IMPACT OF GEOMETRIC CONDITIONS ON WYOMING'S RURAL CRASHES

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ABSTRACT

The main objective of this research is to evaluate the impact of geometric conditions on the safety of Wyoming rural roads. The data used in this research was obtained from the Wyoming crash database. The data was summarized in three functional rural roadway classifications: interstate, state highways, and local roads. Determining the risk associated with various geometric conditions is paramount for improving the current Wyoming State Highway Safety Plan (WSHSP) which was adopted in September of 2006.

Two periods of four years, "before" and "after" September 2006, were analyzed in this paper. A Weighted Severity Index (WSI) value was calculated for every category of combinations of geometric characteristics to determine if any geometric conditions resulted in more severe crashes. The analysis was divided into two phases. The first phase used the WSI to compare the total crash percentage against the Equivalent Property Damage Only (EPDO) percentage for every geometric combination. The findings indicated that four roadway types had the most significant proportion of severe crashes: curved-level and curved-downhill geometric combinations on both state highway and local roads.

The second phase analyzed the four roadway types identified in the first phase of research to determine the proportion of different types of severe crashes. Only roadway departure crashes were analyzed in this phase. The findings indicated that a majority of roadway departure crashes on all four identified roadway types involve rollovers, which have the highest crash severity. The findings of this study will help in revising the comprehensive safety plan for Wyoming to reduce crashes on rural roads statewide.

Keywords: geometric conditions, crash severity, roadway departure, rural roads.

INTRODUCTION

The high cost of highway crashes paid by societies worldwide makes highway safety improvements an important objective of transportation agencies. Highway safety professionals can improve safety through multiple means, one of which is making geometric improvements. Recognizing this, Safety Management Systems (SMS) have been established by the Federal Highway Administration (FHWA) to encourage states to pursue and promote safety and accident investigations. (Karlaftis, 2001).

Local and State transportation agencies are continually faced with decisions concerning the safe operation of roadways. Most safety related improvements have been, more often than not, reactive. This means that the safety countermeasures are applied to roadways only after high crash rates have been observed (WSHSP, 2006). Predicting where crashes are likely to happen is a very useful proactive tool for reducing the number and severity of crashes. Roadway sections found to be the most potentially hazardous would become high priority candidates for safety improvements. Identifying the locations for needed safety improvement is a vital aspect of any safety improvement program due to the limited resources available for such programs (Labi, 2005).

Geometric features on roadways play a major role in driver expectancy, especially when it comes to rural roads. The overwhelming majority of roads in Wyoming are low volume local rural roads that do not meet current design standards. These roads evolved over the past century with little or no design of geometric conditions (WYDOT, 2006). Most of the rural roadways are primarily driven by local drivers who drive the road regularly. Many factors can result in a crash involving even a regular user of a local roadway. These causative factors (such as pavement type, weather, and lighting) also come into play when analyzing the geometrics and safety of a roadway (WYDOT, 2006). By determining if there is a correlation between geometric features and crashes on Wyoming rural roadways, preventive measures could be taken to reduce future crashes.

This study would enable local and state agencies to proactively identify and deal with current and possible high crash areas by quantifying the impact of roadway geometry on crash rates. Instead of waiting for crashes to occur to determine if a rural roadway section warrants a countermeasure, agencies will be able to predict what roadway sections are potentially hazardous (WYDOT, 2006).

LITERATURE REVIEW

Geometric Causative Crash Factors

There are many different factors that cause crashes. Some of the factors, such as animal related crashes, have nothing to do with the geometrics of the roadway. Other crashes, such as roadway departure and rollovers, have been found to be impacted by geometric characteristics of roadways. Horizontal and vertical alignments are the two major geometric characteristics of every roadway. Horizontal curves are measured by their radius, while vertical alignments by their slopes.

Roadway curves are a necessary and important element of nearly all highways, but they are also one of the most complex features. Initially their shape was a result of what seemed reasonable to the builder's eye. Now roadway curves are geometrically designed using computer programs to form perfect circular curves. Despite a long standing design procedure based on sound principles, roadway curves often tend to be high-crash locations.

The geometric variable that most significantly affects the operating speeds and crash experience on horizontal curves is the radius. Horizontal curves having lager curve radii are found to be associated with fewer crashes. By having a large curve radii the lateral forces on the vehicle are reduced, allowing drivers to negotiate the curve more smoothly, reducing the risk of overturning or departing the roadway. When vertical grades are combined with horizontal curves, it has been found that safety is adversely impacted. Also, vertical alignments with a lower average grade have been found to be safer. The lower average vertical grade improves driver's sight distance and allows vehicles to decelerate faster which results in a reduction in the number and severity of crashes (Labi, 2006 and Aram, 2010).

Although several studies over the years have indicated that roadway curves exhibit higher accident rates than straight roadway sections, and that accident rates increase as curve radii decrease, one of the most comprehensive analyses was done by Glennon, Neuman, and Leisch in 1983. This study had some very significant conclusions about roadway curve safety. One significant conclusion was the average single-vehicle ran-off-road (SVROR) crash rate for roadway curves is about four times the average SVROR crash rate for straight roadway segments. Also roadway curves were found to have a higher proportion of fatal and injury accidents than straight segments. Some reasons for this were roadside character, substandard roadway curves, and roadside slope traversal.

Roadside character (roadside slope, clear-zone width, coverage of fixed objects) appears to be the largest contributor to high accident rates on curves. Most curves with high-accident rates, however, usually have multiple contributing factors (i.e., sharper curvature, longer curve lengths, narrower shoulders, and lower pavement skid resistance). Substandard roadway curves are dangerous when drivers do not decrease speeds to match the safe speed of the curve. Roadside slopes on roadway curves need to be flatter than those on straight segments. This is because higher vertical deceleration rates result in a higher potential for rollover crashes (Glennon, Neuman, and Leisch, 1983).

