HYPOTHETICAL ANALYSIS ON COST EFFECTIVENESS OF CENTERLINE RUMBLE STRIPS AS A CRASH COUNTERMEASURE

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HYPOTHETICAL ANALYSIS ON COST EFFECTIVENESS OF CENTERLINE RUMBLE STRIPS AS A CRASH COUNTERMEASURE

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THESIS ABSTRACT

HYPOTHETICAL ANALYSIS ON COST-EFFECTIVENESS OF CENTERLINE RUMBLE STRIPS AS A CRASH COUNTERMEASURE

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Rural roads are mostly undivided highways with high speed, two-way traffic. These factors coupled with inattentive driver behavior increase the risk of frontal and sideswipe collisions. Widening of roads and installation of barriers or medians are expensive improvement options. Centerline Rumble Strips (CLRS) are a cost-effective countermeasure for reducing head-on and sideswipe crash types by warning distracted drivers of lane departures that lead to an intrusion onto the adjoining lane through tactile stimuli.

This study documents the state-of-the-practice pertaining to CLRS across the U.S. and attempts to establish a selection criterion for identifying locations that warrant CLRS installations. Using this selection criterion in the Critical Analysis Reporting Environment (CARE) software, candidate segments warranting CLRS installations in the State of Alabama were identified. Further, an economic analysis was conducted to determine the benefit to cost ratio for the selected locations by attaching a monetary value to individual crash types, namely fatal, injury, and property damage only (PDO) and comparing them to the cost of a CLRS installation. A 14% reduction in the number of crashes was the expected tangible benefit of CLRS. This value was selected from the Insurance Institute of Highway Safety (IIHS) study of 2003. According to this study, “reliable” data from 7 states with a total 210 miles of CLRS was analyzed and it was concluded that sites treated with CLRS had an overall reduction of 14% in lane crossover crash types. Therefore, the number of crashes represented by the 14% were determined for every segment. The savings in crash cost due to the 14% crashes that would be prevented was the expected benefit of CLRS. The monetary amount incurred due to the installation of CLRS was the only cost that was associated with CLRS. Some other factors which may affect the cost of installation could be the cost of traffic control and speed at which the CLRS installation is performed. Cost of installation from the surveys was found to be $0.55/linear foot and was the only cost that was associated with CLRS in this report. The value of the benefit to cost ratio was found to be 16.5 which establishes CLRS as a cost-effective crash countermeasure. Finally, the segments were prioritized based on the crash rates experienced on the individual segments.

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Style manual used**:** MLA Handbook for Writers of Research Papers (5th Edition)

Computer software used: Microsoft Word, Microsoft Excel, Critical Analysis Reporting Environment (CARE), MINITAB.

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CHAPTER 1

INTRODUCTION

1.1 Background

Rural roads in the U.S. account for almost 40% of all motor vehicle travel and carry 20% of the national traffic. However, rural roads also account for 60% of all fatal crashes, out of which 90% occur specifically on two-lane rural roads. The high percentage of crashes may be explained by the fact that rural roads are high speed routes, generally two-lane and without any physical barrier to separate the two-way traffic. Widening of roads and constructing physical barriers are possible crash countermeasures, but these are expensive options. With rural roads accounting for almost 77% of the nation's highways, such an undertaking will come at a premium. Centerline Rumble Strips (CLRS) have been steadily emerging as a crash countermeasure targeted towards reducing lane departure crossover type crashes. CLRS have the potential to significantly reduce the occurrence of these crash types, improving the status of highway safety nationwide. In the U.S. some states have installed CLRS while several other states are actively researching their effectiveness.

1.2 Objectives

The objectives of this report are:

- To explore the current state-of-the-practice of regarding the use of CLRS.
- Establish a selection criteria that defines the locations or segments that warrant CLRS.
- Identify the sections in the State of Alabama that warrant CLRS.
- Conduct an economic analysis to determine the expected benefits of installing of CLRS in these selected locations.

This report does not focus on design procedures associated with CLRS, such as, specifying the dimensions and installation techniques. However, the material developed through this study may be a useful reference for practitioners when deciding if CLRS are an appropriate crash countermeasure.

1.3 Scope

This study is targeted towards estimating the potential, tangible benefits of CLRS in terms of crash cost savings and the actual number of crashes prevented by their installation on two-lane rural routes in Alabama.

An initial and a follow-up survey explored the state-of-the-practice of CLRS across the U.S. Based on the responses obtained, a set of selection criteria identifying locations for CLRS deployment was established. This set of criteria was queried in the

Critical Analysis Reporting Environment (CARE) software and a list of candidate segments for CLRS installation was extracted from the crash database.

The potential tangible benefits of CLRS installations on the suggested sections of the Alabama routes were determined through an economic analysis. Additionally, the economic analysis also attempted to establish unit crash costs for fatal, injury, and property damage only (PDO) crash types.

The results of this study are specific to the state of Alabama. However, the criteria established and the methodology used for the selection of segment locations that warrant the installation of CLRS may be used by other states working towards expanding their existing CLRS projects or by states contemplating the installation of CLRS from scratch.

1.4 Organization of Thesis

This thesis has been organized into seven chapters, Chapter 1 being the current chapter. Chapter 2 is the literature review to summarizing the state-of-the-practice in reference to CLRS installations in various states across the U.S. The information obtained from the literature review also formed the basis for the preliminary and follow-up surveys conducted for further data collection which have been briefly discussed and summarized in Chapter 3.

Chapter 4 describes the data analysis procedures developed to identify the candidate segments for CLRS installations in Alabama. This chapter also has a brief discussion on the CARE software used for data collection and its application in this thesis. The economic analysis conducted to evaluate the potential tangible benefits of

CLRS in comparison to the costs associated with them, which is the cost of installation in this report, and the results of benefit to cost analysis have been described in Chapter 5.

Chapter 6 contains the conclusions from this study followed by recommendations based on the findings from this research and recommendations for future research on CLRS in Chapter 7.

CHAPTER 2

LITERATURE REVIEW

Shoulder rumble strips (SRS) have been used as a crash countermeasure for a long time, both in urban and rural settings. SRS are an inexpensive and efficient method to alert inattentive drivers, drifting off the shoulder of the roadway, through auditory and vibratory stimuli, so proper corrective action can be taken by the driver. In urban areas where opposing direction traffic is separated by either a concrete or grass median, the chances of head-on collisions and sideswipes are low, even during nighttime driving. However, in a rural setting where the roads are two-laned, narrower and with a lack of non-traversable physical traffic control measures such as wide medians or physical barriers, to separate opposing direction traffic, the possibility of head-on collisions and sideswipes is much higher. The fatality rate per 100 million vehicle miles of travel on rural roads is 2.3 and urban is 1.0 *(Persaud et al., 2003)*

Centerline Rumble Strips (CLRS) are similar to SRS in their appearance but are installed in the center of the road to separate two-way traffic. SRS were first installed on the New Jersey Garden State Parkway in 1955 *(Noyce et al., 2004)* and because they have proven to be successful in reducing run-off-the-road (ROR) crashes by almost 60% *(Russel et al., 2003)* CLRS have also been in active consideration. CLRS are installed along the centerline of undivided highways to warn drivers that they are drifting out of their designated lane of travel. Currently, 20 Department of Transportation (DOTs) out of a total of 50 DOTs across the U.S. and some provinces in Canada are actively using CLRS. Research indicates an overall decrease of approximately 21% in head-on and opposing direction sideswipes due to lane crossovers in rural areas when CLRS was present *(Russell et al., 2005).* The remaining majority seems to have concerns regarding CLRS such as:

i) The noise generated by them especially in residential areas,
ii) Pavement deterioration
iii) Collection of water in the grooves and then freezing during winter months,
iv) Collection of debris in the grooves in arid regions, and
v) Safety of motorcycle and bicycle riders.

According to the Insurance Institute for Highway Safety (IIHS), CLRS data examined for 210 miles of two-lane roads in the seven states of California, Colorado, Delaware, Maryland, Minnesota, Oregon and Washington revealed 15% reduction in injuries, 21% decrease in head-on and sideswipe crashes, and a 14% reduction overall in crash rate *(Persaud et al., 2003).*

In the fall of 1999, Kansas Department of Transportation (KDOT) conducted a small scale phone survey to collect and analyze information regarding the CLRS configuration in use and concerns, if any, associated with them (*Russell et al., 2003)*. The survey included the states of Colorado, Arizona, California, Pennsylvania, Oregon, and Washington; and inquired about basic CLRS information. It formed the basis of the next survey conducted by KDOT, focusing on the current practices regarding CLRS, across all 50 states in the U.S. and all Canadian provinces. The responses received for the latter survey indicated that California, Washington, Oregon, Arizona, Massachusetts, Pennsylvania, Colorado, Connecticut, and Alberta had CLRS installed at various locations. The survey response from Alberta, Canada stated that a recent synthesis report revealed that residents were complaining of noise generated due to vehicles traversing over CLRS. Therefore, testing was conducted on various CLRS designs, varying only the groove depth, to determine the tactile responses due to a vehicle traversing over the CLRS installation. Test vehicles for this study included tractor-trailers, pick-up trucks, and motorcycles. Based on the results, recommendations were made on the CLRS configuration considered most suitable for implementation in Canada. The report concluded that, based on the testing, the most suitable shape would be rounded with 300 mm spacing between the strips. A groove depth of 8 mm +/- 2 mm, strip width of 300 mm with painted lines and a length of 175 mm +/- 25 mm would provide the necessary stimuli without excessive external noise.

Another survey conducted by KDOT in 2000, regarding the construction and placing of CLRS and associated noise generated, revealed issues associated with the deployment of CLRS (*Russell et al., 2003)*. These issues included:

i) CLRS can cause confusion if continued through ‘Passing Zones’,

ii) Inattentive drivers may overcorrect (towards left) into the travel lane and lose control, and

iii) Others may not have an understanding of the auditory and vibratory stimuli possibly due to the lack of awareness of CLRS and may steer off into the adjoining opposing-direction traffic lane.

Therefore, KDOT decided to test 12 patterns which were suitable candidates for CLRS. In May 2000, KDOT went ahead and milled in the test patterns on I-135, over ¼ mile stretches, separated by 200 ft gaps. They tested three sets: (i) continuous 12 inch center to center (c/c), (ii)continuous 24 inch c/c, and iii) alternating 12 inch and 24 inch c/c. Each of these patterns consisted of four different widths of 5 inches, 8 inches, 12 inches and 16 inches respectively. A depth of ½ inch was maintained across all configurations. Seven vehicle types were used at 60 mph which is the posted speed limit in Kansas. Background noise was eliminated as much as possible. Interior noise levels and steering wheel vibrations were collected through Quest Technologies Q-300 Noise Dosimeter and External Microphone and the MicroDAQ SA-600 3-Axis Accelerometer, respectively as shown in Figure 2.1.

Quest Technologies Q-300 Noise Dosimeter and External Microphone

MicroDAQ SA-600 3-Axis Accelerometer

Figure 2.1 Dosimeter and Accelerometer *(Russell et al. 2003).*

The Dosimeter collects data at the sampling rate of 32 samples per second and displays the highest decibel reading taken during any one-second period. It was found that the maximum audible response was between 80 dB and 94 dB at 60 mph by the continuous 12 inch c/c spacing followed by alternating 12 inch and 24 inch c/c spacing and the continuous 24 inch c/c. Overall, it was theorized that patterns with higher densities of indentations produced higher average decibel levels *(Russell et al., 2003).* Steering wheel vibrations were collected through an accelerometer, taped to steering, at 4 readings per second. Drivers were instructed to maintain a minimum but safe contact with the steering wheel. This time however, the alternating 12 inch and 24 inch c/c pattern produced maximum vibratory stimuli followed by the continuous 12 inch c/c and continuous 24 inch c/c.

Based on the results of the testing the following two configurations were chosen for further testing on the highway in summer 2003, the results of which have yet to be announced.

i.) The 12 inch c/c continuous, L = 12 inches, and
ii.) The alternating 12 inch & 24 inch, L = 12 inches.

In the above stated configurations, ‘L’ represents the length of the CLRS perpendicular to the centerline of the roadway.

In August 2001, Colorado DOT (CDOT) published a report on 17 miles of CLRS on the winding, mountainous, 2-lane State Highway 119 with limited sight distance *(Outcalt, 2001)*. The solid double yellow striping was the only traffic control device being used on the chosen segment of the highway. The CLRS were milled through “No

Passing" zones only and discontinued at intersections. The cost of the CLRS installation was approximately $0.87/ linear foot, which included all traffic controls, replacement of pavement marker materials and milling costs. Data acquisition was carried out for the duration of 44 months before and after the installation of CLRS.

This report published by CDOT noted that the number of crashes per million vehicles for head-on type reduced by 34% and sideswipes by 36.5%. The 18% increase in AADT when included made the "reductions become even more impressive" *(Outcalt, 2001)*.

Figure 2.2 Centerline Rumble Strips on State Highway 119 in Boulder Canyon, Colorado, (Report CDOT-DTD-R-2001-8).

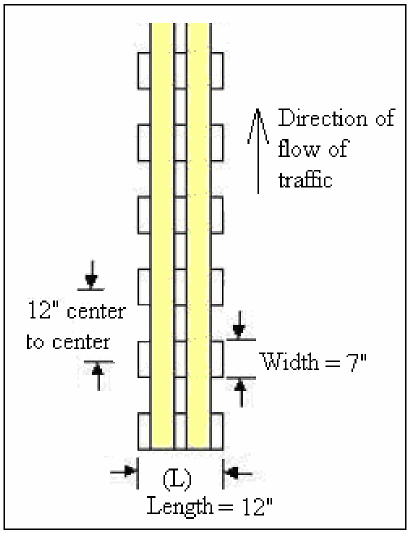


Figure 2.3 Dimensions of CLRS installation, State Highway 119, Boulder Canyon, Colorado

There were concerns regarding the safety of motorcycle and bicycle riders in mountainous regions with no shoulders. Findings indicated that dirt and sand that accumulates in the grooves gets damp during cool weather but as the pavement surface begins to dry up, so does the sand, such that by the time pavement surface is completely dry, there is no water in the grooves. Also, the passing traffic causes air movement that assists the quick drying of grooves. The auditory and vibratory signals remained unaffected by the build-up in grooves. Though no deterioration of asphalt was noted, it was observed that the pavement marking paint tends to wear out faster, due to the traffic traversing over the CLRS.

Studies were conducted for a 2.9 mile section of US 301 with CLRS, in Delaware as shown in Figure 2.4 *(DelDOT, 2001).*

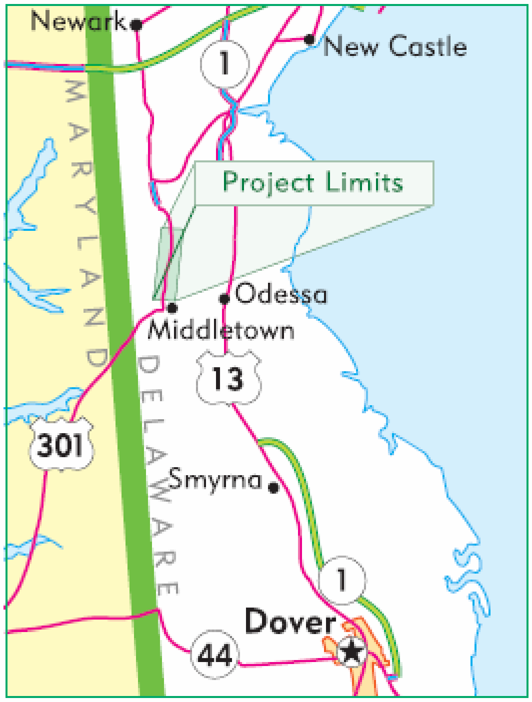


Figure 2.4 Centerline Rumble Strips, the Delaware experience *(DelDOT,2001)*

This was a before-and-after study which compared the average yearly crashes in occurring in a three year period before installation to the average yearly crashes occurring in the seven years duration, post-installation. The study revealed that though the percentage of injury and PDO crashes increased by 4% and 13% respectively, there was a 95% decrease in head-on collisions, 60% decrease on cross-overs, along with a 4% increase in AADT. No fatal crashes were reported during the seven year after-installation period. The cost of installation ranged from \$0.20/ linear foot to \$0.60/ linear foot, depending on the miles of installation (i.e. more miles resulted in lowered installation costs). An overall benefit to cost (B/C) ratio was calculated to be 110 *(Delaware DOT, 2001)*. The values obtained for crash reduction in this case are much higher than reductions reported from other states with CLRS installation. These observations may be attributed to the fact that this was the only section with CLRS in Delaware and may not be reflective of the typical crash reductions observed due to installation of CLRS.

