete Barrier End	0	0	0	0	4	4
Blunt End	0	0	1	1	3	5
Bullnose Attenuator	0	0	4	2	11	17
ET-2000	1	5	15	17	76	114
ET-Plus	0	0	1	1	3	5
Intersection Radius	0	1	0	2	2	5
MELT	0	1	5	2	21	29
SKT-350	0	3	17	31	95	146
SRT-350	0	2	1	3	14	20
Slope Concrete End	0	0	1	2	2	5
Three Strand Cable	0	1	0	3	1	5
Turned-down (median)	1	0	2	1	15	19
Turned-down (shoulder)	8	16	24	16	79	143
Total	**13**	**37**	**88**	**96**	**393**	**627**

Given the crashes that occurred for each guardrail end type, the outcome of each crash's severity follows a multinomial distribution. Guardrail end types with a low frequency of crashes were combined to improve the statistical analysis. As noted in Table 4, the number of guardrail end crashes is under 30 except for the Turn-down (shoulder), ET-2000, BCT and SKT-350. Researchers combined these low frequency guardrail end types into an 'Others' category thus allowing for a more detailed analysis to be completed. Table 5 presents the redistributed guardrail end types.

Table 5: Injury severities by guardrail end type

Guardrail End Type	Injury Severity K	A	B	C	O	Total
BCT	3	8	17	15	67	110
ET-2000	1	5	15	17	76	114
Turned-down (shoulder)	8	16	24	16	79	143
SKT-350	0	3	17	31	95	146
OTHERS	0	5	13	16	61	95
Total	**12**	**37**	**86**	**95**	**378**	**608**

Aggregate Analysis

Based on the category data shown in Table 5, two statistical evaluations were performed. The first was to evaluate differences in the severity distributions of the guardrail end types. The second evaluation determined whether there was a significant difference in severity when comparing between any two guardrail end types.

In the first evaluation, a Pearson χ^2 test was used. The test statistic was calculated by:

$$\chi^2=\sum_i[(n_i-E_i)^2/E_i], \qquad (1)$$

where;

n_i - represents the number of crashes in severity type;
E_i - represents the expected number of crashes in severity type i; and
i - which is the number of crashes of the corresponding severity for the compared guardrail end type.
(Note: $\sum_i n_i=\sum_i E_i$).

Based on the above principal, the χ^2 test statistic was calculated between the guardrail end types. Table 6 depicts the evaluation results. The shaded cells indicate the statistically significant probability distribution differences between the two end types. The χ^2 reference value at significance level 0.1 is 7.779 with four degrees of freedom and 6.251 with three degrees of freedom.

Table 6: χ^2 test statistic between guardrail types

Type	ET-2000	Turned-down (shoulder)	SKT-350	Others
BCT	3.7464	6.6234	13.1191	4.8597
ET-2000	n/a	49.6383	5.6919	2.9792
Turned-down (shoulder)		n/a	36.3050	19.471
SKT-350			n/a	21.288
OTHERS				n/a

The probability evaluations indicated that the severity distributions are significantly different between BCT and SKT-350, ET-2000 and Turn-down (shoulder), SKT-350 and Turn-down (shoulder), Turn-down (shoulder) and 'Others', and SKT-350 and 'Others'.

Guardrail safety evaluation

Since fatalities and incapacitating injuries are of primary concern, two classes of severity were used in this evaluation; specifically, K/A and Non K/A results. To test whether the significant difference exists between the guardrail end types, the test statistics were:

$$Z = (\text{Prob(type 1)} - \text{Prob(type 2)})/\text{Variance(type1 - type2)}$$

The results are given in the Table 7. This test is comparing sets of two guardrail types to determine if a difference exists.

Table 7: Z test statistic between guardrail types

Type - Type	Z Stat	Type - Type	Z Stat
SKT-350 -- Turned-down (shoulder)	-4.4147	Others -- ET-2000	0.0
BCT -- Turned-down (shoulder)	-1.6011	ET2000 -- BCT	-1.3368
ET-2000 -- Turned down(shoulder)	-3.0635	SKT-350 -- BCT	-2.5696
Others -- Turned-down (shoulder)	-2.9725	Others -- BCT	-1.2925
SKT-350 -- ET-2000	-1.3377	SKT-350 -- Others	-1.2463

At a significance level of 0.10, the results show that the ET-2000 was not significantly different than the 'Other' end types. All other comparisons found significant results. Table 8 presents the results of each end type evaluation by final Z score. These results suggest that SKT-350 is associated with lower severity crashes than the overall average of other types while the Turned-down ends are associated with higher severity crashes.

Table 8: Test statistic between guardrail types and overall mean

Guardrail End Type	K/A	Non K/A	Total	Z-score
BCT	11	99	110	0.6330
ET-2000	6	108	114	-1.1823
Turned-down (shoulder)	24	119	143	2.6321
SKT-350	3	143	146	-3.7258
OTHERS	5	90	95	-1.0995
total	49	559	**608**	

Impact of Variables

Researchers also analyzed the impact of variables: Highway types, vehicle types, speed limit, crash impact type, Traffic volume (AADT) on crash severity's distribution. The test statistics indicate that all variables in the data analysis except 'Highway Type' had a significant impact on the distribution of crash severity at significance level of 0.1. Since data did not exist for all the factors, the valid data sample size is different for the different variables considered. Tables 9 and 10 describe the results.