Other studies resulted in somewhat different conclusions regarding the effects of radius, length of curve, etc. They all concluded, however, that roadway curves are significantly more dangerous than straight segments and that SVROR crashes are a predominant aspect of curves which tend to have a higher severity than multi-vehicle crashes.

Safety Improvements

The low traffic volumes on some rural roads make major improvements appear not to be cost effective and usually do not warrant an increased level of law enforcement effort. Persuading local authorities to spend time and money directly on safety improvements is an important step

towards a proactive safety approach. Large financial commitments and complex safety analyses are not always necessary. Historically, liability issues have deterred local agencies from identifying safety concerns, because they fear that they would be exposed to tort liability simply by admitting that safety deficiencies exist on their roadways (Wilson, 2003). Many agencies implement safety ideas at local levels without utilizing a specific safety program due to lack of funding, resources or training to allow safety improvements to be made quickly and effectively (Calvert and Wilson, 1999).

A solution to this is incremental safety improvements. Incremental safety improvements have been found to be an effective strategy in enhancing roadway safety. In order to effectively implement a safety program the functional classification safety improvement guidelines for each classification need to be established (Calvert and Wilson, 1999). In Wyoming, only the highest crash locations state-wide are chosen since they will usually benefit the most from engineering and safety improvements. Funding for roadway improvements is used to improve "hot spot" locations on the local and rural roadways in the state with the greatest Equivalent Property Damage Only (EPDO) (WYDOT, 2006).

Factors that help to reduce the number crashes are recommended by the American Association of State Highway and Transportation Officials (AASHTO) and can be found in the 2010 Highway Safety Manual (HSM). The HSM uses crash modification factors (CMF) for geometric design features to adjust the crash frequencies predicted by safety performance functions (SPF). The effectiveness of an improvement is based on the functional class and current design of a road section. The CMFs that are suggested for rural two-lane road segments are: lane width; shoulder width and type; horizontal curve length; radius and superelevation; vertical grades; centerline rumble strips; passing lanes; roadside design; lighting; and automated speed enforcement. When implemented appropriately, each of these safety improvements has the potential to effectively reduce the number and severity of crashes (HSM, 2010).

OBJECTIVES

The main objective of this research is to evaluate the impact of geometric conditions, and more specifically roadway departure crashes, on the safety of Wyoming rural roads. Determining the risk associated with various geometric conditions would help in developing a plan for Wyoming agencies to reduce high severity crashes on rural roads statewide. A secondary objective for this study is to evaluate the effectiveness of the 2006 Wyoming State Highway Safety Plan (WSHSP) in reducing crashes on Wyoming rural roadways.

DATA COLLECTION

All data utilized in this research was obtained from the Critical Analysis Reporting Environment (CARE) 9 crash database. The CARE 9 crash database is a program that is updated quarterly with all available details of every crash in Wyoming since 1994. Although the data available in the CARE 9 crash database is vast, this research concentrated primarily on the following data: functional classification, crash type, and geometric conditions.

For the analysis, two time periods of four years were selected using the publication of the WSHSP in September 2006 as the median. The "before" analysis is from September 2002 to August 2006. The "after" analysis is from September 2006 to August 2010. The data filtered in three categories: crash severity, time period, and functional classification.

The crash data was summarized into three functional classifications for rural roadways: interstate, state highways, and local roads. Eight combinations of possible geometric conditions were included in the analysis using two horizontal alignment types (straight and curved) and four vertical alignment types (uphill, downhill, curves, and level). These geometric combinations are summarized in Table 1.

Table 1: Analyzed Geometric Combinations

Geometric Combinations	
Horizontal Alignment	**Vertical Alignment**
Straight	Level
Straight	Uphill
Straight	Downhill
Straight	Curve
Curve	Level
Curve	Uphill
Curve	Downhill
Curve	Curve

Although the data available in the CARE 9 crash database is vast, there are still limitations in the program. The main limitation is the information is only as accurate and complete as the officer reporting the crash records it. Although there are numerous classes every year which help officers develop and retain knowledge about reporting crashes, the reporting officers are not expected to be experts on every detail. Thus, detailed information that could be used to enhance safety is not always statistically reliable due to having a chance of either being unreported or reported incorrectly. For example, curve radii, vertical grades, and AADT values are not reported for 93, 68, and 52 percent of crashes, respectively. Also, the CARE 9 crash database has categories for posted speeds and vehicle speeds, but there is no category for speeding. The crashes would have to be analyzed individually in order to determine the number of speeding vehicles, which can be extremely time-consuming.

The CARE 9 crash database identifies different roads by ML numbers. The roads numbers in this system are divided into state highways, county roads, and city streets. In this system, the interstates are included in the state highway network. The three roadway categories in this paper (interstates, state highways, and local roads) were developed by using this reporting style. The interstates were extracted out of the state highway category and county road category was called local roads. This means the roads are not divided by true functional classifications (collectors, arterials, etc.), thus the state highway and county road categories both have a mix of arterials and collectors roads in their respective crash numbers. There is no way to determine the total roadway lengths for the state highway or local roadway crashes. Also, WYDOT currently has not

merged roadway lengths into CARE 9 crash database. This means that it is not possible to find the lengths of the different geometric combination in any roadway category.

DATA ANALYSIS

The analysis of the data was performed in two phases. The first phase concentrated on locating possible geometric conditions on rural interstates, state highways and local roadways in Wyoming which may have significantly higher proportion of severe crashes. The second phase analyzed the geometric combinations identified in the first phase of research as having high severity crashes. Only roadway departure crashes were analyzed in this phase due to their significant percentage.

The EPDO is a performance measure where weighting factors relative to property damage only (PDO) crashes are assigned by severity types to develop a single equivalent combined frequency. In this research, the EPDO values for the five main crash severity levels were based on the comprehensive crash costs, calculated in 2007 dollar values, from the 2010 Highway Safety Manual (AASHTO, 2010). Since Wyoming roadways typically have low crashes number, crash performance measures are more sensitive to fatal crashes and potentially can be over-emphasized. To mitigate this, fatal crashes were combined with incapacitating injury crashes and designated as "critical" crashes, shown below in Equation 1. Also, the two less severe injury types (non-incapacitating and complaint of pain) were combined into a "serious" crash category.

