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RESEARCH REPORT

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Centerline Rumble Strip Effectiveness

PERFORMANCE ANALYSIS OF CENTERLINE RUMBLE STRIPS IN WASHINGTON STATE

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16. ABSTRACT

With a goal of reducing collisions, WSDOT implemented policy for installing centerline rumble strips on undivided highways and invested in funding strategies for those installations in 2006. There have been some limited studies on the effectiveness of those installations, but a more complete study is appropriate.

Most of the previous analysis has been focused on the types of collisions that rumble strips were intended to reduce: specifically, centerline crossovers. Other collision types, such as run-off-the-road-to-the-right, have not been adequately explored previously to determine whether their frequencies have changed. The effectiveness of rumble strips on targeted collision types also needs to be reviewed to determine whether there are any site characteristics that influence effectiveness.

This study evaluates the effectiveness of centerline rumble strips under a variety of traffic and geometric conditions. The findings will result in better guidance on when to use rumble strips to address various collision types.

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EXECUTIVE SUMMARY

By 2004 WSDOT had installed roughly 100 miles of centerline rumble strips (CLRS) on an experimental basis as a countermeasure to reduce cross-centerline collisions. From 2004 through June 2010, WSDOT installed nearly 1,400 additional miles. Although these installations had been monitored, an in-depth study had not been undertaken to fully explore the effectiveness of CLRS in Washington State.

This study was undertaken to determine the effectiveness of CLRS in reducing cross-centerline collisions and to evaluate whether using this countermeasure increased the frequency of run-off-the-road-to-the-right (ROTRR) collisions. The study provided an opportunity to evaluate and, if necessary, modify the current design guidance regarding the use of this countermeasure.

The research team examined specific conditions and variables where CLRS were installed. These included, but were not limited to, traffic volumes, posted speed, lane and shoulder widths, tangent and curve conditions, and other geometric conditions in a before/after review.

The researchers reviewed 493.03 miles in 69 distinct segments of the state highway system where CLRS had been installed for at least 16 months. They studied collision records from 2002 through 2009. Although collision records prior to 2002 were available, they were not used for the detailed analysis due to limited data fields.

The collision dataset was filtered to those collisions that were most likely to be affected by the CLRS countermeasure. The primary focus was on collision events where the lane departure was not associated with an adverse weather condition (snow or ice), an intentional act (such as passing), a medical condition, or an equipment failure that lead to the collision. The researchers physically reviewed each collision record to confirm the dataset's accuracy and evaluate elements not captured in the electronic data.

The study analysis was organized to first look at individual conditions or attributes for the performance of CLRS, and then to study multiple conditions or attributes in attempts to identify the best use or placement of this countermeasure. Issues such as contributing circumstances, posted speed, curvilinear relationships, and others were studied.

Summary of Results

Roadway departure collisions are those where a vehicle leaves its lane of travel to either the left or right and results in a reported collision. The experience detailed in this study clearly shows that the installation of CLRS reduces these collisions regardless of whether the vehicle is crossing the centerline or the right edge stripe. In lane departure circumstances, CLRS are reducing collisions in All Injury Severities by 24.9% and reducing Fatal & Serious Injury collisions by 37.7% (see Table 5.4).

CLRS are not expected to reduce a collision type such as the ROTRR collision (for reasons explained herein). However, the experience in Washington State indicates that the installation of CLRS does reduce the frequency of ROTRR collisions.

When the research team narrowed the lane departure focus to only the ROTRR collisions, they found a 6.9% reduction in All Injury Severities and a reduction of 19.5% for Fatal & Serious Injury collisions (see Table 5.7). The researchers did not anticipate this result. While interesting to observe, the specific mechanics or factors involved were beyond the scope of this study.

The collisions primarily targeted by the CLRS countermeasure are cross-centerline crashes. The experience observed was a 44.6% reduction in All Injury Severities and a 48.6% reduction in Fatal & Serious Injury collisions (see Table 5.8).

The researchers evaluated CLRS performance in cross-centerline crashes by contributing category and found only a single category where there was an increase in collision rate: there was an 18.5% increase in the Fatal & Serious Injury rate for the Speed category. In all other categories, for both All Injury Severities and Fatal & Serious Injury collisions, the researchers observed a reduced collision rate. Reduction rates varied from a high of 75.3% for All Injury Severities in the Asleep/Fatigued category, to a low of 11.4% in All Injury Severities in the Under the Influence category (see Table 5.9).

CLRS performance across all ranges of posted speed limits in the study showed excellent results; no particular speed (or range of speeds) was found to have a negative effect in the reduction of cross-centerline collisions.

Horizontal alignment analysis yielded some interesting results. On the highways studied, CLRS were associated with a 59.0% reduction in cross-centerline collisions on tangents and 26.8% reduction in crashes associated with curves (see Table 5.11). Speed and

Under the Influence of Alcohol or Drugs were primary contributing categories on curved portions of the roadway where a fatal or serious injury occurred.

When reviewing the collision experience on the inside or outside of a curve, the researchers found a distinct difference in the rates. On the outside of a curve, CLRS reduced cross-centerline collisions by 29.5% for All Injury Severities and 36.8% for Fatal & Serious Injury collisions. On the inside of a curve, the performance improvement was slightly less: 22.9% for All Injury Severities and 34.4% for Fatal & Serious Injury collisions (see Figure 5.21). After the installation of CLRS, the Fatal & Serious Injury crash rate was found to be 2.560 (100 mvmt) for the outside of curves compared to 1.575 (100 mvmt) for the inside of curves (see Figure 5.21).

The researchers evaluated the influence of curvilinear alignments, looking at what percentage of a segment's total length was within the limits of a horizontal curve. This evaluation did not produce any notable findings except that the installation of CLRS consistently showed reductions in the collision rates throughout this analysis (see Table 5.12).

WSDOT plans to fund a noise study research project related to CLRS to help determine where CLRS can be installed with minimal adverse affects to nearby residences. This research will assist WSDOT with the further development of installation guidance.

Recommendations

As verified through this study, CLRS are an effective, low-cost, low-maintenance countermeasure that significantly reduces the frequency of collisions, regardless of lane/shoulder width, posted speed limit, or any of the other geometric conditions examined. There are slight increases or decreases in this countermeasure's effectiveness depending on the geometry of the roadway. However, these are minor differences, and they do not suggest that there are situations where this countermeasure should not be installed under the conditions evaluated in this study.

Based on the findings of this research, the researchers recommend that:

- WSDOT maintain its current guidance to reduce cross-centerline collisions.
- WSDOT continue with the installation of CLRS in accordance with current guidance.
- Investment priority be given to locations with AADT < 8,000, combined lane/ shoulder width of 12–17 feet, and posted speeds of 45–55 mph.

SECTION 1: OBJECTIVE / PROBLEM STATEMENT

In 2004 the Washington State Department of Transportation (WSDOT) conducted an evaluation of benefits anticipated from the implementation of an aggressive program to install centerline rumble strips (CLRS) as a countermeasure to reduce cross-centerline collisions. As a result of that initial evaluation, in 2006 WSDOT moved forward with rumble strips as an integral part of its safety program.

At the end of 2008, WSDOT had 878 miles of centerline rumble strips in place and elected to review the effectiveness of that investment to determine what safety benefits had been realized. Early efforts to evaluate crash records indicated that an additional year of data would allow for a substantially larger sampling of installations. While the analysis focused on reducing cross-centerline collisions, WSDOT also wanted to determine what other collision types might have been positively or negatively influenced by CLRS.

This study evaluates the impact of CLRS on targeted and nontargeted collisions on Washington's highways. The study compares collision experience before and after rumble strips were installed. The study attempts to isolate variables such as traffic volume, posted speed, roadway alignment, and lane/shoulder width combinations to determine where these investments have been the most (or least) effective. The findings will be used to make adjustments as appropriate in design policy and project prioritization.

SECTION 2: NARRATIVE SUMMARY

In Washington State, cross-centerline (crossover) and run-off-the-road (ROTR) collisions account for the majority of all fatal and serious injury collisions. As presented in the *Washington State Strategic Highway Safety Plan: Target Zero* (revised 2007), for the 2001–2005 period, cross-centerline collisions averaged 2,400 each year. While that amounts to only 2% of the total annual collisions, it accounts for 11% (351) of annual serious injury collisions and 21% (130) of annual fatal collisions. For the same period, ROTR collisions averaged 10% (12,593) of the total annual collisions, 41% (1,298) of all serious injury collisions, and 56% (159) of annual fatal collisions.

These lane departure collisions and the resulting injuries and fatalities are not unique to Washington State. They are linked to the majority of fatal and serious injury collisions across the nation. According to the Federal Highway Administration (FHWA), in 2008 alone there were 17,818 fatal roadway departure collisions, which resulted in 19,794 fatalities and made up 52% of all fatal collisions in the United States. A roadway departure crash is defined by FHWA as a nonintersection crash that occurs after a vehicle crosses an edge line or a centerline, or otherwise leaves the traveled way. FHWA uses the Fatal Analysis Reporting System (FARS) data for reporting roadway departure crashes: http://www.nhtsa.dot.gov/people/ncsa/fars.html

Centerline crossover and run-off-the-road collisions share a commonality: the driver failed to remain within the travel lane. In Washington State, there are roughly 5,500 miles of two-lane highways. Many of these roadways have narrow rights of way and contain trees, utility poles, fences, ditches, and many other objects that could be impacted by vehicles that leave the roadway. Vehicles that remain on the roadway, but drift across the centerline, are at risk of colliding with vehicles in the opposing lanes. In many cases, it is not feasible to remove or otherwise mitigate all the contributory factors. Rather, it makes sense to consider strategies aimed at keeping drivers on the roadway and in their lanes. Rumble strips are a common strategy for keeping drivers in their travel lanes.

Rumble strips are a pattern of depressions installed in the roadway where an errant vehicle would travel over them. When a vehicle's tire rolls over the depression, rumble strips transmit noise and vibration through the vehicle, thereby alerting the driver that the vehicle is leaving the travel lane. Rumble strips are considered particularly effective in alerting distracted, drowsy, or inattentive drivers.

In Washington State, rumble strips are usually milled into the roadway surface. They are installed on the centerline, on the shoulder outside the fog line, or in both locations. The installation of centerline and/or shoulder rumble strips is dependent upon roadway geometrics, lane and shoulder widths, and whether it is a rural or urban area, with consideration given to expected roadway users. Because they are designed to generate vibration through the vehicle, rumble strips impact the control of bicycles when traversed. Therefore, shoulder usage is a major factor in the consideration of shoulder rumble strips.

WSDOT first used rumble strips on the shoulders of the rural interstate system to reduce run-off-the-road (ROTR) collisions. Those rumble strip installations provided significant reductions in ROTR collisions. Similar trends were reported in other states. Those successes led WSDOT to investigate the possibility that rumble strips installed on the centerline would reduce the number of cross-centerline collisions.

The focus of this report is on the safety performance of centerline rumble strips (CLRS) and their impact on the cross-centerline type of collision. A future report is planned to review the effectiveness of shoulder rumble strips alone and centerline and shoulder rumble strips in combination.

WSDOT's first installation of CLRS was on State Route 522 near Maltby in 1995. The following year, a section on US 12 near Touchet was installed. These initial CLRS installations paved the way for WSDOT to study the effectiveness of these countermeasures in reducing the frequency and severity of crossover collisions.

Results on the performance of the initial US 12 installation were published in the June 20, 2004, edition of WSDOT's *Measures, Markers & Mileposts* (the *Gray Notebook*). The article reported that these installations showed an overall 52% reduction in crossover collisions for the 1996–1997 period. It is noteworthy that two different patterns were installed along this route for comparison purposes. This installation varied the pattern by changing the separation between the grooves from 1 to 2 feet. The 1-foot spacing pattern showed a greater reduction in cross-centerline collisions over the 2-foot spacing pattern (57% versus 47%). WSDOT later adopted the 1-foot spacing pattern as the standard dimension for CLRS installations.

In the fall of 2003, members of WSDOT's Highway Safety Issues Group (HSIG) were asked to develop a Benefit Cost (B/C) analysis of Washington's two-lane highway network to consider the implementation of a statewide CLRS program. The B/C analysis was based on a study by the Insurance Institute for Highway Safety (Persaud, 2003), which reported a 15% reduction in crossover collisions resulting in injury when CLRS were used. The Washington highway network was examined to determine the highest-B/C locations for installing CLRS. With the support of HSIG, the findings were presented to the Washington State Transportation Commission in July 2004. The Commission subsequently approved funding for a safety initiative to install CLRS. The initial effort targeted approximately 20% of the two-lane highway system. These investment decisions were supported by design policy and standards guidance in the WSDOT *Design Manual* and the *Standard Plans*.

The WSDOT *Design Manual* (Chapter 1600, June 2009) states:

1600.07(1)(c) Centerline Rumble Strips

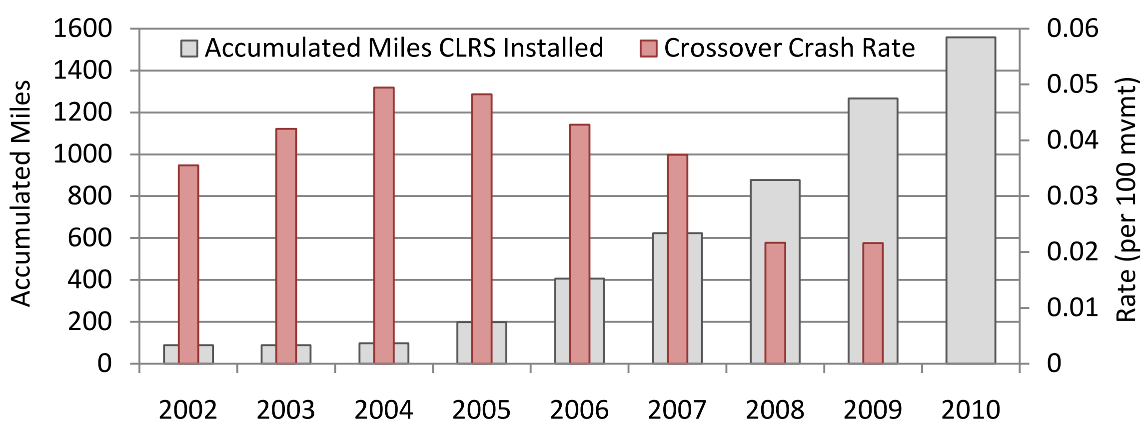
> Centerline rumble strips are placed on the centerline of undivided highways to alert drivers that they are entering the opposing lane. They are applied as a countermeasure for crossover collisions. Centerline rumble strips are installed with no differentiation between passing permitted and no passing areas. Refresh pavement markings when removed by centerline rumble strips.
>
> Drivers tend to move to the right to avoid driving on centerline rumble strips. Narrow lane and shoulder widths may lead to dropping a tire off the pavement when drivers have shifted their travel path. Centerline rumble strips are inappropriate when the combined lane and shoulder widths in each direction are less than twelve feet. (See Chapters 1130 and 1140 for guidance on lane and shoulder width.) Consider short sections of roadway that are below this width when they are added for route continuity.
>
> Apply the following criteria when evaluating the appropriateness of centerline rumble strips:
>
> - An engineering analysis indicates a crossover collision history with collisions considered correctable by centerline rumble strips. Review the collision history to determine the frequency of collisions with contributing circumstances such as inattention, apparently fatigued, apparently asleep, over the centerline, or on the wrong side of the road.
> - Centerline rumble strips are most appropriate on rural roads, but with special consideration may also be appropriate for urban roads. Some concerns specific to urban areas are noise in densely populated areas, the frequent need to interrupt the rumble strip pattern to accommodate left-turning vehicles, and a reduced effectiveness at lower speeds (35 mph and below).
> - Ensure the roadway pavement is structurally adequate to support milled rumble strips. Consult the Region Materials Engineer to verify pavement adequacies.
> - Centerline rumble strips are not appropriate where two-way left-turn lanes exist.

WSDOT's CLRS installation policy aligns well with WSDOT's *Strategic Highway Safety Plan (SHSP): Target Zero*. The SHSP provides a comprehensive framework of specific goals, objectives, and strategies for reducing traffic fatalities and serious injuries. The overall goal of the SHSP is a safe and efficient surface transportation system, with no deaths or serious injuries on state highways by 2030.

The SHSP outlines a specific goal of reducing the frequency and severity of run-off-the-road collisions and crossover collisions. It ranks these collision types as high priorities, directly behind program goals for collisions with the contributing categories of Speed and Under the Influence of Alcohol or Drugs.

From the initial installation in 1994 through June 2010, WSDOT installed over 1,500 miles of CLRS on the state's two-lane undivided highway system (see Figure 1.1).

Figure 1.1 Accumulated Miles CLRS Installed Per Year with Crossover Crash Rate



With numerous years of performance data and substantial miles installed, it is the appropriate time to conduct an in-depth performance evaluation of CLRS on Washington's highways. There are several questions about this safety feature that are integral to this research project:

- Which collision types and driver behaviors are most and least influenced by CLRS?
- Are there specific geometric conditions linked to the most- and least-effective CLRS installations?
- Are there any unanticipated safety consequences associated with WSDOT's installations of CLRS?
- Are policy adjustments needed to maximize the potential for success with CLRS?

The balance of this report attempts to answer these questions. The data gathered will serve as the basis for future investment decisions regarding centerline rumble strip usage on Washington State highways.

SECTION 3: PREVIOUS RESEARCH

Because rumble strips have been installed throughout the country and around the globe, there has been a great deal of research conducted on their usage and effectiveness. There is much diversity, not only in the rumble strips themselves, but also in their placement, the composition of host roadways, climate, driving culture, extent of use, and other factors. Rumble strips have been studied in various ways and at various sites, and although some data from Washington State has been used, there has not been a local, systemwide study.

This section presents a selective overview of existing research. It highlights recent studies, focusing on those that deal with operational issues as well as those that offer recommendations for further research.

1. NCHRP Synthesis 339 (Russell and Rys, 2005) is a comprehensive, detailed digest of CLRS information as of February 2005. Guided by a panel of experts, it summarizes current design practices, installation, configuration, dimensions, visibility, noise, pavement impact, and so on. According to the report, particular attention was paid to available before/after CLRS installation crash data to document the safety aspects of CLRS and the availability of policies, guidelines, warrants, and costs regarding their use and design. The sources include published and unpublished documents, survey results, administrator interviews, case studies, and lessons learned.

   Mentioned among the findings (quote):

   > Although the quality of the statistical analysis used in the studies that report crash reductions is, in most cases, unknown, a comprehensive study using reliable data available from seven states and state-of-the-art statistical methodology found that overall vehicle crashes were reduced by an estimated 15%, injury crashes by an estimated 15%, head-on and opposing-direction crashes by an estimated 21%, and head-on and opposing-direction sideswipe crashes involving injury by an estimated 25%. Available data were insufficient to make any conclusions about reductions in fatal crashes.
   >
   > Benefits beyond safety were also reported by some states.

   Mentioned among the conclusions (quote):

   > States and provinces with CLRS should continue to monitor the CLRS sections and expand their safety databases after CLRS installation.

For consistency within a state or agency, CLRS guidelines should be developed based on engineering judgment considering such things as traffic volume, numbers and/or rates of crossover crashes, roadway type, geometry and location, regional conditions, and experience.

The report's 72-page compendium prompts those conclusions; it documents the array of variations—dimensions, contexts, measures of effectiveness, etc.—characterizing the CLRS study.

Note: Duplicating the literature review contained in NCHRP Synthesis 339 would add little value to this report; however, the following studies either address later studies or present highlights of particular interest.

2. A recent research report (van Schalkwyk and Washington, 2008) prepared for WSDOT contains a chapter on CLRS performance on Washington State routes. The team selected 46.6 miles that had at least two years of data available in both phases, before and after CLRS treatment. The data were analyzed using three methodologies:

    (a) **Naïve Before-After Study** – Measured Collision Reduction Percentage and 95% Confidence Interval for Each Collision Type and Injury Category:

Collision Type*	Injury Category	Collision Reduction	Crash Reduction Confidence Interval**
All Types	All categories	15.1%	(-0.6%, 30.8%)
	Injury Collisions	18.5%	(-3.1%, 40.1%)
	PDO Collisions	12.7%	(-9.7%, 35.1%)
Crossover***	All categories	**42.9%**	(16.3%, 69.5%)
	Injury Collisions	**52.0%**	(24.2%, 79.8%)
	PDO Collisions	27.4%	(-25.4%, 80.2%)
Head-on	All categories	**55.6%**	(6.9%, 104.3%)
	Injury Collisions	**66.7%**	(26.9%, 106.4%)
	PDO Collisions	Sample sizes too small	
Nighttime	All categories	2.4%	(-24.5%, 29.3%)
	Injury Collisions	-7.2%	(-51.4% , 37%)
	PDO Collisions	10.6%	(-21.8%, 42.9%)
Opposite Direction****	All categories	39.4%	(-16.7%, 95.5%)
	Injury Collisions	**65.4%**	(28% , 102.8%)
	PDO Collisions	Sample sizes too small	
Sideswipe Opposite Direction	All categories	28.6%	(-55.3%, 112.5%)
	Injury Collisions	**76.2%**	(40.2%, 112.2%)
	PDO Collisions	Sample sizes too small	

Bold indicates collision reduction.
* Collision types only include non-intersection and non-intersection related collisions
** 95% Confidence Interval
*** Crossover collisions likely include collision types that cannot be addressed through CLRS
**** Opposite direction collisions include only head-on and sideswipe opposite direction collisions.

(b) **Before-After Study with Consideration of Changes in Traffic Volume** – Measured Collision Reduction Percentage and 95% Confidence Interval for Each Collision Type and Injury Category:

Collision Type*	Injury Category	Collision Reduction	Crash Reduction Confidence Interval**
All Types	All categories	23.9%	(-15.5%,63.2%)
	Injury Collisions	28.6%	(-17.7%,74.8%)
	PDO Collisions	24.6%	(-25%,74.1%)
Crossover***	All categories	**58.7%**	(18.9%,98.5%)
	Injury Collisions	**67.9%**	(33%,102.7%)
	PDO Collisions	**61.0%**	(16.4%,105.5%)
Head-on	All categories	**88.2%**	(71.1%,105.4%)
	Injury Collisions	**90.2%**	(72.4%,108%)
	PDO Collisions	Sample sizes too small	
Nighttime	All categories	18.7%	(-38.9%,76.2%)
	Injury Collisions	17.5%	(-54.3%,89.3%)
	PDO Collisions	31.1%	(-27.1%,89.4%)
Opposite Direction****	All categories	**81.2%**	(58.9%,103.4%)
	Injury Collisions	**88.7%**	(70.2%,107.3%)
	PDO Collisions	Sample sizes too small	
Sideswipe Opposite Direction	All categories	**90.6%**	(80.6%,100.5%)
	Injury Collisions	**96.9%**	(88.2%,105.6%)
	PDO Collisions	Sample sizes too small	

Bold indicates collision reduction.
* Collision types only include non-intersection and non-intersection related collisions
** 95% Confidence Interval
*** Crossover collisions likely include collision types that cannot be addressed through CLRS
**** Opposite direction collisions include only head-on and sideswipe opposite direction collisions.

(c) **Empirical Bayes Before-After Study** – Measured Collision Reduction Percentage and 95% Confidence Interval for Each Collision Type and Injury Category:

Collision Type	Injury Category	Crash Reduction	Crash reduction Confidence Interval (95% level)
All Collision Types	All categories	-12.68%	(-24.2%,-1.2%)
	Injury Collisions	-4.58%	(-18.3%,9.1%)
	PDO Collisions	-22.40%	(-37.8%,-7%)
Nighttime	All categories	-9.32%	(-22.9%,4.2%)
	Injury Collisions	-25.61%	(-48.7%,-2.5%)
	PDO Collisions	-52.02%	(-77.5%,-26.5%)

Mentioned among the findings (quote):

With the assumptions and limitations of the EB (Empirical Bayes) before and after study, results suggest that CLRS in the Eastern Region, on segments with a horizontal degree of curvature less than 7, and

> right shoulder widths wider than 5-ft is expected on average to increase: overall collision frequency, property damage only collisions, injury and property damage only nighttime collisions. It is important to point out that the short before-after periods and small sample sizes suggest caution in the use and application of these results.
>
> Results regarding the effect on overall injury collision frequency and nighttime collision frequency were inconclusive.

Mentioned among the recommendations for future research (quote):

> An extended before-after study of CLRS installations across a larger number of sites would be beneficial as sample sizes of the limited effort in this report suggests caution in terms of interpretation. The development of safety performance functions that incorporates roadside characteristics would be of particular benefit to this analysis and the evaluation of other safety investments on two-lane rural highways.

3. A Japanese study (Hirasawa, 2005) compared various types of crossover countermeasures, including CLRS. It compared CLRS of varying dimensions for sound, vibration, and driver perception, and evaluated a total of 69.5 miles (111.9 km) of existing CLRS installations, before and after per count, noting a 55.2% reduction in head-on crashes. Another stated measure of CLRS effectiveness was that the average vehicular lateral position was 8.5 inches (21.6 cm) closer to the shoulder when compared to centerline paint stripes alone: "The rumble strips were regarded as being effective in reducing head-on collisions because they kept vehicles at a proper distance from the centerline."

   There was no exploration on the effect of run-off-the-road-to-the-right collisions. The dimensions of the study's in-service CLRS are slightly shallower, 0.47 inches (12 mm), and wider, 13.77 inches (350 mm), than the WSDOT standard of 0.5 inches to 0.625 inches deep and 12 inches wide.

4. A Colorado study (Outcalt, 2001) examined CLRS effectiveness on a 17-mile segment of winding, mountainous highway, which is of interest to Washington with its many miles fitting that description. The strip dimensions are the same as WSDOT's, except no depth is given. This study compares 44 months of crash experience, before and after CLRS installation. Despite an 18% increase in average daily traffic (ADT), it reports a 34% decrease in head-on crash rate (per million vehicles) and a 36.5% decrease for sideswipe crashes. Outcalt also noted no accelerated deterioration of pavement in the five years observed after installation.

5. One study (Noyce, 2004) examined concerns about CLRS safety. Because rumble strips began service on shoulders, the study suggested that drivers' expectations might prompt them to correct their trajectory farther to the left. Using a driving simulator, 27% of the test subjects did initially steer in the wrong direction, but this improved with experience and exposure. Despite the possibility of a driver reacting improperly, the study concluded that the CLRS driver attentiveness gain still demonstrated their value in improving safety.