Table 9: Crash severity distribution with other different variables

<table>
<tr><th>Variables</th><th>Classes</th><th>K</th><th>A</th><th>B</th><th>C</th><th>O</th><th colspan="2">Total Valid Data</th></tr>
<tr><td rowspan="2">Highway Type</td><td>Divided</td><td colspan="2">33</td><td colspan="2">108</td><td>218</td><td>359</td><td rowspan="2">525</td></tr>
<tr><td>Undivided</td><td colspan="2">12</td><td colspan="2">49</td><td>105</td><td>166</td></tr>
<tr><td rowspan="2">Speed Limit</td><td>Below 55</td><td>0</td><td>0</td><td>5</td><td>6</td><td>44</td><td>55</td><td rowspan="2">627</td></tr>
<tr><td>55 or above</td><td>13</td><td>37</td><td>83</td><td>90</td><td>349</td><td>572</td></tr>
<tr><td rowspan="2">Vehicle Type</td><td>Car</td><td>8</td><td>29</td><td>61</td><td>80</td><td>267</td><td>445</td><td rowspan="2">619</td></tr>
<tr><td>Truck related</td><td>5</td><td>8</td><td>27</td><td>16</td><td>118</td><td>174</td></tr>
<tr><td rowspan="2">Crash impact position</td><td>Front</td><td>8</td><td>30</td><td>69</td><td>68</td><td>260</td><td>435</td><td rowspan="2">602</td></tr>
<tr><td>Side</td><td>5</td><td>7</td><td>14</td><td>26</td><td>123</td><td>175</td></tr>
<tr><td rowspan="3">Traffic Volume (AADT)</td><td>< 10,000, 1</td><td>3</td><td>11</td><td>29</td><td>37</td><td>138</td><td>208</td><td rowspan="3">625</td></tr>
<tr><td>10,001 to 30,000, 2</td><td>2</td><td>14</td><td>33</td><td>23</td><td>118</td><td>190</td></tr>
<tr><td>> 30,000, 3</td><td>8</td><td>12</td><td>26</td><td>36</td><td>136</td><td>217</td></tr>
</table>

Table 10: χ^2 value on the test of variables

Variables	Highway Type	Speed Limit	Vehicle Type	Crash impact position	Traffic Volume (AADT)
χ^2 value	1.9216	103.84	30.065	32.91	1-2: 8.0122 1-3: 8.4515 2-3: 19.736
Reference Value @ 0.1	4.065 Df=2	7.779 Df=4	7.779 Df=4	7.779 Df=4	7.779 Df=4

Unfortunately, six of the guardrail end types had five crashes or less. The lack of crashes with these guardrail end treatments (blunt end, blunt concrete end, intersection radius, sloped concrete end, three-strand cable, and ET-Plus) would not produce any significant results in a statistical analysis. Thus, these guardrail end treatments were not analyzed. Out of the 627 guardrail end crashes, the final data set included 525 crashes that had sufficient data to analyze.

Data Analysis

The 525 crashes were analyzed in two different sections: divided and undivided. Researchers used a statistical analysis to correlate guardrail end treatments with the vehicle type, posted speed limit, crash impact type, and traffic volume. Appendices A through D summarize the fatal crashes, incapacitation injury crashes, non-incapacitating injury crashes, and possible injury crashes for both divided and undivided highways.

Divided Highways

There were 359 crashes on divided highways and they involved all eight of the guardrail end treatment types presented in Table 11. Table 11 shows the aggregated injury severities and percentages within the injury severities for each of the end treatments on divided highways. Both the turned down end treatments and BCT account for a disproportional amount of the fatalities and incapacitating injuries (K/A). More than 51 percent of the K/A injuries occurred in collisions with turned down end treatments, while the number of crashes with turned down ends only accounted for 24 percent of the crashes. Similarly, the BCT accounted for 24 percent of the A/K injuries, while only included in 16 percent of the crashes. The SRT-350 accounts for a larger amount as well. Conversely, the SKT-350 and ET-2000 appear to account for larger proportions of B/C and O crashes. Figure 3 illustrates these trends.

Table 11: Injury severities and percentages by guardrail end type for divided highways

Guardrail End Type		Injury Severity			Total
		A/K	B/C	O	
BCT	Count	8	13	38	59
	% within Injury Severity	24.2	12.0	17.4	16.4
Bullnose Attenuator	Count	0	6	6	12
	% within Injury Severity	0	5.5	2.7	3.3
ET-2000	Count	3	25	53	81
	% within Injury Severity	9.1	23.1	24.3	22.6
MELT	Count	1	5	15	21
	% within Injury Severity	3.0	4.6	6.9	5.8
SKT-350	Count	2	33	57	92
	% within Injury Severity	6.1	30.6	26.1	25.6
SRT-350	Count	2	0	5	7
	% within Injury Severity	6.1	0	2.3	1.9
Turned-down (median)	Count	1	2	11	14
	% within Injury Severity	3.0	1.8	5.0	3.9
Turned-down (shoulder)	Count	16	24	33	73
	% within Injury Severity	48.5	22.2	15.1	20.3
Total	**Count**	**33**	**108**	**218**	**359**
	% within Injury Severity	**100**	**100**	**100**	**100**