Table 2 illustrations how the EPDO factors were established. The HSM comprehensive crash costs were averaged against the number of crashes in the critical and serious categories. This determined the weighted comprehensive costs for the critical and serious categories. The PDO value was not weighted. The EDPO weighting factors were calculated by dividing the weighted comprehensive crash costs by the PDO comprehensive cost. These values are valid for all crashes regardless of functional classification.

Table 2: EPDO Performance Measure Methodology

CRASH SEVERITY		WY Crashes (2000-09)	HSM Comprehensive Crash Costs (2007)	Weighted Comp. Crash Cost	EPDO Weighting Factors
CRITICAL	K	1428	$ 4,810,700.00	$ 976,667.93	110
	A	7631	$ 259,200.00		
SERIOUS	B	16847	$ 94,800.00	$ 75,386.24	8.5
	C	15222	$ 53,900.00		
PDO		118115	$ 8,900.00	$ 8,900.00	1

Equation 1 below is the EPDO formula utilized for the data analysis.

$$EPDO = 110*(A+K) + 8.5*(B+C) + PDO \quad (1)$$

where:
EPDO: Equivalent Property Damage Only
K: Number of Fatal Crashes

A: Number of A injury crashes (incapacitating injuries that will prevent normal activities for more than 24 h)
B: Number of B injury crashes (non-incapacitating injuries that will not prevent normal activities for more than 24 h)
C: Number of C injury crashes (complaint of pain or momentary unconsciousness), and
PDO: Property Damage Only crashes

The EPDO value for each geometric combination and the corresponding total EPDO value were calculated for every functional classification. The total percentage of crashes and the corresponding percentage of the total EPDO value were calculated for every geometric combination in each functional classification. The EPDO performance measure methodology will also assistance Wyoming in attaining the 2006 WSHSP goal of successfully reducing fatal and serious injury crashes by emphasizing the "critical" crash category. Table 3 shows an example from the interstate system of how the total crash numbers and EPDO values were converted into percentages.

Table 3: Total Crash and EPDO Percentages on the Interstate System

Wyoming Rural INTERSTATES Crashes (SEPT 2002-AUG 2006)								
Geometric Combinations		CRASH SEVERITY			Total Crashes	EPDO Values	% Total Crashes	% EPDO
Horizontal Alignment	Vertical Alignment	CRITICAL	SERIOUS	PDO				
Straight	Level	361	870	3298	4529	9592	44.5%	42.4%
Straight	Uphill	149	429	1344	1922	4186.5	18.9%	18.5%
Straight	Downhill	167	323	1245	1735	3878.5	17.1%	17.1%
Straight	Curve	8	25	91	124	250.5	1.2%	1.1%
Curve	Level	64	117	330	511	1315.5	5.0%	5.8%
Curve	Uphill	70	145	388	603	1525.5	5.9%	6.7%
Curve	Downhill	85	155	484	724	1791.5	7.1%	7.9%
Curve	Curve	9	3	14	26	105.5	0.3%	0.5%
TOTAL VALUES		**913**	**2067**	**7194**	**10174**	**22645.5**	**100%**	**100%**

The purpose of this research is to locate geometric sections in Wyoming which consistently result in a significantly higher proportion of severe crashes. Due to the noted data inconsistency in the CARE 9 database, a Weighted Severity Index (WSI) was formulated to eliminate having to analyze the data purely using crash numbers. The WSI does this by identifying geometric conditions that have significantly higher EPDO percentages than percentages of total crashes. The WSI also emphasizes higher crash locations by giving more weight to geometric combinations with larger total crash percentages. Since the WSI multiplies two percentages together, it is multiplied by a factor of 10,000 to display a number instead of a decimal.

Equation 2 illustrates how the WSI values are calculated.

$$WSI = (\%\ EPDO - \%\ Total\ Crash) * (\%\ EPDO) * 10{,}000 \quad (2)$$

where:

WSI:	Weighted Severity Index
% EPDO:	Percentage of total EPDO for each geometric combination
% Total Crash:	Percentage of total crash for each geometric combination

Ranges of severity for the WSI are the following:

- Low, WSI < 0
- Average, WSI = 0
- Moderate, WSI = 0.1 to 15
- High, WSI = 15.1 to 30
- Very High, WSI = > 30

The ranges of severity were established after the WSI values were found for all categories. The ranges were set on a linear scale which was closely represented by the difference between the EPDO and total crash percentages. Geometric combinations with a positive WSI value indicate a higher than average risk. On the other hand, geometric combinations with a negative WSI value indicate a lower than average risk. The WSI values were calculated for every geometric combination reported in this paper.

Phase I: Geometric Analysis on Interstate, State Highway, and Local Roads

The first phase concentrated on the total crash percentage for each geometric combination and compared them against their respective EPDO percentage. A before-after analysis, shown in Table 4, was completed for all rural crashes statewide for the given time periods. This analysis shows a problem statewide with the severity of curve-level and curve-downhill crash. The analysis also shows crash severity improvement on three geometric combinations. An increase in severity was apparent on curve-level sections. The straight-level WSI value also increased, but remained negative, indicating there is still a very low frequency of severe crashes on those sections.

Table 4: Statewide Before-After Analysis.