6. Partly in response to the Noyce study (above), a study in Texas (Miles, 2005) examined the operational effects of CLRS on passing, erratic movements, and lateral position. It noted little difference in passing opportunity, but there was an increase in centerline crossing time and a decrease in gap distance. No erratic movements were recorded, but the study did conclude that the majority of drivers shifted their vehicles' lateral position farther from the centerline. However, the segments under lateral placement scrutiny consisted of only raised buttons at 4-foot spacing for their centerline rumble treatment. The other subject rumbles were milled, 16 inches wide (laterally), and on 2-foot center spacing.

7. Another study (Porter, 2004), which pertained to traffic operations, focused on lateral vehicle placement and speed. It collected data using tape switches at 11- and 12-foot lane width sites, both untreated control, and with a continuous CLRS pattern of ≈ 7-inch ground pairs on 2-foot centers, 6-foot centers pair-to-pair, 18 inches wide (laterally). Findings indicated a significant effect on the mean and variance of vehicle path at both sites.

   On 12-foot lanes, there was a 0.46-foot shift away from centerline, and on 11-foot lanes, a 0.25-foot shift. At both widths, there was a decrease in the lateral position variance. The study cited research (Thompson, 1983) indicating a preference for paths nearer the center of the lane, but balanced that with references (FHWA, 2001; Forest Council, 1980) showing that a reduction in the variance of lateral placement may lead to lower accident rates. The Porter study admitted difficulty in drawing meaningful and accurate conclusions about mean speed and speed variance.

8. A Finnish study (Räsänen, 2005) compared vehicular lateral placement and speed before and after CLRS treatment on a horizontal curve segment of a rural two-lane, two-way undivided roadway. The dimensions of the rumbles approximated those in Washington but were slightly shallower and on 16-inch spacing. Treatment was

placed ≈ 500 feet in advance of a left-turning 1,500-foot-long curve with a 3,248-foot radius. With image-processed, field video recordings, the author concluded that the standard deviation in lateral distribution of passenger cars decreased by over 4 inches, centerline encroachments declined from 9.2% to 2.3%, and there was no change in mean speed after treatment.

9. A Minnesota study (Briese, 2006) investigated the operational effects of CLRS on speed, lateral placement, and centerline incursion. The observed rumble treatment pattern straddled the centerline stripe with a 2-inch buffer on each side; that is, parallel rumble strips 16 inches apart, inside edge to inside edge, 32 inches overall, outer edge to outer edge. The rumbles themselves were 8 inches wide (laterally), slightly shallower than Washington's, proceeding 12 inches on center. Field measurements were taken at sites before and after treatment.

   The study reported a 50% reduction in encroachment by vehicles on the inside of curves and a 76% reduction for outside curve traffic. The author stressed that the inside reduction is important because it is unlikely that those events were intentional, as opposed to the outside, where drivers often "cheat" the curve. The data elements suggest that CLRS had very little effect on travel speed or lateral placement at the study sites (lateral placement was not examined in curves). The author also analyzed the safety effectiveness of CLRS using data from 109 miles of treated versus 215 miles of untreated rural two-lane Minnesota highway. He first compared rates of all crash types and then those typically targeted by CLRS: head-on, opposite-direction sideswipe, and single-vehicle run-off-the-road-to-the-left. His findings as percent change in rate, presented here as "All (Target)" with CLRS, were:

   73% lower (13% higher) crash rate, fatal and serious (A) injury
   42% lower (43% lower) crash rate
   37% lower (37% lower) severity rate
   19% lower (20% lower) crash density
   16% higher (16% higher) ADT

10. Another exploration of operational effects (Spainhour, 2007), based on 579 Florida crash records, attempted to identify characteristics that have a strong positive association with overcorrection. It focused on fatal, run-off-the-road (ROR) crashes using logistic regression techniques and extended the traditional reliance on crash records to include case reviews using a broad variety of resources from various disciplines. It developed a full model involving 23 explanatory variables.

Mentioned among the findings (quote):

> …while fewer than 20% of fatal ROR crashes occurred where rumble strips were present, drivers were more than 50% more likely to overcorrect than when they were not present. On high-speed (70 mph) roadways with rumble strips, there was almost an 80% higher risk of overcorrection in the crash. Thus, while it appears that rumble strips are effective in preventing many ROR crashes, the contribution of auditory and vibratory sensations of rumble strips to panic oversteering should also be investigated.

The paper does not include enough detail to determine whether the rumble strips were CLRS, SRS, placed in parallel, or varied by crash location.

11. NCHRP Report 641 (Torbic, et al., 2009) provides guidance for the design and application of centerline and shoulder rumble strips by investigating their safety effectiveness on different types of roads; optimal placement; optimal dimensions necessary for effect with the least potential for adverse effects; and use in parallel. It explores CLRS effectiveness on curves versus tangents and on different roadway types—urban multilane undivided highways (nonfreeways), urban two-lane roads, rural multilane undivided highways (nonfreeways), and rural two-lane roads—using 2000–2005 data from Minnesota, Pennsylvania, and Washington State.

    The findings conclude (quote):

    > The most reliable and comprehensive estimates to date of the safety effectiveness of centerline rumble strips are for those installed on urban and rural two-lane roads [with their associated standard errors (SE)]:
    >
    > **Urban Two-Lane Roads**
    >
    > Centerline rumble strips (based on results from this research):
    >
    > 40 percent reduction in total (TOT) target crashes (SE = 17) and
    > 64 percent reduction in FI [fatality and injury] target crashes (SE = 27).
    >
    > **Rural Two-Lane Roads**
    >
    > Centerline rumble strips [based on combined results from this research and Persaud et al. (4)]:
    >
    > 9 percent reduction in TOT crashes (SE = 2),
    > 12 percent reduction in FI crashes (SE = 3),
    > 30 percent reduction in TOT target crashes (SE = 5), and
    > 44 percent reduction in FI target crashes (SE = 6) (based on results from this research).

Limited mileage of centerline rumble strips along urban multilane undivided highways (nonfreeways) and rural multilane undivided highways (nonfreeways) prohibited formal evaluation of the safety effectiveness of this treatment along these respective roadway types.

The safety benefits of centerline rumble strips on horizontal curves and tangents, based on TOT target crashes, are remarkably similar, with estimated 47 percent and 49 percent reductions in TOT target crashes, respectively. This result would indicate that the safety effectiveness of centerline rumble strips is, for practical purposes, the same for both curved and tangent alignments.

The target crashes above are head-on and opposite-direction sideswipe crashes. Minnesota and Pennsylvania use 16-inch-wide (laterally) CLRS.

NCHRP Report 641 also examined the least level of stimuli required to alert an inattentive or drowsy driver, with equations provided for determining rumble strip dimensions for a range of operating conditions. It recommends a strip pattern that produces a sound level difference within the passenger compartment in the range of 10 to 15 dBA on typical rural roadways, and 6 to 12 dBA near residential or urban areas. (The WSDOT standard CLRS perform in the upper range based upon the given noise prediction model.)

The report's authors surveyed numerous relevant agencies for their current application and design criteria. They included a summary of the most common practices. (WSDOT's policies and guidance are typical of most of the agencies that responded and do not conflict with any guidance offered in the report.) The report does not verify the safety effects of the variables involving ADT, roadway width, or posted speed limit.

Published mid-2009, with an extensive literature review similar to NCHRP Synthesis 339, NCHRP Report 641 summarizes in greater detail most of the research cited above, as well as many other studies.

SECTION 4: METHODOLOGY / STUDY DESIGN / DATA VALIDATION

Centerline Rumble Strip Locations

For this study, the WSDOT research team reviewed construction contract information to determine where rumble strips have been placed on Washington's highways. The researchers used the Construction Contract Information System (CCIS) application to determine which construction projects included bid items for centerline rumble strips. They then reviewed the contract plans to determine milepost limits where rumble strips were planned or installed. For completed projects, the team used "As-built" plans, and for work underway or planned, they reviewed the original contract plans to obtain this information. The SRWeb tool (highway video log) was used as necessary to resolve questions arising from plan reviews or in collision-matching with rumble strip locations.

The CCIS application provided contract progress dates that allowed the researchers to determine the before and after periods for evaluation of each location where rumble strips were installed. The performance evaluation compared collision experience in the period before centerline rumble strips were installed against the collision experience after rumble strips were installed. The project's "work started" date was used as the closing date for the before evaluation period. The project's "physically complete" date was used as the beginning date of the after evaluation period. The researchers generally ignored collisions that may have occurred between those two dates to ensure traffic patterns influenced by construction activities did not skew the performance results.

The research team assembled these data elements in a rumble strip locations list. The resultant list was used to determine which collisions to focus on during the evaluation. This list provided route milepost locations and dates to guide the team's review of the collision history for each highway segment analyzed in the study.

As of June 2010, there were roughly 315 CLRS segments installed in Washington State, totaling almost 1,500 miles, with an additional 390 miles under contract for installation. The 315 segments were screened to identify those that had sufficient in-service time to produce a meaningful evaluation of collision experience in the period after CLRS were installed. Of the 315 segments, 69 had before and after periods that exceeded 16 months. The team used this minimum-length-of-time condition to determine whether a segment would be included in the analysis. These 69 segments represent 493.03 miles of highway with centerline rumble strips.

For this study, segments along the same state route were considered to be continuous if individual segments were separated by less than 1/10 of a mile. If centerline rumble strips were discontinued for a distance of a 1/10 of a mile or greater, a new segment was defined. In some cases, segment breaks were also defined based on rural/urban functional class changes or jurisdictional changes. While these breaks may exceed 1/10 of a mile, further examination of some of these segments indicates that they were, in effect, a continuous corridor. As a result, in some analyses, these continuous segments may have been analyzed as a single segment rather than the individual components. The researchers analyzed and reported CLRS performance for the entire length of the combined segments.

Over time, multiple contracts may have installed CLRS along the same route. Gaps in time were treated similarly to the gaps in distance, in that separate segments were created to reflect the differing time periods. In some cases, roadway preservation such as repaving of a route may have removed CLRS, added shoulder rumble strips, or replaced CLRS over longer bounds of the previous installation. These cases also led to the creation of discrete segments.

Tables 4.1 and 4.2 reflect the segment length and percentage of miles, the WSDOT regions where they are located, and the corridor lengths for the 69 segments studied.

Table 4.1 Segment Length Distribution

Length Range (Miles)	Segment Count	Sum of Miles	% of Total Miles
Less than 1	8	4.32	0.9%
1 to 5	30	77.98	15.8%
5 to 10	15	115.05	23.3%
10 to 20	10	141.21	28.6%
Greater than 20	6	154.47	31.3%
Total	69	493.03	100%

Table 4.2 Region Length Distribution

WSDOT Region	Segment Count	Sum of Miles	% of Total Miles
1 – Northwest	10	6.28	12.4%
2 – North Central	19	127.07	34.9%
3 – Olympic	22	105.97	21.5%
4 – Southwest	0	0	0%
5 – South Central	6	88.57	18.0%
6 – Eastern	12	65.14	13.2%
Total	69	493.03	100%

Collision Methodology and Targeting

The research team retrieved the collision data records from the Collision Branch of WSDOT's Statewide Travel and Collision Data Office (STCDO). The collision data used for the analysis covers the period from January 1, 1993, through December 31, 2009, with special emphasis on those collision records from 2002–2009. Collisions in this dataset are those Police Traffic Collision Report records that are stored electronically and offer opportunities for a detailed review by analysts. For the earlier years, the Police Traffic Collision Reports have been purged, and limited data fields are available in electronic summaries only. Due to this limited data in the pre-2002 records, there is little detailed analysis reported for the entire 1994–2002 period.

The 2002–2009 collision records retrieved from the STCDO are an electronic coded summary of the circumstances of each Police Traffic Collision Report completed by the investigating law enforcement officer. These records contain detailed information on the circumstances and conditions of the collision. Examples of the data fields collected are: weather conditions, roadway type or character, contributing circumstances, injuries, and collision location. In addition to these data fields, there is additional information contained in the Police Traffic Collision Report that is not contained within the structure of the current coded electronic summary of the collision by the STCDO.

Collision records for all state highways (approximately 733,000) from the 1993–2009 period were downloaded from the STCDO. These were then filtered to all collisions that were located within the limits of the CLRS segments chosen for the study. This filtered set of collisions was further reduced to roadway departure-type collisions, which were likely to be influenced by the presence of CLRS.

In this study, the collisions reviewed by the research team were initially filtered or targeted similarly as those reported in WSDOT research report WA-RD695.1, "Cost Effective Safety Improvements on Two-Lane Rural State Roads in Washington State," Ida van Schalkwyk & Simon Washington, April, 2008. Cross-centerline collisions in that study were defined as "any cross-centerline (crossover) crash that begins with a vehicle encroaching on the opposing lane." This definition further clarified that cross-centerline crashes excluded "any crash that began by running off the road to the right and overcorrecting, and any crash that began by a vehicle going out of control due to water, ice, snow, etc., prior to crossing the centerline."

The influence and performance of CLRS in differing weather conditions was an area of interest to the research team. In the van Schalkwyk and Washington report, those crashes where inclement weather may have had an influence were excluded from the performance reporting. In this analysis, the researchers physically reviewed each collision record and identified the collisions that would have been excluded under the van Schalkwyk definition. Weather-related collisions were included in the initial phases of the analysis and reporting, but they were later screened out as the focus shifted to isolating variables that were directly influencing crash rates.

In targeting the collisions to use in this study, there were instances where the research team elected to exclude collisions from the study set. Those collisions that were excluded fit at least one of the following conditions or circumstances: intentional acts, medically caused, law enforcement activities, avoidance maneuvers, defective equipment, and intersection- or driveway junction-related collisions. Because the researchers were unable to supplement the data available for the pre-2002 collision records with information from the Police Traffic Collision Reports, it was not possible to validate how many of the collisions from that period met the targeted conditions. This led the team to exclude those records from further review.

Rumble strips were not anticipated to influence collisions in circumstances where the driver intentionally crossed the centerline. The determination of whether a crash had an intentional crossing of the centerline came from the researchers' review of the Police Traffic Collision Report. The team flagged those collisions where there was an intentional circumstance or act by the driver with a code for exclusion in the final dataset.

The specific intentional acts the researchers looked for in the collision record reviews were: passing another vehicle (passing defined as crossing the centerline to overtake); avoiding an object, animal, or another vehicle in the roadway; fleeing from law enforcement; a medical condition-caused collision; or operating defective equipment. In each of those situations, the installation of CLRS was not believed to have influenced the frequency or severity of those collision types; therefore, those collisions were excluded from the dataset for any further review in this analysis.

Junction-related collision types are a result of a vehicle making a turning movement onto or off of a state highway, a circumstance that CLRS would not be expected to influence. Those collisions were therefore excluded from the dataset for any further analysis.

The specific types of collisions that CLRS are expected to have the greatest influence on are those where the driver inadvertently departs the lane of travel and enters the opposing traffic lane. These are head-on, opposite-direction side-swipe, and run-off-the-road-to-the-left collisions. The research team excluded other collision types such as rear-end (moving or stopped), turning left/right, and same-direction side-swipe collisions from the dataset because CLRS are not believed to offer any benefit in those circumstances.

In analyzing behavioral characteristics, the researchers considered omitting from the dataset collisions where Over Centerline was coded as a contributing category, as this notation is more of a reference to position on the roadway rather than a factor contributing to the collision. However, those collisions represented almost 13% of the total and were a substantial portion of the overall dataset. As such, they were ultimately included in the analysis. During the analysis, it appeared to the team that there was an overuse of this code by the investigating officers.

In exploring the possibility of CLRS increasing the frequency of run-off-the-road-to-the-right (ROTRR) collisions, the researchers allowed those lane departure collisions that occurred off the roadway to the right to remain in the dataset.

As a result of the research team’s approach for qualifying collision data for further study, they included roughly 8,000 records in the collision analysis.

Collision Analysis

The researchers anticipated that a physical review of the collisions would offer opportunities to evaluate whether a relationship exists in Washington State between rumble strips and driver overcorrection lane departures. In their review of the collision reports, the team identified driver actions that were later labeled “initial actions.” While these were not the *definitive* “initial actions” preceding a collision, this information provided the team opportunities to evaluate the influence of rumble strips on specific driver actions preceding a collision.

In each Police Traffic Collision Report, the information found in the investigating officer’s narrative and drawing provided a significant amount of detail about the circumstances and location in which the collision took place. In order to collect and analyze this additional information, it was necessary for the researchers to review each report. They did so by electronically retrieving the record and recording the additional information in the analysis.

During the course of this study, multiple reviewers examined approximately 8,000 collision reports. This required a large investment in time, and it significantly enhanced the strength of the data and the resulting analysis reported herein.

In this physical review of the collision records, four primary areas (data elements) were reviewed to extract additional information: initial driver actions, weather, curve relationship, and/or additional impact location(s).

In analyzing the initial actions, the research team found two general situations, which were assigned the following unique alpha codes. Both cases involved vehicles departing from their lane of travel prior to overcorrecting back across the lane, ultimately resulting in a collision on the opposite side of the lane from the original departure direction.

- An alpha code of **RX** identifies a collision where the driver first left the roadway to the right and then overcorrected back to the *left*, resulting in a collision across the centerline.
- An alpha code of **XO** identifies a collision where the driver crossed the centerline and overcorrected back to the *right*, resulting in a collision off the roadway to the right.

The research team identified RX- and XO-coded collisions primarily from the collision diagram on the Police Traffic Collision Report. If the diagram illustrated a vehicle leaving its lane of travel as described for the conditions of either RX or XO, the record was coded with the respective initial action. While this approach does provide some insight, those collisions identified as being RX or XO are not believed to cover the entirety of the overcorrection collisions. There are instances where the officer did not adequately describe the event or was not able to determine that the vehicle left its lane of travel. Collisions identified as a RX or XO were collected with the expectation that they would be a large enough sample from which to draw some conclusions regarding those initial action experiences after the installation of CLRS.

Weather-related collisions are defined in the collision reports as those where there was a weather condition at the time of the collision that would likely result in loss of traction. Records flagged for weather included one or more of the following conditions: where roadway surface conditions were noted to be snow, slush, ice, or standing water;

or where weather conditions at the time of the collision were found to be snow, sleet, hail, or freezing rain. To assess the overall effectiveness of CLRS, the researchers included weather-related collisions in some of the initial analysis. However, in an attempt to isolate the performance of CLRS from extreme weather conditions, weather-related collisions were filtered out of the data for much of the analysis.

Roadway Geometry

The influence of roadway geometry on CLRS performance was also an area of interest to the researchers. In particular, they had an interest in comparing performance on horizontal curves with tangent segments of highway. Comparing the effectiveness of the CLRS between curve and tangent portions of the roadway required the research team to identify those collisions where a curve may have influenced the collisions. They matched the collision dataset to the geometric database to identify those crashes that occurred within the bounds of a curve. However, this only identified those collisions that actually occurred within the limits of a horizontal curve, and did not identify those collisions where a curve may have had an influence on the driver's actions or control in following the roadway.

During the review of the Police Traffic Collision Reports, the research team identified instances where the collision occurred just prior to or just following a horizontal curve. This allowed the team to analyze collisions such as traveling too fast through a curve, losing control and crashing just beyond the curve, or "straightening out" in a curve and driving off the roadway. In these cases, a simple comparison of the collision mileposts with the horizontal curve mileposts would not suggest that curvature had any influence on the collision. During the data review process, collision data records were flagged with a "curve location key" identification code for use in later analysis.

The researchers assigned each curve on the state highway system a unique identifier (key) consisting of the state route number and state route milepost value at the beginning point of curvature. This key was used to extract additional information regarding the geometrics of any curve, such as length or radii. It also allowed the researchers to identify curves along a route that may have experienced unusual numbers of lane departure collisions. Any collision record linked to a curve identifier indicates that the crash may have been influenced by that curve.

In evaluating cross-centerline collision experience on curves, the researchers had an interest in evaluating whether curve direction had a significant influence on vehicles crossing the centerline or running off the road to the right. However, the direction of vehicle travel and the direction of a curve listed in the collision record led to confusion in making this determination. In the geometric data, curve direction is normally described as to the left or to the right, based on the increasing milepost direction of the state route. From a driver's perspective, a curve to the right in one direction is a curve to the left in the opposite direction. Consequently, relating to the curve direction as recorded in the Highway Log geometric dataset may contradict a driver's perspective. Using the descriptors of inside or outside a curve, coupled with the direction of the errant vehicle, offers a more meaningful perspective. This approach associates curvature to the perspective of the driver, regardless of whether the vehicle is traveling in the increasing or decreasing milepost direction. For a curve to the right, a departure to the left is classified as outside the curve and a departure to the right is classified as inside the curve. It is this inside and outside perspective that is used in this analysis.

In addition to an analysis of performance related to specific curves, the research team also evaluated whether more curvilinear alignments exhibited performance that differed from straighter alignments. To do this, they identified the percentage of curvature by computing the total length of curves within a segment and dividing that total by the overall length of the segment. (This approach does not have relationship to the radius or "tightness" of the curvature.) A segment with a series of long, gentle curves through the segment had a greater curve percentage over another segment that had a number of short-length, tight-radii curves. Missing curve information prevented the research team from analyzing the influence of specific curve radii.

The STCDO's Roadway Branch reported the roadway and shoulder width data elements used in the study. Using these data, the researchers encountered some limitations in defining lengths of roadway and shoulder widths. (It was rare that the entire length of any specific roadway segment used in the study was of consistent widths in the travel lanes and shoulders. These dimensions may have changed for a number of reasons.) When analyzing linkages between roadway widths and rumble strip performance, the researchers used the width values for the specific crash location. Roadway and shoulder width values are available every 1/100 of a mile in the WSDOT Roadway DataMart; it is this specific set of values used in the analysis.

Rates

To develop a uniform comparison of collision experience between segments of CLRS installed across the state, performance is expressed as a crash rate per million vehicle miles traveled (VMT). Because of the small count of collisions, a rate per 100 million VMT is used with fatal and serious injury collisions. This approach also accounts for changes in crash experience that may be associated with traffic growth (or reduction). Performance increases or decreases between the before and after periods or between individual segments are reported as change in rate in most cases; that is, the after period value is subtracted from the before period value. In some cases, percentage differences between the collision rates are reported.

The VMT is calculated as a weighted average for each segment. The VMT for individual segments does account for changes in traffic volume over time, spanning the period from 1993 to 2008. However, as previously discussed, the collisions analyzed are from the 2002–2009 period. The specific annual average daily traffic (AADT) counts used for segments originated from the STCDO's Highway Usage Branch, primarily from the Annual Traffic Report (ATR). In some cases, more specific information for a segment was sourced from the Highway Usage Branch, as the ATR did not report AADT for locations within the bounds of a specific CLRS segment.

In some reporting, an AADT is presented for the segments. It was calculated by using the reported or researched average daily traffic (ADT) volumes for a specific year. The ADT was then multiplied by the number of days of that specific year for the segment's before and after periods as required. For multiple years, each year was calculated and then summed. This sum was then divided by the total number of days for the entire period to result in the reported AADT. This value allows for comparison of segments that may have differing temporal periods or lengths, or may be used to categorize segments into similar AADT categories. The weighted VMTs or AADTs used in this analysis are only specific to this analysis and should not be assumed to be valid for other uses or analyses.

SECTION 5: FINDINGS

The following results reflect the performance of the 69 highway segments studied, which represent 493 miles. The dataset of 2002–2009 cross-centerline collisions excludes crashes where an intentional crossing of the centerline was identified, as well as crashes caused by a medical condition, an avoidance maneuver, or police intervention or pursuit. Rates are expressed as crashes per million vehicle miles traveled (mvmt) for all injury severities except for Fatal & Serious Injury rates, which are expressed as crashes per 100 mvmt.

To fully understand the impact that centerline rumble strips (CLRS) have on collision experience, the researchers looked for intended and unintended outcomes that may have been influenced by the presence of CLRS. While they targeted cross-centerline collisions for reduction with the application of CLRS, the team also analyzed run-off-the-road-to-the-right (ROTRR) collisions to evaluate whether drivers may have shied away from the CLRS and run off the road, or may have overcorrected after contacting the CLRS. This study collectively defines cross-centerline and ROTRR crashes as "lane departure collisions."

The research team's process in reporting these findings begins with a broad view, incorporating all conditions, collision types, and data elements. The focus then narrows to a specific collision type: cross-centerline collisions and specific component elements or attributes of the dataset.

Incorporating weather-related collisions in the data was problematic. Weather conditions can have an impact on collisions, and they are real-world conditions that cannot be avoided. However, severe weather conditions can have an impact on the ability of CLRS to perform as designed. For example, in certain conditions the rumbles may become filled with compact snow or ice to the point where a driver may not be aware of encountering CLRS. In another case, a driver may lose physical control of a vehicle due to weather or roadway conditions, regardless of being aware of rolling over CLRS, and be unable to regain control before leaving the lane of travel. Conversely, in other conditions such as fresh snow where pavement markings are no longer visible, the rumble strip may still achieve the desired outcome of alerting drivers when they depart from the designated travel lane. Even with the detailed physical review of the collision records by the researchers, there was not enough detail to identify those specific collisions where severe weather conditions directly affected the CLRS performance.

The broadest view in the report is that of all lane departure collisions, including those that may have been influenced by weather conditions. Findings from that analysis are reflected in Table 5.1. For all lane departure collisions, the installation of CLRS resulted in a 20.4% reduction for All Injury Severities and a 30.9% reduction in Fatal & Serious Injury collisions.

Table 5.1 Lane Departure (Weather Inclusive)

Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.534	0.425	0.109	-20.4%
Fatal & Serious Injury	4.738*	3.274*	1.464	-30.9%
Evident Injury	0.122	0.082	0.040	-32.8%
Possible Injury	0.082	0.076	0.006	-7.4%
No Injury	0.258	0.227	0.031	-12.0%
Unknown	0.024	0.007	0.017	-70.6%

Most severe injury of crash (one per crash) *per 100 mvmt

Collisions where a vehicle left the roadway to the right (ROTRR) were not a collision type CLRS were expected effect positively. The researchers wanted to assess whether CLRS might have influenced an increase in the number of ROTRR collisions by drivers "shying" away from the centerline, thereby effectively reducing their lane width and response time. The results in Table 5.2 indicate that this is not the case. There is a reduction 7.6% in All Injury Severities and a 17.1% reduction in Fatal & Serious Injury collisions after installing CLRS.

Table 5.2 ROTRR (Weather Inclusive)

Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.269	0.248	0.021	-7.6%
Fatal & Serious Injury	1.697*	1.407*	0.290	-17.1%
Evident Injury	0.058	0.047	0.011	-18.7%
Possible Injury	0.041	0.042	-0.001	1.1%
No Injury	0.140	0.139	0.001	-0.3%
Unknown	0.013	0.006	0.007	-52.8%

Most severe injury of crash (one per crash) *per 100 mvmt

Cross-centerline collisions are the collision type that CLRS are specifically targeting for reduction. As shown in Table 5.3, the researchers saw a 33.4% reduction in All Injury Severities and a 38.6% reduction in Fatal & Serious Injury collisions for this collision type.