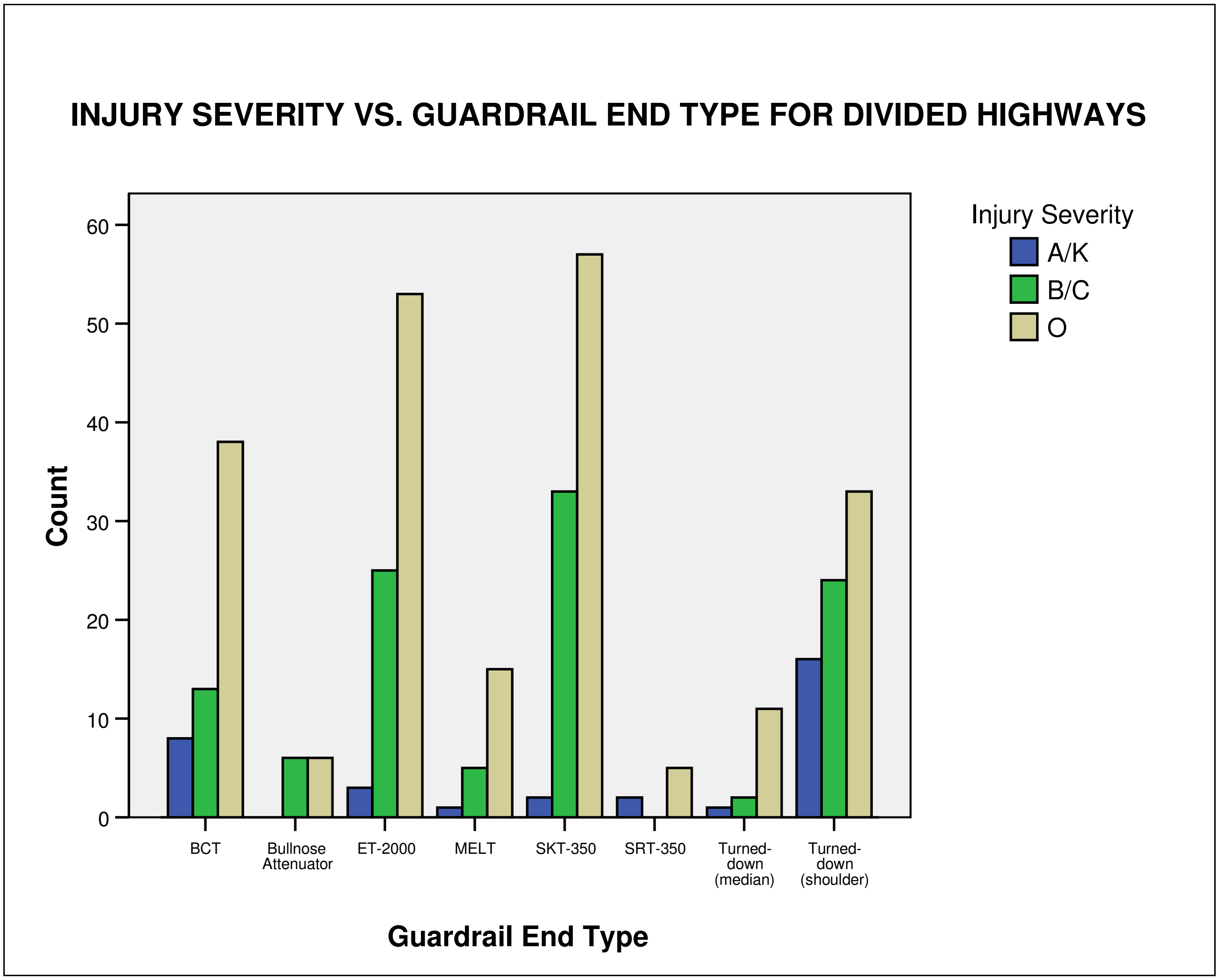

Figure 9: Aggregated injury severities by guardrail end type for divided highways

The researchers conducted a Pearson chi-square test on the divided highway data to determine if any of the variables had an effect on injury severity. The chi-square test confirmed that at a 90 percent level of confidence, one or more of the predictor variables had a statistically significant effect on injury severity ($\chi^2 = 61.47$, df = 22, p = 1.35E-05). The authors then created a likelihood ratio test to see which of the five variables (posted speed limit, AADT, guardrail end type, vehicle type, and crash impact type) in particular had a significant effect on injury severity. Only the main effects were analyzed in the test and are shown in Table 6. Posted speed limit, guardrail end type, and crash impact type were shown to be significant predictor variables at a 90 percent level of confidence. Conversely, AADT and vehicle type are not significant variables in predicting injury severity.

Table 12: Chi-square test of predictor variables vs. injury severity for divided highways

Effect	Likelihood Ratio Tests		
	Chi-Square	Df	P
Intercept	0	0	
Posted Speed Limit	14.257	2	0.001
AADT	0.317	2	0.853
Guardrail End Type	39.052	14	0.000
Vehicle Type	0.651	2	0.722
Crash Impact Type	5.975	2	0.050

A multinomial regression model was considered that included the significant predictor variables. The parameter estimates between each of the guardrail end types in K/A crashes are shown in Table 13. To analyze each of the guardrail end types, an end treatment type was designated as the reference category. For example, the BCT was designated as the reference category in the first column of Table 13. The BCT was then compared to each of the other six guardrail end types (ET-2000, MELT, SKT-350, SRT-350, turned-down median, and turned-down shoulder).

The statistically significant, or highlighted parameter estimates show that turned-down shoulder end treatment is more likely to be associated with K/A crashes than the BCT, ET-2000, SKT-350, and turned-down median end treatments, respectively. Similarly, the BCT and SRT-350 are more likely to be associated with K/A crashes than the SKT-350. These findings generally confirm the findings found in the initial analysis. No conclusions are made from the non-highlighted entries because they are not statistically significant at a 90 percent level of confidence.

The bottom two rows of Table 13 show the intercepts that would be used in the equation of each reference category and statistical significance of these intercepts. All the intercepts are statistically significant. The reader may notice that the B and Exp(B) values for both the bullnose attenuator column and bullnose attenuator row differ significantly in magnitude from the rest of the values in the table. This is due to the fact that there were no K/A injuries for this end treatment.

The parameter estimates between each of the guardrail end types in B/C crashes are shown in Table 14. The statistically significant, or highlighted, parameter estimates show that the bullnose attenuator, ET-2000, SKT-350, and turned-down shoulder end treatments are more likely to be associated with B/C crashes than the BCT end treatment. Moreover, the bullnose attenuator and SKT-350 are more likely to be associated with B/C crashes than turned-down median end treatment. Lastly, the turned down shoulder is more likely to be associated with a B/C crash than the turned down median end treatment. Once again, these findings generally confirm the findings found in the initial analysis. All the intercepts are statistically significant for the B/C crashes. Similar to the K/A table, the B and Exp(B) values for both the SRT-350 column and SRT-350 row differ significantly in magnitude from the rest of the values in the table. This is due to the fact that there were no B/C injuries for this end treatment.