The California DOT tested the effects of CLRS in no passing zones and, after a review of three years of before and after data, found that crashes decreased by 11% and fatalities decreased by a staggering 71%*(Russell et al., 2005).*

As none of the previous studies and evaluations had documented driver behavior and reactions towards CLRS, the University of Massachusetts at Amherst developed simulations models to mimic real conditions and observed the distracted motorist's reflexive reaction to CLRS under varying environmental scenarios *(Noyce et al., 2004).* Both male and female drivers were selected across a range of age groups. Different scenarios that the drivers encountered included (i)the presence of CLRS, (ii) presence of SRS, (iii) passing zones, (iv) no passing zones, (v) curves and (vi) straight stretches. Drivers were distracted by being asked to read billboards and look out for the letter "V". The roadway was shifted in the simulator to make sure that the rumble strip, CLRS or SRS, was encountered. A combination of foggy, nighttime environment and driver distraction created an extreme situation where the driver's reflexive reactions would be evaluated and hence the final results obtained would be reflective of the actual driver reactions on the road.

After analyzing the data, the authors determined that drivers took about 125 milliseconds more to return back into the lane with the presence of CLRS in comparison with the absence of CLRS. They also noted that the return time value decreased as encounters with CLRS increased. Drivers, on average, took 250 milliseconds more to return into the travel lane after running over SRS as compared to CLRS.

Results pertaining to the driver's direction correction, once the CLRS were traversed, indicated that 28% corrected left initially, when encountering CLRS for the first time. Also, 27% corrected left instead of correcting right, 37% corrected left (in curve and in no passing zones, 27% corrected left in curve and in passing zones and between 20 and 23% corrected left on straight segments of the roadway. No opposing traffic was used in any of the simulations. Gender differences were not significant. However, no right direction corrections were made by the drivers traversing SRS. This could mean that drivers are more comfortable with SRS due to previous experiences *(Noyce et al., 2004).*

Figure 2.5 Driving simulator at the University of Massachusetts, Amherst *(Noyce et al., 2004).*

A before-and-after observational study was conducted in Pennsylvania documented the effect of CLRS the lateral placement of vehicle *(Mahoney et al., 2004).* The study defines lateral placement as the "location of vehicle's longitudinal axis relative to a longitudinal road reference system". For this study, the longitudinal axis was assumed to run through the centriod of the vehicle and the longitudinal road reference system was the centerline of the road. Data was collected at four two-lane rural sites in two distinct phases, each separated by a period of about four months. CLRS was installed at two locations with 11 foot and 12 foot lanes, after the first phase of data collection was complete. These were called the 'treatment' sites. Each treatment site had a corresponding 'comparison' site for purposes of before and after data comparison, to identify the influence of factors other than the CLRS, if any, on lateral vehicle placement and speeds of the vehicles. The study concluded that CLRS affected both the mean and variance of lateral placement of vehicle. The shift in vehicle placement was 7.5 inches to the right of the centered vehicle path for 12 foot lane and 3 inches for the 11 foot lane after CLRS were installed; as compared to 2 inches and 6 inches to the right of the centred vehicle path before the CLRS installation. The variance in lateral vehicle placement was also found to decrease significantly post CLRS installation. The study also analysed speed data and no conclusion was drawn between the speeds and presence of CLRS.

A study was recently completed in Japan which worked towards establishing the monetary and safety benefits of CLRS by comparing it with other safety measures being used to prevent head-on collisions *(Hirasawa et al., 2005)*. The development of optimal CLRS configuration and assessment of the safety benefits on the rural two-lane national highways of Hokkaido, which were experiencing fatal head-on collisions, was done through field testing of various configurations of CLRS. This study was conducted to arrive at a configuration that would provide sufficient vibratory and auditory responses in an effort to reduce head-on crash occurrence. Three distinct patterns of groove depths 9 mm, 12 mm and 15 mm were tested at 40, 60, 80 and 100 km/h. It was observed that pattern 3 with 15 mm groove depth provided the highest auditory and vibratory stimuli. Also, all three patterns produced sound levels which were 15 dB higher than the sound generated inside the vehicle on pavements without such warning facilities. Subjective evaluations of the danger felt by the motorists, including bicycle and motorcycle riders was also used in determining the optimal configuration. Observations were made to check the effect of CLRS on driving speeds of vehicles compared to other safety improvements which were the median strip, center poles and chatter bars or traffic bars as shown in .

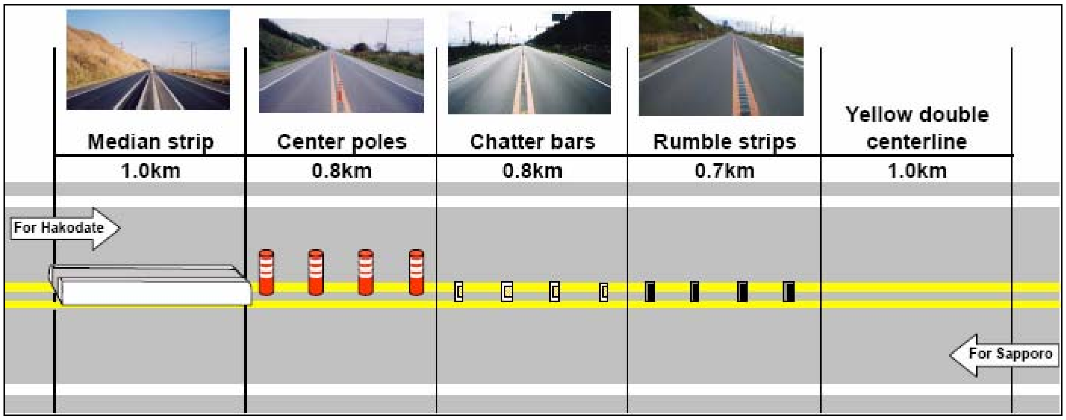


Figure 2.6 Countermeasures Installed on a Section of National Route 5 in Japan *(Hirasawa et al., 2005)*

These four improvements were installed over a single stretch, in succession, for a total length of 4.6 km. The differences in the speeds of the vehicles in one direction only, were noted and it was found that they were within 2km/hr of each other. Hence it was assumed that the different safety measures did not affect driving speeds of the vehicles.

Sound and vibration levels were also measured on winter roads. With slushy road surfaces and CLRS not visible, the sound levels were 75 to 80 dB as compared to 60 to 65 dB in the absence of CLRS and vibrations were 95 to 105 dB when traversing the strips as compared to 90 to 95 dB on smooth pavement. Therefore, the stimuli were found adequate on compacted-snow surface and slushy road surface. A reduction of 55.2% was noted after the CLRS were installed. The study recommended the 12 mm groove depth with 150 mm longitudinal width and 350 mm transverse width. As of March 31, 2005, 111.9 km of CLRS have been installed at 61 locations on Japan's National Route 5.

From the various studies, the reduction, observed and documented across all crash types, after CLRS had been installed in 20 out of 50 states in the U.S. is substantial evidence regarding the credibility of CLRS. Findings of the literature review indicate that research is currently in progress across the U.S. and Canada to arrive at a configuration for CLRS which provides optimal auditory and vibratory stimuli; however, the CLRS dimensions are still not standardized. Studies in Japan noted the optimal CLRS configuration based on combined results of field testing driver inputs. Overall, the results from the various studies conducted, look positive for the potential of CLRS in crash reduction and cost effectiveness at the same time. Though the transportation agencies across the U.S. do have concerns regarding settling of debris, pooling of water in grooves, pavement deterioration, noise generated by vehicles traversing the CLRS and safety of motorcycle and bicycle riders; the reports from field evaluations of CDOT and Japan found some of these concerns invalid.

A survey was therefore conducted by the Auburn University's Highway Research

Center in early 2005 which attempted to explore the current state of practice and collect information on CLRS with regard to concerns, challenges, and costs associated with CLRS.

CHAPTER 3

STATE OF PRACTICE SURVEYS

3.1 Preliminary Survey

A preliminary survey for this study was conducted aimed at obtaining information regarding the state-of-the-practice of CLRS across the U.S., including an estimate of cost of installation and concerns associated with CLRS. The preliminary questionnaire consisted of sixteen questions sent out to all fifty states in December 2004. A response rate of 52% (i.e. 26 out of 50) which included the states as listed below in Table 3.1. The complete questionnaire is available in Appendix A.

Table 3.1 Preliminary Survey Respondents.

Arizona	Arkansas	Colorado	Florida
Hawaii	Idaho	Iowa	Louisiana
Maine	Michigan	Minnesota	Mississippi
Missouri	Montana	Nebraska	New Jersey
Oklahoma	Oregon	Pennsylvania	South Carolina
Texas	Vermont	Virginia	Washington
Wisconsin	Wyoming		

The complete results of the survey have been tabulated in Appendices B1 through B3. The responses are briefly summarized as follows.

1) *Does your state use the Centerline Rumble Strips?*

26 out of 50 states responded to the survey (52%). Out of these 26 states, 13 were using CLRS on actual highway settings (50%). Florida, Missouri and South Carolina had project installation sites for CLRS installed for research purposes and not subjected to the action of traffic (12%) and 10 were not using them at all (38%). In a unique installation, Oklahoma reported that the only application they had of CLRS was on a five lane highway, along the margins of the two-way left turn lane, when speeds exceeded the posted speed limit of 45 mph.

2) *What criteria were used to determine the installation location?*

15 out of 26 states indicated that candidate locations for CLRS installations would be those with higher than average crash history of head-on, sideswipe, and crossover crash types. All of these 15 states have CLRS installed on actual highway settings (58%). Of the remaining 11, 9 states were not using CLRS and two had experimental project installations with evaluations in progress to check the effectiveness of CLRS.

3) *What pattern is being currently used? Rolled/Milled/Corrugated/Raised?*

Fourteen out of the twenty six states that responded to the survey, experimental installations included, are actively using the milled method of construction (54%). Colorado and New Jersey indicated using both rolled and milled. Virginia had used the rolled pattern for 1.5 miles for their pilot site for tested in 1999 but had discontinued its future usage. Florida reported having an experimental project installation using the raised type CLRS.

4) *Please provide the detailed dimensions currently being used for Centerline Rumble Strips OR enclose a copy of the standards / specifications used, with the survey response*.

Out of the 26 states that responded to the survey, the continuous 12 inch c/c pattern is in use in 11 states (43%), followed by continuous 24 inch c/c in four states (15%). The configuration of transverse width of 12 inches and longitudinal width of 7 inches is in use on actual highway settings or experimental projects in five states (19%). The configuration of transverse width of 16 inches and longitudinal width of 7 inches is in use on actual highway settings or experimental projects in 7 states (27%). However, by itself, 12 inches is in use in 9 states (35%) and 16 inches in 8 states (38%). 14 out of 26 states use 7 inch as the longitudinal width (54%). 13 out of 26 states were using minimum groove depth of ½ inch (50%).

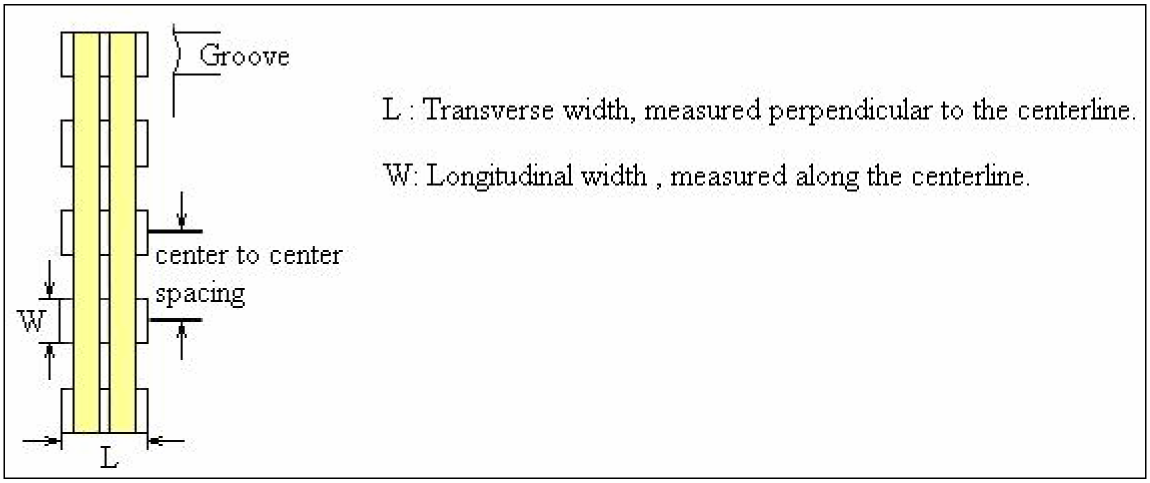


Figure 3.1 CLRS Dimension Nomenclature

5) Does the design configuration vary across the state? (e.g. Topography, rural / urban)?

This question was aimed at getting an estimate on whether location of installation makes an impact on the design of CLRS. Minnesota, Washington and Pennsylvania reported that CLRS design was varied based on location of installation. Configurations remained unchanged in the remaining states.

6) How many miles have been installed and when did the installation commence?

The lengths were reported to vary from a small test section of approximately 5 miles in Wyoming to 1500 miles of CLRS spread out over 250 locations across the state of Pennsylvania. The date of commencement of the first CLRS installation in each state was also requested, to get an estimate of how long CLRS have been in use across the states. The oldest installation, as noted from survey results, was in 1996 in Washington State and the latest in spring 2005. Evidently, CLRS have been in use for at least a decade.

7) Is the cost of installation of Centerline Rumble Strip included along with other contract bid items or is it a separate item? What is the typical cost or range of costs?

Whether CLRS are included as a separate bid item in construction contracts or along with other items is a decision of the state. 9 states listed the installation of CLRS as a separate bid item. The cost was typically around $0.20/linear foot. However, there were states where the cost of installation was as high as $1.50/ linear foot. The highest unit cost for the installation of CLRS was in the state of New Jersey at $4.50/ linear foot.

8) What are the evaluation criteria for effectiveness of Centerline Rumble Strips? (Safety /Cost /Road Geometrics /Weather /Driver inputs / Other /Evaluation underway/ No evaluation done)?

The 8 options provided to describe the effectiveness of CLRS installations are explained as follows:

i) Safety: Crash reduction following the installation of CLRS.

ii) Cost: Savings in crash costs following the installation of CLRS.

iii) Road Geometrics: If CLRS were installed in specific locations, such as no passing zones or curves.

iv) Weather: If weather in the region had any influence on the performance of CLRS.

v) Driver Inputs: These were direct feedbacks from the motorists.

vi) Other: If the sate had a method of evaluation other than those listed.

vii) Evaluation Underway: State conduction research or field evaluation of CLRS

viii) No Evaluation done: No evaluation of any sort has been done till date, to evaluate the effectiveness of CLRS.

In 8 out of 26 states that responded, the primary evaluation criterion was safety (31%), followed by costs in six states (23 %). Michigan reported to relying on driver inputs and influence of weather for evaluation. Four states reported having no evaluation carried out though all four of these were actively using CLRS as seen in Appendix B3.

9) Have the auditory and vibratory levels produced by the chosen pattern been measured?

For CLRS design to be effective, it must be able to generate noticeable vibratory and auditory stimuli, louder than the background noise in a vehicle and higher than vibrations due to the engine of the vehicle. At the time of this survey, from the data collected, Colorado, Pennsylvania and Michigan were the only states that reported having documented the auditory and vibratory response data. However, this data was for SRS. CDOT had measured the auditory and vibratory responses of 14 patterns tested with four different vehicle classes at the 55 mph and 65 mph. Sound measurements were conducted on a smooth pavement to observe the changes in sound level when vehicles traverse over CLRS. The auditory responses varied from about 60 dB to 80 dB. CDOT also tested these 14 patterns for the development of bicycle friendly SRS at speeds of 5, 10, 15 and 20 mph. 29 bicyclists evaluated and compared the SRS sections according to comfort and maneuverability. Vibration levels were measured with an accelerometer mounted on the bicycle. It was concluded that motor vehicles and bicycles have very different requirement with respect to the rumble strip configurations. CDOT recommended using the standard 12 inch continuous pattern with a 12 inches transverse width, 7 inches longitudinal width at a groove depth of 3/8 inch (± 1/8 inch). They found that this depth provided a relatively high level of sound and vibration in motor vehicles and the bicycles could safely traverse across this groove depth without any loss of control. Field evaluations by Pennsylvania DOT revealed that highest average auditory response of 83 dB was recorded at 65 mph. None of the other states reported having measured the auditory or vibratory stimuli.

10) *What were the challenges and/or concerns faced during installation (if any)?*

Challenges and concerns regarding CLRS varied widely across the states, from difficulties in traffic control to maintaining the required uniform depth of CLRS while milling. Complete results have been tabulated in Appendix B1.