Table 5.3 Crossover (Weather Inclusive)

Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.265	0.177	0.089	-33.4%
Fatal & Serious Injury	3.041	1.867	1.174	-38.6%
Evident Injury	0.064	0.035	0.029	-45.5%
Possible Injury	0.041	0.034	0.007	-15.9%
No Injury	0.118	0.087	0.0306	-25.9%
Unknown	0.012	0.001	0.0105	-90.2%

Most severe injury of crash (one per crash) *per 100 mvmt

This analysis reveals that regardless of the influence of adverse weather conditions, CLRS placement resulted in reductions in centerline crossover collisions. More modest reductions were observed in ROTRR collisions.

In an attempt to better quantify the performance of CLRS, the researchers chose to exclude those weather-related collisions from further analysis. While weather conditions are real-world conditions, the research team concluded that the variables associated with those conditions would make a specific performance analysis less accurate. Unless otherwise stated, subsequent data analysis presented in this study excludes collisions flagged for adverse weather conditions.

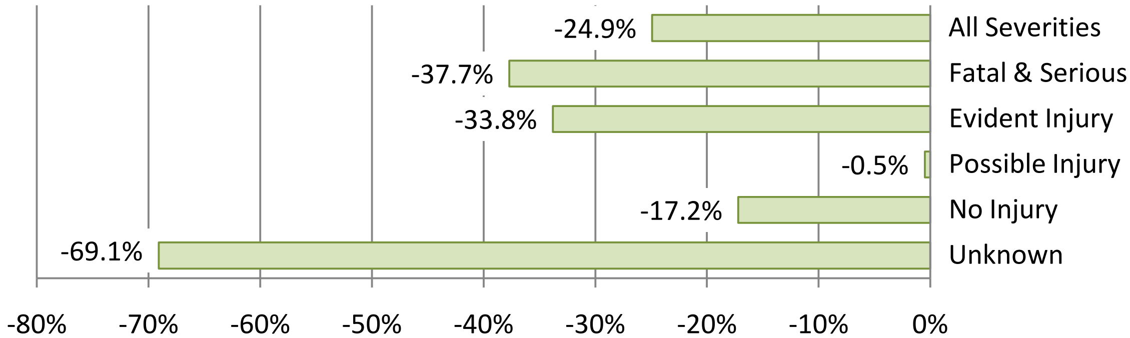
After removing collisions that may have been influenced by weather conditions, the research team found that the frequency and severity of lane departure collisions declined substantially after CLRS were installed (see Table 5.4 and Figure 5.1).

Table 5.4 Lane Departure Crashes: Before and After Rates

Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.318	0.239	0.079	-24.9%
Fatal & Serious Injury	4.011*	2.499*	1.512	-37.7%
Evident Injury	0.085	0.056	0.029	-33.8%
Possible Injury	0.045	0.045	0.000	-0.50%
No Injury	0.129	0.107	0.022	-17.2%
Unknown	0.018	0.006	0.012	-69.1%

Most severe injury of crash (one per crash) *per 100 mvmt

Figure 5.1 Lane Departure Crashes: % Reduction in Injury Severity Rate



Lane Departure Crashes: Contributing Circumstances

Centerline rumble strips target certain contributing circumstances associated with cross-centerline crashes. Targeted contributing circumstances are primarily those where a driver is inattentive, distracted, fatigued, or asleep. It is in these specific circumstances that CLRS are thought to be the most effective in reducing the severity and frequency of collisions.

An investigating officer can select from a list of 44 contributing circumstances and may identify up to 3 circumstances believed to have contributed to the crash. Within this study, the researchers aggregated these 44 choices into 7 categories: Asleep/Fatigued (A/F), Inattentive/Distracted (I/D), Under the Influence of Alcohol or Drugs (UI), Speed, Over Centerline (OCL), Other, and None. Because a single collision report may identify as many as three contributing circumstances, the count of contributing circumstances studied exceeds the number of collisions evaluated.

The contributing category "Other" merits some explanation. An officer selecting this category is directed to describe the specific circumstances in the collision report's narrative. Driver actions prompting an officer to select "Other" are not easily categorized and require a textual description. For this analysis, 19 separate contributing circumstances (see Table 5.5) are combined to report results. Of these 19, many crashes have been excluded from the data for reasons previously described. For example, if the officer identified "improper passing," that collision would be excluded from the dataset, because all intentional crossings of the centerline (passing) have been excluded. In some cases, the contributing circumstance (such as "improper backing") is not a collision type that would be associated with a targeted lane departure crash.

Table 5.5 Contributing Category "Other" Components

Other	Headlight Violation
Did Not Grant RW to Vehicle	Improper Backing
Disregard Stop and Go Light	Improper Parking Location
Disregard Stop Sign – Flashing Red	Improper Signal
Disregard Yield Sign – Flashing Yellow	Improper Passing
Disregard Flagger – Officer	Improper Turn
Fail to Yield Row to Pedestrian	Improper U-Turn
Failing to Signal	Operating Defective Equipment
Failure to Use Xwalk	Driver Not Distracted
Follow Too Closely	

The specific contributing circumstance selections that make up each of the other contributing categories used in this analysis are listed in Appendix A.

Another contributing category that warrants explanation is "Over Centerline" (OCL). This is more a description of a vehicle's position on the roadway than a true contributing circumstance; however, investigating officers frequently select this code in cross-centerline collisions. While a cross-centerline collision cannot occur without being over the centerline, the OCL code offers no meaningful insight into issues of driver behavior. The OCL code is so frequently used that the researchers determined that omitting these collisions from the data was an unacceptable option.

Collisions where OCL was coded as a contributing category saw a 53% reduction in the rate of all collisions and a 56% reduction in Fatal & Serious Injury crashes after CLRS were installed. However, it is not clear what specific conditions, actions, or causes were mitigated for the OCL condition.

After CLRS were installed, lane departure collisions on Washington State highways were effectively reduced in almost all circumstances. Table 5.6 illustrates the effect of CLRS on the various contributing circumstances associated with lane departure collisions in the study. The values presented in parentheses () are Fatal & Serious Injury rates, which are expressed as crashes per 100 mvmt. Rates for all other injury severities are expressed as crashes per mvmt.

Table 5.6 Lane Departure Crash Rates by Contributing Category

Contributing Category	Before Rate	After Rate	Difference	% Change
Asleep/Fatigued (A/F)	0.084 (0.881)	0.049 (0.431)	0.035 (0.451)	-41.0% (-51.1%)
Inattentive/Distracted (I/D)	0.052 (0.463)	0.052 (0.345)	0.000 (0.118)	0.4% (-25.5%)
Under the Influence (UI)	0.059 (1.124)	0.055 (0.689)	0.004 (0.435)	-7.3% (-38.7%)
Speed	0.091 (0.881)	0.065 (0.804)	0.025 (0.077)	-27.7% (-8.8%)
Over Centerline (OCL)	0.052 (1.763)	0.024 (0.775)	0.028 (0.988)	-53.8% (-56.0%)
Other	0.030 (0.154)	0.034 (0.287)	-0.004 (-0.133)	11.4% (86.0%)
None	0.006 (0.000)	0.002 (0.000)	0.004 (0.000)	-62.8% (0.0%)

See Appendix A Fatal & Serious Injury results in () with rate per 100 mvmt

The percentage change of contributing circumstances is favorable throughout All Injury Severities for all lane departure crashes (see Figure 5.2). In all collisions, the researchers observed a modest increase in the Inattentive/Distracted category. When considering only the Fatal & Serious Injury crashes, all but one of the contributing circumstance categories showed a favorable trend in reducing Fatal & Serious Injury crashes. There was an increase observed in the catchall category "Other."

For all lane departure collisions, there are a total of 256 collisions where "Other" is the primary contributing category. Of these, 141 are in the before period and 115 are in the after period. For Fatal and Serious Injury collisions in the "Other" category, the researchers found a total of 17 events: 6 in the before period and 11 in the after period. They concluded that collisions within the "Other" category are somewhat unique events and are generally associated with crash circumstances that may not be correctable by rumble strips. In examining the actions listed in Table 5.5, it is clear that rumble strips are not an effective countermeasure to address a defective piece of equipment on a vehicle, an improper U-turn, or the other causes an officer may select that fall within this category.

Figure 5.2 Lane Departure: % Change by Contributing Category: All Injury Severities

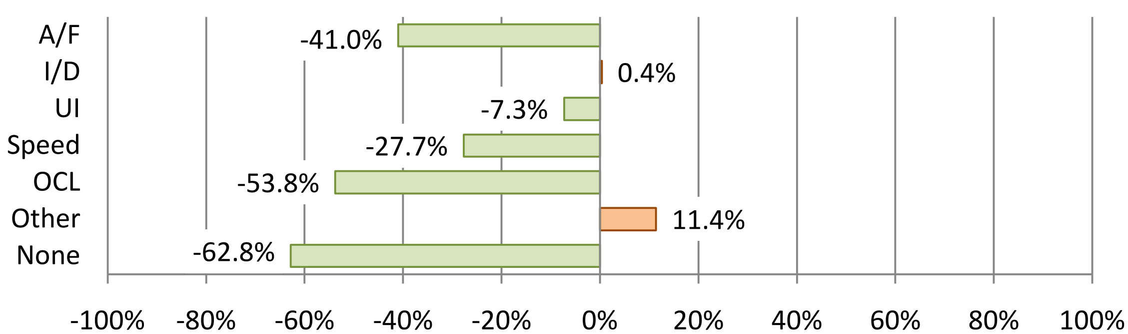


Figure 5.3 Lane Departure: % Change by Contributing Category: Fatal & Serious Injury

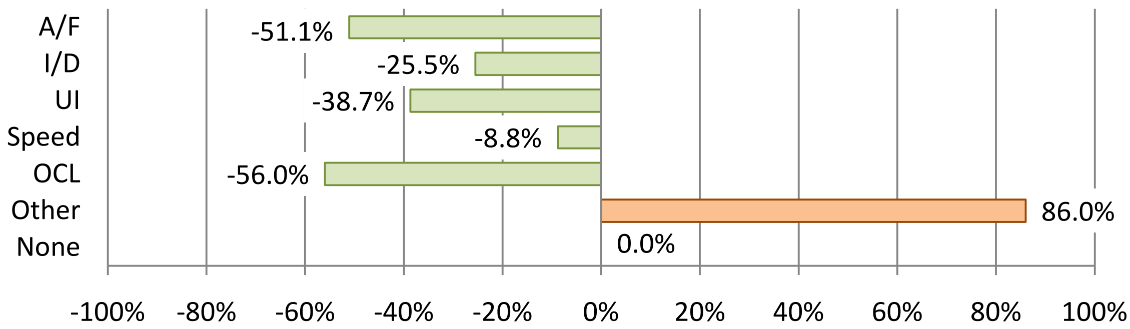
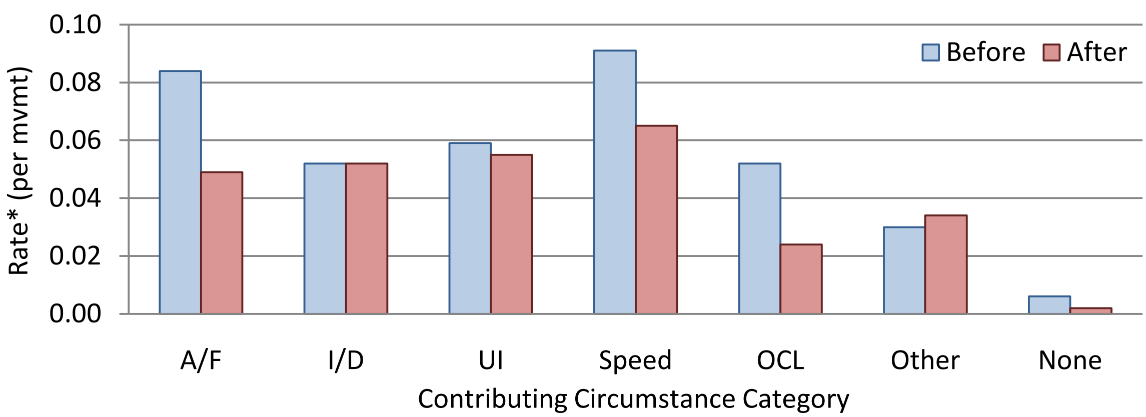


Figure 5.4 Lane Departure Rates by Contributing Category: All Injury Severities

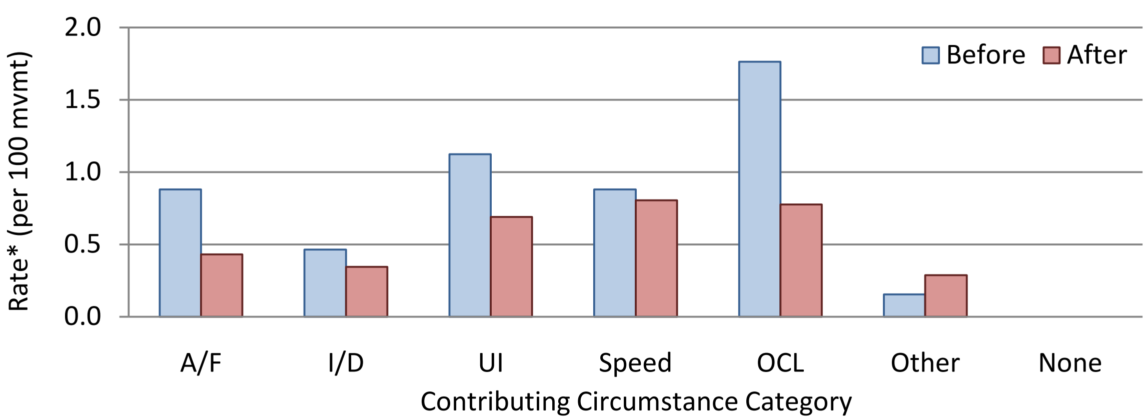


*Rate of collisions with Contributing Circumstance Category

Total Crash Record Counts: 1,445 Before, 834 After

Total Contributing Circumstances Evaluated: 1,702 Before, 987 After

Figure 5.5 Lane Departure Rates by Contributing Category: Fatal & Serious Injury



*Rate of collisions with Contributing Circumstance Category

Total Crash Record Counts: 182 Before, 87 After

Total Contributing Circumstances Evaluated: 239 Before, 116 After

In general, the results for CLRS and the effects for all lane departure crashes by contributing circumstances are positive. Crashes where "asleep" or "fatigued" was identified as a contributing circumstance were reduced by 41% for All Injury Severities (see Figure 5.2) and over 51% for Fatal & Serious Injury crashes (see Figure 5.3).

There are some other interesting results for lane departure collisions. For inattentive or distracted drivers, there was no reduction in the rate for all crashes; the researchers actually observed a very slight increase (see Figure 5.4). When looking at only Fatal & Serious Injury crashes (see Figure 5.5) where inattentive or distracted drivers were identified, there was a collision reduction of over 25%. This trend appears to be linked to ROTRR collisions and becomes more apparent when examining the results of only cross-centerline crashes, discussed later in the report. As CLRS were not expected to be an effective countermeasure for ROTRR crashes involving distracted drivers, these results are not necessarily a surprise.

It is also interesting to note that despite the overall reductions in lane departure crash rates, the researchers observed an increase in the "Other" contributing category for All Injury Severities, as well as in Fatal & Serious Injury crashes. Within the "Other" category, there was an increase of 11.4% in the crash rate for All Injury Severities and an increase of 86% in Fatal & Serious Injury collisions. This increase was found to be linked to ROTRR crashes rather than cross-centerline crashes.

Run-Off-the-Road-to-the-Right (ROTRR) Crash Rates

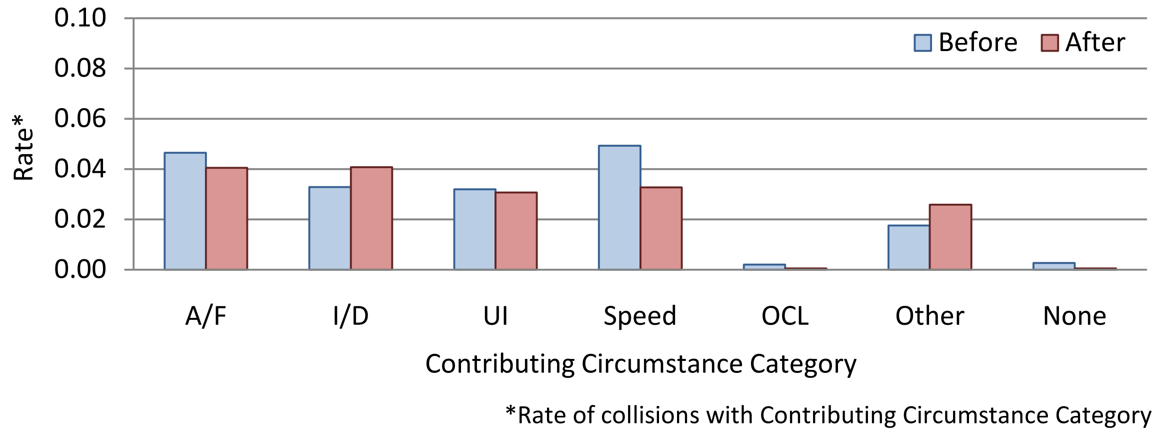
An examination of only the ROTRR crashes reveals a crash reduction of nearly 20% in Fatal & Serious Injury crashes (see Table 5.7). While this type of collision is not targeted for reduction by the application of CLRS, the data indicate there was indeed a reduction within the sites studied. How CLRS influenced the reduction in ROTRR crashes was not identified in this study and requires additional investigation to gain a better understanding. Figures 5.6 and 5.7 show the results by collision rate for the ROTRR collisions by contributing category for All Injury Severities and Fatal & Serious Injury collisions, respectively.

Table 5.7 ROTRR Crashes: Before and After Rates

Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.1659	0.1545	0.0114	-6.9%
Fatal & Serious Injury	1.4985*	1.2062*	0.2923	-19.5%

Most severe injury of crash (one per crash) *per 100 mvmt

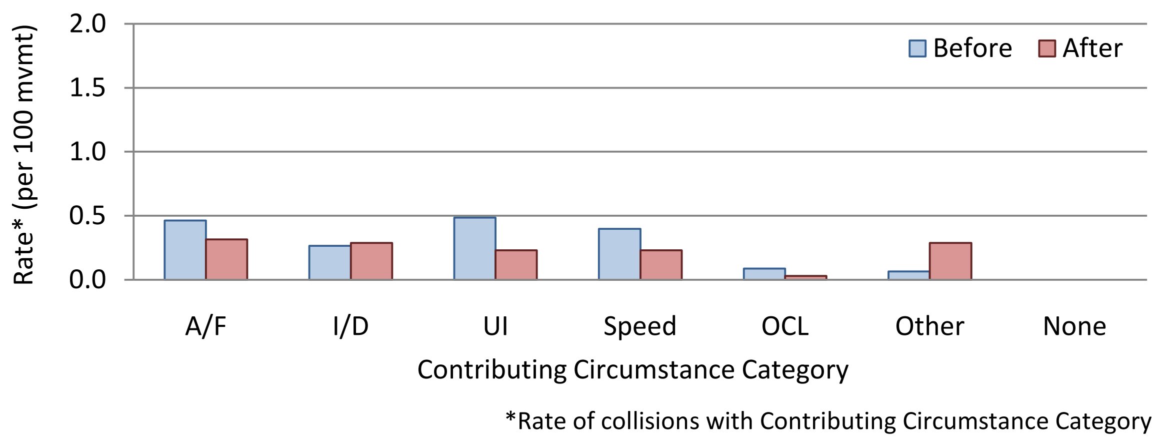
Figure 5.6 ROTRR Rates by Contributing Category: All Injury Severities



Total Crash Record Counts: 755 Before, 540 After

Total Contributing Circumstances Evaluated: 830 Before, 598 After

Figure 5.7 ROTRR Rates by Contributing Category: Fatal & Serious Injury



Total Crash Record Counts: 68 Before, 42 After

Total Contributing Circumstances Evaluated: 80 Before, 48 After

Cross-Centerline (Crossover) Crashes

While it is possible to discuss the effectiveness of CLRS in lane departure collisions in a number of methods or views, this countermeasure specifically targets cross-centerline collisions; therefore, the researchers looked very closely at the influence of CLRS on those collision types. Washington State implemented a CLRS program based on a Benefit/Cost analysis, assuming a 15% reduction in injury collisions. This value was derived from and supported by the Persaud, et al., Insurance Institute for Highway Safety research report "Crash Reduction Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads." Although the data analysis in this study did not precisely follow

Persaud's approach to analyzing collision reductions attributed to CLRS, the researchers observed a nearly 45% reduction in All Injury Severities. For Fatal & Serious Injury crashes, the reduction rate was found to be 48.6%. Table 5.8 shows the before and after performance by injury severity classification.

Table 5.8 Crossover Crashes: Before and After Rates

Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.152	0.084	0.068	-44.6%
Fatal & Serious Injury	2.512*	1.292*	1.220	-48.6%
Evident Injury	0.045	0.020	0.025	-55.5%
Possible Injury	0.020	0.018	0.002	-10.0%
No Injury	0.053	0.033	0.020	-38.9%
Unknown	0.009	0.001	0.007	-86.6%

Most severe injury of crash (one per crash) *per 100 mvmt

As shown in Table 5.9, for Asleep/Fatigued drivers, the researchers observed a 75.3% reduction for all collisions and a 72.6% reduction for Fatal & Serious Injury crashes (shown in parenthesis). For drivers reported to be Inattentive/Distracted, a 40.9% reduction was found for all cross-centerline collisions, with a 71% reduction in Fatal & Serious Injury crashes. These specific driver behaviors are targeted with the installation of centerline rumble strips.

The researchers also observed a reduction in collisions with other contributing circumstances associated with cross-centerline collisions. They observed a 20% reduction in the collision rate for All Injury Severities where Speed is identified as a contributing factor. However, Fatal & Serious Injury crash rates that listed Speed as a factor saw an 18.5% increase in the collision rate. (CLRS are not generally expected to be an effective countermeasure for a speeding vehicle.) The research team was unable to identify any factors that may have been associated with the 18.5% increase in Speed-related Fatal and Serious Injury collisions.

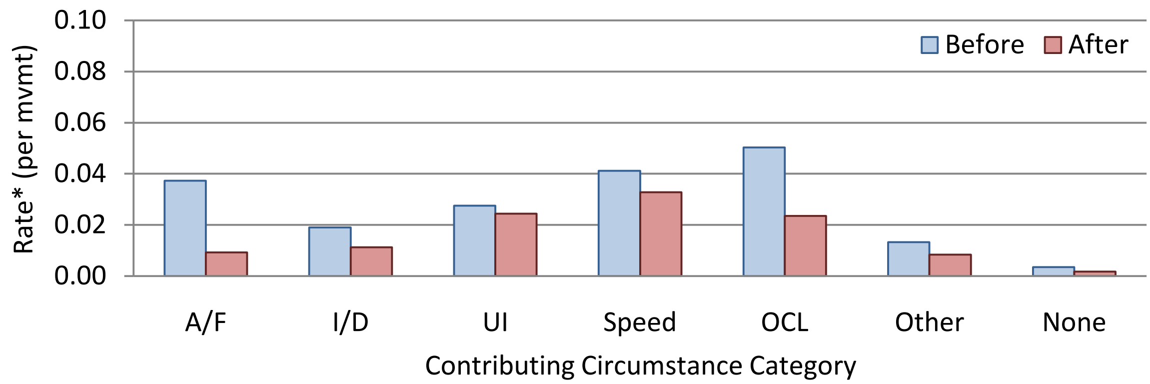
Figures 5.8 and 5.9 graphically illustrate the same data as Table 5.9, with the number of contributing categories referenced by the collision reports. These views, especially the Fatal & Serious Injury collisions, show the significant reduction observed in crossover collisions.

Table 5.9 Crossover Crash Rates by Contributing Category

Contributing Category	Before Rate	After Rate	Difference	% Change
Asleep/Fatigued (A/F)	0.037 (0.419)	0.009 (0.115)	0.028 (0.304)	-75.3% (-72.6%)
Inattentive/Distracted (I/D)	0.019 (0.198)	0.011 (0.057)	0.008 (0.141)	-40.9% (-71.0%)
Under Influence (UI)	0.028 (0.639)	0.024 (0.460)	0.003 (0.180)	-11.4% (-28.1%)
Speed	0.041 (0.485)	0.033 (0.574)	0.008 (-0.090)	-20.6% (18.5%)
Over Centerline (OCL)	0.050 (1.675)	0.024 (0.747)	0.027 (0.928)	-53.1% (-55.4%)
Other	0.013 (0.088)	0.008 (0.000)	0.005 (0.088)	-37.0% (-100%)
None	0.004 (0.000)	0.002 (0.000)	0.002 (0.000)	-51.1% (0.0%)

See Appendix A Fatal & Serious Injury results in () with rate per 100 mvmt

Figure 5.8 Crossover Rates by Contributing Category: All Injury Severities

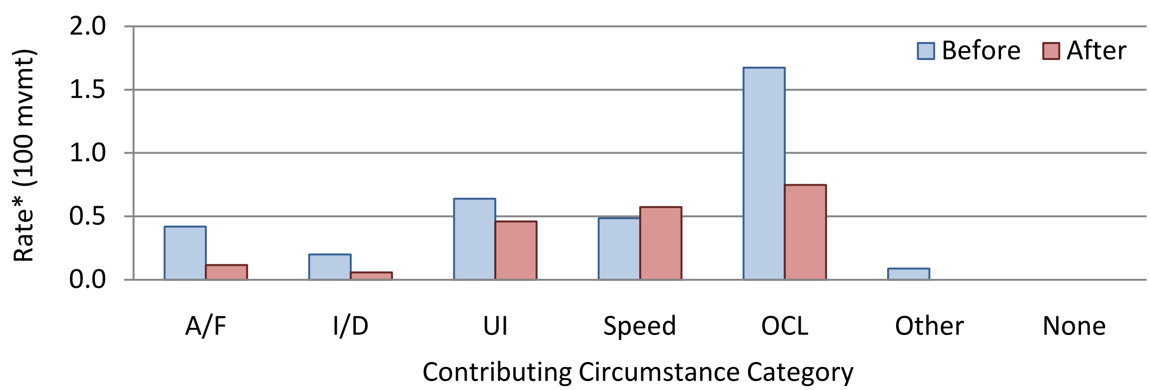


*Rate of collisions with Contributing Circumstance Category

Total Crash Record Counts: 689 Before, 293 After

Total Contributing Circumstances Evaluated: 871 Before, 387 After

Figure 5.9 Crossover Rates by Contributing Category: Fatal & Serious Injury



*Rate of collisions with Contributing Circumstance Category

Total Crash Record Counts: 114 Before, 45 After

Total Contributing Circumstances Evaluated: 159 Before, 68 After

Posted Speed

The research team looked at the effectiveness of CLRS across several ranges of posted speed to assess whether there are speed ranges at which CLRS are most or least effective in reducing cross-centerline collisions.