Table 13: Parameter estimates for the guardrail end type variable in K/A crashes on divided highways

Injury Severity: K/A		Referenced Guardrail End Type							
Compared Guardrail End Type	Parameter Estimate	BCT	Bullnose Attenuator	ET-2000	MELT	SKT-350	SRT-350	Turned-down (median)	Turned-down (shoulder)
BCT	B		16.026	0.872	1.095	1.470	-0.796	0.802	-1.004
	Exp (B)		9122034	2.392	2.990	4.349	0.451	2.230	0.366
	p		0.000	0.231	0.325	0.076	0.408	0.474	0.047
Bullnose Attenuator	B	-19.026		-18.154	-17.931	-17.556	-16.822	-18.224	-20.031
	Exp (B)	0.000		0.000	0.000	0.000	0.000	0.000	2.00E-09
	p						0.996		
ET-2000	B	-0.872	15.154		0.223	0.598	-1.668	-0.070	-1.876
	Exp (B)	0.418	3813344		1.250	1.818	0.189	0.932	0.153
	p	0.231	0.000		0.853	0.524	0.114	0.954	0.006
MELT	B	-1.095	14.931	-0.223		0.375	-1.891	-0.294	-2.100
	Exp (B)	0.334	3050716	0.800		1.454	0.151	0.746	0.123
	p	0.325	0.000	0.853		0.768	0.159	0.842	0.054
SKT-350	B	-1.470	14.556	-0.598	-0.375		-2.266	-0.668	-2.474
	Exp (B)	0.230	2097737	0.550	0.688		0.104	0.513	0.084
	p	0.076	0.000	0.524	0.768		0.046	0.601	0.002
SRT-350	B	0.796	16.822	1.668	1.891	2.266		1.598	-0.208
	Exp (B)	2.217	20222147	5.303	6.629	9.640		4.943	0.812
	p	0.408	0.000	0.114	0.159	0.046		0.241	0.824
Turned-down (median)	B	-0.802	15.224	0.070	0.294	0.668	-1.598		-1.806
	Exp (B)	0.449	4091411	1.073	1.341	1.950	0.202		0.164
	p	0.474	0.000	0.954	0.842	0.601	0.241		0.099
Turned-down (shoulder)	B	1.004	17.031	1.876	2.100	2.474	0.208	1.806	
	Exp (B)	2.730	24903321	6.531	8.163	11.872	1.231	6.087	
	p	0.047		0.006	0.054	0.002	0.824	0.099	
Intercept	B	-8.613	-24.639	-9.485	-9.708	-10.082	-7.816	-9.414	-7.608
	p	0.010	0.000	0.003	0.005	0.002	0.022	0.007	0.020

Table 14: Parameter estimates for the guardrail end type variable in B/C crashes on divided highways

Injury Severity: B/C		**Referenced Guardrail End Type**							
Compared Guardrail End Type	Parameter Estimate	BCT	Bullnose Attenuator	ET-2000	MELT	SKT-350	SRT-350	Turned-down (median)	Turned-down (shoulder)
BCT	B		-1.306	-0.698	-0.064	-0.789	16.181	0.594	-0.891
	Exp (B)		0.271	0.497	0.938	0.454	10645596	1.811	0.410
	p		0.053	0.098	0.917	0.049	0.000	0.479	0.037
Bullnose Attenuator	B	1.306		0.607	1.241	0.517	17.486	1.900	0.415
	Exp (B)	3.690		1.835	3.460	1.676	39277429	6.683	1.514
	p	0.053		0.341	0.114	0.411	0.000	0.051	0.524
ET-2000	B	0.698	-0.607		0.634	-0.091	16.879	1.292	-0.192
	Exp (B)	2.010	0.545		1.885	0.913	21401935	3.642	0.825
	p	0.098	0.341		0.280	0.788	0.000	0.114	0.611
MELT	B	0.064	-1.241	-0.634		-0.725	16.245	0.658	-0.827
	Exp (B)	1.066	0.289	0.530		0.484	11350839	1.931	0.438
	p	0.917	0.114	0.280		0.208	0.000	0.481	0.166
SKT-350	B	0.789	-0.517	0.091	0.725		16.970	1.383	-0.102
	Exp (B)	2.201	0.597	1.095	2.064		23431685	3.987	0.903
	p	0.049	0.411	0.788	0.208		0.000	0.087	0.776
SRT-350	B	-19.181	-17.486	-19.879	-19.245	-19.970		-18.587	-20.071
	Exp (B)	4.68E-09	0.000	0.000	0.000	0.000		0.000	1.92E-09
	p		0.995						
Turned-down (median)	B	-0.594	-1.900	-1.292	-0.658	-1.383	15.587		-1.485
	Exp (B)	0.552	0.150	0.275	0.518	0.251	5876852		0.227
	p	0.479	0.051	0.114	0.481	0.087	0.000		0.071
Turned-down (shoulder)	B	0.891	-0.415	0.192	0.827	0.102	17.071	1.485	
	Exp (B)	2.437	0.661	1.212	2.286	1.107	25944179	4.415	
	p	0.037	0.524	0.611	0.166	0.776		0.071	
Intercept	B	-6.183	-4.877	-5.484	-6.119	-5.394	-22.363	-6.777	-5.292
	p	7.24E-05	0.002	0.000	0.000	0.000	0.000	0.000	0.000

Finally, the parameter estimates for the posted speed limit and vehicle type variables are shown in Table 15. The table shows that only the posted speed limit variable is statistically significant in K/A crashes, while both posted speed limit and crash impact type are significant in B/C crashes. Front crash impact types are more likely than sideswipe crash impact types to result in B/C crashes.

Table 15: Parameter estimates for the posted speed limit and crash impact type variables on divided highways

			Parameter Estimate		
Injury Severity			**B**	**Exp(B)**	**p**
K/A	Posted Speed Limit		0.104	1.109	0.041
	Crash Impact Type	Front	0.546	1.726	0.268
		Sideswipe	0		
B/C	Posted Speed Limit		0.072	1.075	0.002
	Crash Impact Type	Front	0.646	1.907	0.024
		Sideswipe	0		

The results show that crashes with turned down shoulder end treatments are more likely than all the other end treatments to lead to K/A injuries. The turned down shoulder is more likely than the BCT, turned down median, MELT or ET-2000, and SKT -350 to lead to K/A injuries. The results of the SRT-350 were not considered because of the extremely low number of crashes (2).