11) Have any warrants, policies, or guidelines been created which are directed towards the installation of the Centerline Rumble Strip?

Colorado, Pennsylvania and Oregon reported having active guidelines for CLRS, at the time of this survey. Missouri, Washington State and Virginia were working towards developing guidelines or policies, while the remaining 20 states did not have any because they either had only experimental installations or were not using CLRS.

12) Were any special signs developed to alert the motorists about the presence of the Centerline Rumble Strips ahead-on the road? If yes, please describe in detail or include figure.

Colorado, Idaho and Michigan reported that they had developed signs to alert the motorists about the CLRS installations. Idaho placed a portable message sign trailer at the two ends of each installation indicating "NEW CENTERLINE RUMBLE STRIPS NEXT <u>XX</u> MILES". Michigan DOT installed a yellow warning sign stating "CENTERLINE RUMBLE STRIPS AHEAD". Colorado DOT installed the yellow warning signs, shown in Figure 3.2 and Figure 3.3.

Figure 3.2 Sign developed by CDOT to alert the motorists.

Figure 3.3 Sign developed by CDOT to alert the motorists.

13) *How were the general public, made aware of this 'new' installation?*

Out of the 26 states, 6 actively made the public aware of the 'new' installation though public meetings, media services and public service announcements (23%). Two states let motorists 'discover' the CLRS by themselves; seven states reported that no additional attempt was made to make the general public aware of the presence of the newly installed CLRS. No additional information was provided regarding initial impact of CLRS.

14) Did regional factors have any effect on performance of Centerline Rumble Strips? (e.g. Snow in the northern regions, debris buildup in the grooves in dry, arid regions or any other related factors).

Though the installation locations of CLRS vary from mountainous terrain to deserts and urban to rural, nine states (out of the 26 that responded) which were actively using CLRS, as reported in the survey responses, did not find any influence of regional factors on CLRS (35%).

15) *Was any special consideration given to bicycle or motorcycle traffic during the design or selection of installation locations*?

Apart from Wyoming, none of the states have expressed concern for bicycle and motorcycle riders. Maine had noted concern for motorcycles. Wisconsin and Missouri are reviewing the effect of CLRS on bicyclists and motorcyclists. However, bicycle riders are not of particular concern presently.

16) Any additional comments?

This question made room for any additional comments from the DOT responding to the survey about CLRS. Comments from the state DOTs have been included in Appendix B1.

The complete results of the preliminary questionnaire are as tabulated in Appendices B1, B2 and B3. The major concerns across the states, as noted through this survey, are associated with noise, maintenance, accumulation of debris in grooves, pavement deterioration and concern for motorcyclists.

3.2 Follow-up Survey

Amongst the states that responded to the preliminary survey, since only some of the states are actively using CLRS in a real highway setting, the next step was to focus on those states and obtain more specific and detailed information pertaining to CLRS. Based on the responses received from the preliminary survey, 13 states which reported having active CLRS installations (i.e. installations on actual highway settings were chosen for the follow-up survey). However three states could not be reached. The ten states contacted to further information on CLRS installations are as tabulated in Table 3.2 The states were contacted between March and early May 2005.

Table 3.2 Candidate States for the Follow–up Survey.

Arkansas	Colorado	Michigan	Minnesota
Nebraska	Oregon	Pennsylvania	Virginia
Wisconsin	Wyoming		

For the follow-up survey the person in charge of CLRS installations for the respective state was directly contacted. The complete results of the survey have been included in Appendix C. Arkansas DOT could not be reached via e-mail or telephone. The responses to the questions for the follow-up survey are briefly summarized as follows.

1) How were the dimensions for CLRS decided upon?

Since design configurations of CLRS are analogous to SRS, it would be informative to know the methods that the sates were adopting to arrive at the patterns and dimensions being used. At the time of survey, Pennsylvania was the only state that reported to having done extensive research to come up with their design. No response was obtained from Arkansas, Michigan and Wyoming. The remaining seven states have dimensions based off SRS.

2) According to the state's response, no values for auditory/vibratory stimuli have been provided. If no tests have been conducted, how was the depth of the grooves decided?

Though this question was covered in the preliminary survey, none of the respondents, except Colorado, reported to having measured the tactile stimuli, though, for bicycle friendly SRS. Of the ten states that were contacted, Colorado, Minnesota, Nebraska and Wisconsin reported that auditory and vibratory responses of the groove depth of SRS were considered acceptable. Pennsylvania and Virginia reported that the CLRS groove depth in use was determined through research and field testing of various groove depths and measuring the tactile stimuli responses.

3) What audible levels were considered "noise" by the residents?

During the preliminary survey, several states had expressed concern for noise generated by vehicles traversing over the CLRS. Colorado, Oregon, Pennsylvania and Wyoming responded that noise was not a concern. Minnesota had guidelines to stay within noise levels in residential areas. Minnesota was one of the three states that reported having the design configuration vary across the state as response for question number five in the preliminary survey. Nebraska reported “any noise at all” to be noise but did not report following any guidelines for installations to mitigate the noise. None of the states provided an exact value for sound levels considered “noise”.

4) How was the depth of the groove measured while milling?

Achieving the correct groove depth is essential for providing the right amount of tactile stimuli. This question was targeted towards exploring the methods applied to make sure the groove depth is milled to the designed groove depth. These methods included performing manual checks at regular length intervals or at the end of the day and using electronic devices installed on-board the milling equipment which permit a +/- 5% margin of error during milling operations. Also, from the preliminary survey responses, it was observed that more states had provided a margin of error for groove depth than the other two dimensions. For example, the design for CLRS groove depth in New Jersey is ½ inch +/- 1/8 inch as compared to only one state having tolerance for the longitudinal and transverse width. This means that the grooves are required to be milled to ½ inch depth and the +/- 1/8 inch in the design accounts for variations in groove depth, that are likely to occur when the actual milling of CLRS takes place. None of the states, with the exception of Wisconsin, reported having any margin for the dimensions of transverse or longitudinal width. The complete results have been tabulated in Appendix C.

5) Do the installation locations cover both rural and urban?

In response to this question, 6 of the 10 states that participated in the follow-up survey reported using the CLRS in rural areas (60%). Out of these six states, three had CLRS installed strictly in the rural area and three sates reported having CLRS installed mostly in rural areas. Out of the remaining four, one (i.e. Virginia) had CLRS installed in both rural and urban settings. No responses could be obtained from three states.

The findings of the two surveys helped in identifying the variables that must be included in the selection criterion when identifying locations that warrant CLRS installation (e.g. locations with high crossover crash history, two lane and high speed routes) and also those factors whose inclusion is optional in the selection criterion were also noted (e.g. presence of passing zones, no passing zones, rural, urban and presence of traffic control devices). The survey was helpful in collecting the cost information for CLRS installations. Concerns and challenges associated with CLRS maintenance and installations were also noted though the surveys (e.g. build-up of debris in the grooves, pavement deterioration, wearing off of the pavement marker material and safety of motorcycle and bicycle riders). However, further investigation on these concerns is beyond the scope of this report. An application of CLRS, not found previously in any of the reports in literature review were reported by the state of Okalahoma, which uses only uses CLRS on the margins of the two-way left turn lane on five lane highways, where speeds exceed 45 mph.

CHAPTER 4

DATA ANALYSIS

Based on the survey responses, the criteria defining the locations in Alabama warranting the installation of CLRS were identified. Using the Critical Analysis Reporting Environment (CARE) software, a filter was constructed to incorporate the criteria with some additions and modifications to them, to retrieve the required dataset, from the CARE crash database. A 'filter' represents a specific set of attributes / criteria against which all data are compared and only matching data are retrieved from the crash database. These filters can be those predefined in the software or created by the user to retrieve specific datasets. CARE software provides 250 variables to choose from to construct a user-defined filter. A variable is defined as "a discrete attribute of the events or objects in a *CARE* database" *(CARE User Manual, version 7.5.9).* The result was a list of 73 segments. The crash rate for each segment was calculated and the list was prioritized based on the crash rates experienced on individual segments.

4.1 Critical Analysis Reporting Environment (CARE)

The CARE software was developed by a research group in the Department of Computer Science at the University of Alabama. First developed in 1982, CARE originally stood for *Cities Accident RAPID Evaluation*. Constant updates are being worked into the software so that the latest version will take advantage of technological advancements. CARE is a sophisticated data analysis tool with its own proprietary database structures. Though it was primarily designed for the analysis of traffic accidents, it has the capability to analyze most of the crash data once that is imported into the CARE database. The CARE crash database for Alabama is based on the information obtained from the crash reporting Alabama Uniform Traffic Accident Report (AUTAR) forms. The AUTAR forms are completed by law enforcement personnel across the state of Alabama at the site of a crash. This information is then entered into the crash database by the state Department of Public Safety.

The following points need to be noted about the coding scheme for roadways in CARE *(CARE User Manual, version 7.5.9)*:

i) All major highways, for example, the interstates, are mileposted.
ii) Urban streets and roads and less-used rural roads use a link-node scheme, where each intersection has a node number and each road has a link number.
iii) Node numbers are unique to each county, but not necessarily statewide.

Presently Dr. David B. Brown from the Department of Computer Science at the University of Alabama heads the research and development of CARE.

4.2 Segment Characteristics

CLRS are targeted towards reducing the head-on and sideswipe crashes that occur due to centerline crossovers. Though the possibility of CLRS reducing the run-off-the-road (ROR) crashes cannot be overlooked in CARE, however, filter criteria could not be established that would make a clear distinction between the left ROR (e.g. centerline crossover) from right ROR crashes (e.g. vehicle running off the lane on the right hand side). Based on the literature review, survey responses and the data availability in CARE, the following set of criteria was established which defined the sites to be included in this analysis:

i) The route must be a federal or state highway only;
ii) Only those crashes occurring along the route should be included;
iii) Crashes occurring at intersections should not be included;
iv) The posted speed limit must be between and inclusive of 45 mph to 55 mph;
v) The crash types as defined in CARE must only be 'head-on' or 'left front angle' or broadside left'; and
vi) Segments must be a two-lane roadway;

4.3 CARE Filter Development

The 1994 to 2003 Alabama crash data for CARE version 7.5.9 was used for data extraction in this study. The software works on the principle of filters, which is a querying technique to retrieve the relevant data from a dataset. This means that a set of criteria needs to be defined and data in the entire database is compared with these criteria. The data is selected and retrieved only if it matches the criteria. Since, a very specific dataset was required for analysis, it was necessary to construct a filter specific to the analysis. The following variables available in CARE matched the above mentioned criteria and were therefore used in the development of the filter:

i) (V 010) Highway class: Federal, State;

ii) (V 011) Intersection: Not intersection related;

iii) (V 062) Speed limit posted (mph): 41-45, 46-50, 51-55;

iv) (V 063) Initial impact : head-on or left front angle or left broad side only; and

v) (V 082) Two – lane only.

The number in parentheses (e.g. (V 010)) represents the code or the designation assigned to the variable in CARE, followed immediately by the variable name (e.g. 'highway class'). The values following the variables (e.g. 'federal, state'), are further options available within the variable. From this point onwards, throughout this report, the term head-on refers to 'head-on or left front angle' crash types and sideswipe refers to 'left broad side only' crash type as shown in Figure 4.1.

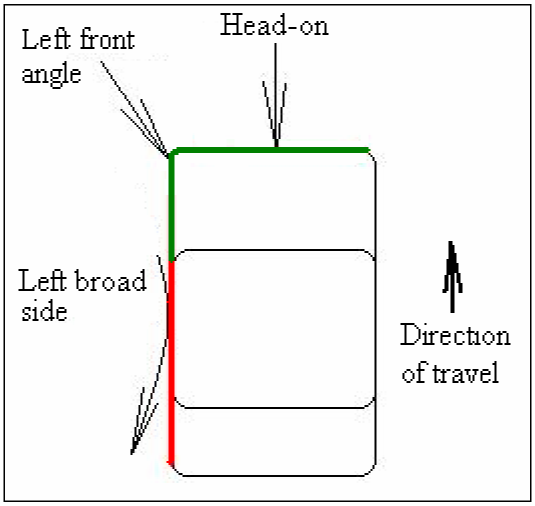
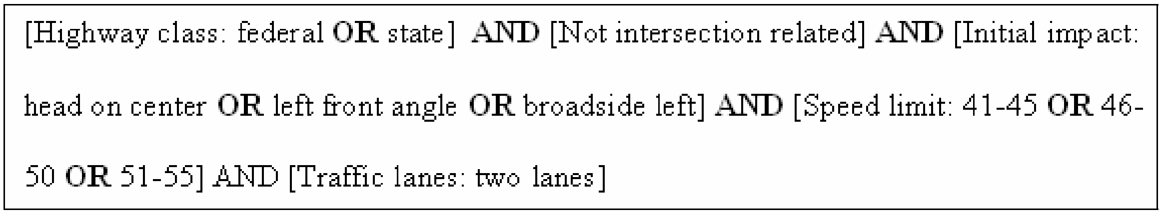


Figure 4.1 Impact Points on the Vehicle

To construct the filter, the chosen variables were first combined within themselves with ‘OR’ logic. For example, for the highway class category, the route would have to be either state OR federal in order to be selected. Then, all variables were combined with each other using the ‘AND’ logic. Figure 4.2 is a simplified representation of the filter constructed in CARE which has been used in this study.



[Highway class: federal **OR** state] **AND** [Not intersection related] **AND** [Initial impact: head on center **OR** left front angle **OR** broadside left] **AND** [Speed limit: 41-45 **OR** 46-50 **OR** 51-55] AND [Traffic lanes: two lanes]

Figure 4.2 Simplified version of the CARE filter.

This means that when the data retrieval process started, a particular dataset would have had to satisfy one option listed for each of the five variables (OR logic) and thus satisfy all five variables combined together (AND logic) which represents the selection criteria. To make sure that the retrieved data set was correct the following validation check was performed.

Filter Validation Check

Three separate filters were created. Filter A, would determine the number of crashes occurring for the crash type ‘head-on only’. The Filter B would determine the number of crashes occurring for the crash type ‘sideswipes only’. The sum of crashes from these two filters was compared with the number of crashes resulting from Filter C, which determined all the crashes that occurred under the ‘head-on or left front angle or left broadside’ crash types.

To construct each of these filters, all four variables as previously mentioned were used; changing only the crash type for '(V063) Initial Impact' depending on the filter being constructed.

1. Criteria for Filter A, head-on only:
    - (V 063) Initial impact: head-on or left front angle;

2. Criteria for Filter B sideswipe only:
    - (V 063) Initial impact: left broad side only;

3. Criteria for Filter C, head-on or sideswipe:
    - (V 063) Initial impact: head-on or left front angle or left broad side;

The number of crashes filtered through Filter A and Filter B, respectively, were summed and the total was compared with the number of crashes obtained from Filter C. The values returned were:

- Filter A (81,377) + Filter B (4,684) = 86,061 crashes
- Filter C = 86,061 crashes

The sum of Filters A and B was equal to Filter C, therefore validating the filter for data extraction process to make sure data extracted is correct and inclusive. It is to be noted that Filters A and B were constructed for the purpose of the validation check only. Filter C was the only filter used in CARE for all crash data extraction purposes.

It was observed, from the survey results, that CLRS have been installed mostly in rural and selected urban environments. Therefore, in the construction of Filter C, both rural and urban locations were considered. Also, no traffic control unit was specified since some routes may not have any control; therefore it is possible that some crashes may be excluded from the dataset, which may be a limitation of the filter. Both ‘Passing’ and ‘No Passing’ zones have been considered since the survey responses indicated that CLRS have been installed in both passing and no passing zones.

4.4 Identifying Candidate Segments

The next step was to determine the locations that warrant the installation of CLRS. This study utilizes 10 years (i.e. 1994 to 2003) worth of Alabama crash data. The filter was set to Filter C. The ‘Location’ module available in CARE finds high accident location for any subset, by allowing the user to specify the number of accidents to define a high crash location. Therefore, before generating the list of segments, the maximum and minimum values for the number of crashes occurring on a segment need to be specified and only those segments that fell within a specific range would be selected. The default values for maximum and minimum were ‘unlimited’ and 25, respectively. For the purpose of this analysis; the default values were taken without making any changes. Segments with fewer than 25 crashes were not considered for data analysis. The ‘Hotspots – Segments’ option available within the ‘Locations’ module was found most suitable in retrieving the required dataset because, this option identified a crash location based on its milepost data. Therefore, using the ‘Hotspots-segments’ option available within the ‘Locations’ module or menu, the required dataset was retrieved.