As shown in Figure 5.10 and Table 5.10, of the 493 miles represented in the crossover collisions, there are limited miles represented for highways with posted speeds below 45 mph. Those miles represent only 2.4% of the highway miles evaluated. Because of the limited exposure and the possibility of a random event skewing the results, the team chose to exclude posted speeds below 45 mph from further analysis.

Figure 5.10 Posted Speed: Study Miles & Percent of Total

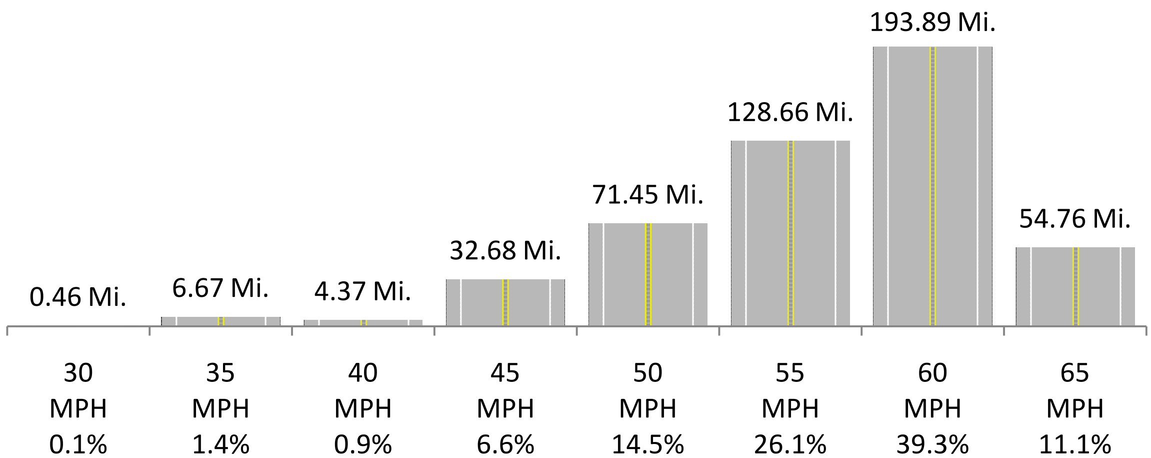


Table 5.10 Crossovers at Posted Speed

MPH	Miles	Before Crash Count	After Crash Count	Before Crash Rate	After Crash Rate	Difference In Rate	% Change In Rate
30	0.46	0 (0)	0 (0)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0% (0%)
35	6.67	14 (1)	8 (0)	0.166 (1.186)	0.124 (0.000)	0.042 (1.186)	25.5% (100%)
40	4.37	13 (2)	2 (0)	0.182 (2.798)	0.035 (0.000)	0.147 (2.798)	80.9% (100%)
45	32.68	40 (6)	5 (0)	0.183 (2.740)	0.026 (0.000)	0.157 (2.740)	-85.8% (-100%)
50	71.45	172 (35)	100 (18)	0.203 (4.136)	0.154 (2.779)	0.049 (1.357)	-24.0% (-32.8%)
55	128.66	206 (33)	96 (11)	0.137 (2.193)	0.076 (0.867)	0.061 (1.326)	-44.7% (-60.5%)
60	193.89	208 (33)	70 (15)	0.135 (2.138)	0.067 (1.429)	0.068 (0.709)	-50.5% (-33.2%)
65	54.76	36 (4)	12 (1)	0.144 (1.554)	0.062 (0.518)	0.078 (1.036)	-55.5% (-66.7%)

Fatal & Serious Injury results in () with rate per 100 mvmt

Figures 5.11 and 5.12 display posted speeds above 40 mph with before and after crash rates for All Injury Severities and Fatal & Serious Injury crashes. They also show the percentage of miles in the dataset for each speed.

Figure 5.11 Crossover Rates by Posted Speed: All Injury Severities

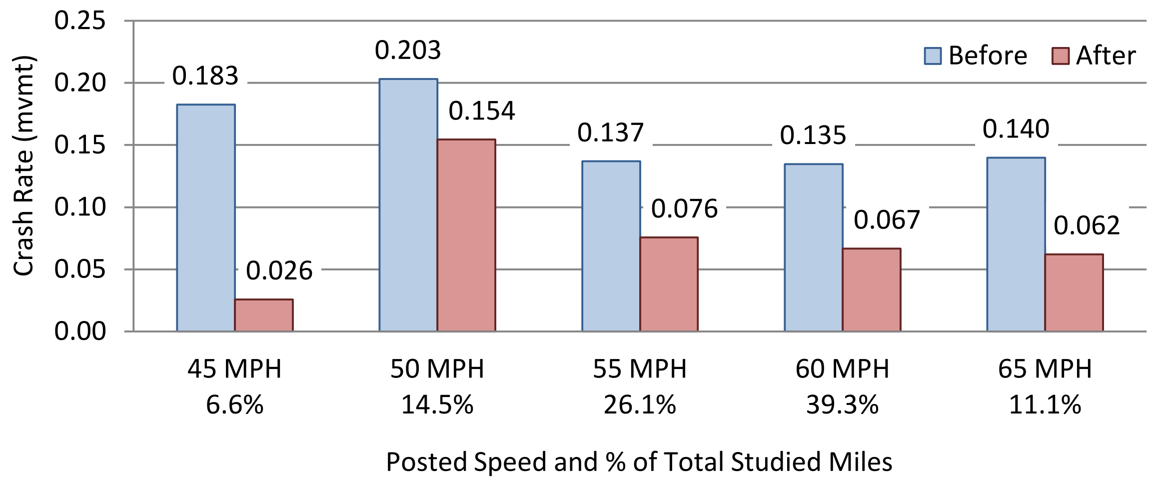
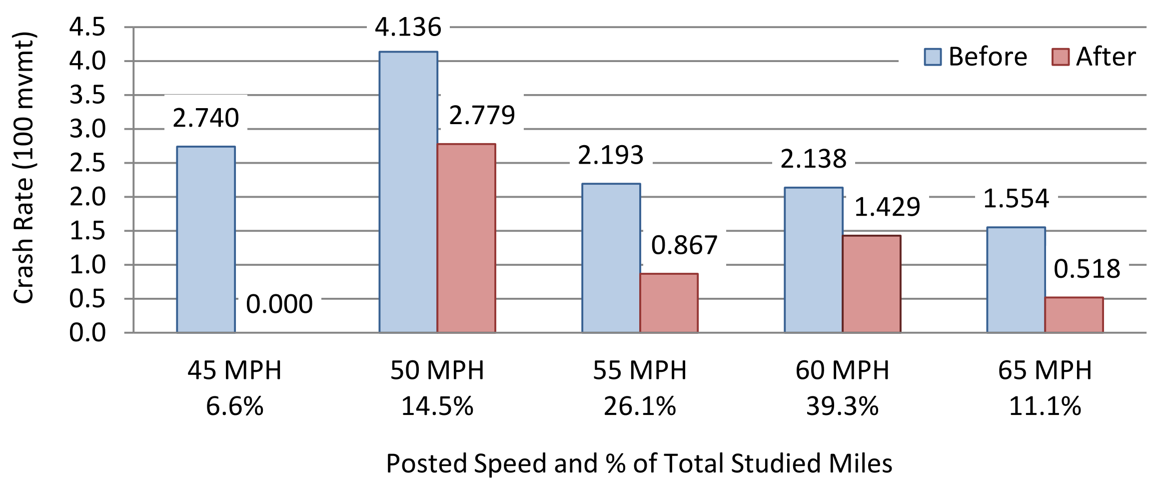


Figure 5.12 Crossover Rates by Posted Speed: Fatal & Serious Injury

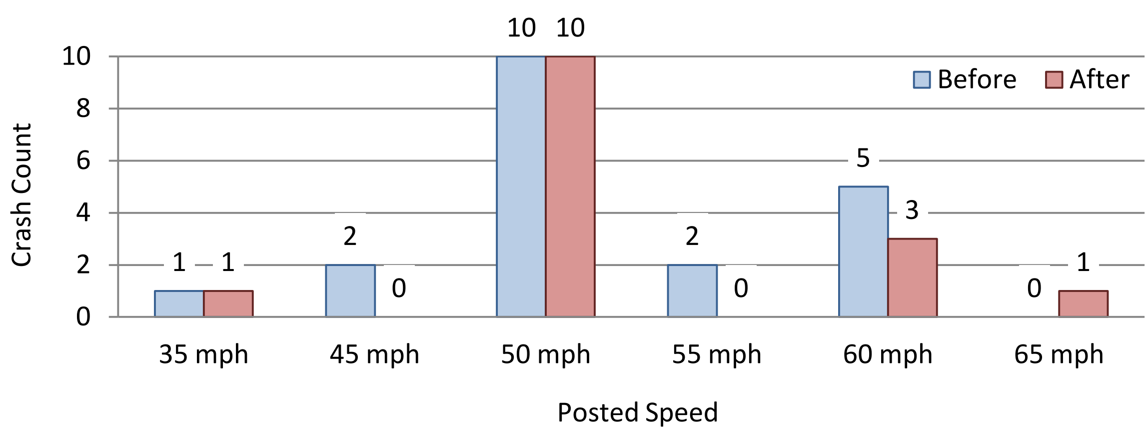


This analysis revealed that where CLRS were installed with a 50 mph posted speed, the Fatal & Serious Injury rate was significantly higher than for any other speed. Although reduced by 32.8%, the rate for the after period was still significantly higher than for all other posted speeds. As the researchers looked more closely at the data for the 50 mph posted speed, they isolated a particular class of vehicles in specific locations that were heavily influencing the rate of Fatal & Serious Injury collisions. It was found that motorcycle crashes on highways with 50 mph posted speeds were a significant factor in generating this higher rate of Fatal & Serious Injury crashes. Out of the 982 collision events in the crossover crash dataset, 35 were motorcycle collisions: 20 of these were in the before period and 15 were in the after period.

Motorcycles

There are a few interesting trends that can be extracted from this set of collisions. Of the 35 motorcycle crashes, 14 resulted in fatal or serious injuries. In the before period collisions, 30% resulted in fatal or serious injuries; in the after period, 53% resulted in fatal or serious injuries. Of all 35 motorcycle collisions, 20 occurred on highways with a posted speed of 50 mph (see Figure 5.13). All 20 of these fell within three of the 69 segments analyzed. Of these 20 collisions, 19 were clustered within very short portions of two separate state routes. On SR 7, six collisions occurred within a 0.11-mile segment and another four within a 0.84-mile segment. On SR 14, three collisions occurred within a 0.04-mile segment and another six within a 0.05-mile segment. The locations identified along these two routes were associated with just over 55% of all motorcycle crashes in the dataset.

Figure 5.13 Motorcycle Crash Count by Posted Speed



The research team found that motorcycle crashes were heavily influenced by horizontal curves, which were linked to 30 of the 35 crashes. Of those 30, 26 were lane departures to the outside of the curve. The team found that 16 motorcycle crashes were influenced by four specific curves.

In looking at contributing circumstances for the 35 motorcycle collisions in the dataset, it is clear that CLRS are not an effective countermeasure for this class of vehicle. The primary contributing circumstances CLRS are expected to influence are those where an operator is asleep, fatigued, or distracted. There are no reported instances of asleep or fatigued in either the before or after period associated with motorcycle collisions, as shown in Figure 5.14. The rate of inattentive or distracted drivers is substantially higher in the after period.

Figure 5.14 Motorcycle Crash Contributing Category Distribution: Before and After

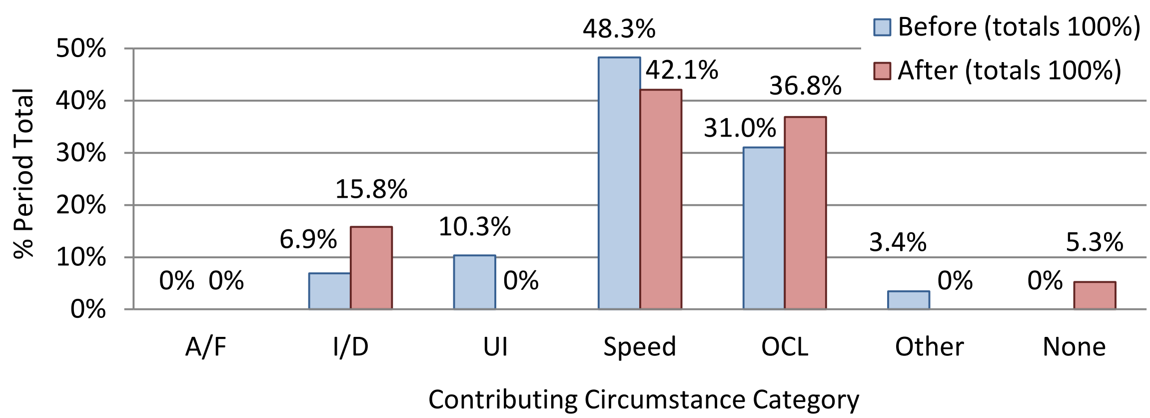
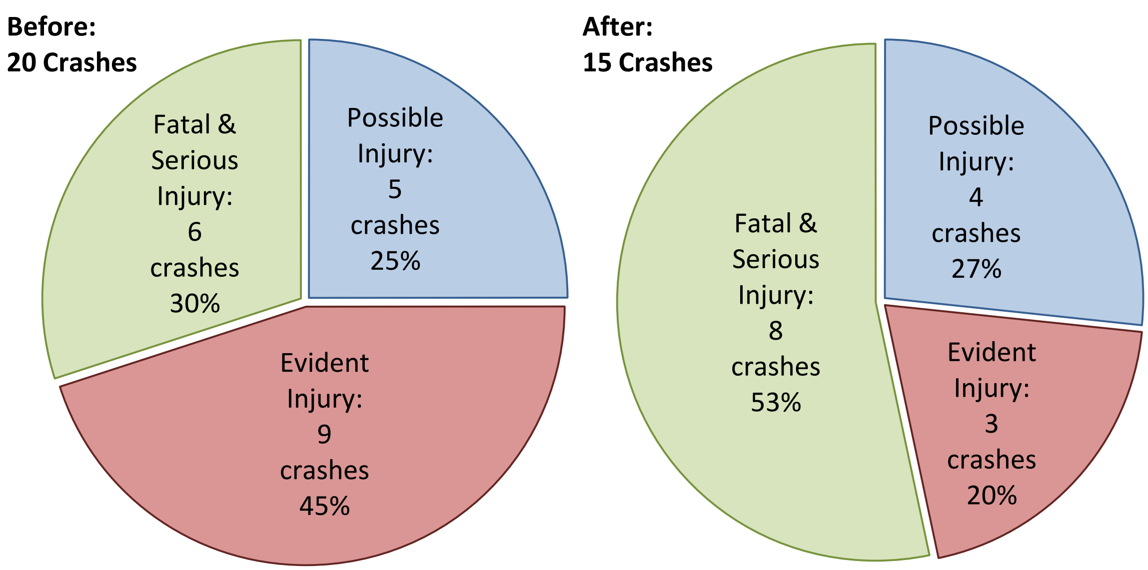


Figure 5.15 Motorcycle Crash Injury Severity Distribution: Before and After



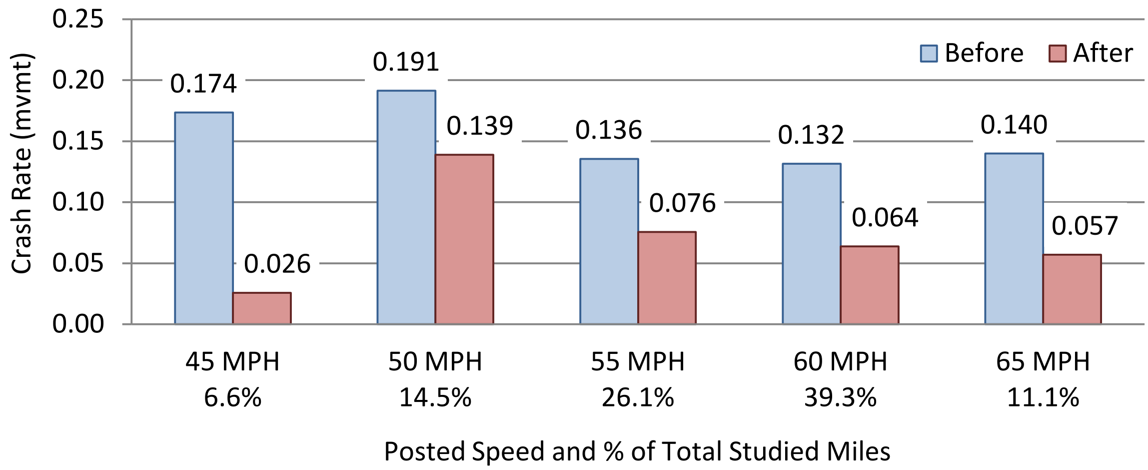
Excluding Motorcycles

While the motorcycle findings (see Figure 5.15) are an interesting study on their own, it is clear that they are skewing portions of the CLRS analysis. For that reason, these 35 motorcycle collisions were excluded from the dataset.

Posted Speed (Excluding Motorcycles)

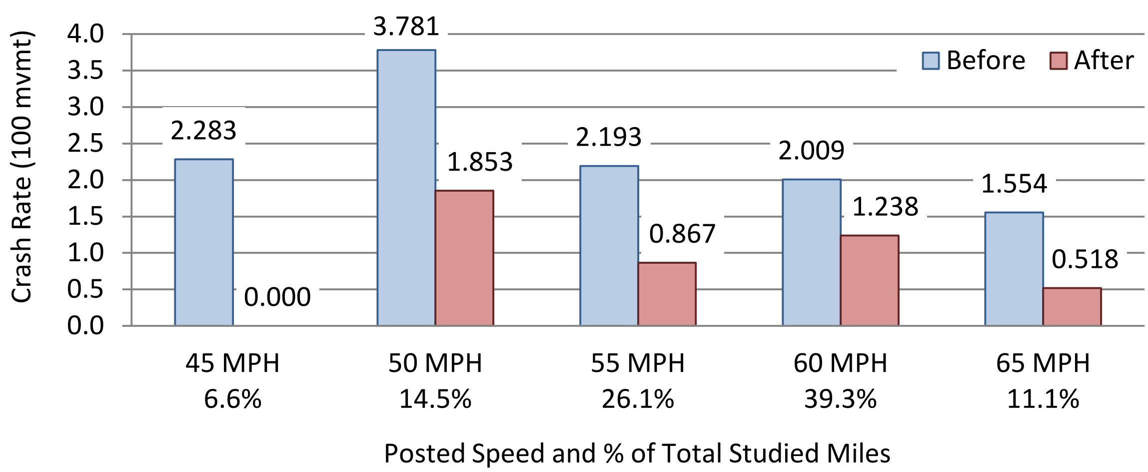
In the All Injury Severities view excluding motorcycle crashes, shown in Figure 5.16, the change in rates, even in the 50 mph range, is subtle. What is apparent is that the trend-line of both periods indicates that as posted speed increases above 50 mph, the rate of any injury decreases.

Figure 5.16 Crossover Rates by Posted Speed (Excluding Motorcycles): All Injury Severities



The Fatal & Serious Injury rates determined without the presence of motorcycle collisions reflects a dramatic change in the 50 mph range (see Figure 5.17). Changes in collision rates in the other speed ranges are much more subtle, as would be expected, since the motorcycle collisions were more randomly dispersed across the other speed ranges.

Figure 5.17 Crossover Rates by Posted Speed (Excluding Motorcycles): Fatal & Serious Injury



As in the All Injury Severities view, the Fatal & Serious Injury rates in the before period exhibit a similar trendline, suggesting that as speed increases, the rate of a fatal or serious injury collision is lower. That trend is not as clearly illustrated in the after period, with an upward "bump" at 60 mph. However, it does show that where CLRS are installed, there are reduced collision rates across the entire range of speeds.

Posted Speed: Contributing Circumstance Category

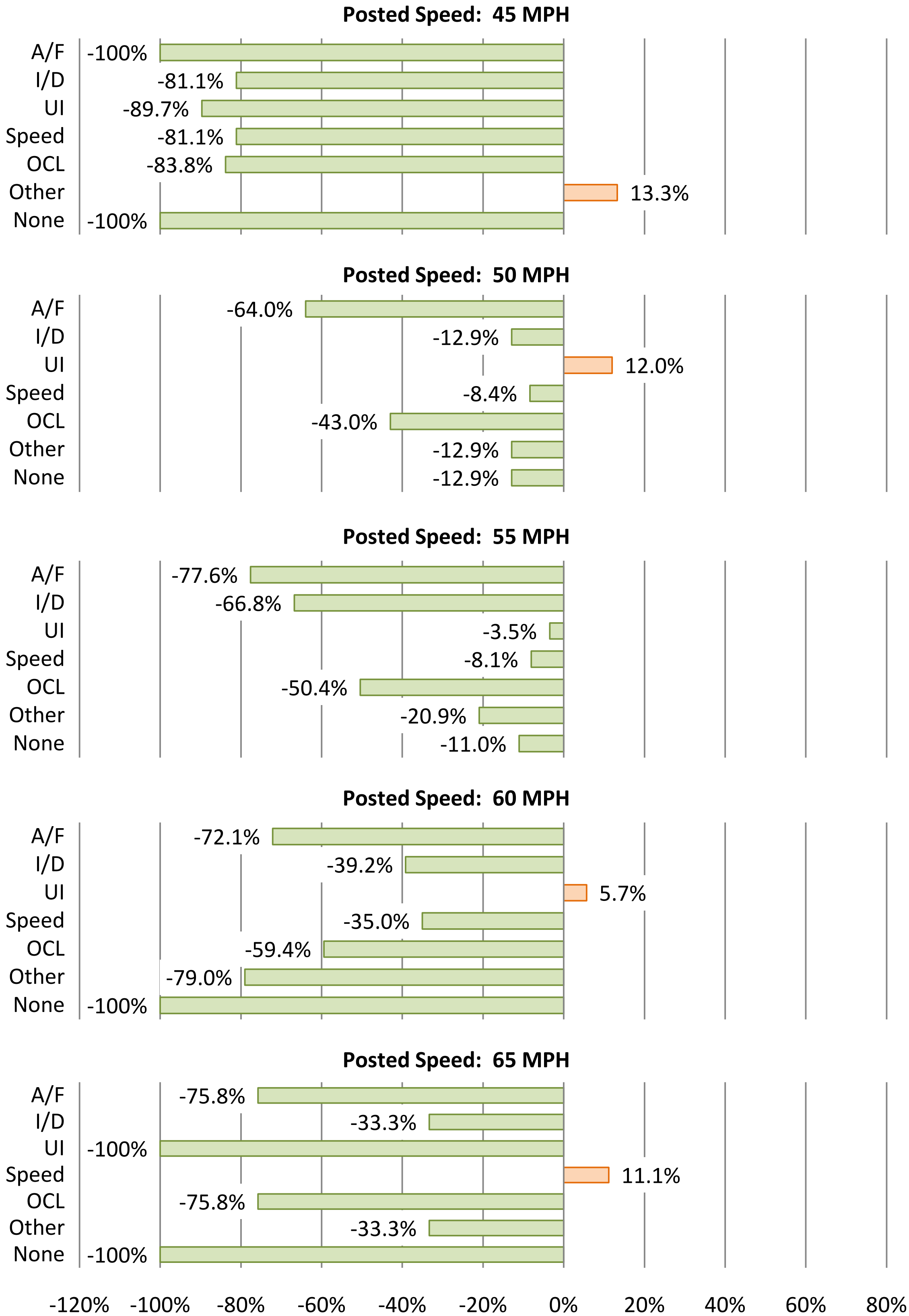
Figure 5.18 illustrates the percentage difference in crash rates observed when comparing the before and after periods. This figure provides a multivariant view, illustrating the influence on various contributing categories at different posted speeds. Bars to the left of 0% (negative % change) indicate a reduction in crash rates, while bars to the right reflect an increase in crash rates.

Washington State installed CLRS as a countermeasure to target collisions where driver behavior included Asleep/Fatigued or Inattentive/Distracted. The researchers observed substantial reductions in the collision rate for these contributing categories across all posted speed ranges evaluated. Collisions where Asleep/Fatigued was identified as a contributing category were reduced more consistently and to a greater degree than collisions where Inattentive/Distracted behaviors were identified.

The researchers theorize that the difference in effectiveness of rumble strips for these contributing categories may be closely linked to the type of behaviors involved. Distracted behaviors such as grooming, adjusting the radio, or using a cell phone are conscious decisions made by the driver, whereas fatigue is not. In these instances, encountering rumble strips may not result in decisions to discontinue the inattentive behaviors.

As previously mentioned, CLRS' effect on cross-centerline collisions results in a very stable reduction trend for collisions where Asleep/Fatigued was identified as a factor. The Inattentive/Distracted category generally shows a declining level of collision reduction as posted speed increases. The 50 mph posted speed range is the lone exception to this trend. The Over Centerline (OCL) category also exhibits a general trend. With the exception of the 45 mph posted speed range, this evaluation suggests that collision reduction levels increase for OCL collisions as the posted speed increases. Collisions where all other contributing categories are identified display a more random pattern of collision reduction levels.

Figure 5.18 Crossover: % Rate Change by Cont. Category at Posted Speed: All Inj. Severities



Horizontal Alignment – Tangents and Curves

The researchers evaluated roadway geometry in this study to determine whether CLRS performance was influenced by horizontal alignment or roadway width. Crashes were evaluated to determine whether they occurred on a tangent or were related to a curve in the roadway.

A curve relationship was based on either of two conditions: the crash occurred within the physical limits of a horizontal curve per the State Horizontal Alignment dataset or, based on review of the collision report, the research team interpreted that a horizontal curve influenced the collision. For example, the team may have identified a collision where the driver straightened out a curve or overcorrected entering or exiting a horizontal curve in the roadway.

It was through this analysis that the researchers identified those crashes where the collision was influenced by the horizontal curve. The dataset consists of a total of 947 crashes (excluding motorcycles).

CLRS are reducing the frequency of cross-centerline collisions regardless of a roadway's horizontal alignment. However, the difference in effectiveness between a tangent and a curved segment of the roadway is significant. Table 5.11 illustrates the effectiveness of CLRS for All Injury Severities. In the after period, the collision rate is roughly three times higher on a curve than on a tangent for all crashes as well as Fatal & Serious Injury collisions. There are some interesting trends identified by taking a closer look at the contributing factors.