Undivided Highways

There were 166 crashes on the undivided highways and involved only six of the guardrail end treatment types. Table 16 shows the aggregated injury severities and percentages of the severities for the end treatments for undivided highways. Both the turned down end treatments and ET-2000 seem to account for a disproportional amount of the fatalities and incapacitating injuries (A/K). More than 58 percent of the A/K injuries in the data set occurred in collisions with turned down end treatments, while the number of crashes with those treatment types only accounted for 38 percent of all the crashes in the data set. Similarly, the ET-2000 accounted for 25 percent of the A/K injuries, while only occurring in 13 percent of the crashes. However, there were only three A/K crashes which may not effectively represent this end type. Conversely, the BCT, MELT, SKT-350 and SRT-350 appear to account for larger proportions of B/C and O crashes than the percentage of crashes these end treatments are involved in. Figure 4 illustrates these findings.

Table 16: Injury severities and percentages by guardrail end type for undivided highways

Guardrail End Type		Injury Severity			Total
		A/K	**B/C**	**O**	
BCT	Count	1	13	14	28
	% within Injury Severity	8.33	26.53	13.33	16.87
ET-2000	Count	3	4	14	21
	% within Injury Severity	25.00	8.16	13.33	12.65
MELT	Count	0	1	5	6
	% within Injury Severity	0	2.04	4.762	3.61
SKT-350	Count	1	12	24	37
	% within Injury Severity	8.33	24.49	22.86	22.29
SRT-350	Count	0	4	7	11
	% within Injury Severity	0	8.163	6.667	6.63
Turned-down (shoulder)	Count	7	15	41	63
	% within Injury Severity	58.33	30.61	39.05	37.95
Total	**Count**	**12**	**49**	**105**	**166**
	% within Injury Severity	**100**	**100**	**100**	**100**

A chi-square test confirmed that at a 90 percent level of confidence, the predictor variables did not have a statistically significant effect on injury severity (χ^2 = 24.821, df = 18, p = 0.130). Nonetheless, the authors conducted likelihood ratio test to see which of the five variables, if any, had a significant effect on injury severity. Only the main effects were analyzed. These results of the likelihood ratio test are shown in Table 17. Only posted speed limit, was a significant predictor variable of injury severity at a 90 percent level of confidence. Since AADT, guardrail end type, vehicle type, and crash impact type were not significant variables in predicting injury severity for undivided highways, a multinomial logistic regression model was not created.

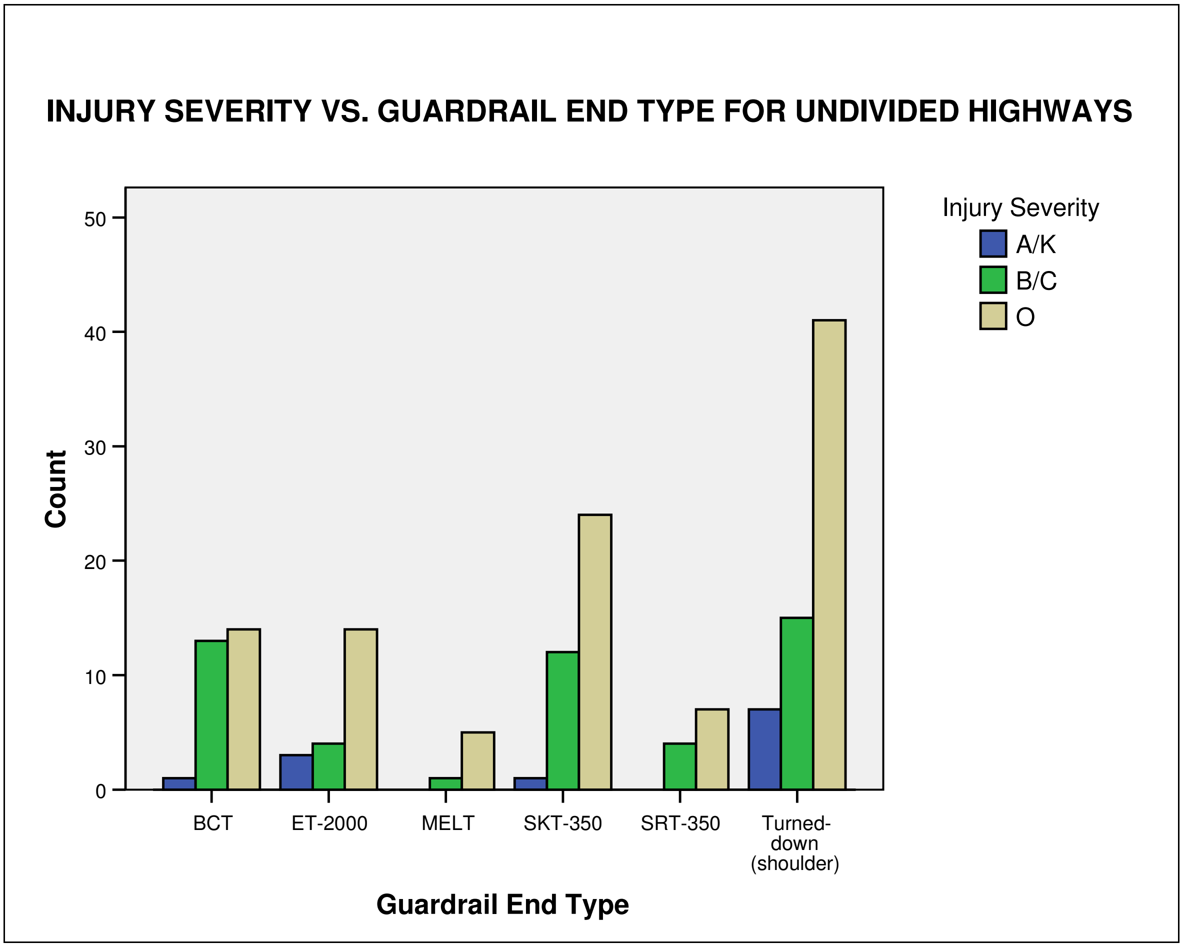

Figure 10: Injury severities by guardrail end type for undivided highways

Table 17: Aggregated injury severities by guardrail end type for undivided highways

	Likelihood Ratio Tests		
Effect	**Chi-Square**	**df**	**Sig.**
Intercept	0	0	
Posted Speed Limit	6.158	2	0.046
AADT	0.873	2	0.646
Guardrail End Type	13.837	10	0.181
Vehicle Type	4.626	2	0.099
Crash Impact Type	0.755	2	0.686

CHAPTER V - CONCLUSIONS & RECOMMENDATIONS

This research effort began with an objective of determining the frequency and safety impacts of crashes involving guardrail end hits. A focus was on turned down guardrail ends, in which Wisconsin still has many, as well as the other types of guardrail ends that exist. The goal of this research was to develop quantifiable evidence on the safety effects of the existing end guardrail end treatments.