The list comprised of 73 locations for the State of Alabama, sorted by total ‘head-on’ and ‘sideswipe’ crash types, identified first by the county, followed by the area or city that the segment passed through and lastly by the beginning and an ending node. Finally, the link number (e.g. S-53) and brief description of the link were also available. The total numbers of crashes were further categorized by fatal, injury, and PDO for each segment, in the CARE output. The beginning and ending mileposts for a segment were identified and have been included in Appendix E.

The number of crashes meeting the criteria, occurring on these 73 segments, summed to 2,659 compared to the 86,061 crashes all across Alabama, obtained initially. This difference is explained by the fact that the list was truncated at segments with a minimum of 25 crashes. The remaining segments had fewer than the specified minimum number of crashes and fell outside the specified range and therefore were not considered.

4.5 Candidate Segment Prioritization

The next task was to prioritize the segments. At first glance, the number of crashes occurring on the segment would seem to be the deciding factor. However, for total number of crashes on a segment to be the method of prioritization, the segment lengths would have to be equal. Using the milepost data obtained previously, the individual segment lengths were determined. No milepost data was available for several segments located in urban areas. This is because some of the crashes on segments through urban areas are reported as mileposted, while others are reported as non-mileposted with only the beginning and ending nodes.

The segment lengths were obtained by taking the difference between the mileposts, when the data was available. The missing milepost data was obtained from the Alabama Department of Transportation (ALDOT). The term 'Link' used in CARE represents the segment between two intersections which are marked by two nodes as seen in Figure 4.3.

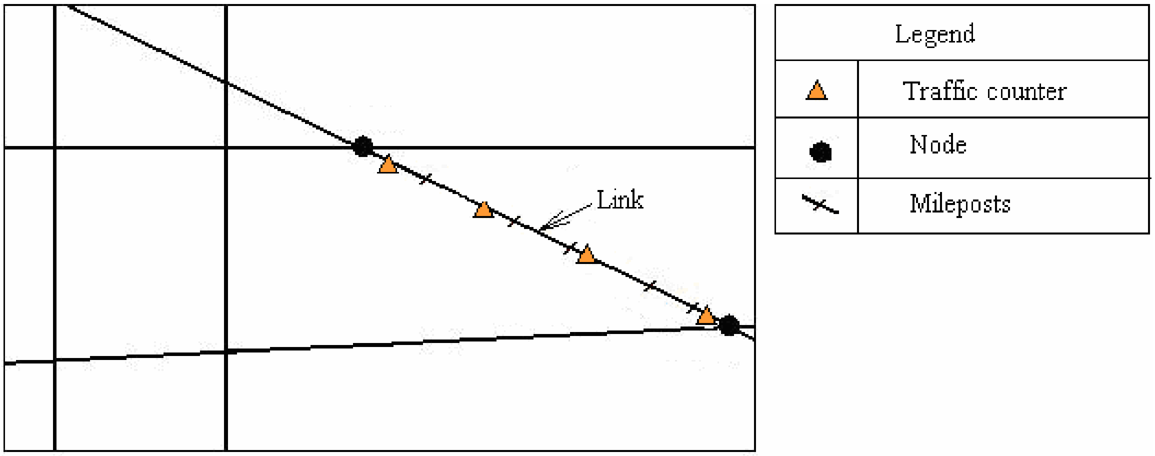


Figure 4.3 Illustrations of Segment Terminologies in CARE.

In this report, however, the term 'Segment' refers to the section between the mileposts for which segment length was calculated. The ends of the segment may not necessarily coincide with the two nodes that define a link in CARE as seen in Figure 4.4

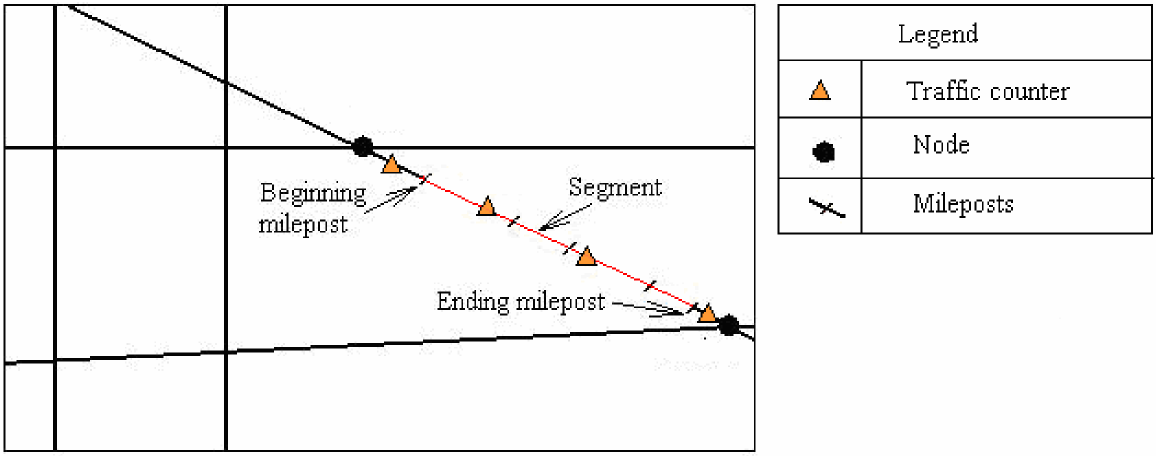


Figure 4.4 Illustrations of Modified Segment Terminologies.

The segment lengths were compared and found to be of varying lengths. Therefore the first approach of prioritizing the segments based purely on total number of crashes occurring on the segment would no longer be considered. The new prioritization approach was to calculate a crash rate for individual segments. This approach normalized the crash data by eliminating the bias that arose due to the non-uniformity of segment lengths. The following standard formula developed by Garber and Hoel was used to determine the crash rate (crashes/ million vehicle miles of travel (MVMT) :

$$\text{Crash Rate} = \left[\frac{N_C * 10^6}{L * N_{veh}}\right] \qquad (4.1)$$

Where,

N_C = number of crashes on the segment;

L = length of the segment (miles); and

N_{veh} = total number of vehicles *(Garber and Hoel, 2001).*

The traffic data required to determine the ‘total number of vehicles’ on the segment was obtained from the ALDOT 2004 Traffic Statistics website. Once the beginning and ending mileposts of segments were identified in CARE, the traffic data was taken off the counters located between the two mileposts as previously described in Figure 4.3 and Figure 4.4 previously.

A majority of the segments had traffic counters within the beginning and ending milepost. However, for segments where traffic counters were not found within the segment but immediately outside of the segment, the traffic data from that counter was taken under the following assumptions. This is illustrated in Figure 4.5 :

i) No route merged with or diverged from, between the segment end and the counter which was outside the segment.

ii) If there was more than one traffic counter immediately before or immediately after the segment with very close values of annual average daily traffic (AADT), then the average of the two counters was taken.

Figure 4.5 is an illustration of the ALDOT’s 2004 traffic statistics website. The example segment which has been drawn over the map, shown in the figure, is segment number 27 as noted in Appendix E. As seen, the actual segment is between mileposts 1.58 and 1.21, but no traffic counters, which are represented by the yellow dots, can be found within the segment. There is a traffic counter immediately outside of the segment. Between milepost 1.58 and the traffic counter, there are no routes merging with or diverging from the route. Therefore, according to the first assumption, the traffic data from that counter can be taken for the purpose of this study.

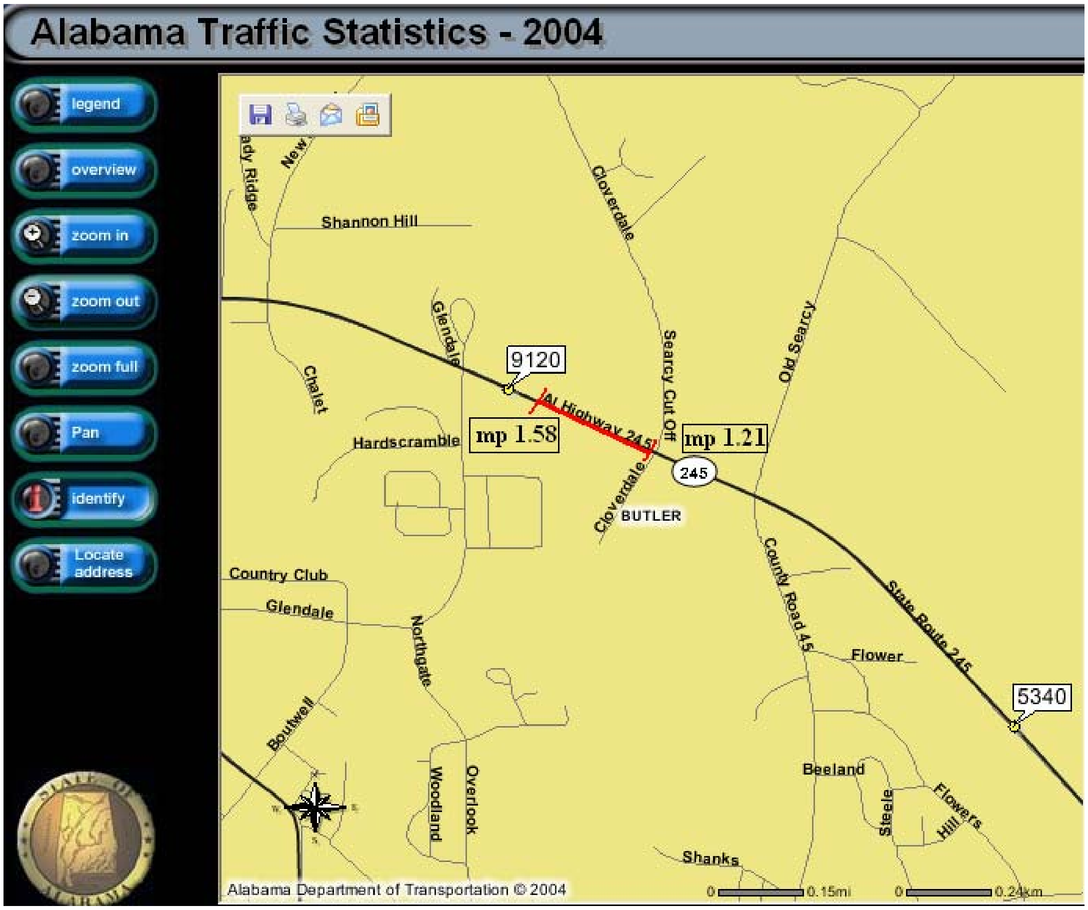


Figure 4.5 Illustration of ALDOT's 2004 Traffic Statistics Webpage

If the counters were outside of the segment and were not found to satisfy either of the above stated criteria, no traffic data was collected from those counters. Traffic data from counters was gathered for the years 1994 through 2003 to maintain consistency with the CARE data. To determine the AADT in case of multiple traffic counters within a segment, the AADT for each year was summed and then the algebraic average was taken. The averages were then added up to arrive at the cumulative AADT for a segment, over a ten year period. This was done for all the years from 1994 through 2003 for every segment (Appendix F). An example calculation is shown below for segment number 58, which is State route 15 (Lee Rural) in Lee County.

Table 4.1 Traffic Data for Example Segment # 58

	AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT
	4140	4250	4350	4530	4960	5260	5310	5140	5230	5200	
	4610	4740	4930	4760	5310	5190	5220	4990	5120	5130	
Avg. AADT	4375	4495	4640	4645	5135	5225	5265	5065	5175	5165	49185

The AADT values for the years 1994 through 2003 were obtained from the Alabama traffic statistics website. The segment had two traffic counters hence the two rows of AADT for the ten years. The average AADT was the arithmetic average of yearly AADT volumes. The total AADT was found to be 49,185. This value was multiplied by 365 to arrive at total number of vehicles which was 17,952,525. Segment length in miles and total number of crashes, obtained from CARE, were 18.8 and 27, respectively. Using the formula stated in equation 4.1, the crash rate was calculated to be 0.08 for this segment.

4.6 Results and Findings

The results of the segment prioritization, based on the crash rate, are listed in detail in Appendix G. The following plot shows the distribution of crash rates on the 55 segments. The histogram of crash rates reveals a positively skewed distribution as crash rates are comparatively high on certain segments, as seen in Figure 4.6.

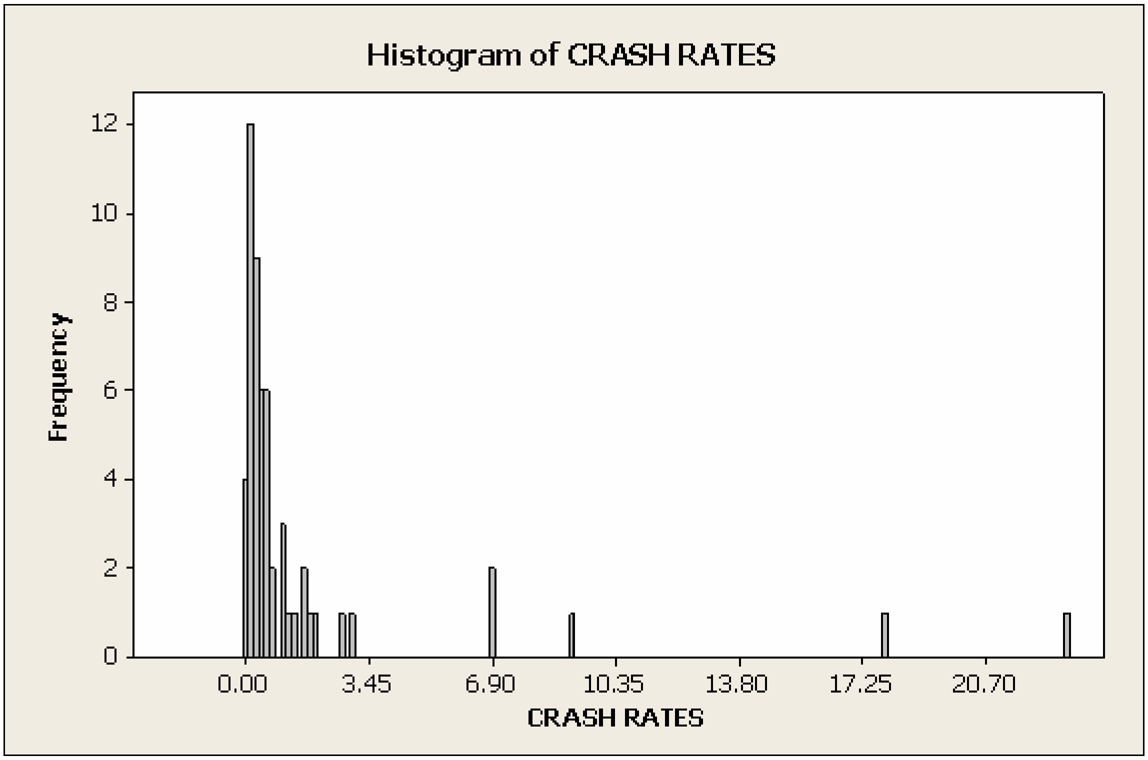


Figure 4.6 Distribution of Crash Rates

Crash rates could not be determined for two segments i.e. # 28 and # 30 due to the unavailability of milepost data. Though segment lengths for most of the segments were available from ALDOT, the beginning and ending milepost information was unavailable for 18 segments as listed in Table 4.2. These segments were excluded from data analysis.

Table 4.2 Segments Excluded From Analysis

Sl No.	Segment #	County	City	State Route	Missing Data type
1	3	Lee	Opelika	S-169	Traffic
2	9	Shelby	Pelham	S-261	Traffic
3	11	Tuscaloosa	Northport	S-13	Traffic
4	13	Shelby	Pelham	S-261	Traffic
5	19	Walker	Jasper	S-4	Traffic
6	26	Jefferson	Hoover	S-150	Traffic
7	28	Elmore	Wetumpka	S-14	Milepost
8	30	Shelby	Alabaster	S-119	Milepost
9	32	Shelby	Pelham	S-261	Traffic
10	33	Lee	Opelika	S-1	Traffic
11	42	Colbert	Muscle Shoals	S-133	Traffic
12	51	Elmore	Millsbrooke	S-14	Traffic
13	52	Baldwin	Spanish Fort	S-225	Traffic
14	64	Mobile	Saraland	S-158	Traffic
15	69	Etowah	Rainbow City	S-77	Traffic
16	70	Walker	Jasper	S-118	Traffic
17	72	Jefferson	Hoover	S-150	Traffic
18	73	Jefferson	Hoover	S-150	Traffic

With milepost information unknown, it was not possible to determine the location of these segments on their respective links and therefore traffic counters could not be located either. Without any traffic data, crash rate could not be calculated and therefore they were discarded from the final list of 55 segments which were prioritized based on crash rate. The next task was to conduct an economic analysis on these 55 segments to determine the unit crash costs for fatal, injury, and PDO crash types and therefore determine the expected benefits of CLRS installation in terms of savings in crash costs due to the crashes prevented.