Table 5.11 Crossovers at Horizontal Alignment: All Injury Severities

Horizontal Alignment	Miles	Before Crash Rate	After Crash Rate	Difference in Rate	% Change In Rate
Tangent	339.45	0.123 (2.028)	0.050 (0.649)	0.072 (1.379)	-59.0% (-68.0%)
Curve	153.58	0.207 (3.226)	0.152 (2.068)	0.055 (1.158)	-26.8% (-35.9%)

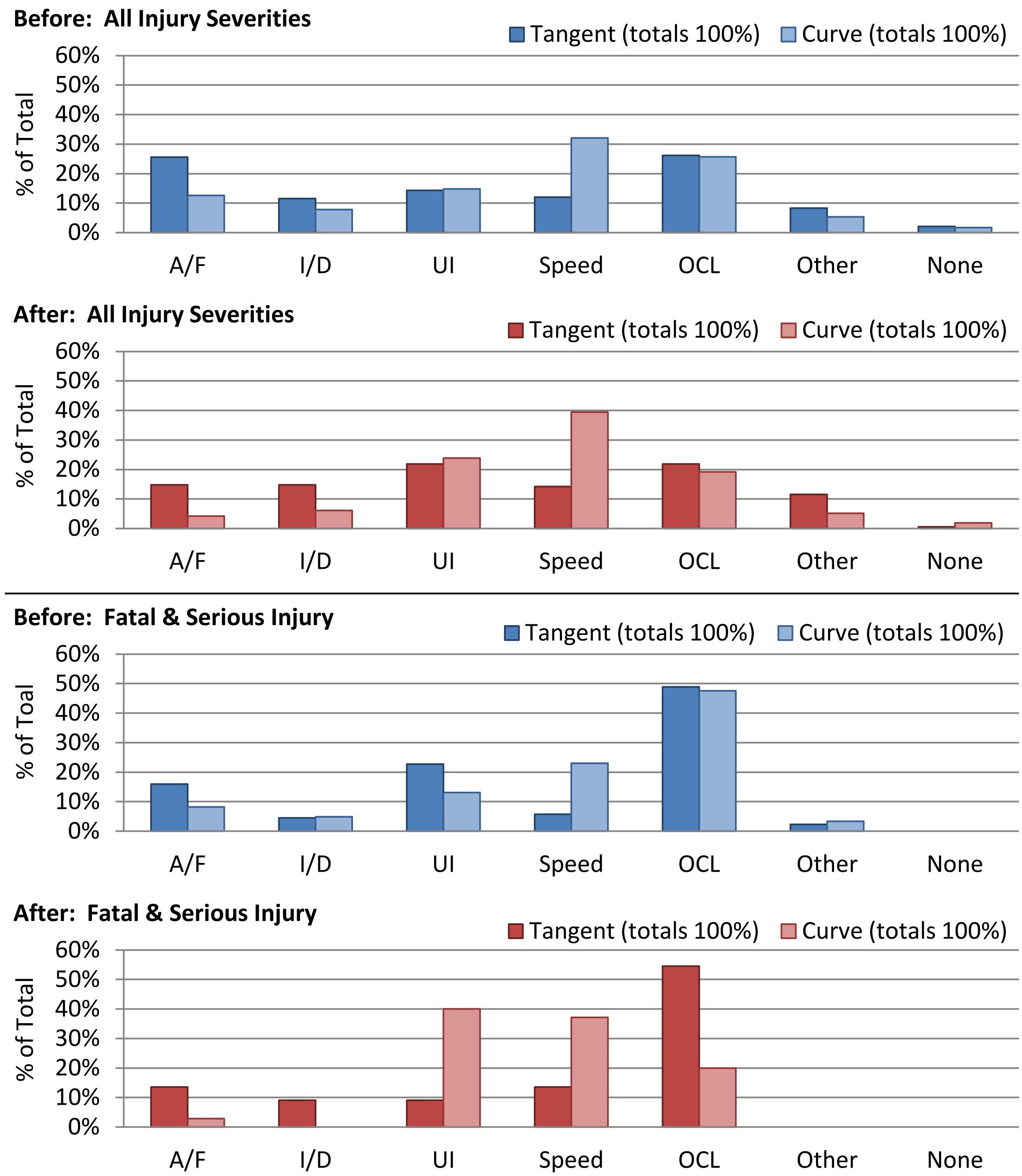
Fatal & Serious Injury results in () with rate per 100 mvmt

In looking at the contributing causes reported by the investigating officer, the researchers found clear differences between tangent and curve crashes. Most notable are crashes where Speed is associated with collisions on curves at over twice the frequency of tangent segments. The graphs for the after period for All Injury Severities and Fatal & Serious Injury in Figure 5.19 illustrate that the trend continues after rumble strip installation. Asleep/Fatigued is slightly more likely to be a contributing cause on a tangent, and Inattentive/Distracted crashes occur a little more often on curves.

Figure 5.20 compares tangents and curves, illustrating the total contributing circumstances reported and the percentage of that total reflected by the various categories. Note that this figure represents counts rather than rates. In both the All Injury Severities and the Fatal & Serious Injury charts, the distribution of the contributing categories is notably different for curves and tangents. The trends for All Injury Severities are similar when comparing before and after periods. For Fatal and Serious Injuries, the most notable changes are on curves, where the after period reflects a reduction in the Over Centerline category and an increase in the Under the Influence category.

Figure 5.19 Tangent/Curve Crash Contributing Circumstance Category Rates

Figure 5.20 Contributing Category Distribution at Horizontal Alignment



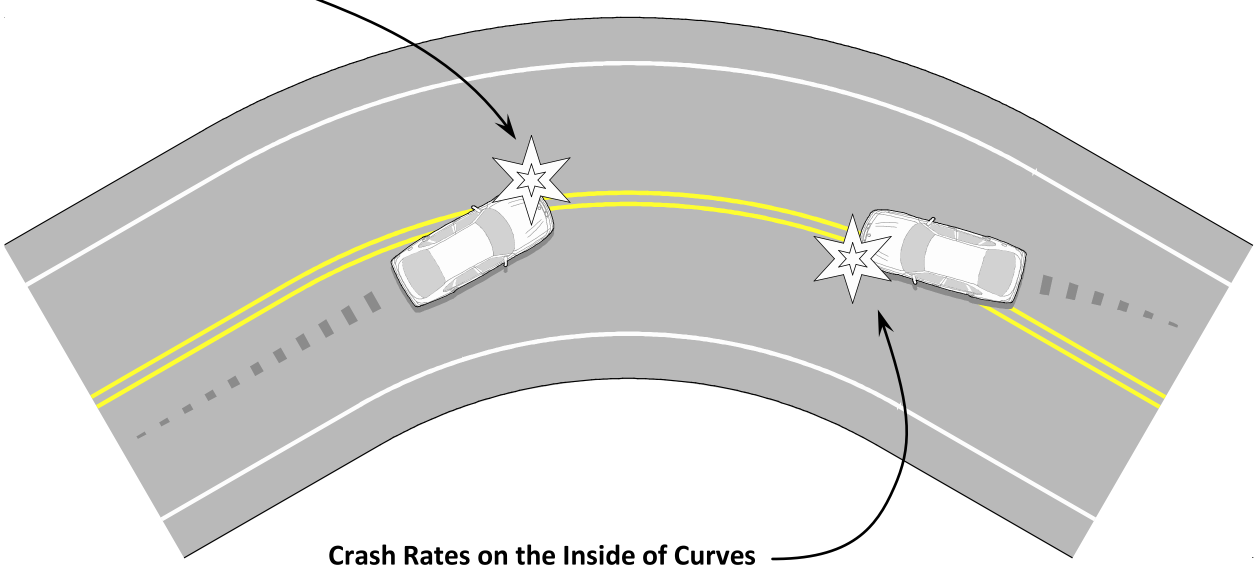
Curve Crash: Inside vs. Outside

When a crash occurred within the influence of a curve, the researchers determined the crash location in relationship to the curve itself. On any curve, it is possible to have a cross-centerline crash to the inside in one travel direction and an outside crash in the opposite travel direction. A crash to the inside of a curve would reflect a situation where the vehicle was on a path with a smaller radius than the roadway alignment. A crash to the outside of a curve reflects the vehicle on a path with a larger radius than the roadway alignment. The diagram in Figure 5.21 illustrates the inside/outside relationship to a curve. To calculate crash rates to the inside or the outside of curves, the volume of traffic used for an annual average daily traffic number is halved due to the singular direction of travel for these descriptive types of collisions.

Figure 5.21 Inside vs. Outside Curve Crash Illustration with Rates

Crash Rates on the Outside of Curves

Before*	After*	Difference	% Change
0.243 (4.051)	0.171 (2.560)	0.072 (1.491)	-29.5% (-36.8%)



Crash Rates on the Inside of Curves

Before*	After*	Difference	% Change
0.171 (2.401)	0.132 (1.575)	0.039 (0.825)	-22.9% (-34.4%)

*Based on Lane VMT, i.e., half of the % length curve VMT
Fatal & Serious Injury results in () with rate per 100 mvmt

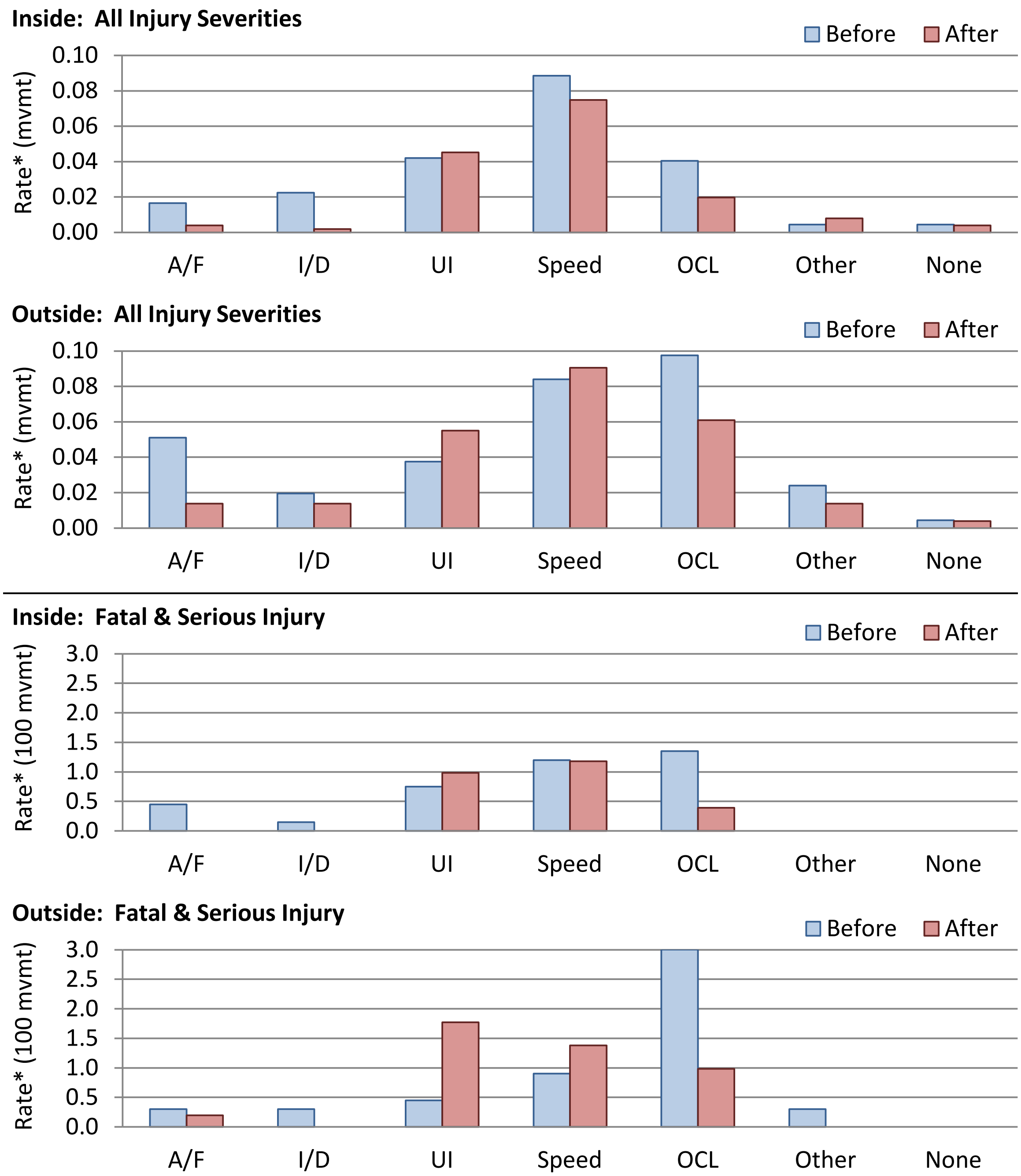
The curve data consists of 430 records; of those, 181 crashes were inside and 249 were outside. The before period consisted of 276 crashes; of those, 114 were inside and 162 were outside. The after period had 154 crashes; of those, 67 were inside and 87 were outside. The percentage split between inside or outside in both the before and after periods for all crashes remains roughly equal, with approximately 60% of collisions to the outside and 40% to the inside for both periods. Approximately the same 60%/40% ratio was observed for Fatal & Serious Injury crashes.

Figure 5.21 shows that CLRS are effective in reducing cross-centerline crashes on curves. However, the Fatal & Serious Injury collision rate for crashes to the outside of a curve was found to be significantly higher than for crashes to the inside of a curve. Crashes to the outside of a curve were almost twice as likely to result in fatal or serious injuries. The increased severity appears to be linked to multivehicle collisions. A higher percentage of the crashes to the outside of the curve were found to involve multiple vehicles compared to crashes to the inside of curve. In spite of the difference in rates of Fatal & Serious Injury collisions, the study results indicate that CLRS are nearly equally effective in reducing these collisions, whether they are associated with crashes to the inside or the outside of a curve. The reduction in Fatal & Serious Injury collisions is 34.4% for crashes to the inside of a curve and 36.8% for crashes to the outside of the curve.

To explore crash experience on curves more fully, the research team evaluated contributing circumstances associated with collisions to the inside and to the outside of a curve. Findings from that analysis are presented in Figure 5.22.

The contributing categories of Asleep/Fatigued, Inattentive/Distracted, and Over Centerline demonstrated the most significant reductions in collision frequency attributed to horizontal curves after the installation of centerline rumble strips. The researchers observed this for All Injury Severities as well as for Fatal & Serious Injury only. Interestingly, when Under the Influence or Speed were identified as contributing factors, collisions were found to increase in frequency after the installation of centerline rumble strips. The most noticeable increases were found with Fatal & Serious Injury collisions on the outside of the curve.

Figure 5.22 Inside & Outside Curve Crash Contributing Circumstance Category Rates

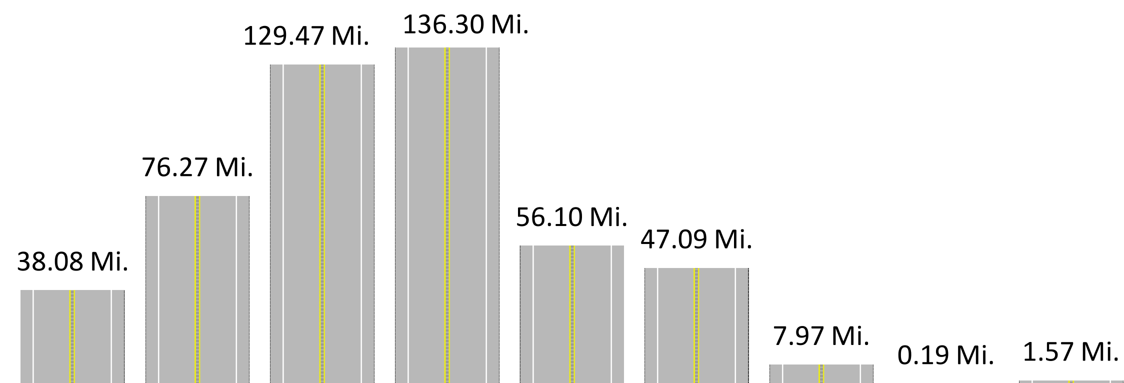


*Rate of collisions with Contributing Circumstance Category

Segment Percent Length Curve

As previously stated, the research team observed that cross-centerline collision frequency is greater on curves than on tangents. In an effort to learn more about the influence of horizontal alignment, the researchers attempted to quantify the degree of curvature for the study segments, but found that the dataset had some missing data elements in the horizontal curvature information. Implementing a different approach, the team identified the portion of the roadway in a horizontal curve as a percentage of the overall segment length. While this approach did not allow for analysis of how sharp the curves were, identifying the percentage of an alignment that was curvilinear provided another means to compare the performance of curves against tangents. Highway segments were then evaluated in bands of 10% increments. Figure 5.23 shows this distribution of the study mileage by percent length of curve with the number of associated miles, percentage of the study, and percentage number of the collisions that occurred within those bands in both the before and after periods.

Figure 5.23 Segment Percent Length Curve Distributions



% Length Curve	0 to < 10%	10 to < 20%	20 to < 30%	30 to < 40%	40 to < 50%	50 to < 60%	60 to < 70%	70 to < 80%	≥ 80%
% System	7.7%	15.5%	26.3%	27.6%	11.4%	9.6%	1.6%	0.0%	0.3%
% Before Crashes	5.5%	18.5%	23.0%	30.5%	10.3%	10.9%	1.2%	0.0%	0.0%
% After Crashes	6.1%	18.0%	21.9%	29.1%	10.1%	12.9%	1.8%	0.0%	0.0%

Table 5.12 and Figures 5.24 and 5.25 illustrate the crash experience before and after CLRS installation grouped by the percentage of the alignment in curvature. With the exception of the Fatal & Serious Injury category in the 60 to 70% band, all groupings showed significant reductions in crash rates. The exception to this finding is a circumstance where there was a single Serious Injury collision in the after period, with none in the before period.

Table 5.12 Segment Percent Length Curve: Crossover Rates

Range*	Miles	Before Crash Rate	After Crash Rate	Difference in Rate	% Change In Rate
0 to < 10%	38.08	0.084 (0.684)	0.041 (0.484)	0.043 (0.199)	-51.2% (-29.2%)
10 to < 20%	76.27	0.184 (2.675)	0.121 (1.450)	0.063 (1.450)	-34.4% (-45.8%)
20 to < 30%	129.47	0.105 (1.161)	0.051 (0.499)	0.051 (0.662)	-51.7% (-57.0%)
30 to < 40%	136.30	0.179 (3.695)	0.103 (1.405)	0.076 (2.290)	-42.3% (-62.0%)
40 to < 50%	56.10	0.123 (2.849)	0.064 (1.375)	0.059 (1.474)	-47.8% (-51.7%)
50 to < 60%	47.09	0.353 (5.799)	0.191 (2.651)	0.162 (3.148)	-45.9% (-54.3%)
60 to < 70%	7.97	0.167 (0.000)	0.127 (2.542)	0.040 (-2.542)	-24.0% (100.0%)
70 to < 80%	0.19	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.0% (0.0%)
≥ 80%	1.57	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.0% (0.0%)

*Determined per segment, then grouped Fatal & Serious Injury results in () with rate per 100 mvmt

Prior to installing the CLRS countermeasure, the 50 to 60% band had the highest Fatal & Serious Injury collision rate at 5.799 per 100 mvmt. After installation of CLRS, a 54% reduction was observed, dropping the rate to 2.651 per 100 mvmt.

Figure 5.24 Segment Percent Length Curve – Crash Rates: All Injury Severities

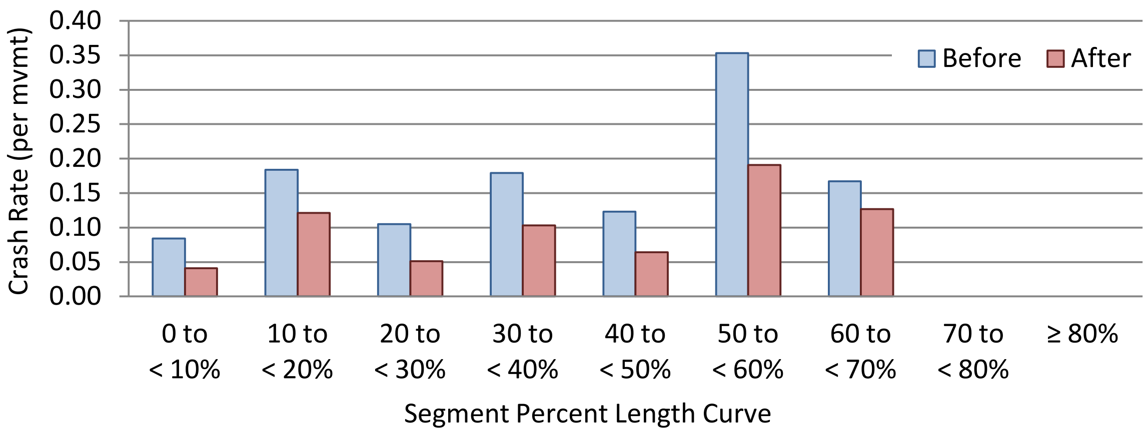
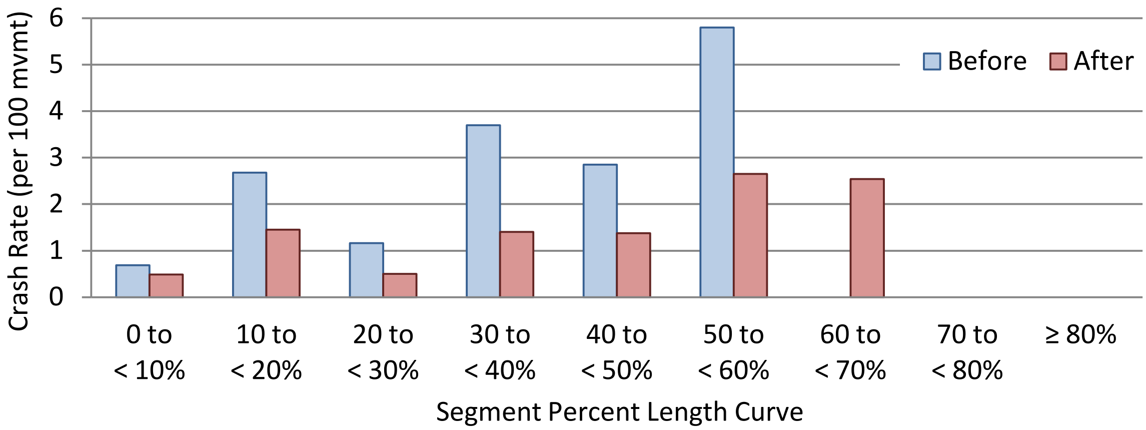


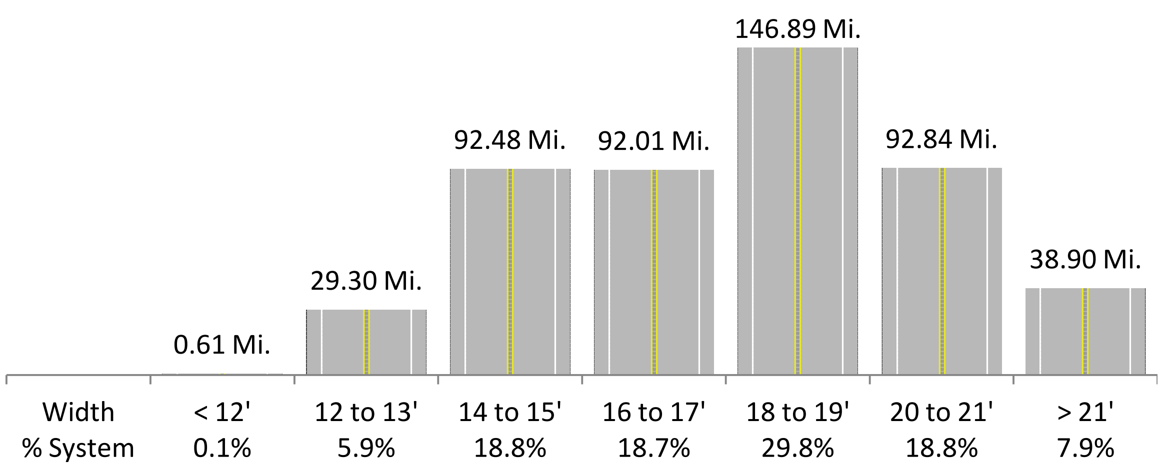
Figure 5.25 Segment Percent Length Curve – Crash Rates: Fatal & Serious Injury



Lane and Shoulder Widths

The researchers explored lane and shoulder widths to evaluate whether they had any impact on the effectiveness of CLRS. The team anticipated that wider lanes would offer more time for recovery and more room for avoiding errant cross-centerline vehicles. The values presented in their evaluation reflect the combined lane and shoulder width for a single travel direction: from the centerline to the outer edge of the paved shoulder (see Figure 5.26).

Figure 5.26 Lane and Shoulder Combined Paved Width Distribution



The findings for All Injury Severities (presented in Table 5.13) seem to validate the research team's theory that wider roadways are linked to greater effectiveness in crash reduction after the installation of CLRS. Focusing on the crash rates in the after period, the researchers observed a steady decline in collision rates for roadways wider than 13 feet. Although the decline in crash rates is not consistent across all roadway width bands, a declining trend was observed for roadways wider than 15 feet for Fatal and Serious Injury crashes. The addition of CLRS resulted in substantial reductions in crash rates for all roadway width bands. Figure 5.27 illustrates the difference in crash rates for All Injury Severities, comparing the performance before and after rumble strips were installed. Figure 5.28 provides a similar look for Fatal and Serious Injury collisions.

What is not clear from this analysis is how much of the collision experience is associated with lane/shoulder width versus posted speed. Lane/shoulder width is clearly linked to posted speed for the locations analyzed in this study. As the posted speed increases, the lane/shoulder width also increases.