Based on the findings of the literature review and the research objectives, the following hypothesis was developed:

- Turn down guardrail end impacts lead to more serious injury outcomes and are more unsafe than other guardrail ends analyzed.

To test this hypothesis, the research tasks presented in this report were completed. The results of this research led to the following conclusions:

- In the data set obtained, turn down guardrail end treatments were associated with a higher proportion of fatalities and incapacitating injuries due to guardrail end hits than the other guardrail end treatments commonly used in Wisconsin.
- The ET-2000 and SKT-350 were effective in reducing the severity of guardrail end hits.

The results were clear in finding that turn down guardrail ends provide the least effective safety record of guardrail end treatments analyzed within Wisconsin. Therefore, it is recommended that turn down guardrail ends are removed and replaced with current and future rehabilitation and reconstruction roadway improvements.

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Appendix A - Fatal Crash Summary

Divided Highways

HW	County (Crash Rate)	Fatal	Guardrail Type	Road Condition	Month Year	Driver Age
HW-39	Columbia	1	Turned Down (shoulder)	No Info	Dec. 2002	67
	Columbia	1	Turned Down (shoulder)	No Info	Jul. 2003	40
	Columbia	1	Turned Down (median)	Wet	Feb. 2004	32
	Dane	1	Turned Down (shoulder)	No Info	Nov. 2004	30
	Columbia	3	Turned Down (shoulder)	No Info	Aug. 2005	16
HW-41	Brown	1	Turned Down (shoulder)	Snow	Dec. 2005	72
HW-43	Brown	1	Turned Down (shoulder)	No Info	Aug. 2005	38
HW-51	Dane	1	Turned Down (shoulder)	No Info	Oct. 2005	24
I-94	Dane	1	BCT	No Info	Jul. 2004	45
	Jefferson	1	Turned Down (shoulder)	No Info	Apr. 2004	44
	Waukesha	2	BCT	No Info	May. 2005	23

Undivided Highways

HW	County (Crash Rate)	Fatal	Guardrail Type	Road Condition	Month Year	Driver Age
HW-114	Calumet	1	ET-2000	No Info	Jun. 2003	18
HW-78	Lafayette	1	BCT	No Info	No. 2004	42

Appendix B - Incapacitating Injury Crash Summary

Divided Highways

HW	County (Crash Rate)	Injuries	Guardrail Type	Road Condition	Month Year	Driver Age
HW-12	Dane	2	BCT	No Info	Sep. 2005	30
HW-14	Dane	1	Turned-down (shoulder)	No Info	Feb. 2004	17
	Dane	1	Turned-down (shoulder)	No Info	Dec. 2004	47
HW-29	Clark	2	BCT	No Info	Jun. 2003	18
	Marathon	1	Turned-down (shoulder)	No Info	Nov. 2004	20
HW-39	Dane	1	MELT	No Info	May. 2003	61
	Marathon	1	BCT	No Info	Jan. 2004	24
	Waushara	2	SRT-350	No Info	May. 2004	73
	Columbia	1	Turned-down (shoulder)	No Info	Mar. 2005	38
	Dane	3	Turned-down (shoulder)	No Info	Aug. 2005	18
HW-41	Waukesha	5	SKT-350	No Info	Jun. 2003	19
	Outagamie	1	ET-2000	Snow	Dec. 2004	50
HW-43	Manitowoc	1	BCT	No Info	Nov. 2004	46
HW-51	Marathon	1	ET-2000	No Info	Jul. 2004	28
HW-61	Grant	1	Turned-down (shoulder)	No Info	Sep. 2004	27
I-94	Dunn	1	SKT-350	Ice	Mar. 2003	21
	Jackson	6	SRT-350	No Info	Mar. 2003	48
	Jackson	3	ET-2000	No Info	Mar. 2003	34
	Jefferson	2	Turned-down (shoulder)	No Info	Feb. 1004	20
	Dunn	1	Turned-down (shoulder)	No Info	Mar. 2004	51
	Eau Claire	3	BCT	No Info	Aug. 2004	53
	Jackson	1	BCT	Snow	Jan. 2005	18

Undivided Highways

HW	County (Crash Rate)	Injuries	Guardrail Type	Road Condition	Month Year	Driver Age
HW-10	Buffalo	2	Turned-down (shoulder)	No Info	Dec. 2002	56
HW-12	Walworth	1	Turned-down (shoulder)	Ice	Dec. 2003	21
HW-14	Sauk	1	ET-2000	No Info	Oct. 2003	40
	Vernon	2	Turned-down (shoulder)	Snow	Jan. 2004	15
HW-37	Buffalo	1	Turned-down (shoulder)	Wet	Mar. 2004	26
HW-69	Green	1	SKT-350	No Info	May. 2005	21
HW-80	Richland	1	Turned-down (shoulder)	No Info	Jun. 2003	33
HW-133	Grant	1	ET-2000	No Info	Jan. 2003	21
HW-162	La Crosse	1	Turned-down (shoulder)	No Info	Sep. 2005	53
HW-213	Rock	1	Turned-down (shoulder)	No Info	Jul. 2003	45