STATEWIDE Rural Weighted Severity Index (SEPT 2002 - AUG 2006)					STATEWIDE Rural Weighted Severity Index (SEPT 2006 - AUG 2010)					
Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Change in WSI After WSHSP
Horizontal Alignment	Vertical Alignment				Horizontal Alignment	Vertical Alignment				
Straight	Level	48.83%	40.42%	-340.1	Straight	Level	48.7%	43.7%	-219.1	121.0
Straight	Uphill	12.50%	11.96%	-6.5	Straight	Uphill	12.3%	9.4%	-26.9	-20.4
Straight	Downhill	13.15%	13.92%	10.7	Straight	Downhill	11.8%	11.5%	-4.1	-14.8
Straight	Curve	1.21%	1.10%	-0.1	Straight	Curve	2.1%	2.2%	0.2	0.3
Curve	Level	9.24%	12.34%	38.2	Curve	Level	10.2%	13.6%	46.6	8.4
Curve	Uphill	5.23%	6.85%	11.1	Curve	Uphill	5.3%	7.0%	11.7	0.6
Curve	Downhill	9.45%	12.67%	40.8	Curve	Downhill	8.5%	11.2%	30.6	-10.3
Curve	Curve	0.38%	0.74%	0.3	Curve	Curve	1.1%	1.4%	0.4	0.2

To help indicate which functional classification(s) contributed to the high severity geometric combinations in Table 4 an analysis was performed on the interstate, state highways, and local roadways as described in the following sections.

Interstate

The before-after analysis on the rural interstate sections is shown in Table 5. Interstates are typically known for their conservative geometric designs since they regularly carry high traffic volumes at higher speeds. For this reason the geometrics of interstates usually adhere to driver expectancy to help prevent high speed crashes from happening. The before-after results indicate the crash severity was low to moderate for all the geometric combinations except curve-downhill sections, which were found to be high severity. Straight-downhill was initially almost considered high severity also, but was reduced to low following the WSHSP implementation.

Table 5: Interstate Before-After Analysis.

INTERSTATE Rural Weighted Severity Index (SEPT 2002 - AUG 2006)					INTERSTATE Rural Weighted Severity Index (SEPT 2006 - AUG 2010)					
Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Change in WSI After WSHSP
Horizontal Alignment	Vertical Alignment				Horizontal Alignment	Vertical Alignment				
Straight	Level	44.52%	40.26%	-171.3	Straight	Level	45.8%	43.1%	-116.6	54.7
Straight	Uphill	18.89%	17.08%	-31.0	Straight	Uphill	17.8%	15.5%	-36.8	-5.8
Straight	Downhill	17.05%	17.86%	14.4	Straight	Downhill	14.8%	14.2%	-8.3	-22.7
Straight	Curve	1.22%	0.95%	-0.3	Straight	Curve	2.6%	2.8%	0.6	0.8
Curve	Level	5.02%	6.68%	11.1	Curve	Level	6.1%	7.5%	10.2	-0.9
Curve	Uphill	5.93%	7.44%	11.3	Curve	Uphill	5.5%	7.0%	11.1	-0.2
Curve	Downhill	7.12%	8.91%	16.0	Curve	Downhill	6.3%	8.6%	19.3	3.4
Curve	Curve	0.26%	0.82%	0.5	Curve	Curve	1.0%	1.3%	0.4	-0.1

State Highway

Table 6 shows the before-after analysis results performed on rural state highway geometric combinations. The results before the WSHSP implementation illustrate that the curve-level and curve-downhill sections had very-high severity crashes. Although the curve-downhill sections improved following the WSHSP implementation, they are still considered to be producing high severity crashes. The curve-uphill and straight-uphill sections also have a slightly improved crash severity index. Curve-level sections indicated very high severity crashes in both the before and after analyses.

Table 6: State Highway Before-After Analysis.

STATE HIGHWAY Rural Weighted Severity Index (SEPT 2002 - AUG 2006)					STATE HIGHWAY Rural Weighted Severity Index (SEPT 2006 - AUG 2010)					
Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Change in WSI After WSHSP
Horizontal Alignment	Vertical Alignment				Horizontal Alignment	Vertical Alignment				
Straight	Level	54.0%	42.5%	-489.0	Straight	Level	52.8%	45.9%	-319.8	169.2
Straight	Uphill	9.5%	10.2%	7.0	Straight	Uphill	9.2%	7.0%	-15.3	-22.3
Straight	Downhill	10.6%	11.3%	7.6	Straight	Downhill	9.9%	10.3%	3.8	-3.8
Straight	Curve	1.1%	1.0%	-0.1	Straight	Curve	1.6%	1.6%	0.1	0.2
Curve	Level	10.1%	14.0%	55.8	Curve	Level	11.2%	15.6%	68.5	12.7
Curve	Uphill	4.9%	7.0%	14.2	Curve	Uphill	5.4%	7.2%	13.6	-0.6
Curve	Downhill	9.5%	13.6%	55.8	Curve	Downhill	9.0%	11.4%	26.7	-29.1
Curve	Curve	0.3%	0.4%	0.0	Curve	Curve	0.9%	1.1%	0.1	0.1

Local Roads

The before-after analysis performed on the Wyoming local rural roadways is displayed in Table 7. The results of the crash severity before the WSHSP implementation illustrate the curve-level and curve-downhill sections had very-high severity crashes. The straight-downhill sections also had high severity, but similar to the curve-level sections improved significantly after the WSHSP implementation. The curve-downhill sections also improved but were still considered to be producing very-high severity crashes.

Table 7: Local Roadway Before-After Analysis.

LOCAL Rural Weighted Severity Index (SEPT 2002 - AUG 2006)					LOCAL Rural Weighted Severity Index (SEPT 2006 - AUG 2010)					
Crash Type		TOTAL	EPDO	Weighted Severity Index	Crash Type		TOTAL	EPDO	Weighted Severity Index	Change in WSI After WSHSP
Horizontal Alignment	Vertical Alignment				Horizontal Alignment	Vertical Alignment				
Straight	Level	42.3%	32.6%	-317.9	Straight	Level	43.9%	36.9%	-258.7	59.2
Straight	Uphill	4.2%	4.1%	-0.2	Straight	Uphill	3.9%	3.9%	0.0	0.2
Straight	Downhill	11.0%	13.2%	29.6	Straight	Downhill	8.2%	9.2%	8.9	-20.7
Straight	Curve	1.6%	1.8%	0.4	Straight	Curve	2.6%	3.2%	1.6	1.3
Curve	Level	19.2%	21.9%	60.5	Curve	Level	20.8%	21.2%	8.2	-52.3
Curve	Uphill	4.1%	4.6%	2.1	Curve	Uphill	4.3%	5.8%	8.5	6.4
Curve	Downhill	16.3%	19.7%	67.2	Curve	Downhill	14.1%	16.9%	47.5	-19.7
Curve	Curve	1.3%	2.0%	1.5	Curve	Curve	2.1%	3.0%	2.5	1.0