Table 5.13 Lane and Shoulder Combined Paved Width: Crossover Rates

Width*	Miles	Before Crash Rate	After Crash Rate	Difference in Rate	% Change In Rate
< 12'	0.61	0.153 (0.000)	0.000 (0.000)	0.153 (0.000)	-100.0% (0.0%)
12 to 13'	29.30	0.195 (3.511)	0.132 (1.058)	0.063 (2.453)	-32.2% (-69.9%)
14 to 15'	92.48	0.220 (4.409)	0.119 (1.671)	0.102 (2.738)	-46.2% (-62.1%)
16 to 17'	92.01	0.161 (2.523)	0.115 (1.064)	0.046 (1.459)	-28.6% (-57.8%)
18 to 19'	146.89	0.146 (2.033)	0.075 (1.494)	0.072 (0.539)	-49.0% (-26.5%)
20 to 21'	92.84	0.084 (0.821)	0.041 (0.501)	0.041 (0.320)	-49.7% (-39.0%)
> 21'	38.90	0.108 (2.198)	0.031 (0.254)	0.077 (1.944)	-71.7% (-88.4%)

*Centerline to Edge of Paved Shoulder Fatal & Serious Injury results in () with rate per 100 mvmt

Figure 5.27 Crossover Rates by Paved Lane & Shoulder Width: All Injury Severities

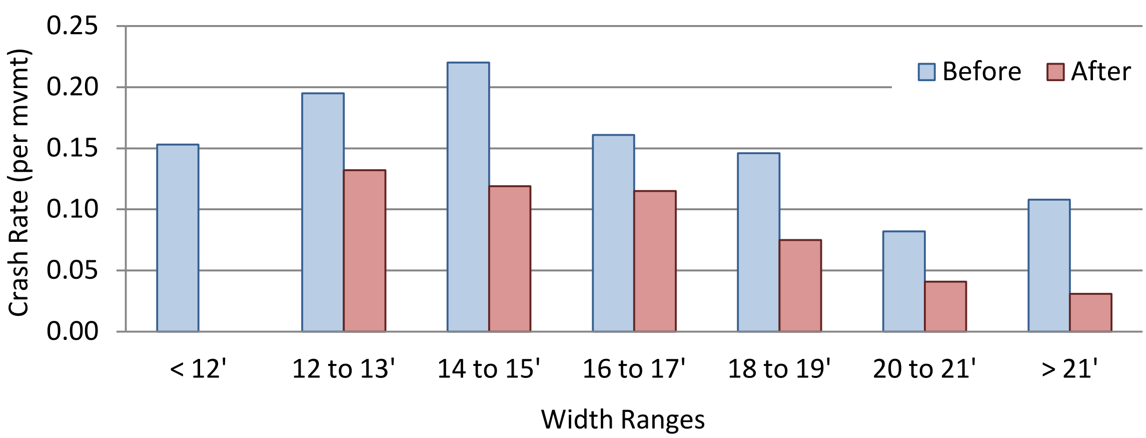
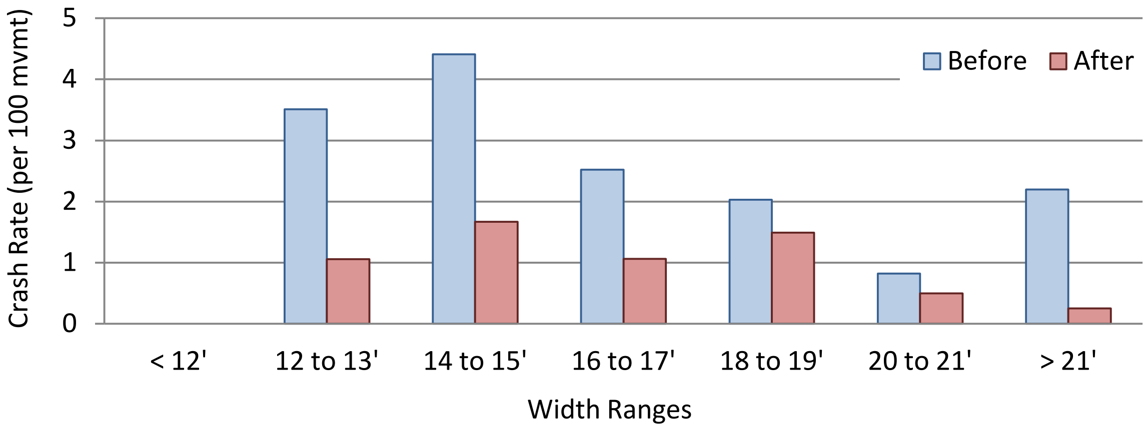


Figure 5.28 Crossover Rates by Paved Lane & Shoulder Width: Fatal & Serious Injury



Lighting Conditions

The research team explored whether there were differences in the effectiveness of CLRS in daylight or darkness hours. The lighting conditions used in this analysis were derived from the coding on each collision report. Table 5.14 summarizes the data from those collision reports. Unlike the performance analyses presented elsewhere in this report, the collision rates for various lighting conditions should not be compared with rates found herein. It was not possible to accurately assess traffic volumes associated with specific lighting conditions. Consequently, the rates for lighting conditions are calculated using the total VMT per phase (before or after). For that reason, the rate figures are relatively low compared to those shown for other analyses. However, Table 5.14 still presents a means of comparing CLRS performance among the various lighting conditions.

Table 5.14 Lighting Condition

Lighting Condition	Crash Count	Before Crash Rate	After Crash Rate	Difference in Rate	% Change In Rate
Dark–No Street Lights	331	0.048 (0.595)	0.032 (0.402)	0.016 (0.193)	-32.4% (-32.4%)
Dark–Street Lights Off	11	0.001 (0.022)	0.001 (0.029)	0.000 (-0.007)	8.6% (30.3%)
Dark–Street Lights On	28	0.004 (0.044)	0.003 (0.000)	0.001 (0.044)	-15.7% (-100%)
Dawn	25	0.005 (0.066)	0.001 (0.000)	0.003 (0.066)	-75.2% (-100%)
Daylight	520	0.084 (1.521)	0.040 (0.603)	0.045 (0.917)	-52.9% (-60.3%)
Dusk	28	0.005 (0.132)	0.002 (0.029)	0.003 (0.103)	-56.6% (-78.3%)
Unknown	4	0.001 (0.000)	0.000 (0.000)	0.001 (0.000)	-100% (0%)

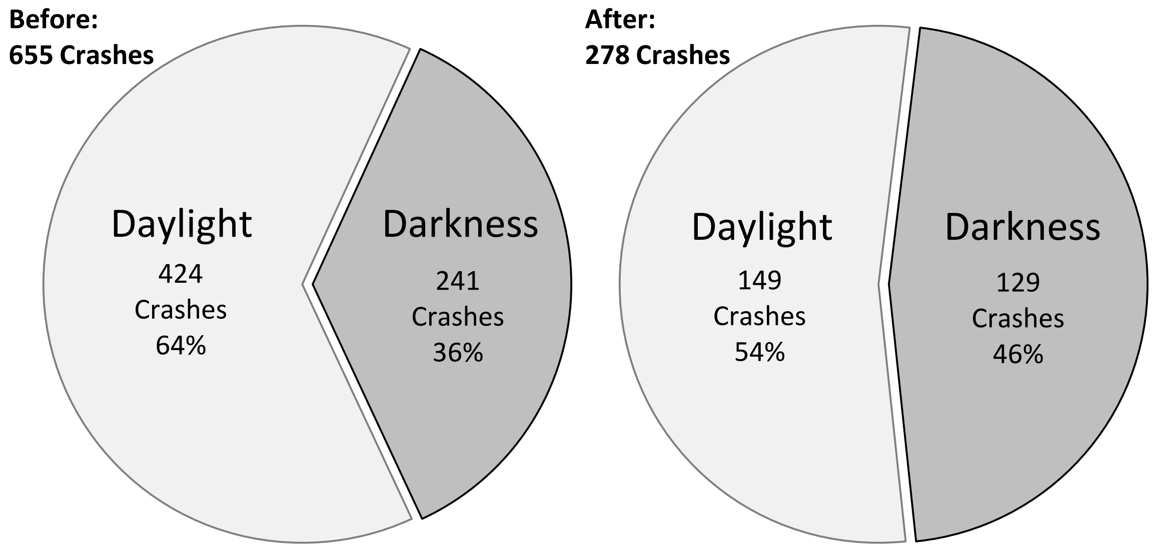
Fatal & Serious Injury results in () with rate per 100 mvmt

The “unknown” category is due to an incomplete field on the collision report by the investigating officer. There are 4 records in this category, all in the before period. It is likely that 2 collisions occurred at dawn, 1 during the day, and the last at dark with no street lights; however, this cannot be confirmed. The injury severities of these 4 unknown lighting conditions consisted of 2 possible and 2 unknown injuries. These 4 records were not included in the following analysis because of the lack of certainty as to the lighting conditions.

Daylight vs. Darkness

Figure 5.29 shows the percentage of collisions that occurred in either daylight or darkness conditions. The daylight portion of this analysis includes all crashes that occurred during dawn, daylight, and dusk.

Figure 5.29 Daylight vs. Darkness: Before and After Crash Distribution



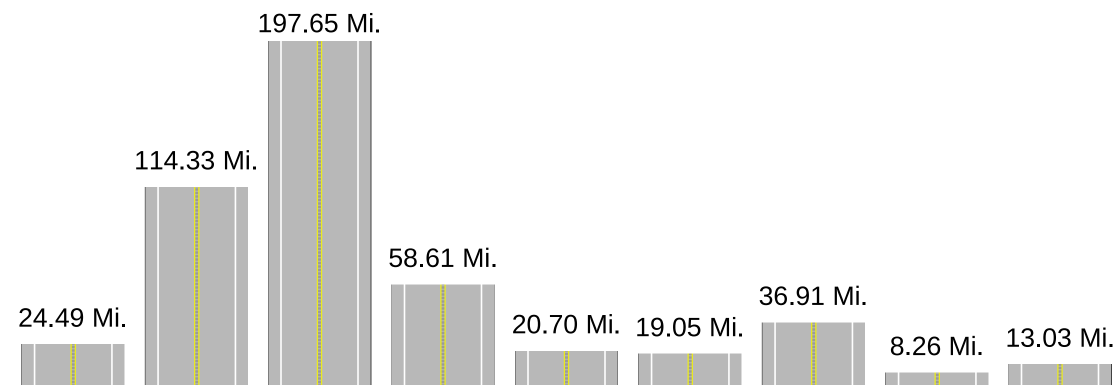
It is clear that the majority of collisions occurred during the daylight hours in both periods. After the CLRS installation, the difference in percentage between daylight and darkness decreases. This suggests that CLRS are more effective during daylight conditions.

Further exploration of the effectiveness of CLRS in either lighting condition is problematic, primarily in the calculation of an accurate VMT value to generate collision rates. There are variances in the daylight hours throughout the year, and determining the corresponding traffic volumes would require an extensive analysis, which is not supported by readily available data. With the benefits achieved through the installation of CLRS, it is highly unlikely that operational differences between daylight and darkness conditions would lead to changes in policy.

AADT

The researchers examined the effectiveness of CLRS on the basis of annual average daily traffic (AADT) volumes to assess whether CLRS are more or less effective in reducing cross-centerline collisions at differing traffic volumes. To assess this, the team elected to break the AADT in 2,000 AADT bands. Within the 493.03 study miles, the AADTs ranged from less than 2,000 to greater than 17,000; 75.2% of the miles fell within the range of 2,000 to 7,999 AADT (see Figure 5.30).

Figure 5.30 AADT Range Distribution



AADT Range	< 2000	2000 to 3999	4000 to 5999	6000 to 7999	8000 to 9999	10,000 to 11,999	12,000 to 13,999	14,000 to 16,999	≥ 17,000
% System	5.0%	23.2%	40.1%	11.9%	4.2%	3.9%	7.5%	1.7%	2.6%

The installation of CLRS has reduced the collision rate for cross-centerline collisions in all of the AADT ranges examined. This was observed for all collisions and for Fatal and Serious Injury collisions, with one exception: for Fatal and Serious Injury collisions in the ≥ 17,000 range, the researchers observed an increase in the collision rate. Table 5.15 and Figures 5.31 and 5.32 show the level of performance during the before and after periods across the AADT ranges.

Table 5.15 AADT Range: Crossover Collision Rates

Range*	Before Crash Rate	After Crash Rate	Difference in Rate	% Change In Rate
< 2000	0.338 (2.939)	0.063 (0.000)	0.275 (2.939)	-81.4% (-100.0%)
2000 to 3999	0.216 (3.788)	0.103 (2.011)	0.113 (1.778)	-52.1% (-46.9%)
4000 to 5999	0.148 (2.022)	0.096 (1.372)	0.052 (0.650)	-35.2% (-32.1%)
6000 to 7999	0.177 (4.030)	0.108 (0.896)	0.069 (3.134)	-39.2% (-77.8%)
8000 to < 9999	0.163 (2.223)	0.137 (1.209)	0.026 (1.014)	-16.0% (-45.6%)
10,000 to 11,999	0.092 (1.961)	0.049 (0.443)	0.043 (1.518)	-46.8% (-77.4%)
12,000 to 13,999	0.128 (1.937)	0.049 (0.446)	0.079 (1.491)	-61.7% (-77.0%)
14,000 to 16,999	0.081 (1.426)	0.017 (0.000)	0.064 (1.426)	-79.0% (-100.0%)
≥ 17,000	0.065 (0.562)	0.024 (1.342)	0.041 (-0.078)	-63.6% (138.7%)

*Determined per segment, then grouped Fatal & Serious Injury results in () with rate per 100 mvmt

Figure 5.31 AADT Range – Collision Rates: All Injury Severities

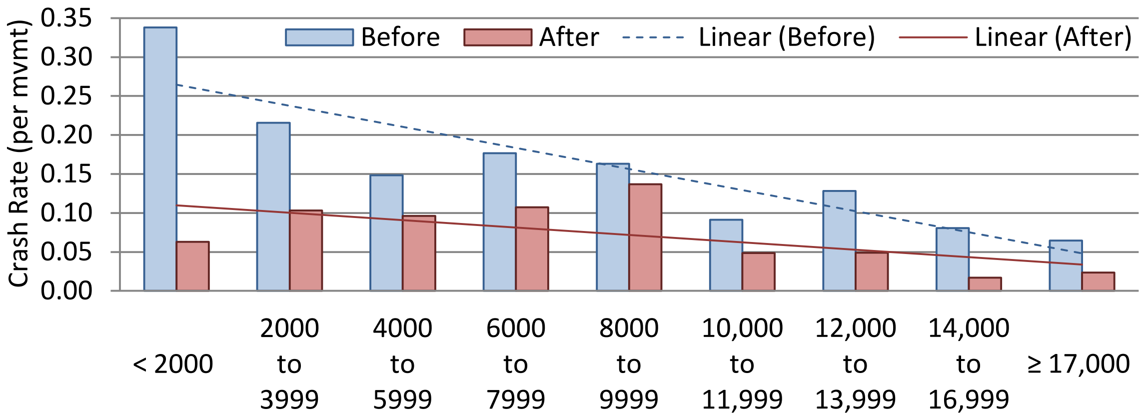
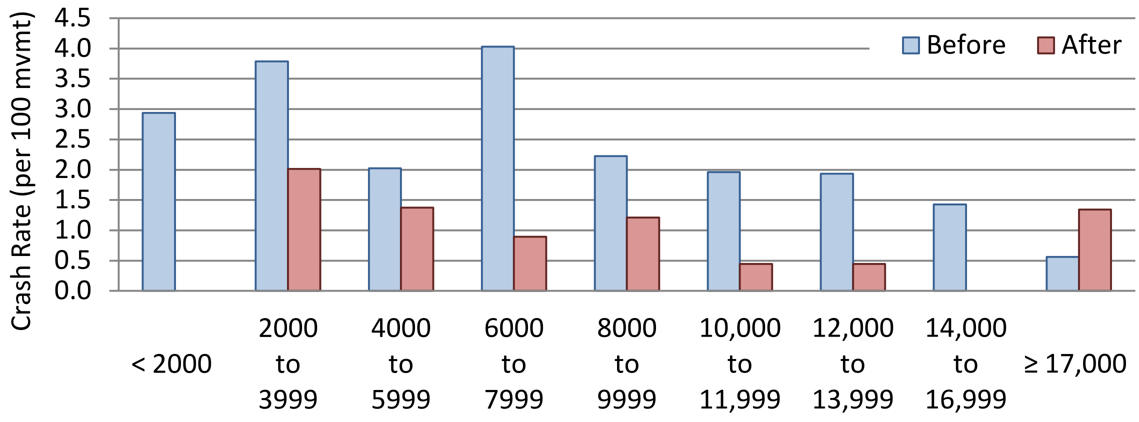


Figure 5.31 displays a linear trend line, which indicates that the lower the AADT, the higher the rate of cross-centerline collisions. Whether this is associated with traffic volume, or it is a function of geometric conditions such as roadway and shoulder width or other variables such as speed limit, is still unclear. This issue is examined more extensively in the discussion on multivariable analysis. In general, higher-volume facilities are constructed using higher design standards. Figure 5.32 displays the Fatal & Serious Injury data by the AADT ranges, similar to what is shown is Figure 5.31, with the exception that no trendline is added.

Figure 5.32 AADT Range – Collision Rates: Fatal & Serious Injury



As illustrated in Figures 5.33 and 5.34, the installation of CLRS reduces collision rates across the AADT ranges, with the lone exception noted for volumes above 17,000. Vertical bars above the 0.00 reference line indicate a reduced collision rate and bars below 0.00 indicate an increased collision rate.

Figure 5.33 AADT Range – Difference in Rate: All Injury Severities

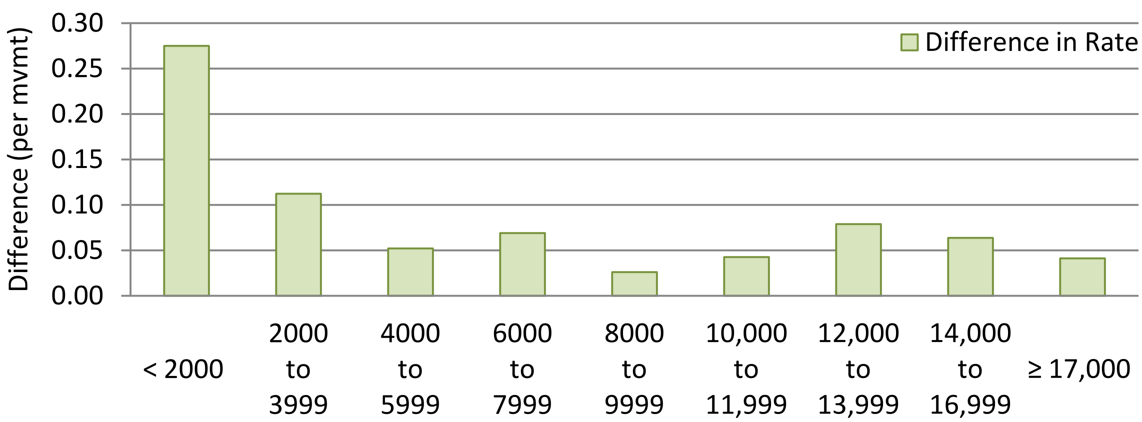
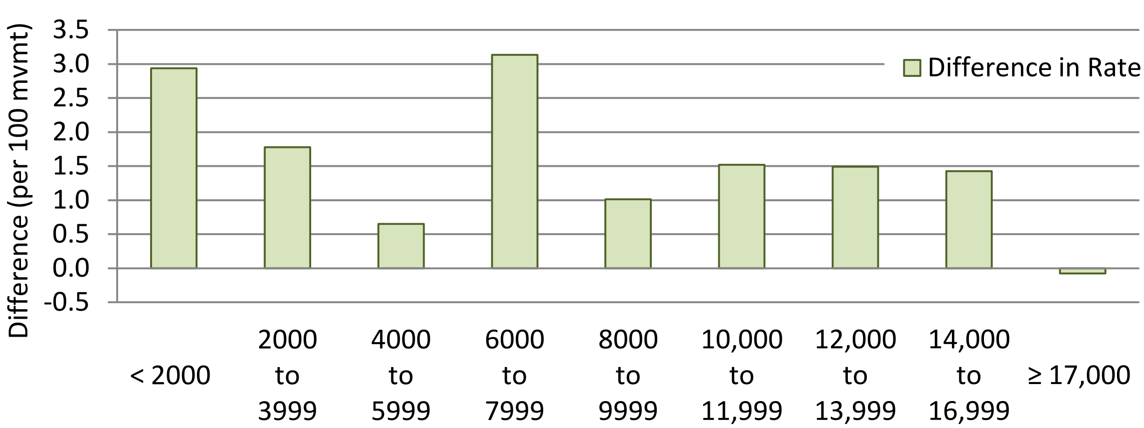


Figure 5.34 AADT Range – Difference in Rate: Fatal & Serious Injury



Overcorrection Collisions

Early in the data acquisition process, the researchers attempted to identify collisions where the driver of a vehicle may have left the travel lane and overcorrected in an attempt to return to the lane, ultimately resulting in a collision.

While reviewing collision reports, the researchers identified those situations when the investigating officer indicated that a vehicle first crossed the centerline or, alternatively, the right shoulder edge line, and then overcorrected back across the travel lane. These collisions were identified with one of two alpha codes:

- An alpha code of **XO** identifies a collision where the driver crossed the centerline and overcorrected back to the right, resulting in a collision off the roadway to the right.
- An alpha code of **RX** identifies a collision where the driver first left the lane(s) to the right and then overcorrected back to the left, resulting in a collision across the centerline.

The dataset contained 395 collisions that were identified as either XO or RX. Of these 395, there were 109 that were also defined as weather-related collisions. Excluding the weather-related collisions, 95 collisions were identified as XO, with 50 records in the before period and 45 records in the after period. For the RX dataset, there were 191 collisions, with 124 records in the before period and 67 records in the after period.

The researchers do not believe that these 395 records encompass the entirety of the crashes where drivers overcorrected. Whether by omission or a lack of evidence, an investigating officer may not have noted this condition, as officers are not required nor instructed to do so. However, even with the caveat that all the overcorrection collisions may not be available, some analysis is possible.

XO Discussion

One of the issues that the researchers wanted to explore was whether CLRS were influencing ROTRR collisions. It was anticipated that the dataset of XO collisions would present some clarity on this possibility. The XO collisions are a subset of the ROTRR collisions. As previously noted, the researchers found that CLRS reduced the rate of all ROTRR collisions by 6.9% and Fatal & Serious Injury collisions by 19.5% (see Table 5.7).

Table 5.16 XO Collisions: Before & After Rates

Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.011	0.013	-0.002	17.3%
Fatal & Serious Injury	0.044*	0.115*	-0.071	160.7%

Most severe injury of crash (one per crash) *per 100 mvmt

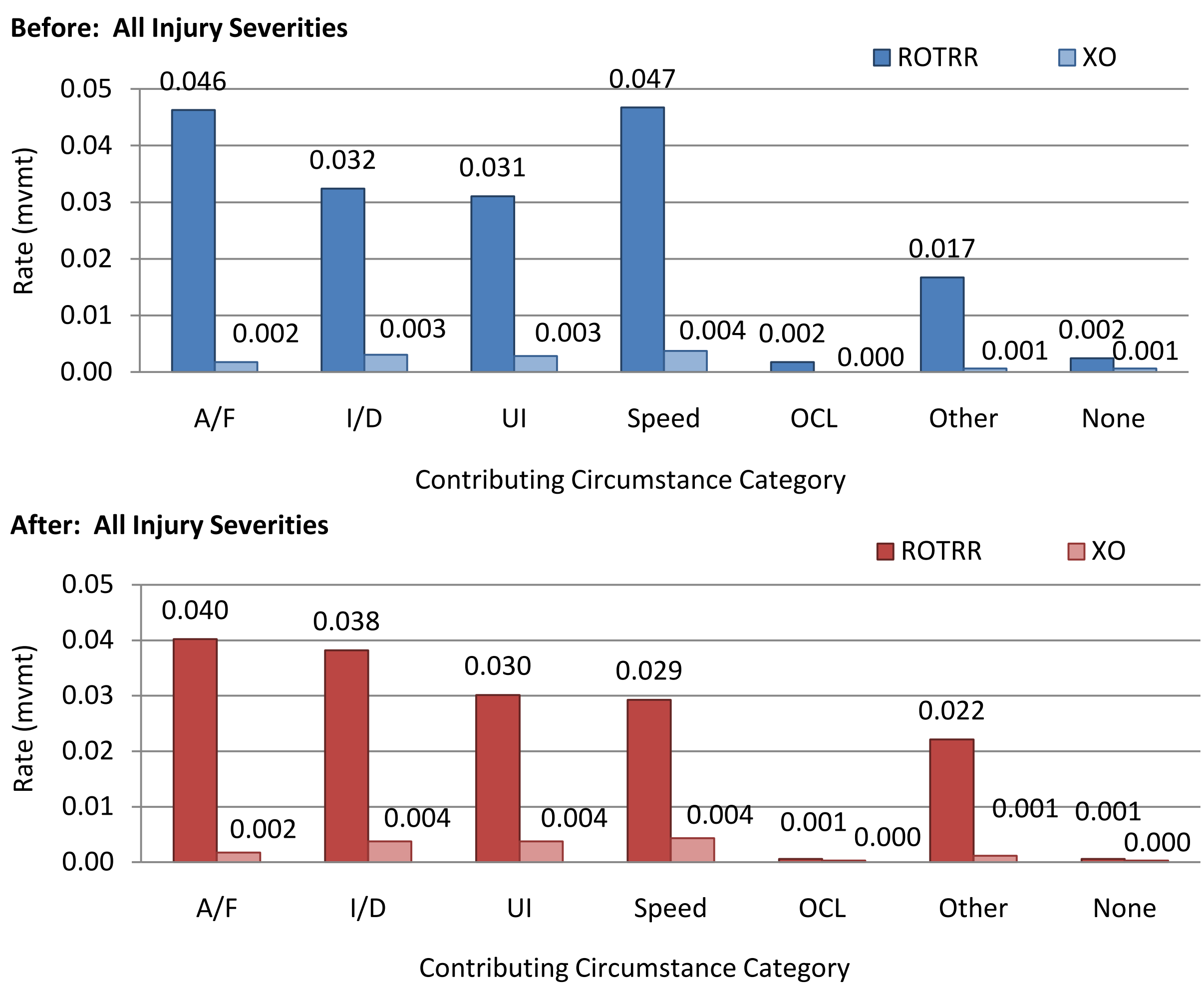
Table 5.16 shows the collision rates for the set of XO collisions, with an increase in the All Injury Severities collision rate of 17.3% after the installation of CLRS. The Fatal & Serious Injury collision rate shows a 160.7% increase in the after period. While the percentage increase in Fatal and Serious Injury collisions is substantial, it is a result of working with small numbers, changing from 2 crashes in the before period to 3 in the after period. These numbers indicate that overall, ROTRR collisions have been reduced; however, those collisions involving drivers who overcorrected have increased in frequency. The researchers explored roadway geometry and driver behavior issues as they looked for the possible causes of this difference in performance.