Appendix C - Non Incapacitating Injury Crash Summary

Divided Highways

HW	County (Crash Rate)	Injuries	Guardrail Type	Road Condition	Month Year	Driver Age
	Winnebago	2	SKT-350	Ice	Jan. 2005	56
HW-10	Waupaca	3	SKT-350	No info	Nov. 2005	54
	Walworth	1	ET-2000	No info	Jan. 2003	20
HW-12	Dane	1	Bullnose Attenuator	Snow	Jan. 2003	26
	Dane	1	Turned-down (shoulder)	No info	Apr. 2004	46
	Rock	1	SKT-350	Wet	Nov. 2004	25
HW-14	Dane	1	Turned-down (shoulder)	No info	Jul. 2005	72
	Dane	1	Turned-down (shoulder)	Ice	Dec. 2004	45
	Dane	1	BCT	Wet	Mar. 2004	23
HW-18	Dane	1	BCT	No info	Jun. 2004	52
HW-29	Shawano	1	MELT	No info	Aug. 2005	61
HW-35	La Crosse	1	SKT-350	No info	Jun. 2005	35
	Columbia	1	Turned-down (shoulder)	Wet	Mar. 2003	32
	Dane	1	Turned-down (shoulder)	Wet	Apr. 2003	35
	Marquette	1	BCT	No info	May. 2003	53
	Rock	1	SKT-350	Wet	Nov. 2003	17
	Rock	5	SKT-350	No info	Nov. 2003	46
	Dane	1	Turned-down (shoulder)	Snow	Feb. 2004	38
	Marathon	1	BCT	No info	Feb. 2004	33
	Columbia	2	Turned-down (shoulder)	No info	Jan. 2005	34
	Portage	1	ET-2000	No info	Apr. 2005	75
	Dane	2	Turned-down (shoulder)	No info	Apr. 2005	21
HW-39	Columbia	1	Turned-down (shoulder)	No info	Jun. 2005	25

	Oconto	3	ET-2000	Blnk	Jan. 2004	15
	Brown	1	Turned-down (shoulder)	Wet	Apr. 2004	51
HW-41	Outagamie	1	ET-2000	No info	Mar. 2005	25
	Walworth	1	SKT-350	Snow	Jan. 2004	24
	Sheboygan	2	MELT	Snow	Feb. 2004	45
	Ozaukee	1	MELT	No info	Jul. 2004	16
	Walworth	1	BCT	No info	Mar. 2005	18
	Milwaukee	1	ET-2000	No info	Jul. 2005	52
	Ozaukee	1	ET-2000	No info	Jul. 2005	25
HW-43	Walworth	1	SKT-350	No info	Nov. 2005	20
	Washington	1	Turned-down (shoulder)	Snow	Jan. 2004	26
	Milwaukee	1	SKT-350	Snow	Jan. 2004	20
HW-45	Washington	1	Turned-down (median)	No info	Oct. 2005	43
HW-51	Marathon	1	SKT-350	No info	Apr. 2005	35
HW-53	Chippewa	1	Turned-down (shoulder)	No info	Apr. 2003	31
	Monroe	1	Bullnose Attenuator	Ice	Jan. 2003	20
	Juneau	1	BCT	No info	Aug. 2004	20
	Sauk	1	BCT	Ice	Dec. 2004	72
	Monroe	2	SKT-350	No info	Jun. 2005	48
I-90	Monroe	2	SKT-350	Wet	Jun. 2005	57
	Dunn	3	Bullnose Attenuator	No info	Jul. 2003	19
	Jackson	2	ET-2000	No info	Sep. 2003	21
	Milwaukee	1	ET-2000	No info	Nov. 2003	22
	Racine	1	SKT-350	No info	Dec. 2003	18
	Jackson	1	ET-2000	No info	Jun. 2004	65
	Jefferson	2	Turned-down (shoulder)	No info	Aug. 2004	52
	Waukesha	3	BCT	No info	Sep. 2004	18
	Milwaukee	1	ET-2000	No info	Sep. 2004	19
	Jackson	1	BCT	Ice	Jan. 2005	22
I-94	Jackson	1	ET-2000	Ice	Jan. 2005	32
HW-151	Dane	1	Turned-down (shoulder)	No info	Apr. 2005	48

HW-441	Outagamie	1	Bullnose Attenuator	No info	Sep. 2004	23

Undivided Highways

HW	County (Crash Rate)	Injuries	Guardrail Type	Road Condition	Month Year	Driver Age
HW-10	Pepin	1	Turned-Down (Shoulder)	No Info	Jul. 2004	46
	Jackson	1	SKT-350	Wet	Sep. 2005	68
HW-12	Eau Claire	1	SKT-350	Wet	Dec. 2004	45
HW-13	Adams	1	MELT	No Info	Jan. 2005	32
HW-14	Vernon	1	Turned-Down (Shoulder)	Snow	Mar. 2003	40
HW-23	Iowa	1	Turned-Down (Shoulder)	No Info	Apr. 2005	80
HW-35	St. Croix	2	Turned-Down (Shoulder)	No Info	Apr. 2004	28
HW-40	Chippewa	1	SKT-350	No Info	Aug. 2003	20
HW-51	Dane	1	BCT	No Info	Sep. 2004	35
HW-53	Trempealeau	1	ET-2000	No Info	Sep. 2004	42
HW-54	Trempealeau	1	Turned-Down (Shoulder)	No Info	Oct. 2005	21
HW-60	Richland	6	SRT-350	No Info	May. 2003	75
	Dodge	1	BCT	No Info	Feb. 2005	48
	Columbia	1	ET-2000	No Info	May. 2005	19
HW-61	Grant	1	Turned-Down (Shoulder)	No Info	Feb. 2003	21
	Crawford	1	BCT	No Info	Mar. 2003	35
HW-78	Dane	1	BCT	No Info	Aug. 2003	23
HW-80	Richland	1	Turned-Down (Shoulder)	Snow	Jan. 2003	21
HW-83	Waukesha	1	Turned-Down (Shoulder)	No Info	Jul. 2005	22
	Racine	1	Turned-Down (Shoulder)	Ice	Nov. 2005	16
HW-93	Trempealeau	1	BCT	Snow	Feb. 2005	24
HW-130	Richland	1	BCT	No Info	Dec. 2004	54