Initial Findings

The Phase I analysis results indicated that, in general, the severity of crashes on geometric sections improved after the 2006 WSHSP implementation. The results demonstrate compelling evidence that horizontal curves pose a much higher risk to drivers than straight sections on rural Wyoming state highway and local roadways. This most likely explains the high severity crashes occurring on the curve-level and curve-downhill sections statewide, as shown in Table 4.

Additional analysis will be conducted on crashes occurring on local and state highway locations with curve-level and curve-downhill geometric combinations in phase II. The interstate sections on the other hand generally did not have high severity crashes; performing additional analysis on the interstate sections was determined unnecessary.

Phase II: Analysis of Roadway Departure Crashes on High Severity Geometric Conditions

The main goal of the 2006 WSHSP is to place a heavier emphasis on improving safety in four areas: roadway departure crashes, use of safety restraints, impaired driving, and speeding. These four areas represent the greatest opportunities to reduce harmful crashes (WYDOT, 2006). Since severe run-off-roadway (ROR) crashes are generally associated with roadway curves, phase II will only analyze road departure crashes. In this analysis, a roadway departure crash is defined as a crash where a vehicle leaves its lane and runs off the road, opposite direction, sideswipe, and head-on crashes.

Wyoming reported that 37 percent of fatal and serious injury crashes in 2004 were associated with roadway departures (WYDOT, 2006). To determine what type(s) of ROR crashes are causing the high severity the severity and first harmful event (FHE) of every ROR was found. It should be noted that although they are not being analyzed, driver fatigue, impaired driving, and speeding are contributing factors that have been found to result in roadway departure crashes (WYDOT, 2006).

Phase II analysis was performed on the four identified roadway versus geometric combinations identified in phase I: state highway and local roads with curve-downhill and curve-level sections. These crashes were filtered in the CARE 9 program by roadway departure crashes only. The state highway FHE for each crash was compared against three categories: roadway conditions, presence of rumble strips, and the crash severity. For the local roadway FHE, the presence of rumble strips were replace by an analysis of road surface (paved versus unpaved) due to unpaved roads do not have rumble strips. Only the top five FHE in each category were compared against the three above mentioned categories. The crash severity was analyzed for both the four year before and after periods, while the other categories only analyzed the crashes occurring after the 2006 WSHSP implementation.

State Highway Curve-Downhill Sections

This section summarizes the before-after results for roadway departure crashes on the state highway curve-downhill sections shown in Table 8. The before and after WSI values of 426.8 and 309.3, respectively, for rollover crashes indicate that while they are by far the most harmful roadway departure crash type, the severity was greatly reduced. The earth embankment berm crashes increased to be considered high, but were not comparable at all to the rollover crash severity.

Table 8: State Highway Before-After Analysis on Curve-Downhill Sections.

Wyoming Rural State Highway Crashes (Sept 2002-Aug 2006)							
Roadway Deptarture Crashes		Severity on Curve-Downhill Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	10.4%	14.9%	15.8%	41.1%	49.7%	**426.8**
	Guardrail Face	1.2%	4.4%	6.2%	11.8%	7.0%	**-33.8**
	Earth Embankment or Berm	0.8%	3.5%	3.3%	7.7%	4.8%	**-13.8**
	Other Non-Collision MC Loss of Control	3.3%	2.1%	1.5%	6.8%	14.9%	**119.2**
	Fence including Post	0.4%	1.2%	4.8%	6.4%	2.4%	**-9.6**
	Other	4.4%	6.6%	15.1%	26.1%	21.3%	**-102.9**
	TOTAL	**20.5%**	**32.8%**	**46.7%**	**100.0%**	**100.0%**	

Roadway Depature Crashes		Severity on Curve-Downhill Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	6.6%	16.4%	12.5%	35.5%	42.8%	**309.3**
	Guardrail Face	1.3%	2.6%	8.2%	12.0%	8.3%	**-31.0**
	Earth Embankment or Berm	1.8%	3.8%	4.1%	9.7%	11.3%	**18.1**
	Delineator Post	0.8%	2.3%	4.6%	7.7%	5.3%	**-12.7**
	Trees or Shrubbery	1.0%	1.8%	4.3%	7.2%	6.4%	**-4.9**
	Other	4.3%	4.6%	18.9%	27.9%	26.0%	**-49.3**
	TOTAL	**15.9%**	**31.5%**	**52.7%**	**100.0%**	**100.0%**	

A separate analysis was performed on roadway conditions and the presence of rumble strips for the crashes occurring after the 2006 WSHSP, shown in Table 9. Since 46 percent of crashes occurred on dry roadway surfaces, 54 percent of all the crashes occurred on other-than-dry roadway surfaces. This suggests that a majority of the crashes are partially correlated to wet or slick road conditions. Table 9 also shows that 44 percent of crashes did not report the presence of rumble strips, however, a majority of the crashes that did report rumble strips indicated "no rumble strips" in the area of the crash. Nevertheless, no inference should be made which suggests rumble strips aid in crash reduction since the proportion of roadway length statewide with rumble strips are not known.

Table 9: State Highway Road Condition and Rumble Strip Analysis on Curve-Downhill Sections.