CHAPTER 5

ECONOMIC ANALYSIS

The goal of carrying out an economic analysis was to establish the benefit to cost ratio to identify the potential benefits for a CLRS installation to justify the economic feasibility of CLRS. Similar analyses have been conducted in the past to evaluate the monetary benefits of SRS. One such case was the evaluation of SRS for a New York State Throughway *(Perrillo, 1998).* Crash data from before (1991) and after (1997) the installation of the SRS was used to determine the savings in crash costs due to crashes prevented. The life of SRS, which was assumed to be about 6 years, was also factored in to calculate the benefits. Costs associated were the cost of milling the SRS, sweeping and discarding of the excess asphalt and maintenance and protection of traffic.

For this analysis in this report, the unit cost of each fatal, injury, and PDO crashes type was determined An expected reduction of 14% in the number of crashes following the CLRS installation was applied. This estimated reduction was selected from the IIHS study of 2003. This study analyzed all crash data considered 'reliable' from 7 states with 210 miles of CLRS and concluded that sites treated with CLRS had overall crash were reductions of 14%. The expected savings in crash costs (benefits) had the CLRS been in place were calculated. No assumptions were made for the expected life for CLRS as no data was available regarding the same (probably because CLRS have not been in use on highways as long as SRS). The installation cost for CLRS was determined from the responses obtained from survey of state transportation agencies. CLRS would be considered cost-effective if the benefit to cost ratio is greater than 1.

5.1 Unit Crash Costs

As seen previously in Appendix E, each of the segments had the total number of crashes broken down into fatal, injury and PDO. However, ‘Injury’ can range from being a bruise to being a critical injury requiring immediate medical assistance. The National Highway Traffic Safety Administration (NHTSA) report *Economic Impact of Motor Vehicle Crashes 2000* uses the Modified Abbreviated Injury Scale (MAIS) to sub-classify the ‘Injury’ crash type into six distinct slots to differentiate the injury levels and to classify an injury due to accidents for analysis and economic evaluation purposes. The MAIS injury categories are as follows:

MAIS 0: Uninjured
MAIS 1: Minor injury
MAIS 2: Moderate injury
MAIS 3: Serious injury
MAIS 4: Major/multiple
MAIS 5: Unsurvivable

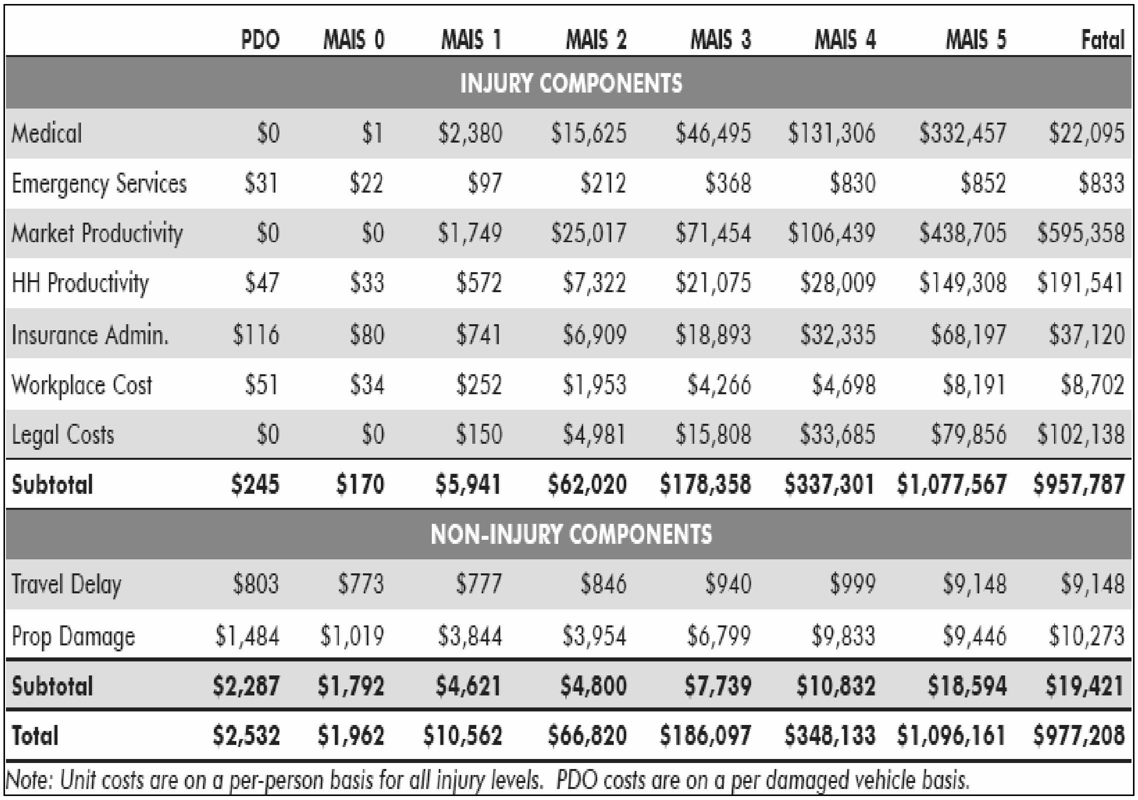
PDO is used to describe those crashes in which nobody was injured in any manner. MAIS 5 represents an ‘Unsurvivable’ injury crash type which is different from the fatal crash type. The MAIS 5 describes a crash type in which the occupant or occupants of the vehicle have been critically injured due to the crash, but the crash would not have killed the occupant or occupants immediately, at the crash site. Fatal describes the crash type which resulted in immediate death of the occupant or occupants.

The unit cost of injuries, as shown in

Table 5.1 **was obtained from the NHTSA report *Economic Impact of Motor Vehicle Crashes 2000* which estimates the crash costs for the year 2000. Number of crashes for the year 2000, also obtained from the same report, are as shown in**

Table 5.2. Though the report provided both reported and unreported crashes, it did not specify how the numbers of unreported crashes were obtained. Therefore, for the purpose of this study, only the crash numbers for reported crashes were used.

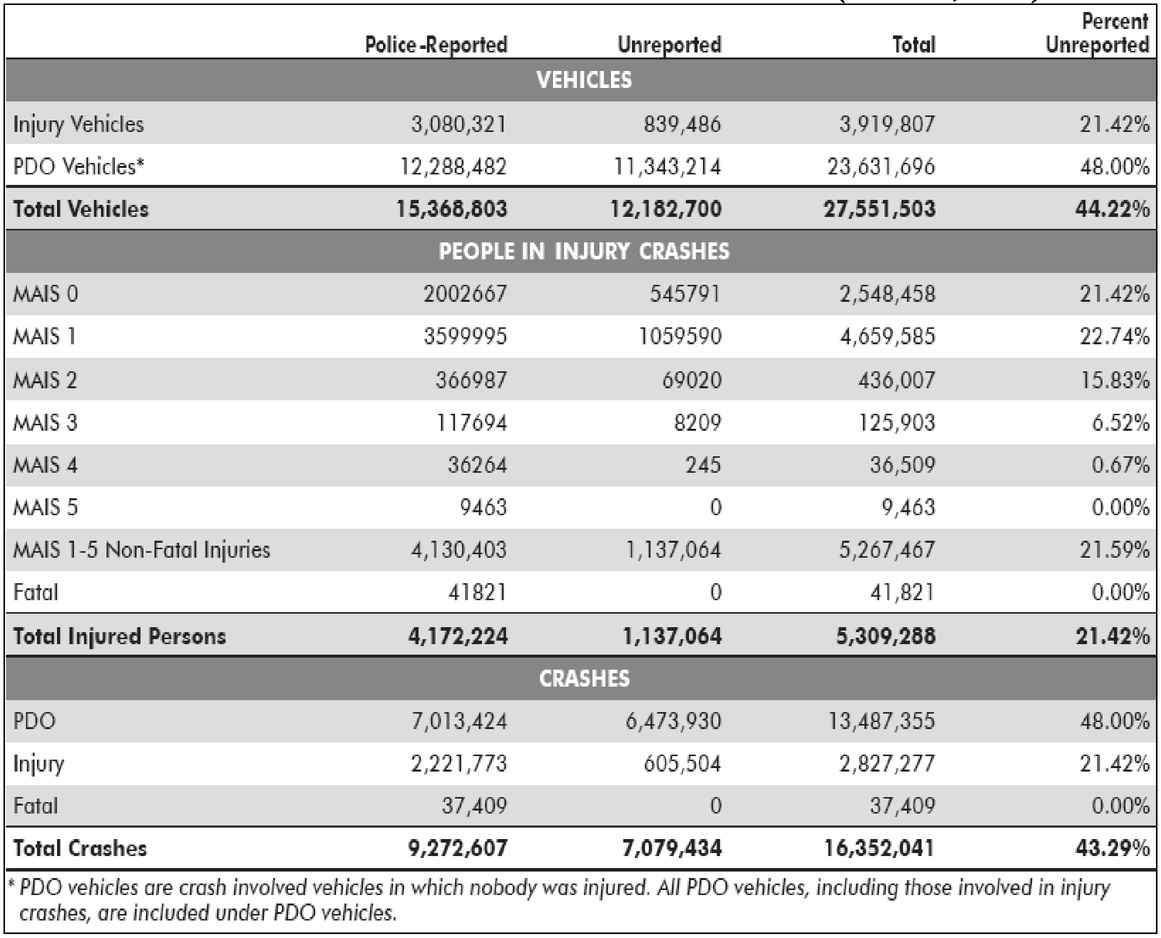
Table 5.1 Unit Crash Costs for the Year 2000, *(NHTSA, 2002)*.



	PDO	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
INJURY COMPONENTS								
Medical	$0	$1	$2,380	$15,625	$46,495	$131,306	$332,457	$22,095
Emergency Services	$31	$22	$97	$212	$368	$830	$852	$833
Market Productivity	$0	$0	$1,749	$25,017	$71,454	$106,439	$438,705	$595,358
HH Productivity	$47	$33	$572	$7,322	$21,075	$28,009	$149,308	$191,541
Insurance Admin.	$116	$80	$741	$6,909	$18,893	$32,335	$68,197	$37,120
Workplace Cost	$51	$34	$252	$1,953	$4,266	$4,698	$8,191	$8,702
Legal Costs	$0	$0	$150	$4,981	$15,808	$33,685	$79,856	$102,138
Subtotal	**$245**	**$170**	**$5,941**	**$62,020**	**$178,358**	**$337,301**	**$1,077,567**	**$957,787**
NON-INJURY COMPONENTS								
Travel Delay	$803	$773	$777	$846	$940	$999	$9,148	$9,148
Prop Damage	$1,484	$1,019	$3,844	$3,954	$6,799	$9,833	$9,446	$10,273
Subtotal	**$2,287**	**$1,792**	**$4,621**	**$4,800**	**$7,739**	**$10,832**	**$18,594**	**$19,421**
Total	**$2,532**	**$1,962**	**$10,562**	**$66,820**	**$186,097**	**$348,133**	**$1,096,161**	**$977,208**

Note: Unit costs are on a per-person basis for all injury levels. PDO costs are on a per damaged vehicle basis.

Table 5.2 Total Number of Crashes in the Year 2000 *(NHTSA, 2002)*



	Police-Reported	Unreported	Total	Percent Unreported
VEHICLES				
Injury Vehicles	3,080,321	839,486	3,919,807	21.42%
PDO Vehicles*	12,288,482	11,343,214	23,631,696	48.00%
Total Vehicles	**15,368,803**	**12,182,700**	**27,551,503**	**44.22%**
PEOPLE IN INJURY CRASHES				
MAIS 0	2002667	545791	2,548,458	21.42%
MAIS 1	3599995	1059590	4,659,585	22.74%
MAIS 2	366987	69020	436,007	15.83%
MAIS 3	117694	8209	125,903	6.52%
MAIS 4	36264	245	36,509	0.67%
MAIS 5	9463	0	9,463	0.00%
MAIS 1-5 Non-Fatal Injuries	4,130,403	1,137,064	5,267,467	21.59%
Fatal	41821	0	41,821	0.00%
Total Injured Persons	**4,172,224**	**1,137,064**	**5,309,288**	**21.42%**
CRASHES				
PDO	7,013,424	6,473,930	13,487,355	48.00%
Injury	2,221,773	605,504	2,827,277	21.42%
Fatal	37,409	0	37,409	0.00%
Total Crashes	**9,272,607**	**7,079,434**	**16,352,041**	**43.29%**

** PDO vehicles are crash involved vehicles in which nobody was injured. All PDO vehicles, including those involved in injury crashes, are included under PDO vehicles.*

The following procedure was developed to determine the single representative cost of injury across the MAIS scale. The number of injuries in each MAIS category were divided by the sum of injuries across all MAIS categories and then multiplied by their respective cost. For example, the total numbers of injury occurring in year 2000 were 6,133,070 out of which, MAIS 0 accounts for 2,002,667 injuries or 0.3265 of the total number of injuries. This percentage was multiplied with $1,962; the cost of MAIS 0 in year 2000 to arrive at the weighted average cost of $640.66 for MAIS 0. This was done for each category and the resulting values were summed to obtain a weighted average cost, representative of the cost of an injury crash type. This was calculated to be $18,160 as tabulated in Table 5.3.

Table 5.3 Representative Cost of Injury.

Injury Scale	Crash Cost in year 2000 ($)	#Reported Injuries in year 2000	Weighted average Crash cost per MAIS category ($)
MAIS 0	1,962	2,002,667	640.66
MAIS 1	10,562	3,599,995	6,199.69
MAIS 2	66,820	366,987	3,998.34
MAIS 3	186,097	117,694	3,571.21
MAIS 4	348,133	36,264	2,058.46
MAIS 5	1,096,161	9,463	1,691.32
	Total	6,133,070	**18,160**

The injury costs stated in the report were on a per-person basis and it is very likely that more than one person was involved in the crash. The number of people involved in the head-on or sideswipe crash types was retrieved from the CARE database and it was determined that on average (weighted average), for the head-on and sideswipe crash types occurring on the original 73 segments, there were approximately 1.7 vehicles/crash and 1.5 occupants/vehicle. Occupants per vehicle were converted to occupants per crash by simple multiplication of the two factors:

$$[1.5 \text{ occupants/veh}] * [1.7 \text{ veh / crash}] = 2.55 \text{ occupants / crash} \qquad (5.1)$$

This average value of 2.55 occupants / crash was factored into the calculation of cost per unit-crash for fatal and injury crash types. As the CARE crash database being used for this analysis extends over a period of ten years (1994 to 2003), the dollar value calculated for the year 2000 would not be a representative value for the crashes spanning across ten years. A monetary value midway across the analysis period, which may be more representative of the crash cost, was determined. According to the Bureau of Labor Statistics, the Consumer Price Index had a 3% yearly inflation rate during the 1994 to 2003 period. Using the 3% per year inflation rate, the 2000 dollar value was deflated by 4.5% to arrive at a unit cost midway between 1998 and 1999 which marks the midpoint of the ten year analysis period.

This procedure is illustrated in the following calculation of the unit cost of an injury crash type. The weighted average unit cost of injury crash type for the year 2000 was found to be $18,159. This value was deflated by 4.5% (at the rate of 3% deflation per year) to arrive at the dollar value midway between the years 1998 and 1999 which was found to be $17,342. This value was then multiplied with 2.55 to factor in the average number of people involved in an injury crash type to arrive at $44,223.

Unit crash costs for fatal and PDO were taken directly from the NTHSA report mentioned previously and the 2.55 occupants/crash and 1.7 vehicles / crash were then factored in the costs. The costs were deflated by 4.5 % and the final values of per-crash costs for fatal, injury, and PDO, respectively, have been summarized in Table 5.4.

Table 5.4 Final Unit Crash Cost per Crash Type

Crash Type	Cost per unit crash type ($)
Fatal	2,426,407
Injury	44,223
PDO	4,110

5.2 Benefit to Cost Ratio

The estimated 14% reduction was applied to determine number of crashes prevented, following the installation of CLRS. Savings in crash costs due to number of crashes prevented was the expected benefit of CLRS. The costs associated with CLRS included the cost of installation only.