While examining the curve/tangent component of the collisions, it was found that there was a minor shift in the ratio of collisions occurring on curves or tangents within these ROTRR collisions. The entire ROTRR collision sets (including XO) in the before period had a roughly equal split between curve and tangent locations. 48.1% (362 of 753 collisions) occurred on a curve and 51.9% (391 of 753 collisions) on a tangent. In the after period, this changed slightly, with 51.3% (276 of 538 collisions) occurring on a curve and 48.7% on a tangent (262 of 538 collisions). Narrowing the focus to only the XO subset yielded a substantially different split. The before period showed that 28% (14 of 50 collisions) of XO collisions occurred on a curve and 72% (36 of 50 collisions) occurred on a tangent. With the installation of CLRS, they found that 37.8% occurred on a curve (17 of 45 collisions) and 62.2% (28 of 45 collisions) occurred on tangents.

The XO subset was also found to have a different distribution of contributing circumstances than the ROTRR set. Figure 5.35 shows the before and after collision rates by contributing circumstance for the ROTRR set and the XO collision subset. For the XO collisions, it can be seen that CLRS installations have little influence on collision rates. When evaluating contributing circumstances, the greatest change in rates for the ROTRR set is observed in the Speed category. For the entire set of ROTRR collisions, the rate dropped from 0.047 per mvmt to 0.029 per mvmt. However, within the subset of XO collisions, there was no change within the Speed category; the before rate of 0.004 remains the same in the after period. The Asleep/Fatigued category also saw a reduction in rates from 0.046 in the before period to 0.040 in the after period, while the XO subset saw no change within this same category. Within the Inattentive/Distracted category, the researchers observed an increase in the collision rate 0.032 for the before period, increasing to a 0.038 in the after period. For the XO set in this category, the rate showed a very modest increase from 0.003 to 0.004.

Within the ROTRR collisions, the data suggest that XO-type events are increased with the installation of CLRS. However, it is not clear whether this increase is due to the primary contributing circumstance previously noted or whether the driver is being startled into an overcorrection by crossing CLRS, or a combination of both; the resulting increase is slight. Further examination is limited by the quantity of data available, particularly in the Fatal and Serious Injury categories. The Fatal and Serious Injury XO data set consisted of 5 events: 2 in the before period and 3 in the after.

Figure 5.35 ROTRR and XO: Rates by Contributing Category



The research team was unable to isolate factors associated with the increase in XO collisions through their review of roadway geometry and driver behavior issues.

RX Discussion

The RX collisions reflect circumstances where a vehicle first left the roadway to the right, then overcorrected back across the centerline. They are a subset of the cross-centerline collisions. As previously noted, the researchers found that CLRS reduced the rate of all cross-centerline collision rates for All Injury Severities by 44.6% and 48.6% for Fatal & Serious Injury collisions (see Table 5.8). Collision rates and percent of change for the RX collision subset are shown in Table 5.17. A 29.6% reduction in All Injury Severities and a 1.4% increase in Fatal & Serious Injury rates were observed.

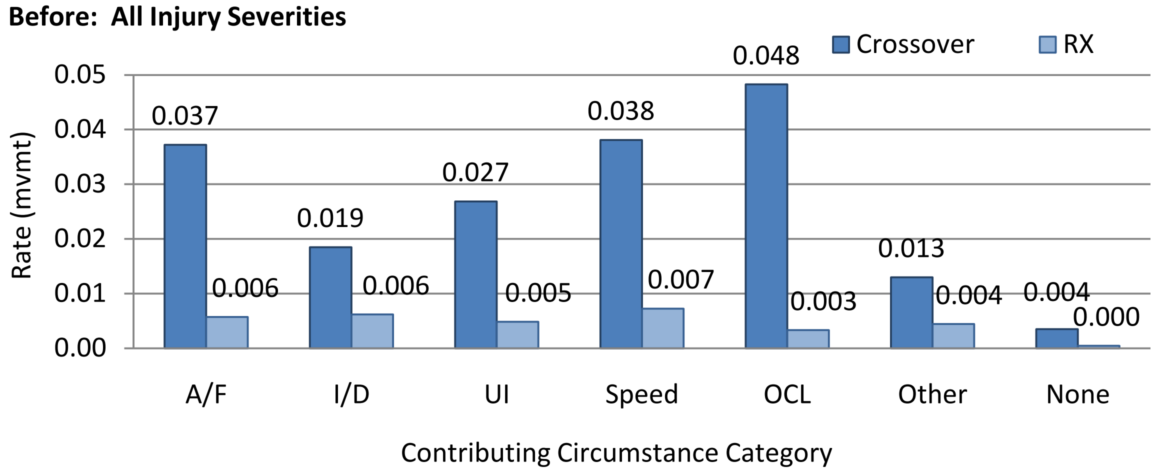
Table 5.17 RX Collisions: Before and After Rates

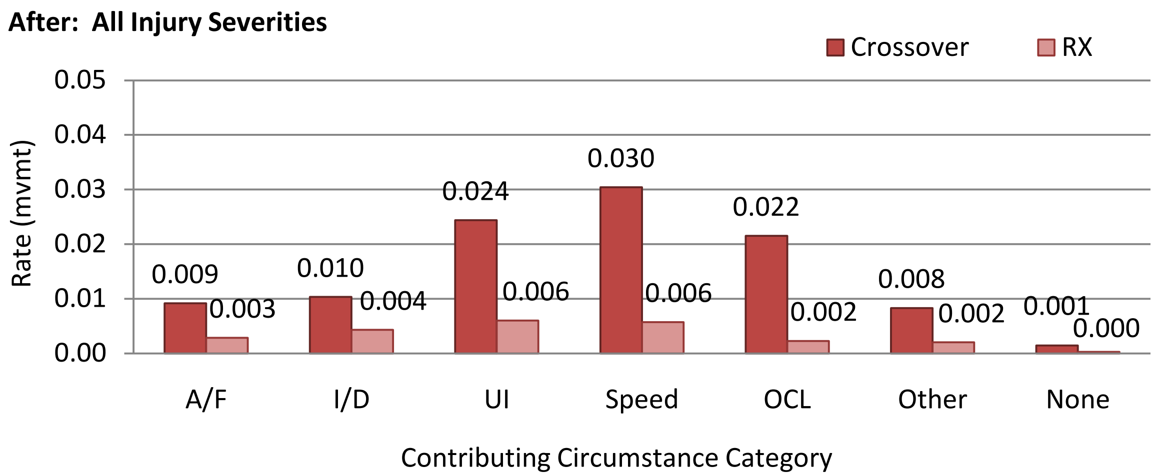
Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.027	0.019	0.008	-29.6%
Fatal & Serious Injury	0.198*	0.201*	-0.003	1.4%

Most severe injury of crash (one per crash) *per 100 mvmt

Driver behavior was examined to further understand the influence that CLRS has on RX collisions. Figure 5.36 graphs the crash rates for cross-centerline collisions and the RX subset in the before and after periods by contributing category. For cross-centerline collisions, a reduction was observed for all contributing categories after the installation of CLRS. As shown, the influence on RX crash rates is not as dramatic as it is for the larger set of cross-centerline collisions.

Figure 5.36 Crossover and RX: Rates by Contributing Category





While the targeted cross-centerline collisions have been reduced after the installation of CLRS, they do not appear to have had as much influence on the rate of RX collisions.

Multivariable Analysis

The previous sections evaluated CLRS performance over a number of individual variables such as posted speed, contributing categories, horizontal alignment, inside/outside of curves, percent length of curve, lane/shoulder widths, and daylight/darkness conditions. The researchers attempted to identify those combinations of variables associated with the best- or worst-performing installations. They explored the multivariable analysis to determine whether the findings might offer insight into design guidance for future installations.

The research team's exploration of variable combinations was extensive; however, reporting on each set of variables and the techniques or tools used was cumbersome and in many instances did not lead to noteworthy findings. This report presents only those sets of variables where interesting trends were observed. Figure 5.37 illustrates one of the tools used and is presented as an example of the process that describes the relationship between the variables.

One of the bivariant combinations examined was the relationship between posted speed limit and lane and shoulder width. Figure 5.37 provides a graphical depiction of those variables. The first three tables on the left side are the crash rates for All Injury Severities, and on the right side are the crash rates for Fatal & Serious Injury. The upper tables are the before period rates, the middle tables are the after period rates, and the bottom tables list the difference in rates.

The fourth table on the bottom left presents the miles of exposure in the study set by posted speed and lane and shoulder widths. As previously mentioned, the value (in feet) of lane and shoulder width is the combined width of the lane and shoulder. The Miles of Exposure table provides information on the sample size used to generate each rate. This information was extremely useful when assessing performance, as small samples do not yield confidence in the findings. The shading in this table was used as a visual aid in the analysis: the darker the shade, the larger the value. This example illustrates that the miles of CLRS installed within the study set increase as posted speed limits and the lane/shoulder width increase, peaking at 60 mph and 18–19' widths, with a total of 73.30 miles.

Figure 5.37 Crossover Crashes: Posted Speed by Paved Width

All injury Severities

Before Rate

Width ↓	< 45	45	50	55	60	65	All
<12'	0.000		0.143	0.219	0.000		0.153
12-13'	0.052	0.237	0.267	0.192	0.000	0.000	0.195
14-15'	0.228	0.167	0.201	0.256	0.200	0.118	0.220
16-17'	0.000	0.343	0.169	0.123	0.190	0.097	0.161
18-19'	0.147	0.094	0.189	0.115	0.143	0.171	0.146
20-21'	0.064	0.070	0.157	0.070	0.093	0.051	0.082
>21'	0.135	0.103	0.000	0.094	0.116		0.108
All	0.155	0.174	0.191	0.136	0.132	0.140	0.147

Posted Speed →

After Rate

Width ↓	< 45	45	50	55	60	65	All
<12'	0.000		0.000	0.000	0.000		0.000
12-13'	0.070	0.050	0.249	0.105	0.068	0.000	0.132
14-15'	0.065	0.104	0.118	0.155	0.029	0.048	0.119
16-17'	0.000	0.055	0.213	0.081	0.092	0.118	0.115
18-19'	0.000	0.000	0.097	0.071	0.085	0.053	0.075
20-21'	0.189	0.000	0.027	0.046	0.038	0.045	0.041
>21'	0.168	0.000	0.000	0.007	0.048		0.031
All	0.069	0.026	0.139	0.076	0.064	0.057	0.080

Posted Speed →

Δ Rate

Width ↓	< 45	45	50	55	60	65	All
<12'	0.000		0.143	0.219	0.000		0.153
12-13'	-0.018	0.187	0.018	0.088	-0.068	0.000	0.063
14-15'	0.163	0.063	0.083	0.102	0.171	0.070	0.102
16-17'	0.000	0.288	-0.043	0.042	0.098	-0.021	0.046
18-19'	0.147	0.094	0.092	0.044	0.058	0.118	0.072
20-21'	-0.126	0.070	0.130	0.024	0.054	0.005	0.041
>21'	-0.033	0.103	0.000	0.087	0.068		0.077
All	0.086	0.148	0.052	0.060	0.068	0.083	0.068

Fatal and Serious Injury

Posted Speed →

Before Rate (100mvmt)

Width ↓	< 45	45	50	55	60	65	All
<12'	0.000		0.000	0.000	0.000		0.000
12-13'	0.000	1.973	6.676	3.390	0.000	0.000	3.511
14-15'	2.175	2.387	4.017	5.836	4.000	3.935	4.409
16-17'	0.000	6.231	4.013	1.533	2.116	0.000	2.523
18-19'	7.368	0.000	2.549	1.398	2.254	1.772	2.033
20-21'	0.000	2.330	2.611	0.467	0.974	0.000	0.821
>21'	0.000	0.000	0.000	1.562	2.729		2.198
All	1.792	2.283	3.781	2.193	2.009	1.554	2.380

Posted Speed →

After Rate (100mVMT)

Width ↓	< 45	45	50	55	60	65	All
<12'	0.000		0.000	0.000	0.000		0.000
12-13'	0.000	0.000	1.660	1.742	0.000	0.000	1.058
14-15'	0.000	0.000	2.358	1.982	0.000	0.000	1.671
16-17'	0.000	0.000	2.127	0.450	1.316	0.000	1.064
18-19'	0.000	0.000	1.381	0.508	2.538	0.764	1.494
20-21'	0.000	0.000	0.000	0.774	0.348	0.000	0.501
>21'	0.000	0.000	0.000	0.000	0.484		0.254
All	0.000	0.000	1.853	0.867	1.238	0.518	1.063

Posted Speed →

Δ Rate

Width ↓	< 45	45	50	55	60	65	All
<12'	0.000		0.000	0.000	0.000		0.000
12-13'	0.000	1.973	5.016	1.648	0.000	0.000	2.453
14-15'	2.175	2.387	1.659	3.854	4.000	3.935	2.738
16-17'	0.000	6.231	1.886	1.083	0.800	0.000	1.459
18-19'	7.368	0.000	1.168	0.890	-0.284	1.008	0.539
20-21'	0.000	2.330	2.611	-0.307	0.626	0.000	0.320
>21'	0.000	0.000	0.000	1.562	2.245		1.944
All	1.792	2.283	1.929	1.326	0.770	1.036	1.317

Miles of Exposure

Posted Speed →

Width ↓	< 45	45	50	55	60	65	All
<12'	0.04		0.30	0.20	0.06		0.61
12-13'	1.22	10.99	6.95	7.35	2.36	0.43	29.30
14-15'	5.49	10.87	23.92	41.02	6.86	4.32	92.48
16-17'	0.89	4.88	25.26	25.78	31.69	3.52	92.01
18-19'	1.72	2.02	11.64	20.91	73.30	37.29	146.89
20-21'	1.12	2.90	2.65	25.77	51.20	9.20	92.84
>21'	1.10	1.03	0.72	7.63	28.41		38.90
All	11.59	32.68	71.45	128.66	193.89	54.76	493.03

The other tables are read similarly; however, in those reporting rates, values of zero (0) may represent either no exposure or no collisions. The tables reporting change in rate (Δ) use negative numbers to indicate a higher collision rate after the installation of CLRS compared to the before period.

Reviewing multiple data combinations in these tables, changes in rates and miles of exposure aided the researchers in conducting some comparative analyses on multiple variables. This helped them identify those variable conditions that contributed to increased or decreased performance where CLRS were installed.

Multivariable Combinations

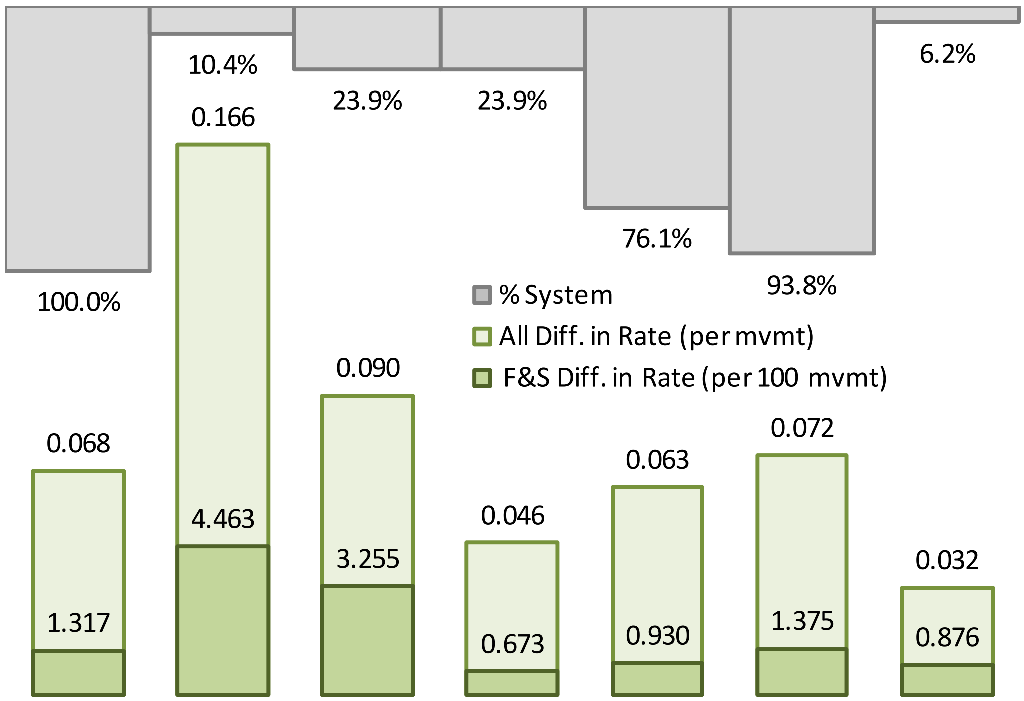
Reviewing all potential combinations of variables yields a daunting number of permutations. The research team's approach was to explore different combinations of variables and focus on those that demonstrated potential to differentiate crash rates. Variables such as time of day, drivers' gender, or make of vehicle were not pursued because they did not offer value in influencing design criteria. The researchers did not expend much effort on the exploration of discrete sets of variables based on small sample sizes. Variables selected for analysis are listed in Table 5.18. Each column heading denotes the general variable, and the conditions or range of each set are shown under the column heading.

Table 5.18 Analysis Variables

AADT	Horizontal Alignment **Cur/Tan**	Functional Class **R/U**	Paved Lane & Shoulder **Width**	Posted **Speed**	% Length Curve **%L C**	Contributing Category
< 2000	Tan	R1	< 12'	30	0 to <10%	A/F
2000 to 3999	Curve	R2	12 to 13'	35	10 to <20%	I/D
4000 to 5999	In	R3	14 to 15'	40	20 to <30%	UI
6000 to 7999	Out	Rural	16 to 17'	45	30 to <40%	OCL
8000 to 9999		U1	18 to 19'	50	40 to <50%	Speed
10000 to 11999		U2	20 to 21'	55	50 to <60%	Other
12000 to 13999		Urban	> 21'	60	60 to <70%	None/NS
14000 to 16999				65	70 to <80%	
≥ 17000					≥ 80%	

Figure 5.38 is a compilation of a number of variable datasets and the performance values found with those specific conditions. It also displays the specific conditions represented for each column: traffic volumes in AADT, speed ranges, lane/shoulder widths, curve/tangent alignment, percentage of length to curve, and rural or urban classification. Values presented in the graph represent the difference in the crash rate between the before and after condition. The percentage of the overall system mileage represented in each set of variables is illustrated by a drop-down bar at the top of the figure. Data are presented using column numbers to simplify reading of the figure.

Figure 5.38 Multivariable Results



Column:	1	2	3	4	5	6	7
Crash Type:	Crossover	Crossover	Crossover	ROTRR	Crossover	Crossover	Crossover
Attribute: AADT	All	< 8000	< 8000	< 8000	or ≥ 8000	All	All
Speed	All	& 45 to 55	& 45 to 55	& 45 to 55	or <45 or >55	> 35	≤ 35
Width	All	& 12 to 17'	& 12 to 17'	& 12 to 17'	or <12 or >17'	& ≥ 12'	or < 12'
Cur/Tan	All	& tangent	All	All	All	All	All
% L C	All	& 30 to <60	All	All	All	All	All
R/U	All	All	All	All	All	& Rural	or Urban
All Before Rate	0.1474	0.2372	0.2697	0.2871	0.1233	0.1528	0.1064
All After Rate	0.0798	0.0708	0.1792	0.2414	0.0606	0.0805	0.0743
All Diff. in Rate	0.0676	0.1664	0.0905	0.0457	0.0626	0.0723	0.0322
F&S Before Rate*	2.3799	5.4739	5.2072	2.2698	1.8211	2.4429	1.9002
F&S After Rate*	1.0626	1.0109	1.9522	1.5972	0.8909	1.0675	1.0242
F&S Diff. in Rate*	1.3173	4.4631	3.2550	0.6726	0.9302	1.3754	0.8760
Miles	493.03	51.24	118.04	118.04	374.99	462.27	30.76
% System	100.0%	10.4%	23.9%	23.9%	76.1%	93.8%	6.2%

* per 100 mvmt

Figure 5. 38 Multivariable Results (continued)

Column 1 represents the entire 493 miles studied.

Column 2 represents the conditions where the greatest difference in rate was observed by the researchers. It is understood that the conditions of a tangent roadway segment and percent of length/curve are not easily modified.

Column 3 describes the same conditions as column 2 (greatest Δ), except that it does not filter for the percent of length/curve and tangent roadway segments.

Column 4 describes the same conditions as column 3; however, it evaluates ROTRR collision rates rather than cross-centerline collisions. These criteria were evaluated to determine the effect on ROTRR collisions under conditions where CLRS are most effective.

Column 5 represents the remaining system mileage after removing column 3 from the data. In effect, this removes the best-performing 23.9% of the system. Interestingly, the delta is only moderately depressed over column 1, which indicates general effectiveness of CLRS regardless of geometric conditions.

Column 6 represents the mileage where all variables evaluated are compliant with current WSDOT *Design Manual* (June 2009) criteria. This represents 93.8% of the miles studied. The difference in rate under the specified design guidance is slightly better than the entire system.

Column 7 represents those miles where one or more of the variables evaluated is inconsistent with current WSDOT *Design Manual* (June 2009) criteria. This column represents mileage not included in column 6; it is 6.2% of the miles studied. This dataset suggests that the difference in rates is significantly below the delta the entire system is reporting.

It is interesting to note that column 3 criteria (traffic volumes below 8,000 AADT, posted speeds in the 45 to 55 mph range, and roadway lane and shoulder widths in the 12- to 17-foot range) significantly outperform the design guidance shown in column 6. Column 3 criteria yield a 58% improvement in the reduction rate for fatal and serious injury crashes compared with current design criteria. The researchers observed a 20% improvement in the reduction rate when looking at all severities.

SECTION 6: CONCLUSIONS / RECOMMENDATIONS

WSDOT has been aggressively installing CLRS on two-lane routes since 2004 as a means of reducing the frequency of cross-centerline collisions. WSDOT instituted the CLRS program based on previous research, which reported a 15% reduction in the number of cross-centerline collisions that resulted in injury after installing this countermeasure. In reality on Washington State highways, cross-centerline collisions have been reduced by 44.6% for All Injury Severities and by 48.6% in the Fatal & Serious Injury crashes (see Table 5.8).

CLRS are very effective in reducing collisions where Asleep/Fatigued drivers are a factor, with a 75.3% reduction for All Injury Severities and a 72.6% reduction in Fatal & Serious Injury collisions. For those collisions where a driver is noted to be Inattentive/Distracted, the results are also favorable, with a 40.9% reduction for All Injury Severities and a 71.0% reduction in the Fatal & Serious Injury collisions (see Table 5.9).

The differences in performance for those circumstances are believed to be related to differences in types of behavior. Distracted drivers are those who intentionally take their attention from the driving task and place it elsewhere, such as adjusting the radio, talking/texting on a cell phone, or interacting with the vehicle's occupants. This diversion of the driving task to another action is substantially different from a driver who is dozing off. Drivers do not intentionally take a nap behind the wheel; however, they are likely to engage in some of the activities listed in the Inattentive/Distracted category.

In some of the more interesting findings, the data showed that on a horizontal curve, the Fatal & Serious Injury rate was almost twice as high for those lane departures to the outside of a curve (straightening out a curve) than to the inside of the curve. CLRS are almost equally effective in reducing Fatal & Serious Injury collisions on both the outside (the 36.8% reduction shown in Figure 5.21) and inside (the 34.4% reduction shown in Figure 5.21) of a curve.

CLRS are more effective on tangents than curves in reducing Fatal & Serious Injury cross-centerline collisions, with a 68% reduction on tangents and a 35.9% reduction on curves (see Table 5.11). These results are associated with the types of contributing categories most often seen in these two roadway alignments. Collisions along highway tangents are most often related to the Asleep/Fatigued driver, in contrast to a curve where those collisions are most often linked to the contributing factor of Speed (see Figure 5.19).

As seen in this study, CLRS are an effective countermeasure regardless of lane/shoulder width, posted speed limit, or any of the other geometric condition examined. There are slight increases or decreases in this countermeasure's effectiveness depending on the geometry of the roadway. However, these are minor differences and do not suggest that there are situations where this countermeasure should not be installed under the conditions evaluated in this study.

Recommendations

The researchers recommend that WSDOT's current guidance continue to be implemented to reduce cross-centerline collisions. The researchers also recommend that investment priority be given to locations with AADT < 8,000, combined lane/shoulder width of 12–17 feet, and posted speed of 45–55 mph.

With consideration of available funding, investment priorities, and site-specific conditions, it is the research team's opinion that the installation of CLRS be pursued for all highways that comply with design guidance. CLRS have proven to be a low-maintenance, cost-effective countermeasure for significantly reducing the frequency of cross-centerline collisions.

GLOSSARY

AADT	Annual Average Daily Traffic: The estimated average daily traffic over a period of one year.
ADT	Average Daily Traffic: The estimated total traffic volume passing a point or on a road segment during a given time period (from one day to one year), divided by the number of days in that time period.
Asleep/Fatigued	Either of the contributing circumstances of “Asleep” and “Fatigued” as noted by the investigating officer of a reported collision.
ATR	Annual Traffic Report: A yearly publication of the WSDOT Traffic Data Office’s Highway Usage Branch.
Avoidance	The act or actions of a motor vehicle operator to avoid or evade an unexpected roadway condition. This may include animals, debris, or other roadway users. The act or actions must be described by the investigating officer. Any evasive maneuver described by the investigating officer would be included in this category.
B/C	Benefit/Cost analysis: A calculation that describes the anticipated value of benefits realized by installing a safety feature in comparison with the initial installation cost and life cycle costs of the feature. Values are expressed as a ratio.
CLRS	Centerline rumble strips: Rumble strips installed on the centerline of the roadway.
Collision	A crash event that results in a death, injury, or a minimum of $700 property damage and involves at least one motor vehicle on a public roadway.
Collision Rate	The number of reportable collisions for a specified segment of public roadway per 1 million vehicle miles of travel, unless otherwise stated.
Contributing Circumstance	A driving action that best describes, in the investigating officer’s opinion, the primary factors associated with a collision. If available, first, second, and third contributing circumstances are collected for each motor vehicle driver, pedalcyclist, and pedestrian involved.
Curve	A nontangential portion of the roadway. A curve-related collision within this study may not have actually occurred within the physical limits of the horizontal curve (begin and end of the curve); however, the curve was believed to have had an influence on the collision.
Evident Injury	Any injury that is evident to observers at the scene of the collision where the injury occurred.