WYOMING Rural STATE HIGHWAY Roadways Roadway Departure Crashes Curve-Downhill Sections (September 2006 - August 2010)						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	17.6%	13.6%	3.1%	1.3%	**35.5%**
	Guardrail Face	3.3%	6.1%	2.3%	0.3%	**12.0%**
	Earth Embankment or Berm	4.6%	4.1%	1.0%	0.0%	**9.7%**
	Delineator Post	4.3%	2.8%	0.5%	0.0%	**7.7%**
	Trees or Shrubbery	2.8%	3.3%	0.8%	0.3%	**7.2%**
	Other	13.6%	11.5%	2.6%	0.3%	**27.9%**
	TOTAL	**46.3%**	**41.4%**	**10.2%**	**2.0%**	**100.0%**

		RUMBLE STRIP			
		Yes	No	Un-Reported	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	4.9%	16.6%	14.1%	**35.5%**
	Guardrail Face	1.3%	5.4%	5.4%	**12.0%**
	Earth Embankment or Berm	0.3%	2.0%	7.4%	**9.7%**
	Delineator Post	0.8%	4.9%	2.0%	**7.7%**
	Trees or Shrubbery	0.3%	3.1%	3.8%	**7.2%**
	Other	2.6%	14.1%	11.3%	**27.9%**
	TOTAL	**10.0%**	**46.0%**	**44.0%**	**100.0%**

State Highway Curve-Level Sections

This section summarizes the before-after results for roadway departure crashes on the state highway curve-level sections shown in Table 10. The before and after WSI values of 344.5 and 508.2, respectively, for rollover crashes once again indicates that they are by far the most harmful roadway departure crash type. In the "after" category, the total and EPDO percentage were reduced but became more severe due to the increase gap between the two. The delineator post crashes were found to be reduced in severity yet not comparable at all to the rollover crash severity.

Table 10: State Highway Before-After Analysis on Curve-Level Sections.

Wyoming Rural State Highway Crashes (Sept 2002-Aug 2006)							
Roadway Deptarture Crashes		Severity on Curve-Level Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	10.9%	21.1%	14.4%	46.3%	52.9%	**344.5**
	Fence including Post	1.3%	2.9%	9.4%	13.6%	6.6%	**-46.0**
	Earth Embankment or Berm	1.5%	4.0%	2.7%	8.1%	7.5%	**-4.7**
	Delineator Post	2.5%	1.5%	3.5%	7.5%	11.1%	**39.9**
	Guardrail Face	1.5%	1.5%	2.7%	5.6%	6.7%	**7.1**
	Other	3.1%	5.4%	10.2%	18.8%	15.3%	**-53.8**
	TOTAL	**20.7%**	**36.3%**	10.2%	**100.0%**	**100.0%**	

Wyoming Rural State Highway (Sept 2006-Aug 2010)							
Roadway Deptarture Crashes		Severity on Curve-Level Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	9.7%	15.9%	12.2%	37.8%	48.3%	**508.2**
	Fence including Post	1.7%	2.7%	13.4%	17.8%	8.7%	**-78.9**
	Delineator Post	2.5%	1.7%	6.0%	10.1%	11.6%	**17.6**
	Guardrail Face	0.4%	1.7%	3.7%	5.8%	2.5%	**-8.2**
	Earth Embankment or Berm	0.8%	2.1%	2.7%	5.6%	4.4%	**-5.1**
	Other	5.0%	6.8%	11.2%	22.9%	24.4%	**36.6**
	TOTAL	**20.0%**	**30.8%**	**49.2%**	**100.0%**	**100.0%**	

A separate analysis was performed on roadway conditions and the presence of rumble strips for the crashes occurring after the 2006 WSHSP, shown in Table 11. About 58 percent of the all the crashes occurred on dry roadway surfaces. Similar to the curve-downhill findings about 43 percent of crashes recorded did not report the presence of rumble strips. No rumble strips were present in the area of the crash in 73 percent of the crashes reporting the presence of rumble strips (41.7 percent of the 57.2 percent reporting rumble strips).

Table 11: State Highway Road Condition and Rumble Strip Analysis on Curve-Level Sections.

WYOMING Rural STATE HIGHWAY Roadways Roadway Departure Crashes Curve-Level Sections (September 2006 - August 2010)						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	23.8%	10.7%	3.1%	0.2%	**37.8%**
	Fence including Post	8.9%	7.0%	1.4%	0.4%	**17.8%**
	Delineator Post	6.8%	2.3%	0.6%	0.4%	**10.1%**
	Guardrail Face	2.5%	2.7%	0.6%	0.0%	**5.8%**
	Earth Embankment or Berm	3.3%	1.7%	0.6%	0.0%	**5.6%**
	Other	13.0%	7.4%	2.1%	0.4%	**22.9%**
	TOTAL	**58.3%**	**31.8%**	**8.5%**	**1.4%**	**100.0%**

		RUMBLE STRIP			
		Yes	No	Un-Reported	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	6.6%	15.1%	16.1%	**37.8%**
	Fence including Post	3.7%	8.1%	6.0%	**17.8%**
	Delineator Post	1.2%	4.3%	4.5%	**10.1%**
	Guardrail Face	1.0%	1.7%	3.1%	**5.8%**
	Earth Embankment or Berm	0.4%	1.7%	3.5%	**5.6%**
	Other	2.5%	11.0%	9.5%	**22.9%**
	TOTAL	**15.5%**	**41.7%**	**42.8%**	**100.0%**

Local Roadway Curve-Downhill Sections

This section summarizes the before-after results for roadway departure crashes on local road curve-downhill sections shown in Table 12. The before and after WSI values of 664.6 and -80.7, respectively, for rollover crashes indicates a tremendous reduction in their severity. This occurred because the before-after PDO crashes increased by over 10 percent. The earth embankment crashes were to increase in severity due to a small increase in critical crashes, although total crashes were reduced by almost 6 percent.

Table 12: Local Road Before-After Analysis on Curve-Downhill Sections.