Appendix D - Possible Injury Crash Summary

Divided Highways

HW	County (Crash Rate)	Injuries	Guardrail Type	Road Condition	Month Year	Driver Age
HW-10	Waupaca	1	ET-2000	No Info	Mar. 2003	36
	Waupaca	1	SKT-350	No Info	Nov. 2004	35
HW-30	Dane	1	MELT	Snow	Dec. 2005	16
HW-35	Trempealeau	1	ET-2000	Wet	Feb. 2005	21
HW-39	Rock	1	Turned-down (shoulder)	Snow	Jan. 2003	25
	Columbia	1	Turned-down (median)	Snow	Feb. 2003	16
	Portage	1	ET-2000	No Info	Jun. 2003	21
	Columbia	1	Turned-down (shoulder)	No Info	Feb. 2004	23
	Rock	1	SKT-350	Wet	Apr. 2004	28
	Rock	3	SKT-350	Snow	Feb. 2005	31
	Waushara	3	SKT-350	No Info	Apr. 2005	19
HW-41	Waukesha	1	SKT-350	No Info	Feb. 2003	51
	Oconto	1	Turned-down (shoulder)	No Info	May. 2003	18
	Brown	1	SKT-350	No Info	Jun. 2004	24
	Washington	1	ET-2000	No Info	Jul. 2004	42
	Brown	1	SKT-350	Snow	Jan. 2005	23
	Outagamie	2	ET-2000	No Info	Apr. 2005	25
HW-43	Milwaukee	1	ET-2000	No Info	Dec. 2003	51
	Rock	2	BCT	Ice	Jan. 2004	32
	Sheboygan	1	ET-2000	Snow	Jan. 2004	37
	Milwaukee	1	ET-2000	No Info	Mar. 2004	20
	Ozaukee	1	ET-2000	Wet	May. 2004	19
	Brown	1	Turned-down (shoulder)	Wet	May. 2004	20
	Milwaukee	1	SKT-350	Snow	Jan. 2005	19
	Waukesha	4	BCT	Snow	Feb. 2005	40
	Sheboygan	2	ET-2000	Ice	Mar. 2005	48
	Waukesha	1	SKT-350	Snow	Mar. 2005	18

	Manitowoc	1	BCT	No Info	Mar. 2005	14
	Milwaukee	1	ET-2000	No Info	Jun. 2005	17
	Brown	1	SKT-350	No Info	Jul. 2005	69
HW-45	Milwaukee	1	SKT-350	No Info	Jun. 2004	35
	Milwaukee	1	SKT-350	No Info	Aug. 2005	31
HW-51	Marathon	1	SKT-350	No Info	Oct. 2003	28
	Marathon	2	SKT-350	No Info	Apr. 2004	26
	Marathon	1	BCT	No Info	Jul. 2004	29
HW-53	La Crosse	1	Turned-down (shoulder)	Snow	Jan. 2005	31
HW-90	Monroe	1	Turned-down (shoulder)	Snow	Jan. 2003	24
	Sauk	1	Turned-down (shoulder)	Ice	Mar. 2004	55
	La Crosse	1	Bullnose Attenuator	No Info	May. 2004	19
	Columbia	1	Bullnose Attenuator	Wet	Oct. 2004	51
I-94	Monroe	2	MELT	Snow	Feb. 2003	72
	Waukesha	1	SKT-350	Wet	Jun. 2003	53
	Waukesha	2	ET-2000	Snow	Jan. 2004	34
	St. Croix	1	ET-2000	No Info	May. 2004	36
	Dunn	1	SKT-350	Ice	Jan. 2005	20
	Milwaukee	1	ET-2000	Wet	Jan. 2005	25
	Dunn	1	SKT-350	Ice	Mar. 2005	49
	St. Croix	1	SKT-350	No Info	May. 2005	24
	Dunn	1	Turned-down (shoulder)	No Info	Jun. 2005	41
	Monroe	1	Turned-down (shoulder)	No Info	Dec. 2005	58
HW-151	Dane	1	SKT-350	No Info	Jul. 2005	33
	Dane	1	SKT-350	No Info	Sep. 2005	27
HW-172	Brown	1	Turned-down (shoulder)	Wet	Feb. 2004	28

Undivided Highways

HW	County (Crash Rate)	Injuries	Guardrail Type	Road Condition	Month Year	Driver Age
HW-11	Green	1	SRT-350	No Info	Nov. 2003	16
	Walworth	1	BCT	No Info	Apr. 2004	22
HW-13	Clark	1	SKT-350	No Info	Sep. 2004	22
HW-14	Rock	1	BCT	No Info	Feb. 2003	44
HW-15	Outagamie	1	Turned-down (shoulder)	Snow	Feb. 2005	27
	Outagamie	1	BCT	No Info	Apr. 2005	27
HW-16	La Crosse	2	SKT-350	Ice	Dec. 2003	62
	Monroe	1	BCT	Snow	Jan. 2005	20
	La Crosse	1	Turned-down (shoulder)	No Info	May. 2005	22
HW-32	Kenosha	1	Turned-down (shoulder)	No Info	Sep. 2004	31
HW-33	Ozaukee	1	Turned-down (shoulder)	Snow	Jan. 2004	18
HW-35	Buffalo	1	SKT-350	No Info	Feb. 2003	34
	Buffalo	1	SKT-350	No Info	Apr. 2005	81
HW-37	Eau Claire	1	SRT-350	No Info	Aug. 2005	35
HW-48	Barron	2	Turned-down (shoulder)	No Info	Feb. 2003	18
HW-52	Langlade	1	Turned-down (shoulder)	No Info	Aug. 2005	72
HW-54	Outagamie	1	SRT-350	Snow	Mar. 2003	17
HW-58	Richland	1	BCT	No Info	Dec. 2002	41
HW-59	Rock	1	SKT-350	Snow	Jan. 2004	37
HW-60	Columbia	1	ET-2000	Snow	Feb. 2004	39
	Crawford	1	SKT-350	Snow	Jan. 2005	21
	Crawford	1	SKT-350	Snow	Dec. 2005	18
HW-64	Taylor	1	BCT	Snow	Feb. 2003	16
HW-65	St. Croix	1	SKT-350	Snow	Mar. 2005	30
HW-67	Fond Du	1	BCT	Snow	Mar. 2005	28
	Sheboygan	1	ET-2000	No Info	Jul. 2005	49

HW-70	Price	1	SKT-350	No Info	Jun. 2003	27