5.2.1 Costs

The cost of installation was determined from the preliminary survey responses. The cost of installation as reported in the survey ranged from $0.10/ linear foot to $1.52/ linear foot. No definitive relationship could be established between the cost and miles of installation because more miles did not consistently translate into reduced installation costs and vice versa. Hence, the representative cost of installation of CLRS was determined through the arithmetic mean. The average cost was found to be $0.55/ linear foot and this value was used for calculations in establishing installation costs associated with CLRS. Cost of installation of CLRS in New Jersey was reported as $4.50/ linear foot compared to the next lower cost of installation, which was $1.52/ linear foot as reported in the survey. Therefore, this value was considered an outlier, which is shown by an asterisk towards the upper end in Figure 5.1. This value was therefore not included in the calculation of cost of installation. The boxplot from MiniTab also shows the 75th percentile cost, the median or 50th percentile and 25th percentile. These values have been used later in the report for sensitivity analysis.

Also, for the calculation of costs associated with CLRS, only the cost of installation was taken into account.

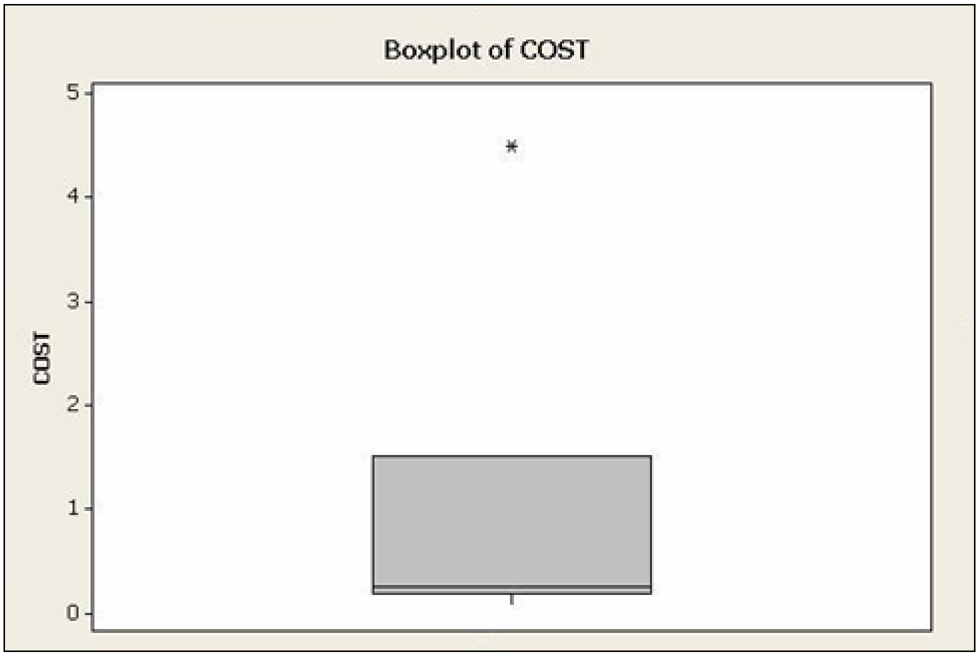


Figure 5.1 Cost Data for CLRS Installation

5.2.2 Benefits

The benefits were the savings in crash costs due to the installation of CLRS. It has been reported that up to a 14% overall reduction was observed in head-on and sideswipe crash types due to the installation of CLRS *(Persaud et al., 2003).* This study analyzed all crash data considered 'reliable' from 7 states with 210 miles of CLRS and concluded that sites treated with CLRS had overall crash were reductions of 14%. Therefore, numbers of crashes represented by the 14% were determined for every segment. Then this number was broken down by weighted average into fatal, injury, and PDO. The cost of fatal, injury, and PDO were calculated these were summed up to arrive at a total cost for each of the three crash types. This procedure was done for each of the 55 segments (Appendix H). Also, it was assumed that crash severity index does not change on a particular segment across the years and across the crash types for the entire analysis period (1994 to 2003).

5.3 Results and Findings

The cost of installation at $0.55/ linear foot for a total of 224.67 miles was found to be $676,167. These miles did not include the segments for which data was unavailable. The benefits or cost savings in terms of crashes prevented was found to be $7,727,380. The benefit to cost ratio was calculated using the following formula:

$$\text{B/C ratio} = \frac{\text{Cost savings due to crashes prevented}}{\text{Cost of installation of CLRS}} \qquad (5.2)$$

The costs incurred did not include the crash costs because the remaining 86% of the crashes would be expected to have occurred, regardless of the presence of the countermeasure. The benefit to cost ratio was found to be 16.5.

5.4 Sensitivity Analysis

Since the cost of installation and reductions observed, following the deployment of CLRS have the big impact on the benefit to cost ratio, a sensitivity analysis was conducted to observe:

i) The impact of cost of installation of CLRS on the benefit to cost ratio; and

ii) The impact of percentage reduction in number of crashes on the benefit to cost ratio.

5.4.1 Cost of Installation of CLRS vs. Benefit to Cost ratio

The costs of installation chosen for the analysis are as shown in Table 5.5 and the corresponding plot in Figure 5.2. The percentile costs were obtained form the boxplot in Figure 5.1.

It is seen from the plot that by as that as cost of installation increases, the B/C ratio decreases. Benefits calculated remained unchanged for this calculation. The estimated crash reduction of 14% was applied when calculating the benefits for the given values of installation costs.

Table 5.5 Cost Values for Sensitivity analysis

Benefit($)	Cost, $/ L.F.		Cost ($)	B/C
10,961,898	Lowest cost reported from survey	0.10	118625.8	92.4
	25th percentile	0.20	237251.5	46.2
	50th percentile	0.26	308427	35.5
	Arithmetic average	0.55	652441.7	16.5
	75th percentile	1.51	1803112	6.0
	Highest cost reported from survey	1.52	1791249	6.0

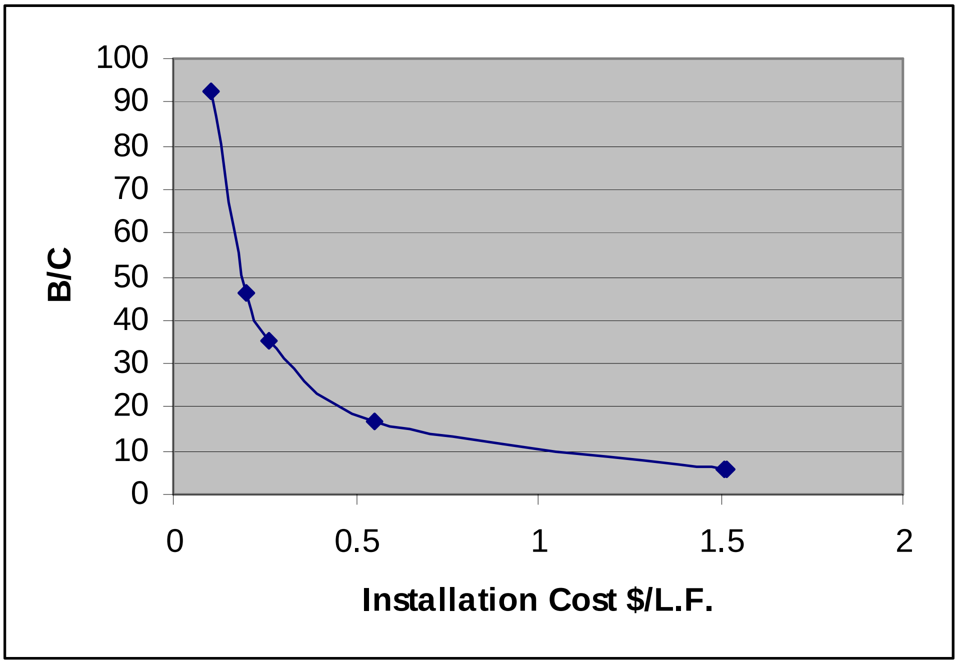


Figure 5.2 Sensitivity of Benefit to Cost Ratio (B/C) to CLRS Installation Cost

5.4.2 Crash Reduction vs. Benefit to Cost ratio

The crash reduction following the installation of CLRS, documented from the studies discussed in the literature review, were applied to this hypothetical study to observe the effects of crash reductions on the overall benefit to cost ratio. The reductions applied and the corresponding study where these reductions were observed are shown in Table 5.6 and the values have been plotted in Figure 5.3. The cost of installation was kept constant at $0.55/ linear foot for this part of analysis.

Table 5.6 Overall Crash Reductions Observed

SOURCE	OBSERVED REDUCTION	B/C
IIHS	14%	16.5
IIHS	21%	25.2
Minnesota	40%	48.0
Washington State	50%	60.0
Japan	55.2%	66.2
Delaware	60%	72.0

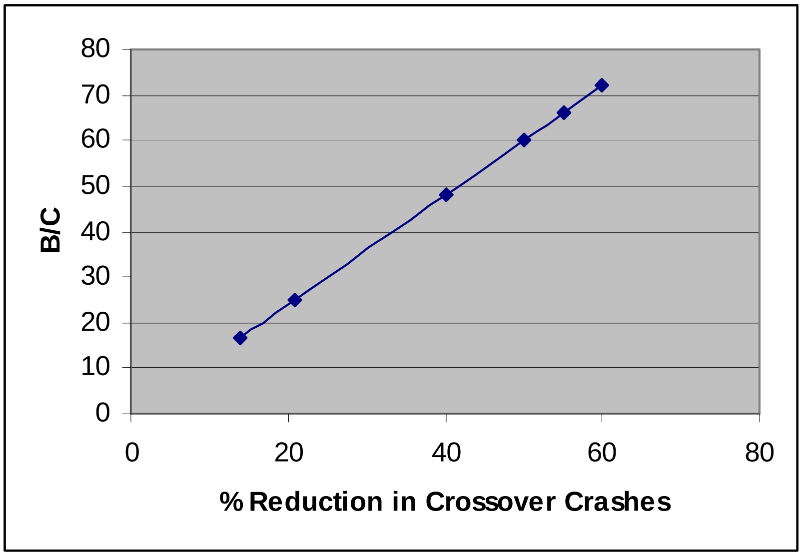


Figure 5.3 Sensitivity of B/C ratio to Overall Crash Reductions

It is observed, both from the values in

Table 5.6 and Figure 5.3, that benefit to cost ratio demonstrates an almost linear relationship with percentage crash reductions observed.

CHAPTER 6

CONCLUSIONS

The results of both the survey of current practice and economic analysis indicate that CLRS are a cost-effective countermeasure for reducing the head-on and sideswipe crash types. Studies documenting the influence of traffic volumes observed that the changes in traffic volume had a pronounced effect on the crash reductions by CLRS. Higher AADT volumes resulted in increased crash reduction, provided that the number of crashes did not increase proportionately with increase in traffic volumes, as shown in equation 4.1. Since CLRS installations are targeted on reducing collisions due to lane crossovers, their deployment focuses primarily on two-lane rural routes and selected urban areas.

6.1 State-of-the-Practice

Though the safety of motorcyclists is of concern, the majority of the states have not directly considered bicycle riders. This may be attributed to the fact that bicycle riders tend to ride towards the outer edge of the traveled way or within the designated lane and it is less likely that bicycles will traverse across the CLRS as compared to vehicles traversing across them. The noise generated by vehicles traversing over the CLRS is not a concern in most states, most probably because CLRS is being installed mostly in rural areas, as reported in the surveys. It was noted that out of the 26 states that responded to the survey, 10 states (38%) specify a tolerance in the dimensions of groove depth. It may therefore be inferred that during milling operations it is tougher to achieve the exact groove depth than it is to achieve the other two dimensions. The state-of-the-practice surveys also reveal that CLRS dimensions vary both within the state and between the states.

6.2 Crash Reporting and Crash Data Management

The CARE software, used in identification and prioritization of the candidate segments, proved to be very efficient in the extraction of the required data from the CARE crash database. The software provides 250 variables to choose from to construct the filter in order to retrieve specific crash data. Accuracy of these filters was reinforced through a filter validation check.

The manner in which data has been coded in the crash database may be a limiting factor when retrieving crash data. For example, a head-on or sideswipe type crash with another vehicle may not be differentiated from a head-on collision or sideswipe with a fixed object because the crash reporting form, which is the basis for data in the CARE crash database, does not provide the option to do so.

6.3 Potential CLRS Benefits

The IIHS study of 2003 reports that a 14% overall reduction has been observed in the number of crashes, following the CLRS installation across seven states in the U.S.

The expected crash reduction of 14% applied to this study, estimates that there would be almost no fatal crashes on the candidate segments, once the CLRS are installed; as seen in Appendix H. At $0.55/ linear foot, which is the cost estimate derived from the survey results; the cost of installation is low. In addition to this, the CLRS can be retrofitted to most of the existing pavement. The (hypothetical) economic analysis reveals a benefit to cost ratio of 16.5 for installation of CLRS on candidate segments in Alabama, which reinforces the advantages of CLRS.

Thus, positive findings are evident from the surveys and economic analysis conducted herein. Based on the survey responses, 13out of the total 50 states (26%) across the U.S. were actively using the CLRS while five out of 50 states (10%) were conducting research and field tests to evaluate the effectiveness of CLRS, at the time of the survey. Due consideration needs to be given towards widespread application of CLRS on two-lane roadways and other areas where there are higher than average incidences of head-on and sideswipe type crashes.

Finally, though the results of this study are specific to the state of Alabama, the procedure for selection of candidate locations and data analysis can be applied to almost any state to determine locations that warrant CLRS. This methodology does not account for variations in road geometrics and may therefore be making the benefit to cost ratio indicative of the effectiveness of CLRS for a variety of road profiles.

CHAPTER 7

RECOMMENDATIONS

7.1 Data Entry in Crash Reporting Forms

The crash reporting forms certainly need to be updated to either include more variables in order to accurately categorize a crash or some means should be provided within the form for the law enforcement officer to enter details of the crash.

The crashes are reported based on their milepost location in rural areas and based on nodes in an urban area which results in a non-uniform crash database. The manner in which the location of a crash is entered in the crash reporting form needs to be standardized.

7.2 CLRS Installations

The benefit to cost ratio of 16.5 together with an estimated crash reduction of 14% in head-on and sideswipe type crashes, which would almost eliminate fatal crashes are strong indicators of the advantages of CLRS. Therefore, installation of CLRS on the candidate segments is strongly recommended. Appendix G is the complete list of candidate segments, prioritized based on their crash rates in the state of Alabama.

7.3 Recommendations for Future Research

Applications of CLRS are still in their early stages, which leaves plenty of room for future investigations and research. The following are a few of the areas recommended for further study pertaining to CLRS applications.

- ALDOT should conduct a pilot project on selected locations followed by a study of installation effects aimed towards suggesting a ‘best’ dimension for CLRS. The locations and number of segments chosen for trial installations is a decision of ALDOT. Data should be collected on tactile responses and noise generated. A study should also document driver responses, impact of CLRS on motorcycles traveling at high speeds and impact of CLRS on bicyclists.
- It is recommended that ALDOT establish guidelines and warrants for CLRS installations for the state of Alabama.
- The changes in traffic volumes must be documented along with changes in the number of crashes following CLRS installation, to get a better estimate of the impact of CLRS on crash reduction.
- Work needs to be done in documenting the impact of alignment and road geometrics, such as curves, on the performance of CLRS.
- A study that takes into account other traffic control measures, such as pavement markings, in conjunction with CLRS is also strongly recommended.

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APPENDIX A

PRELIMINARY SURVEY

Auburn University Highway Research Center Study of Transportation Agencies Regarding Centerline Rumble Strips Practices

1. Does your agency use the Centerline Rumble Strips? Proceed if yes. If no, please explain briefly if there were any specials concerns. Are the Center Line Rumble Strips in consideration for future?

2. What criteria were used to determine the installation location?

3. What pattern is being currently used? Check the applicable.
   - ☐ Rolled
   - ☐ Milled
   - ☐ Corrugated
   - ☐ Raised

4. Please provide the detailed dimensions currently used in Centerline Rumble Strip OR enclose a copy of the standards / specifications used, with the survey response

5. Does the design configuration vary across the state? (e.g. topography, rural/urban)

6. How many miles have been installed, and when did the installation commence?

7. Is the cost of installation of Centerline Rumble Strip included along with other contract bid items or is it a separate item? What is the typical cost or range of costs?

8. What are the evaluation criteria for effectiveness of Centerline Rumble Strips:
   - ☐ Safety (e.g. Crash data, statistics)
   - ☐ Costs (e.g. benefit to cost ratio)
   - ☐ Road Geometrics
   - ☐ Weather
   - ☐ Driver inputs
   - ☐ Other ________________________
   - ☐ Evaluation underway
   - ☐ No evaluation done

9. Have the auditory and vibratory levels produced by the chosen pattern been measured?

10. What were the challenges and/or concerns faced during installation (if any)?

11. Have any warrants, policies or guidelines been created which are directed towards the installation of the Centerline Rumble Strip?

12. Were any special signs developed to alert the motorists about the presence of the Centerline Rumble Strips ahead on the road? If yes, please describe in detail or include figure.