Wyoming Rural Local Roadway Crashes (Sept 2002-Aug 2006)							
Roadway Deptarture Crashes		Severity on Curve-Downhill Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	7.4%	22.8%	18.0%	**48.2%**	59.4%	**664.6**
	Earth Embankment or Berm	1.0%	6.8%	8.0%	**15.8%**	9.9%	**-57.8**
	Fence including Post	1.0%	3.2%	8.0%	**12.2%**	8.2%	**-33.0**
	Trees or Shrubbery	0.0%	1.6%	2.6%	**4.2%**	0.9%	**-3.0**
	Non-Collision MC Loss of Control	1.9%	1.0%	1.3%	**4.2%**	12.8%	**111.3**
	Other	1.0%	3.9%	10.6%	**15.4%**	8.7%	**-58.7**
	TOTAL	**12.2%**	**39.2%**	**48.6%**	**100.0%**	100%	

Wyoming Rural Local Roadway Crashes (Sept 2006-Aug 2010)							
Roadway Deptarture Crashes		Severity on Curve-Downhill Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	5.7%	17.1%	28.6%	**51.4%**	49.8%	**-80.7**
	Fence including Post	0.5%	2.4%	9.0%	**11.9%**	5.1%	**-34.6**
	Earth Embankment or Berm	1.4%	3.3%	5.2%	**10.0%**	11.8%	**21.7**
	Trees or Shrubbery	0.5%	3.8%	5.2%	**9.5%**	5.6%	**-22.0**
	Ditch	0.5%	1.9%	2.4%	**4.8%**	4.4%	**-1.6**
	Other	3.3%	0.0%	9.0%	**12.4%**	23.3%	**254.7**
	TOTAL	**11.9%**	**28.6%**	**59.5%**	**100.0%**	100%	

A separate analysis was performed on roadway conditions and roadway surface for the crashes occurring after the 2006 WSHSP, shown in Table 13. As shown, 55 percent of the all the crashes occurred on dry roadway surfaces. Also, 68 percent of all local curve-downhill crashes occurred on unpaved sections. Only the crashes occurring on paved section could have rumble strips applicable, but rumble strips were not analyzed for local road crash. It should be noted that 0.5 percent of the type of road surface was un-reported.

Table 13: Local Road Condition and Road Surface Analysis on Curve-Downhill Sections.

WYOMING Rural LOCAL Roadways - Roadway Departure Crashes Curve-Downhill Sections (September 2006 - August 2010)						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	TOTAL
First Harmful Event (FHE)	Overturn or Rollover	33.8%	12.4%	1.0%	4.3%	**51.4%**
	Fence including Post	4.3%	4.8%	1.0%	1.9%	**11.9%**
	Earth Embankment or Berm	5.7%	3.3%	0.5%	0.5%	**10.0%**
	Trees or Shrubbery	2.9%	4.8%	0.5%	1.4%	**9.5%**
	Ditch	2.9%	0.5%	0.5%	1.0%	**4.8%**
	Other	5.2%	5.2%	1.4%	0.5%	**12.4%**
	TOTAL	**54.8%**	**31.0%**	**4.8%**	**9.5%**	**100.0%**

		Road Surface		
		Paved	Unpaved	TOTAL
First Harmful Event (FHE)	Overturn or Rollover	13.8%	37.6%	**51.4%**
	Fence including Post	4.3%	7.6%	**11.9%**
	Earth Embankment or Berm	4.3%	5.7%	**10.0%**
	Trees or Shrubbery	2.9%	6.2%	**9.0%**
	Ditch	1.4%	3.3%	**4.8%**
	Other	4.8%	7.6%	**12.4%**
	TOTAL	**31.4%**	**68.1%**	**99.5%**

The results are consistent with Table 7 which shows a large reduction in crash severity for local curve-downhill. This occurred even though the total crash percentage was about 14 percent higher than the other three geometric sections analyzed. This suggests that the crash severity for these geometric conditions is impacted heavily by the severity of rollover crashes. Thus, finding a way to reducing the severity of rollover crashes should greatly assist in reducing the overall severity of crashes on geometric conditions.

Local Roadway Curve-Level Sections

This section summarizes the before-after results for roadway departure crashes on local road curve-level sections shown in Table 14. The before and after WSI values of 457.4 and 847.3, respectively, for rollover crashes proves again that they are by far the most harmful roadway departure crash type. In the "after" category, the total and EPDO percentage were reduced but became more severe due to a 2 percent increase in critical crashes. In fact, about 55 percent of the rollover crashes were either serious or critical crashes.

Table 14: Local Road Before-After Analysis on Curve-Level Sections.

Wyoming Rural Local Roadway Crashes (Sept 2002-Aug 2006)							
Roadway Deptarture Crashes		Severity on Curve-LEVEL Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	4.5%	21.0%	18.0%	43.4%	52.2%	**457.4**
	Fence including Post	0.0%	4.5%	12.3%	16.8%	3.8%	**-49.4**
	Earth Embankment or Berm	1.8%	4.8%	8.7%	15.3%	18.7%	**63.6**
	Trees or Shrubbery	0.3%	1.2%	2.7%	4.2%	3.5%	**-2.5**
	Utility Pole or Light Support	0.3%	1.2%	1.5%	3.0%	3.4%	**1.3**
	Other	1.8%	4.2%	11.4%	17.4%	18.5%	**20.9**
	TOTAL	**8.7%**	**36.8%**	**54.5%**	100.0%	100%	

Wyoming Rural Local Roadway Crashes (Sept 2006-Aug 2010)							
Roadway Deptarture Crashes		Severity on Curve-LEVEL Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	6.5%	14.2%	17.0%	37.7%	53.5%	**847.3**
	Fence including Post	1.5%	7.7%	15.7%	25.0%	15.8%	**-145.4**
	Earth Embankment or Berm	0.6%	3.1%	7.7%	11.4%	6.4%	**-32.1**
	Trees or Shrubbery	0.9%	1.9%	3.4%	6.2%	7.6%	**10.9**
	Ditch	0.0%	2.5%	2.2%	4.6%	1.5%	**-4.6**
	Other	1.9%	3.4%	9.9%	15.1%	15.2%	**1.9**
	TOTAL	**11.4%**	**32.7%**	**55.9%**	100.0%	100%	

Table 15 shows another analysis performed on roadway conditions and roadway surface for the crashes only occurring after the 2006 WSHSP. As shown, 60 percent of the all the crashes occurred on dry roadway surfaces. Also, 52 percent of all local curve-level crashes occurred on unpaved sections. It should be noted that 0.3 percent of the type of road surface was un-reported. The results suggest that some drivers may be driving too fast for weather or surface conditions. Also, the large percent of crashes hitting fences suggest recovery areas or slopes may not be adequate enough for drivers' speeds.