Fatal Collision	Any collision that results in the death of one or more persons due to injuries sustained in the collision. Injuries resulting in death within 30 days of the collision are included in this category.
Fatal and Serious Injury Collision Rate	The number of reportable fatal and serious injury collisions for a specified segment of public roadway per 100 million vehicle miles of travel, unless otherwise stated.
FHWA	Federal Highway Administration
Horizontal Alignment	The geometric attributes of a roadway on a horizontal plane, primarily the tangents or curves of a roadway.
Inattentive/ Distracted	An aggregation of a number of contributing circumstances noted by the investigating officer. There are a number of specific choices the officer may select that would be included in this category: Inattention, Driver Operating Handheld Telecommunication Device, Driver Operating Hands-free Wireless Telecommunication Device, Driver Operating Other Electronic Devices, Driver Adjusting an Audio or Entertainment System, Driver Smoking, Driver Eating or Drinking, Driver Reading or Writing, Driver Grooming, Driver Interacting with Passengers, Animals or Objects in the Vehicle, Other Driver Distractions Inside the Vehicle, Driver Distractions Outside the Vehicle, and Unknown Driver Distraction.
Initial Action	A study-defined circumstance where a vehicle driver initially leaves the lane of travel to the left or to the right and subsequently overcorrects, resulting in a collision. (See "RX" or "XO" for specific initial actions.)
Intentional Acts	A collision where the vehicle operator intentionally collides with another vehicle or fixed object. Vehicles fleeing law enforcement that are involved in a collision while being pursued are also considered intentional acts.
Medical	A collision where the investigating officer states the collision was a result of a medical condition or circumstance.
No Injury	No reported or observed bodily injury due to the collision.
None	A contributing circumstance category where the investigating officer found no contributing circumstance by the vehicle operator; see Appendix A.
Other	A contributing circumstance category where the investigating officer found a contributing circumstance by the vehicle operator that did not meet the choices offered by the Police Collision Traffic Report; see Appendix A.

Over Centerline	The circumstance where a vehicle crosses into an opposing traffic lane.
Passing	For this analysis, passing is defined as an intentional crossing of the centerline to overtake another vehicle; the legality of the maneuver is not relevant.
Possible Injury	Any injury reported or claimed that is not a fatal, serious, or evident injury.
ROTR	Run-off-the-road: A lane departure collision.
ROTRR	Run-off-the-road-to-the-right: A lane departure collision off the right side of the roadway.
Rumble Stripes	A series of milled/formed depressions or raised thermo-plastic devices installed along the right edge stripe; width dimensions will exceed the width of the edge stripe.
Rumble Strips	A series of milled/formed depressions or raised thermo-plastic devices installed on a roadway to alert a driver by means of vibration and/or noise generated from tires rolling over the rumble strips. Normally positioned for travel when the driver leaves the designated travel way. (See Appendix D for WSDOT's Standard Plans for rumble strips.)
Rural	All areas, incorporated and unincorporated, with a population of less than 5,000.
RX	Describes an "initial action" by the driver of a collision where the driver first leaves the traveled way to the right and then overcorrects to cross the centerline, where a reportable collision occurs. This element must have been described or otherwise indicated by the investigating officer.
STCDO	Statewide Travel and Collision Data Office: The WSDOT office formerly known as TDO.
Segment	A specific length of roadway defined for analysis.
Serious Injury	Any injury that prevents the injured person from walking, driving, or continuing normal activities at the time of the collision.
SHSP	*Strategic Highway Safety Plan; Target Zero:* A federally required report, developed to identify Washington State's traffic safety needs and to guide investment decisions in order to achieve significant reductions in traffic fatalities and disabling injuries. The stated goal of the SHSP is to reach zero deaths and serious injuries on Washington State roadways by the year 2030.

Speed	A contributing category or narrative description noted by the investigating officer. This includes the contributing circumstances of exceeding stated speed limit and exceeding reasonable safe speed; see Appendix A.
SRS	Shoulder rumble strips: Rumble strips installed on the right shoulder of the roadway outside the fog line.
Tangent	A straight stretch of roadway.
TDO (see STCDO)	Transportation Data Office
Transverse Rumble Strips	Rumble strips installed across the traveled portion of the roadway, used to alert drivers to a change in roadway character or to traffic control ahead.
Under the Influence	Contributory circumstances noted by an investigating officer; this category includes alcohol and/or drugs (illegal drugs, legal drugs, or prescription or over-the-counter medications or drugs).
Urban	Any incorporated area with a population over 5,000.
VMT	Vehicle miles traveled: A calculation of the number of miles traveled by all vehicles over a specified length of roadway and period of time. Calculated by the number of vehicles per day (ADT) multiplied by the length of the segment of roadway multiplied by the number of days in the evaluation period.
Weather related	Relates to a collision report where the investigating officer noted the roadway conditions of snow/slush, ice, or standing water.
WSDOT	Washington State Department of Transportation
XO	Describes an "initial action" of a collision where the driver first crosses over the centerline and then overcorrects to the right and leaves the roadway, where a reportable collision occurs. This element must have been described or otherwise indicated by the investigating officer.
X-over	Any collision with an impact point across the centerline from the involved vehicle's travel direction. The collision may involve one or more vehicles, with an impact location in either the travel lanes or off the roadway to the left.

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APPENDIX A: CONTRIBUTING CATEGORY TRANSLATION TABLE

Contributing Category	Contributing Circumstance
Asleep/Fatigued	Apparently Asleep Apparently Fatigued Apparently Ill
Inattentive/Distracted	Inattention Driver Adjusting an Audio or Entertainment System Driver Grooming Driver Eating or Drinking Driver Interacting with Passengers, Animals, or Objects in the Vehicle Driver Operating Other Electronic Devices Driver Operating Handheld Telecommunication Device Driver Operating Hands-free Wireless Telecommunication Device Driver Reading or Writing Driver Smoking Other Driver Distractions Inside the Vehicle Driver Distractions Outside the Vehicle Unknown Driver Distraction
Under Influence	Under Influence of Alcohol Under Influence of Drugs Had Taken Medication
Speed	Exceeding Reas. Safe Speed Exceeding Stated Speed Limit
Over Centerline	Over Centerline On Wrong Side of Road
Other	Other Did Not Grant RW to Vehicle Disregard Stop and Go Light Disregard Stop Sign – Flashing Red Disregard Yield Sign – Flashing Yellow Disregard Flagger – Officer Fail to Yield Row to Pedestrian Failing to Signal Failure to Use Xwalk Following Too Closely Headlight Violation Improper Backing Improper Parking Location Improper Signal Improper Passing Improper Turn Improper U-Turn Operating Defective Equipment Driver Not Distracted
None	None (Blank)

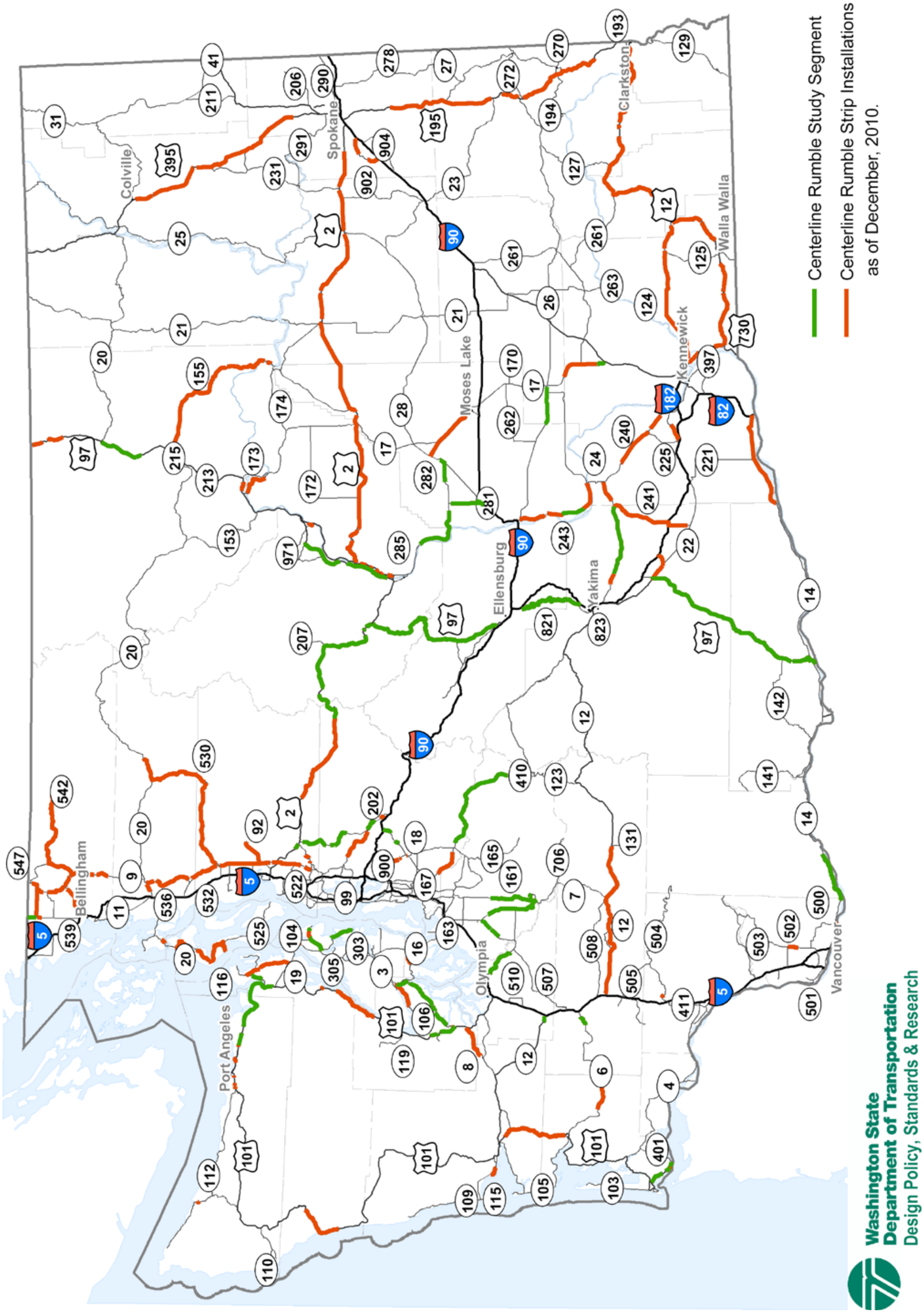
APPENDIX B: LIST OF STUDY SEGMENTS

State Route	Begin Milepost	End Milepost	Crossover: All Injury Severity Before Rate	After Rate	Change in Rate	Fatal & Serious Injury Before Rate	After Rate	Change in Rate
002	12.74	14.33	0.0338	0.0154	0.0184	0.0000	0.0000	0.0000
002	56.76	60.14	0.0000	0.0492	-0.0492	0.0000	0.0000	0.0000
002	60.49	68.43	0.1672	0.1271	0.0402	0.0000	2.5418	-2.5418
002	70.81	99.12	0.0849	0.0431	0.0418	0.9989	1.2325	-0.2336
002	100.91	101.57	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
002	102.37	103.95	0.0291	0.2098	-0.1807	2.9095	0.0000	2.9095
003	3.56	8.37	0.2595	0.0641	0.1954	7.2092	1.2828	5.9264
003	9.07	10.63	0.2406	0.0516	0.1890	0.0000	0.0000	0.0000
003	10.91	18.00	0.1981	0.1834	0.0147	3.0479	1.3102	1.7377
003	18.01	20.37	0.4131	0.0410	0.3722	10.3286	0.0000	10.3286
003	21.30	24.77	0.0930	0.1430	-0.0501	2.3241	4.0871	-1.7630
006	46.67	49.60	0.1568	0.0675	0.0893	3.9202	0.0000	3.9202
007	27.00	44.58	0.1964	0.1381	0.0583	3.1977	2.5892	0.6085
012	44.77	46.22	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
012	315.00	315.07	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
014	21.58	36.96	0.4198	0.2749	0.1449	6.1741	2.7492	3.4249
017	7.59	9.99	0.3831	0.1833	0.1999	15.3249	18.3267	-3.0018
018	20.96	22.13	0.1789	0.0000	0.1789	2.5558	0.0000	2.5558
018	25.08	27.60	0.0913	0.0000	0.0913	1.3041	0.0000	1.3041
020	2.80	6.21	0.1666	0.1324	0.0342	4.1662	0.0000	4.1662
024	9.80	30.50	0.2367	0.0771	0.1596	2.9591	0.0000	2.9591
026	31.17	42.34	0.1660	0.0262	0.1398	3.5567	0.0000	3.5567
028	10.17	19.12	0.1985	0.0299	0.1686	7.7212	0.0000	7.7212
028	19.12	27.70	0.0403	0.0629	-0.0225	0.0000	0.0000	0.0000
028	36.48	43.62	0.1352	0.0000	0.1352	0.0000	0.0000	0.0000
097	0.00	1.88	0.2774	0.0000	0.2774	6.9346	0.0000	6.9346
097	2.59	8.91	0.0172	0.0708	-0.0535	0.0000	0.0000	0.0000
097	9.29	13.68	0.0937	0.0801	0.0135	3.1224	4.0064	-0.8841
097	14.22	33.52	0.1926	0.0598	0.1327	2.4073	0.9974	1.4099
097	33.52	61.37	0.1473	0.0673	0.0800	2.4554	0.7476	1.7078
097	136.60	149.68	0.0180	0.0332	-0.0152	0.0000	0.0000	0.0000
097	149.69	158.80	0.1768	0.0456	0.1312	0.0000	0.0000	0.0000
097	158.81	172.00	0.1911	0.0671	0.1241	4.7782	1.6765	3.1017
097	172.01	184.42	0.0841	0.0833	0.0009	0.9349	3.3304	-2.3955
097	261.31	264.02	0.2885	0.2256	0.0630	0.0000	0.0000	0.0000
097	301.31	314.32	0.0320	0.0584	-0.0264	0.0000	1.1680	-1.1680

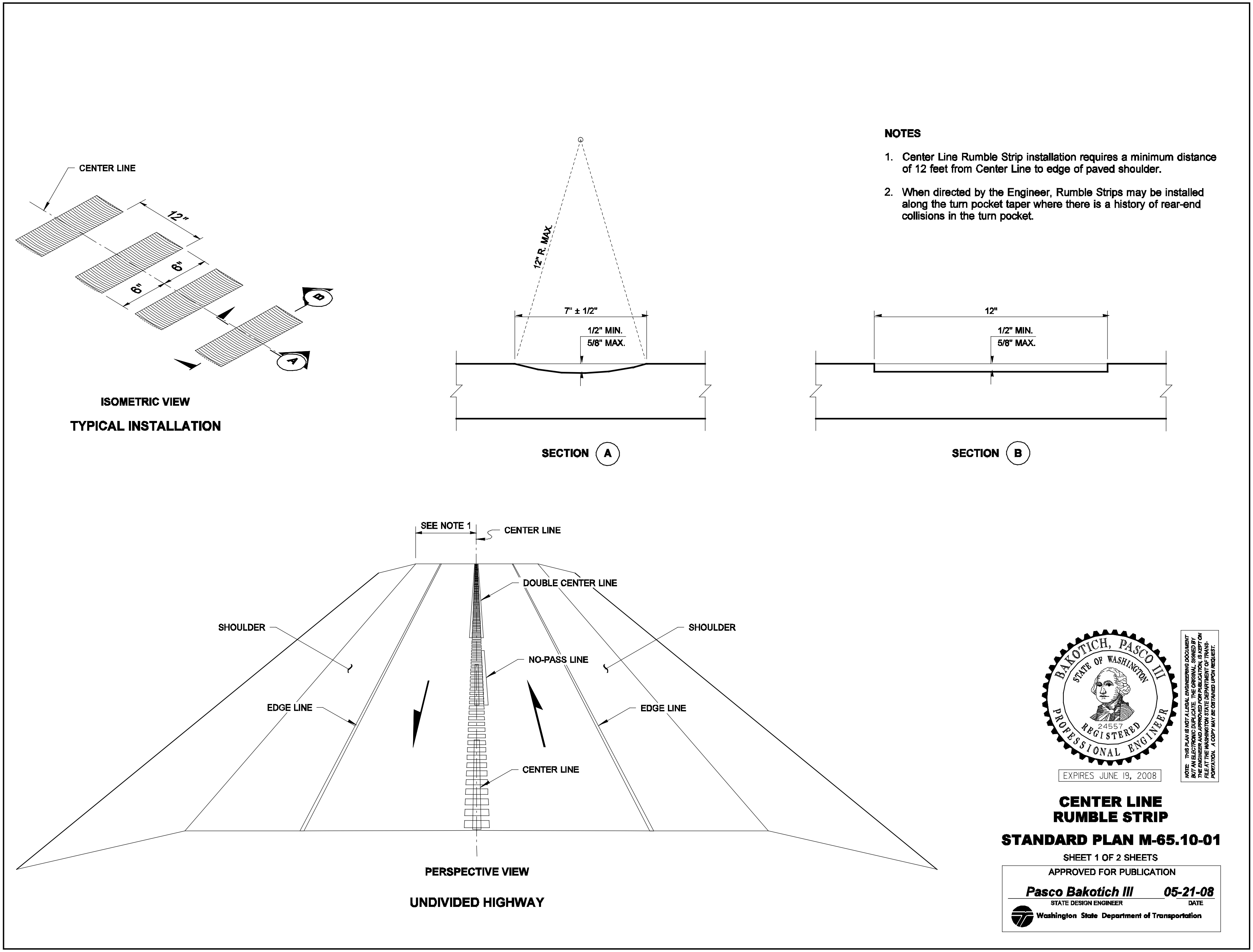
APPENDIX B: LIST OF STUDY SEGMENTS (CONTINUED)

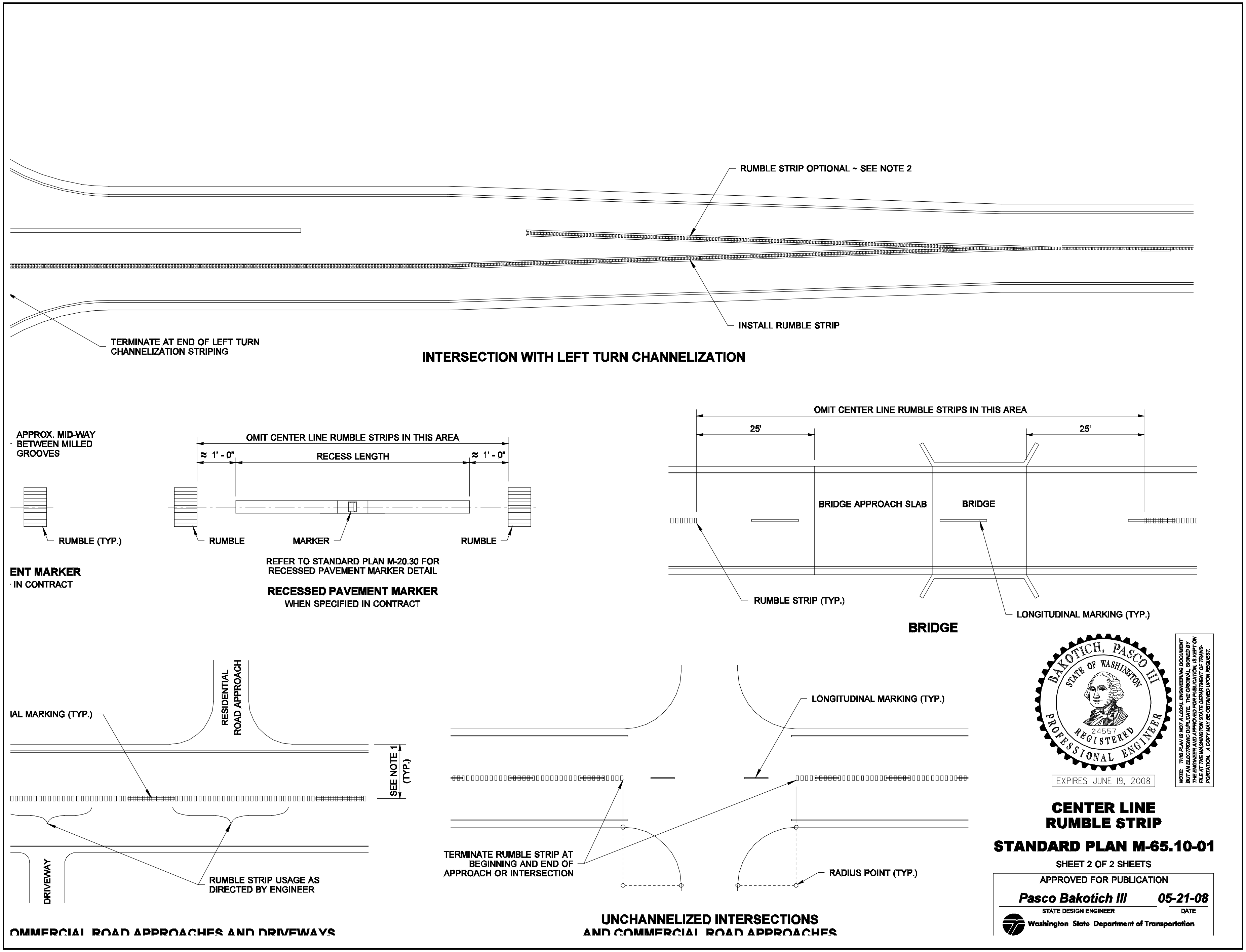
State Route	Begin Milepost	End Milepost	Crossover: All Injury Severity Before Rate	Crossover: All Injury Severity After Rate	Crossover: All Injury Severity Change in Rate	Fatal & Serious Injury Before Rate	Fatal & Serious Injury After Rate	Fatal & Serious Injury Change in Rate
97AR	201.56	214.28	0.1588	0.0758	0.0830	0.0000	1.5164	-1.5164
97AR	216.90	230.15	0.1261	0.1097	0.0165	2.9109	1.8282	1.0828
101	0.47	1.85	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
101	2.46	2.75	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
101	2.91	3.83	0.0847	0.1935	-0.1088	0.0000	0.0000	0.0000
101	5.10	9.39	0.3150	0.2834	0.0316	4.8457	5.6671	-0.8214
101	257.21	260.89	0.0463	0.0373	0.0090	1.1573	1.8637	-0.7064
101	262.92	284.83	0.0912	0.0298	0.0614	1.6096	0.2291	1.3806
101	341.51	343.32	0.1121	0.0000	0.1121	0.0000	0.0000	0.0000
101	343.56	343.74	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
101	344.46	349.23	0.0818	0.0273	0.0545	1.8187	0.0000	1.8187
104	22.71	23.67	0.0422	0.0000	0.0422	0.0000	0.0000	0.0000
161	3.41	4.29	0.6663	0.1233	0.5430	39.9757	0.0000	39.9757
161	4.30	4.65	0.3350	0.6200	-0.2850	0.0000	0.0000	0.0000
161	4.66	6.74	0.3223	0.0494	0.2729	10.7445	0.0000	10.7445
161	6.75	8.10	0.1165	0.2097	-0.0932	0.0000	0.0000	0.0000
161	8.11	15.94	0.2653	0.2445	0.0208	3.1206	1.4382	1.6824
161	15.94	17.47	0.1551	0.1133	0.0418	7.7531	0.0000	7.7531
202	21.94	25.60	0.1784	0.1440	0.0344	1.9820	0.0000	1.9820
203	6.75	12.50	0.2213	0.2040	0.0173	5.5331	1.5692	3.9639
203	12.72	13.80	0.0530	0.0000	0.0530	0.0000	0.0000	0.0000
203	15.13	23.20	0.1529	0.1326	0.0202	0.8992	0.0000	0.8992
243	8.55	15.11	0.2848	0.2002	0.0847	0.0000	0.0000	0.0000
281	0.13	9.96	0.0337	0.0262	0.0075	1.1241	0.0000	1.1241
281SPBURKE	2.65	4.21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
305	0.21	6.82	0.0548	0.0181	0.0368	0.0000	1.8057	-1.8057
307	0.00	5.25	0.1720	0.0475	0.1244	1.7196	0.0000	1.7196
410	25.93	57.50	0.3666	0.1795	0.1871	9.7771	7.6949	2.0822
507	36.52	39.50	0.0795	0.0193	0.0602	0.0000	0.0000	0.0000
507	39.60	43.41	0.1036	0.0838	0.0198	0.0000	0.0000	0.0000
510	4.50	14.46	0.1756	0.1051	0.0705	2.7441	1.3142	1.4298
539	12.58	15.08	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
821	0.13	24.62	0.3380	0.0629	0.2750	2.9390	0.0000	2.9390

APPENDIX C: MAP OF CLRS



APPENDIX D: CENTERLINE RUMBLE STRIP STANDARD PLAN





RUMBLE STRIP OPTIONAL ~ SEE NOTE 2
INSTALL RUMBLE STRIP
TERMINATE AT END OF LEFT TURN CHANNELIZATION STRIPING
INTERSECTION WITH LEFT TURN CHANNELIZATION
APPROX. MID-WAY BETWEEN MILLED GROOVES
RUMBLE (TYP.)
ENT MARKER
IN CONTRACT
OMIT CENTER LINE RUMBLE STRIPS IN THIS AREA
≈ 1' - 0"
RECESS LENGTH
≈ 1' - 0"
RUMBLE
MARKER
RUMBLE
REFER TO STANDARD PLAN M-20.30 FOR RECESSED PAVEMENT MARKER DETAIL
RECESSED PAVEMENT MARKER
WHEN SPECIFIED IN CONTRACT
OMIT CENTER LINE RUMBLE STRIPS IN THIS AREA
25'
25'
BRIDGE APPROACH SLAB
BRIDGE
RUMBLE STRIP (TYP.)
LONGITUDINAL MARKING (TYP.)
BRIDGE
IAL MARKING (TYP.)
RESIDENTIAL ROAD APPROACH
SEE NOTE 1 (TYP.)
DRIVEWAY
RUMBLE STRIP USAGE AS DIRECTED BY ENGINEER
OMMERCIAL ROAD APPROACHES AND DRIVEWAYS
LONGITUDINAL MARKING (TYP.)
TERMINATE RUMBLE STRIP AT BEGINNING AND END OF APPROACH OR INTERSECTION
RADIUS POINT (TYP.)
UNCHANNELIZED INTERSECTIONS
AND COMMERCIAL ROAD APPROACHES
BAKOTICH, PASCO III
STATE OF WASHINGTON
24557
REGISTERED
PROFESSIONAL ENGINEER
EXPIRES JUNE 19, 2008
NOTE: THIS PLAN IS NOT A LEGAL ENGINEERING DOCUMENT BUT AN ELECTRONIC DUPLICATE. THE ORIGINAL, SIGNED BY THE ENGINEER AND APPROVED FOR PUBLICATION, IS KEPT ON FILE AT THE WASHINGTON STATE DEPARTMENT OF TRANSPORTATION. A COPY MAY BE OBTAINED UPON REQUEST.
CENTER LINE
RUMBLE STRIP
STANDARD PLAN M-65.10-01
SHEET 2 OF 2 SHEETS
APPROVED FOR PUBLICATION
Pasco Bakotich III
05-21-08
STATE DESIGN ENGINEER
DATE
Washington State Department of Transportation