13. How were the general public made aware of this “new installation”?

14. Did regional factors have any effect on performance of Centerline Rumble Strips? (E.g. snow in the northern regions, debris buildup in the groves in dry, arid regions or any other related factors.)

15. Was any special consideration given to bicycle or motorcycle traffic during the design or selection of installation locations?

16. Any additional comments?

17. Who may we contact if follow up information on Centerline Rumble Strips is needed?

Thank you for your time!

Please return the completed survey in the postage-paid envelope provided, or send it to:

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Department Of Civil Engineering,
Harbert Engineering Center,
Auburn University,
AL 36849-5337
Ph: (334) 844-6271
E-mail: rturochy@eng.auburn.edu

APPENDIX B

PRELIMINARY SURVEY RESPONSES

APPENDIX B1

PRELIMINARY SURVEY RESPONSES

Auburn University Highway Research Center - Study of Transportation Agencies Regarding Centerline Rumble Strip Practices

		[Q1]	[Q2]	[Q5]	[Q6]	[Q7]	[Q10]	[Q11]	[Q12]	[Q13]	[Q14]	[Q15]	[Q16]
Sl. No.	**State**	**CRS in use?If not, any reason.**	**Criterion to determine location for installation**	**Variation in CRS design across state**	**Miles of CRS and date when started**	**Separate bid item or included with other costs. Cost of installation**	**Challenges Faced / Concerns**	**Warrants / Policies / Guidelines specific to CRS deployment**	**Signs developed to alert motorists**	**Efforts towards Public awareness of CRS**	**Influence of regional factors (if any)**	**Motorcycle traffic concerns (if any)**	**Additional comments by state DOT**
1	AR	Yes	NA	No	74 miles Fall / Winter 2004	Separate bid item $0.2/L.F	Safety of traveling public and workers while the installation was in progress	No	No	By observation	Data not collected	No	None
2	AZ	No	CRS not in use										
3	CO	Yes	crash history of location	No	44.3 miles Date NA	Usually a separate item Cost NA	Bicycle rider concerns	Standards included	Standards included	Public announcement	No	Yes, CRS have a positive result	NA
4	FL	No do have an experimental project setup	2-lane road with high rate of opposite direction lane crossovers.	No	NA	With other contract bid items		No	No	None yet	No	Yes	Installing a 'Rainline' project with audible bumps at a 2" spacing for evaluation
5	HI	No	CRS not in use										NA

		[Q1]	[Q2]	[Q5]	[Q6]	[Q7]	[Q10]	[Q11]	[Q12]	[Q13]	[Q14]	[Q15]	[Q16]
Sl. No.	**State**	**CRS in use?If not, any reason.**	**Criterion to determine location for installation**	**Variation in CRS design across state**	**Miles of CRS and date when started**	**Separate bid item or included with other costs. Cost of installation**	**Challenges Faced / Concerns**	**Warrants / Policies / Guidelines specific to CRS deployment**	**Signs developed to alert motorists**	**Efforts towards Public awareness of CRS**	**Influence of regional factors (if any)**	**Motorcycle traffic concerns (if any)**	**Additional comments by state DOT**
6	ID	Yes	Enhance safety of highway US-12 for the up and coming Lewis and Clarke Bicentennial event	No	~ 65 miles Summer/Fall 2004	Separate bid item $0.24/ L.F (total of 116,800 LF)	Maintaining required uniform depth on the CRS alignment (grinder had trouble staying aligned with the centerline)	No	Yes	1)Public news release 2) added a portable message sign trailer at each end of the project indicating new CRS next XX miles	No	1)Advanced signage for notification 2)Bicycles are not to be on the centerline	1) first time being used in Idaho 2)Installed on double yellow striped curves only, where noise would not effect adjacent residential development 3) Concern for Maintenance Forces when roadway patching is necessary 4) Evaluation of CRS being done in No Passing zones 5) CRS installation'Working well'
7	IA	No					CRS not in use						1)CRS will be used as a tool to reduce crashes in high crash locations 2) have talked to other states and are ready for installation 3) interested in the NCHRP on-going study
8	LA	No					CRS not in use						

		[Q1]	[Q2]	[Q5]	[Q6]	[Q7]	[Q10]	[Q11]	[Q12]	[Q13]	[Q14]	[Q15]	[Q16]
Sl. No.	**State**	**CRS in use?If not, any reason.**	**Criterion to determine location for installation**	**Variation in CRS design across state**	**Miles of CRS and date when started**	**Separate bid item or included with other costs. Cost of installation**	**Challenges Faced / Concerns**	**Warrants / Policies / Guidelines specific to CRS deployment**	**Signs developed to alert motorists**	**Efforts towards Public awareness of CRS**	**Influence of regional factors (if any)**	**Motorcycle traffic concerns (if any)**	**Additional comments by state DOT**
9	ME	No					CRS not in use						1)Expected future installation locations include (a) Rural 2-lane areas (b) Locations with high instance of lane cross-overs (c) Low speed 4 lane segments 2)Contemplating the use as a part of the lane departure strategies 3) Concerns are for noise and effect on motorcyclists.
10	MI	Yes	A 4-lane section with slightly higher than average head-on crash-rate	NA	7 miles Fall 2002	Separate bid item $0.10/L.F (shoulder)	none	Not yet	A Yellow warning sign "Centerline Rumble Strips ahead"	Newspaper, TV News	No	Gaps at intersection and some drives,	1) Depth of 3/8" chosen due to noise concerns 2) 3/8" is less jarring than 1/2" and provided smooth moving operations 3) More CRS usage in future 5) Painted SRS are better visible in night and protected from snow plough damage

		[Q1]	[Q2]	[Q5]	[Q6]	[Q7]	[Q10]	[Q11]	[Q12]	[Q13]	[Q14]	[Q15]	[Q16]
Sl. No.	**State**	**CRS in use?If not, any reason.**	**Criterion to determine location for installation**	**Variation in CRS design across state**	**Miles of CRS and date when started**	**Separate bid item or included with other costs. Cost of installation**	**Challenges Faced / Concerns**	**Warrants / Policies / Guidelines specific to CRS deployment**	**Signs developed to alert motorists**	**Efforts towards Public awareness of CRS**	**Influence of regional factors (if any)**	**Motorcycle traffic concerns (if any)**	**Additional comments by state DOT**
13	MO	Pilot project (Under testing)	Team assembled to determine the criteria	NA	12 mile test section 2003	Given as change order (change pav marking material) $61, 559 (~$0.97/L.F)	1)Centerline Joint placement 2) to seal/not seal the milled CRS 3)life of pavement 4) width to choose 5)ice formation in grooves in winter operations 6) effect of water in grooves and its effect on the retroreflectivity of the stripe 7)will the glass beads stick to both sides of the strip face?	under development	No	Let the public 'discover' the CRS by themselves. Future installations will have newspaper announcements and public meetings	Data not collected	Team still reviewing all CRS installations for motorcyclists and bicyclists	Responding to a similar survey for BYU for UDOT
14	MT	No Has some concerns						CRS not in use					Concerns include 1) Location (Only at no passing zones in both directions?) 2) Effect on motorcycles 3)lane configuration (2-lane only, 4-lane undivided?) 3) Water and ice accumulation 4) Maintenance

		[Q1]	[Q2]	[Q5]	[Q6]	[Q7]	[Q10]	[Q11]	[Q12]	[Q13]	[Q14]	[Q15]	[Q16]
Sl. No.	**State**	**CRS in use?If not, any reason.**	**Criterion to determine location for installation**	**Variation in CRS design across state**	**Miles of CRS and date when started**	**Separate bid item or included with other costs. Cost of installation**	**Challenges Faced / Concerns**	**Warrants / Policies / Guidelines specific to CRS deployment**	**Signs developed to alert motorists**	**Efforts towards Public awareness of CRS**	**Influence of regional factors (if any)**	**Motorcycle traffic concerns (if any)**	**Additional comments by state DOT**
15	NE	Yes	higher than average head-on collisions and run-off-the-road crashes	No	30 miles Date NA	NA	NA	No	No	No	No	Gaps at intersection were not milled	NA
16	NJ	Yes	Accident history and severity opposing direction side-swipe and head-on collision	No	NA	Paid for separately $4.50/L.F	Not aware of any	No	No	Let the public 'discover' the CRS by themselves.	No	No	Installed in "No Passing" zones only
17	OK	Yes On one segment only.CRS not in use otherwise	CRS not in use										only use of CRS is on a 5-lane highway, along the margins of the two-way left turn lane, when speeds exceed 45 mph.
18	OR	No	CRS not in use										Experimental. Limited resources Data not provided (see 'CLRS Details') Crossover Crashes in some regions & watch the fieled and figure out the target area BUT not promoting

		[Q1]	[Q2]	[Q5]	[Q6]	[Q7]	[Q10]	[Q11]	[Q12]	[Q13]	[Q14]	[Q15]	[Q16]
Sl. No.	**State**	**CRS in use?If not, any reason.**	**Criterion to determine location for installation**	**Variation in CRS design across state**	**Miles of CRS and date when started**	**Separate bid item or included with other costs. Cost of installation**	**Challenges Faced / Concerns**	**Warrants / Policies / Guidelines specific to CRS deployment**	**Signs developed to alert motorists**	**Efforts towards Public awareness of CRS**	**Influence of regional factors (if any)**	**Motorcycle traffic concerns (if any)**	**Additional comments by state DOT**
19	PA	Yes	Accident history and severity opposing direction sideswipe and head-on collision)	May vary	1500 miles over 250 locations	Separate bid item $1.50/L.F (avg)	1)shallow bituminous overlays degraded after milling. Thus guidelines revised to require a minimum depth of overlay 2) mechanical difficulties and problems with paint gun cartridges during early stages of CRS deployment but resolved later by modification of painting equipment.	1)Standards included 2)Currently rewriting guidelines to remove CRS based on ADT requirements	No	No	No	1)None for bicycle traffic due to lack of it ion CRS 2)CRS not perceived hazardous to motorcycles , hence no concession	None
20	SC	No	CRS not in use										Under research for expected install in 2005. Crash history of location, and its pattern will be the selection criterion

		[Q1]	[Q2]	[Q5]	[Q6]	[Q7]	[Q10]	[Q11]	[Q12]	[Q13]	[Q14]	[Q15]	[Q16]
Sl. No.	**State**	**CRS in use?If not, any reason.**	**Criterion to determine location for installation**	**Variation in CRS design across state**	**Miles of CRS and date when started**	**Separate bid item or included with other costs. Cost of installation**	**Challenges Faced / Concerns**	**Warrants / Policies / Guidelines specific to CRS deployment**	**Signs developed to alert motorists**	**Efforts towards Public awareness of CRS**	**Influence of regional factors (if any)**	**Motorcycle traffic concerns (if any)**	**Additional comments by state DOT**
21	TX	No Effectiveness of CRS in research. Results awaited					CRS not in use						Evaluation criteria will be safety and costs
22	VT	No					CRS not in use						
23	VA	Yes	1)Higer crash frequencies 2) request from local agencies and citizens (The road sections on Route 460 had experienced High frequency of COCL crashes.)	No	15 Miles Oct 1999	Both $1.52/ L.F	1)Installation on road 'zones' (passing, special zones) 2)CLRS with markers, RPMS 3) Maintenance issues such as CL joint and marking longitivity 4)Special TCDs to supplement	under development	No	No	No	No	Effectiveness of CRS on needs to be statistically identified. Issues stated under "challenges faced" need to be studied
24	WA	Yes	Crash history	Yes	110 miles 1996	Separate bid item $0.28/L.F (avg.) (varies from $0.13/l/f to $0.76/l/f)	NA	under development	No	NA	No	No	Need a copy of the summary of the response data Collected by AU

		[Q1]	[Q2]	[Q5]	[Q6]	[Q7]	[Q10]	[Q11]	[Q12]	[Q13]	[Q14]	[Q15]	[Q16]
Sl. No.	**State**	**CRS in use?If not, any reason.**	**Criterion to determine location for installation**	**Variation in CRS design across state**	**Miles of CRS and date when started**	**Separate bid item or included with other costs. Cost of installation**	**Challenges Faced / Concerns**	**Warrants / Policies / Guidelines specific to CRS deployment**	**Signs developed to alert motorists**	**Efforts towards Public awareness of CRS**	**Influence of regional factors (if any)**	**Motorcycle traffic concerns (if any)**	**Additional comments by state DOT**
25	WI	Yes	Locations with higher than average crash rate on rural highways, centerline cross-overs, highway must have 12' lanes with 3' paved shoulders (Highway 142, near Kenosha, WI	NA	Miles NA Spring 2005	no bid prices as of now $0.13 - $0.75/L.F (MNDOT data)	Traffic control	No	No	Signs and newspaper	Data not collected	maybe later	1) CRS not yet installed 2) IIHS completed a report on this topic in Sept 2003 3)Paper presentation by Dave Noyce of UW-Madison at Jan 2004 TRB .
26	WY	Yes	(test) locations with high instance opposing direction crashes - US-287, South of Laramie, WY	No	~ 5 miles Date NA	NA	Difficult traffic control	Not yet	No	Public meetings and public service announcement	CRS helped drivers stay on road during blizzard conditions	Cyclists concern "Vehicles are less likely to cross centerline to provide additional space when they pass bicycles in this area".	Data insufficient to be able to study effectiveness of CRS yet

APPENDIX B2
RESPONSES TO QUESTION #3

Sl. NO.	STATE	GROOVE	Peculiarities (if any)	Pattern	T.W (inch)	Margin +/- (inch)	L.W (inch)	Margin +/- (inch)	Groove Depth (inch)	Margin +/- (inch)	Notes
1	AR	Milled	-	12" continuous	16	0	7"	1/2"	1/2" (min) 5/8" (max)	0	
2	AZ	CRS not in use									
3	CO	Milled (mostly) Rolled	GRIND-IN RS		12"	0	5"	0	3/8"	0	Two- lane divided & Four- lane undivided highways (Asphalt & Concrete)
		Milled (mostly) Rolled	FORMED OR ROLLED	24" Continuous	12"	0	2.375"	0	1/2" (min) 1" (max)	0	1)Two- lane divided & Four- lane undivided highway (concrete only) 2)Maximum groove depth of 3/16" from top of travel lane after RS completion to top of concrete travel lane.
4	FL				CRS not in use						Raised patternn was used for an experimental installation
5	HI				CRS not in use						
6	IA				CRS not in use						
7	ID	Milled	-	12" continuous	12"	0	7"	1/2"	1/2" (min) 5/8" (max)	0	Groove depth = 110 mills +/- 5 mills
8	LA				CRS not in use						
9	ME				CRS not in use						
10	MI	Milled	-	12" continuous	12"	0	7"	0	3/8"	0	For noise concerns depth = 3/8 inch
11	MN	Milled	-	12" continuous	12"	0	7"	0	0.5"	0	

Sl. NO.	STATE	GROOVE	Peculiarities (if any)	Pattern	T.W (inch)	Margin +/- (inch)	L.W (inch)	Margin +/- (inch)	Groove Depth (inch)	Margin +/- (inch)	Notes
12	MS				CRS not in use						
13	MO				CRS not in use						
14	MT				CRS not in use						
15	NE	Milled	-	12" continuous	16"	0	7"	0	1/2" (max) to 5/8"(min)	0	
16	NJ	Milled and Rolled	-	12" continuous	16"	0	7"	0	1/2"	1/8"	SRS dimensions. Maybe same for CRS
17	OK				CRS not in use						
18	OR	Milled	Type E : Pattern A	24" continuous	16"	0	7"	0.6"	1/2"	0.06" OR 3/50"	Rural highway with median. Used in No Passing zones
		Milled	Type E : Pattern B	24" & 48" alternating	16"	0	7"	0.6"	1/2"	0.06" OR 3/50"	Rural highway without median. For Use in No Passing Left, No Passing Right and Passing sections.
		Milled	Type D (Rural highways WITH Median. Experimental Instalation)	12" continuous	16"	0	7"	0.6"	1/2"	0.06" OR 3/50"	(1) EXPERIMENTAL installation (2)Min Requirements: 12 ft.lanes and paved shoulders (3) CRS installed at center if median = 4ft (4)For median >4ft. CRS installed at 12 inch inside each median strip (5) State Traffic Engineer's approval required prior to installation
19	PA	Milled	Detail #1	24" & 48" alternating	16"	0	7"	1/2"	1/2"	1/16"	1)Lane width 12 ft.or more with minimum 3' paved shoulder 2) Roadway with 11ft. Lanes and minimum 3ft. Paved shoulder, use Detail # 1 or # 2
		Milled	Detail #2	24" continuous	14" to 18"	0	7"	1/2"	1/2"	1/16"	used on roadway with 1) 11 ft. lane and no shoulder or shoulder less than 3 ft. 2) 10ft. Lane with or without shoulder