Table 15: Local Road Condition and Road Surface Analysis on Curve-Level Sections.

WYOMING Rural LOCAL Roadways - Roadway Departure Crashes Curve-Level Sections (September 2006 - August 2010)						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	TOTAL
First Harmful Event (FHE)	Overturn or Rollover	26.2%	5.2%	1.5%	4.6%	**37.7%**
	Fence including Post	11.7%	9.9%	2.2%	1.2%	**25.0%**
	Earth Embankment or Berm	7.4%	2.8%	0.3%	0.9%	**11.4%**
	Trees or Shrubbery	4.0%	1.5%	0.6%	0.0%	**6.2%**
	Ditch	1.9%	0.9%	0.6%	1.2%	**4.6%**
	Other	8.6%	5.6%	0.6%	0.3%	**15.1%**
	TOTAL	**59.9%**	**25.9%**	**5.9%**	**8.3%**	**100.0%**

		Road Surface		
		Paved	Unpaved	TOTAL
First Harmful Event (FHE)	Overturn or Rollover	15.1%	22.5%	**37.7%**
	Fence including Post	12.0%	12.7%	**24.7%**
	Earth Embankment or Berm	4.0%	7.4%	**11.4%**
	Trees or Shrubbery	2.8%	3.4%	**6.2%**
	Ditch	2.5%	2.2%	**4.6%**
	Other	11.1%	4.0%	**15.1%**
	TOTAL	**47.5%**	**52.2%**	**99.7%**

CONCLUSIONS

The main objective of this research is to evaluate the impact of geometric conditions, and more specifically roadway departure crashes, on the safety of Wyoming rural roads. Determining the risk associated with various geometric conditions would help in developing a plan for Wyoming agencies to reduce high severity crashes on rural roads statewide. A secondary objective for this study is to evaluate the effectiveness of the 2006 Wyoming State Highway Safety Plan (WSHSP) in reducing crashes on Wyoming rural roadways.

Implemented in September 2006, the WSHSP was used as a center point for the four year "before" and "after" analysis. The CARE 9 crash database was utilized as the primary crash analysis tool. The analysis was conducted on the Wyoming rural interstates, state highways, and local roadways and included eight combinations of geometric conditions. It was determined that curve-downhill and curve-level crashes on both the rural state highways and local roadways were more severe than other geometric combinations and needed further analysis. It was determined unnecessary to perform a more detailed analysis on the interstate system. Roadway departure crashes were observed to be the largest contributor of severe crashes on these sections, the secondary analysis exclusively focused on those areas. Since local roads have a combination of paved and unpaved sections, as well as a major difference in average annual daily traffic (AADT) from state highways, the two functional classes were independently analyzed. It was concluded that rollover crashes were the most severe roadway departure crash type in in every phase II analysis by accounted for at least 37 percent of the crashes.

The general findings suggest that crashes are occurring probably because drivers are going too fast for weather or/and surface conditions on curve-level and curve-downhill sections. The

results from phase II suggested that crash severity for these geometric sections is impacted heavily by the severity of rollover crashes. Thus, finding a way to reducing the severity of rollover crashes should greatly assist in reducing the overall severity of crashes on geometric conditions.

The secondary objective for this study is to evaluate the effectiveness of the 2006 WSHSP in reducing crashes on Wyoming rural roadways. The results from local and state highway analysis indicate some room for improvement. One concern is the high percentage of critical and serious crashes still occurring on both the curve-level and curve-downhill sections. Although the WSI values increased in some cases, the overall analysis suggests that safety improvements following the WSHSP implementation are aiding in the reduction of crash severity on hazardous geometric sections. The planning through construction phases of projects can take years to complete once a safety plan is in place. Given a few more years and additional implemented safety projects, the analysis should show the real impact of the plan.

RECOMMENDATIONS

Since rollovers are so prominent in the roadway departure crashes on state highways, cost effective safety improvements should be considered for these sections. Advanced warning signs for curves, shoulder and/or center rumble strips on paved curved sections, increasing shoulder width, and improving curve alignments should be implemented, whenever warranted, to help reduce crashes on local and state highway rural roads.

Advanced warning signs for curves would help increase roadway drivers alertness. Shoulder and center rumble strips would alert inattentive or speeding drivers prior to departing the roadway and crossing the roadway centerline, respectively. Increasing shoulder widths would allow more time for drivers to recover if departing the traveled way before leaving the asphalt. Refining the alignment of curves improves the drivability of a road and decreases the potential for crashes. Combining these measures on all curve-downhill and curve-level state highway and local road sections should help reduce harmful crashes, as well as are a proactive step toward improving safety across Wyoming.

Apart from roadway departures crashes, the other main factors identified by the 2006 WSHSP that contribute to changes in crash severity are alcohol, safety restraints and speeding. By improving response by drivers in these categories, there will undoubtedly be a reduction in rollover crashes as well as the severity and number of crashes statewide. Two important factors that will affect driver behavior and aid in accomplishing this are the continued education of drivers and enforcement of laws.

The Wyoming legislature passed a speed limit law, lowering the speed limit to 55 mph on unpaved roads statewide effective July, 2011. In addition, WYDOT implemented recently a statewide sign program which will provide advance warning signs to high risk rural local roads statewide. While these changes alone may not be as effective as anticipated, the continuation of driver education programs and strict enforcement has the potential to effectively aid in reducing crash severity statewide in Wyoming.

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