Sl. NO.	STATE	GROOVE	Peculiarities (if any)	Pattern	T.W (inch)	Margin +/- (inch)	L.W (inch)	Margin +/- (inch)	Groove Depth (inch)	Margin +/- (inch)	Notes
20	SC				CRS not in use						
21	TX				CRS not in use						
22	VT				CRS not in use						
23	VA	Milled	-	12" continuous	12"	0	7"	0	1/2"	0	A 1.5 mile Rolled pattern was installed as a first pilot site for testing by one District in 1999 and this type of CLRS will not be used in the future.
24	WA				CRS not in use						
25	WI	Milled	-	24" continuous	8"	1/2 "	7"	1/2"	1/2" (min) 3/8" (max)	0	
26	WY	Milled	-	12" continuous	12"	0	7"	0	1/2"	0	

APPENDIX B3
RESPONSES TO QUESTION # 8 AND # 9

		Evaluation Criteria								Measuring Stimuli	
Sl No	States	Safety	Costs	Road geometrics	Weather	Driver Inputs	Evaluation Underway	No Evaluation Done	Other	Auditory	Vibratory
1	AZ						CRS not in use				
2	AR						X			No	No
3	CO	X	X	X						www.dot.state.co.us/publications/researchreports.htm	
4	FL							X			
5	HI						CRS not in use				
6	ID	X	X	X						No	No
7	IA						CRS not in use				
8	LA						CRS not in use				
9	ME						CRS not in use				
10	MI	X	X	X	X	X	X			No	No
11	MN							X		No	No
12	MS										
13	MO	X	X							No	No
14	MT										
15	NE	X	X	X						No	No
16	NJ							X		No	No
17	OK										
18	OR										
19	PA								Crash data		
20	SC						CRS not in use				
21	TX										
22	VT						CRS not in use				
23	VA							X		No	No
24	WA						X			No	No
25	WI	X							UW-Wisconsin will evaluate	No	No
26	WY	X		X	X					No	No

APPENDIX C

FOLLOW-UP SUMMARY

APPENDIX C
SUMMARY OF FOLLOW-UP SURVEY RESPONSES

Sl.No.	Question	State	Response
1	How were the dimensions of the CRS decided upon?	Arkansas	NA
		Colorado	TW = 12" due to the presence of double yellow in NPZ
		Michigan	NA
		Minnesota	Used in areas with ADT>5000. Watched other states (mostly Kansas and Pennsylvania) -watched performance of different designs at test facility -installation of these designs given to one contractor- start with 5" . Move to 24" & 48" alternating ,6" also not good (both found unfit with 8"tires on police cars). Hence used8" BUT installation costs are $2/ft.
		Nebraska	Same as SRS
		Oregon	NA
		Pennsylvania	Research
		Virginia	NA
		Wisconsin	Similar to Minnesota; based off SRS
		Wyoming	NA
2	CRS configuration: according to the DOT's response, no values for auditory/vibratory stimuli have been provided. so, how was the depth of the grooves decided upon?	Arkansas	NA
		Colorado	Depth determined through a study conducted to develop bicycle friendly RS
		Michigan	NA
		Minnesota	Tweak off the SRS
		Nebraska	By acceptance of SRS
		Oregon	NA
		Pennsylvania	Tests conducted on different groove depths; 50 or 60 dB was found to be the lower end.
		Virginia	0.35" not creating much stimulus ; 0.50" =Adequate stimuli, easy construction and maintenance (5% tolerance)
		Wisconsin	Tweaked off the SRS
		Wyoming	NA
3	What audible levels were considered "noise" by the residents?	Arkansas	NA
		Colorado	People do complain but DOT not bothered. Puts then in areas of high ROR crashes
		Michigan	NA
		Minnesota	CRS had to be 400ft away from the residential area to stay within noise levels. Used (For the first 170m of installation) 24" continuous pattern - guest editorial in newspaper read that CRS causes noise but is in the interest to save live
		Nebraska	Any noise at all
		Oregon	Not a problem since CRS placed on tight curves only . Installations still experimental
		Pennsylvania	Not a concern
		Virginia	NA
		Wisconsin	There is a concern, but not a major one
		Wyoming	Not a problem

Sl.No.	Question	State	Response
4	How was the depth of the groove measured while milling?	Arkansas	NA
		Colorado	Manual checks at the end of day
		Michigan	NA
		Minnesota	Periodic checks by Inspectors
		Nebraska	Regular checks during milling with a T-shaped tool
		Oregon	Contractor was given a certain margin (details NA)
		Pennsylvania	Roller cut the groove to required depth (margin of error permitted hence ok)
		Virginia	On-board computer allows +/- 5% of groove depth for margin
		Wisconsin	NA
		Wyoming	NA
5	Does installation locations cover both rural and urban area?	Arkansas	NA
		Colorado	Mostly rural
		Michigan	NA
		Minnesota	Rural (Speed limit> 55mph)
		Nebraska	RS ,normally, not placed in urban environment
		Oregon	NA
		Pennsylvania	Meant for rural but used in urban settings too
		Virginia	Both
		Wisconsin	Rural
		Wyoming	Rural

NA: Implies that no response could be elicited for that question or the state could not be contacted.

APPENDIX D

FILTER CONSTRUCTION IN CARE

APPENDIX D

FILTER CONSTRUCTION IN CARE

The logic for filter C as constructed in CARE was:

(((((HIGHWAY CLASS==FEDERAL) | (HIGHWAY CLASS==STATE)) & (INTERSECTION==NOT INTRSCTN RELATED)) & (((INITIAL IMPACT - VEH C==HEAD ON CENTER) | (INITIAL IMPACT - VEH C==LEFT FRONT ANGLE)) | (INITIAL IMPACT - VEH C==BROADSIDE LEFT))) & (((SPEED LIMIT - VEH C==41-45 MPH) | (SPEED LIMIT - VEH C==46-50 MPH)) | (SPEED LIMIT - VEH C==51-55 MPH))) & (TRAFFIC LANES - UNIT C==TWO LANES)

Where:

| = OR logic

& = AND logic

UNIT C /VEH C= Driver or vehicle that caused the crash according to the police officer.

APPENDIX E

LIST OF SEGMENTS WARRANTING CLRS INSTALLATIONS

APPENDIX E
LIST OF SEGMENTS WARRANTING CRS INSTALLATION

Sl no.	County	City	Link	Node 1	Node 2	Description 1	Description 2	Beginning Milepost	Ending Milepost	Fatal	Injury	PDO	Total
1	MADISON	MADISON RURAL	S-53	7570	7587	ARDMORE HWY at JEFF RD	ARDMORE HWY at BURWELL RD	327.4	330.2	1	27	106	134
2	TUSCALOOSA	NORTHPORT	S-13	887	888	AL 13 US 43 at CITY ST 1801 & CL	NO DESCRIPTION AVAILABLE	205.04	205.36	0	13	62	75
3	LEE	OPELIKA	S-169	141	1180	MATTHEWS ST at S169	S169 CRAWFORD RD at CORPORATE LIMIT	NA	NA	0	18	43	61
4	MOBILE	MOBILE RURAL	S-16	7749	7753	PADGETT SWITCH RD CO 81 at SR 16 US 90	MURRAY HILL RD at US HWY 90 SR-16	8.5	18	0	11	48	59
5	SHELBY	PELHAM	S-261	522	524	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	4	5.84	0	5	54	59
6	WALKER	JASPER	S-4	81	83	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	64.14	64.57	0	6	51	57
7	CULLMAN	CULLMAN	S-157	9182	9184	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	1.91	1.97	0	9	47	56
8	DEKALB	FORT PAYNE	S-7	65	1073	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	233.05	233.41	0	10	44	54
9	SHELBY	PELHAM	S-261	500	522	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	5.69	5.84	0	6	47	53
10	MOBILE	MOBILE RURAL	S-42	8706	8820	MOFFAT RD US HWY 98 at SNOW RD	ED GEORGE RD CO 581 at SR 42 US 98 MOFFAT RD	9	12	1	16	35	52
11	TUSCALOOSA	NORTHPORT	S-13	880	882	AL 13 US 43 at FLATWOODS RD 1286	AL 13 US 43 at CITY ST 5388 & CL	204.2	204.68	0	15	33	48
12	AUTAUGA	AUTAUGA RURAL	S-6	7352	7353	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	132.21	136.1	1	14	31	46
13	SHELBY	PELHAM	S-261	79	524	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	5.91 - 5.84	5.91	0	1	45	46
14	CULLMAN	CULLMAN	S-157	1358	9182	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	1.97	2.09	0	7	38	45
15	MONTGOMERY	MONTGOMERY	S-3	4725	4742	MOBILE HWY SR-3 US-31 at WEST BLVD	ESTATE AVE at WEST BLVD SR-3 US-31	179.68	180.43	0	9	35	44

Sl no.	County	City	Link	Node 1	Node 2	Description 1	Description 2	Beginning Milepost	Ending Milepost	Fatal	Injury	PDO	Total
16	CALHOUN	CALHOUN RURAL	S-204	7223	7259	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	0.25	0.3	1	14	28	43
17	SHELBY	PELHAM	S-261	370	657	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	4.94	5.33	0	10	32	42
18	SAINT CLAIR	MOODY	S-25	98	7912	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	173.63	174.57	0	11	31	42
19	WALKER	JASPER	S-4	83	92	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	64.56	65.11	0	3	38	41
20	SHELBY	SHELBY RURAL	S-119	7979	7980	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	21	23.8	0	5	36	41
21	MOBILE	MOBILE RURAL	S-16	7748	7749	US HWY 90 ALA 16 at FOWL RIVER BRIDGE	PADGETT SWITCH RD CO 81 at SR 16 US 90	9.7	14.7	0	12	28	40
22	CLEBURNE	CLEBURNE RURAL	S-1	7665	7833	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	213.1	220.9	1	19	17	37
23	CHILTON	CHILTON RURAL	S-22	7583	7666	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	59.3	63.6	1	8	27	36
24	RUSSELL	RUSSELL RU	S-8	7506	7539	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	206.6	210.9	4	12	20	36
25	MOBILE	MOBILE RURAL	S-217	8862	11688	COLEMAN DAIRY RD CO 758 at SR 217 LOTT RD	BOX RD CO 748 at SR 217 LOTT RD	10.5	11.5	0	11	25	36
26	JEFFERSON	HOOVER	S-150	148	9419	BESSEMER CUT-OFF RD at RIVER CHASE DR	NO DESCRIPTION AVAILABLE	11.19	11.43	0	7	28	35
27	BUTLER	GREENVILLE	S-245	409	411	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	1.21	1.58	0	6	28	34
28	ELMORE	WETUMPKA	S-14	300	337	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	NA	NA	0	7	27	34
29	COOSA	COOSA RURAL	S-38	7389	7390	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	61.8	63.2	0	13	20	33
30	SHELBY	ALABASTER	S-119	7501	7503	COUNTY ROAD 26 at MONTEVALLO RD SR119 N JCT	COUNTY ROAD 26 at MONTEVALLO RD SR119 S JCT	10.18	10.37	0	11	22	33
31	AUTAUGA	AUTAUGA RURAL	S-3	7516	7520	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	186.42	186.87	0	9	24	33
32	SHELBY	PELHAM	S-261	468	500	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	5.42	5.85	0	0	32	32

Sl no.	County	City	Link	Node 1	Node 2	Description 1	Description 2	Beginning Milepost	Ending Milepost	Fatal	Injury	PDO	Total
34	MONTGOMERY	MONTGOMERY RURAL	S-3	7398	7403	ALABAMA HWY 3 US-31 at I-65 INTERCHANGE	ALABAMA HWY 3 US-31 at FICSHER RD	175.74	178.98	2	6	23	31
35	SAINT CLAI	ST. CLAIR	S-53	7423	7527	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	221.5	227	0	7	24	31
36	DALLAS	DALLAS RURAL	S-41	7497	7709	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	120.5	123.15	1	5	25	31
37	MOBILE	MOBILE RURAL	S-16	7868	12626	TUNG AVE N at US HWY 90 SR-16	BROADVIEW DR W at US HWY 90 SR-16	10.1	18.5	0	7	24	31
38	PIKE	PIKE RURAL	S-87	7110	7228	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	50	57.4	0	8	22	30
39	DEKALB	FORT PAYNE	S-7	180	1073	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	232.59	233.06	1	4	25	30
40	COOSA	COOSA RURAL	S-22	7769	7786	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	104.7	107.1	0	14	16	30
41	TUSCALOOSA	TUSCALOOSA RURAL	S-6	7765	7816	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	32.9	37.6	0	11	19	30
42	COLBERT	MUSCLE SHOALS	S-133	493	979	ALA 133 & WILSON DAM HWY at AVALON AVE	ALA 133 & WILSON DAM HWY at BLAINE ST	3.26	3.53	0	7	23	30
43	GENEVA	GENEVA RURAL	S-52	188	7515	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	39.7	45.5	0	12	18	30
44	TUSCALOOSA	NORTHPORT	S-13	888	889	NO DESCRIPTION AVAILABLE	AL 13 US 43 at CITY ST 1749 & CL	205.04	205.57	0	8	21	29
45	WALKER	WALKER RURAL	S-257	8560	8902	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	3.4	6.1	0	6	23	29
46	AUTAUGA	AUTAUGA RURAL	S-6	7351	7352	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	131.8	142	1	11	17	29
47	WALKER	WALKER RURAL	S-69	8292	8302	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	209.9	214.6	1	16	12	29
48	MONTGOMERY	MONTGOMERY RURAL	S-9	7416	7418	ALABAMA HWY 9 US-331 at TEAGUE RD	SNOWDOUN CHAMBERS RD at SR-9 US-331	95	99.43	0	9	20	29
49	LIMESTONE	ATHENS	S-127	8	122	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	1.48	2.09	0	8	20	28
50	ELMORE	ELMORE RURAL	S-14	8078	8083	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	164.3	168.7	0	6	22	28

	County	City	Link	Node 1	Node 2	Description 1	Description 2	Beginning Milepost	Ending Milepost	Fatal	Injury	PDO	Total
51	ELMORE	MILLSBROOK	S-14	8415	8664	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	NA	NA	0	12	16	28
52	BALDWIN	SPANISH FO	S-225	8743	14944	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	0.14	1	0	7	21	28
53	ETOWAH	ETOWAH RURAL	S-179	7169	7172	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	4.6	7.2	0	13	15	28
54	RUSSELL	RUSSELL RU	S-1	7355	7838	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	98.09	98.78	0	7	21	28
55	MADISON	MADISON RURAL	S-53	7593	9564	ARDMORE HWY at KELLY SPRING RD	NO DESCRIPTION AVAILABLE	325.4	327.2	0	3	25	28
56	MONTGOMERY	MONTGOMERY RURAL	S-3	7375	7383	ALABAMA HWY 3 US-31 at MCGEHEE RD	ALABAMA HWY 3 US-31 at RUDDER RD	0.7	1.74	0	5	23	28
57	MONTGOMERY	MONTGOMERY	S-3	2283	3098	WEST BLVD SR-3 US-31 at B'HAM HWY	MONEY RD at WEST BLVD	183.31	183.86	0	8	19	27
58	LEE	LEE RURAL	S-15	7124	7125	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	179.2	198	0	10	17	27
59	AUTAUGA	PRATTVILLE	S-14	57	140	WASHINGTON FERRY RD at SR 14	DEER TRACE ST at SR 14	152	155	1	11	15	27
60	LEE	LEE RURAL	S-38	7189	7200	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	101.1	112.5	0	5	22	27
61	MOBILE	MOBILE RURAL	S-188	7436	7439	ALABAMA HWY 188 at GRAND GARDENS DR SE JCT	ALABAMA HWY 188 at FOUR MILE RD	4.5	7	1	14	11	26
62	CULLMAN	CULLMAN	S-157	9182	9190	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	0.99	1.97	0	4	22	26
63	BALDWIN	BALDWIN RURAL	S-42	7485	7486	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	61.5	75.5	0	5	21	26
64	MOBILE	SARALAND	S-158	121	413	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	2.83	4.31	0	8	18	26
65	CHEROKEE	CHEROKEE RURAL	S-9	7703	7742	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	264.6	269.3	1	14	10	25
66	BLOUNT	BLOUNT RURAL	S-3	7523	7534	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	NA	NA	1	11	13	25
67	PERRY	PERRY RURAL	S-219	7234	7440	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	11.5	15.4	0	13	12	25
68	DALLAS	DALLAS RURAL	S-14	7183	7187	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	118	120.25	0	9	16	25

	County	City	Link	Node 1	Node 2	Description 1	Description 2	Beginning Milepost	Ending Milepost	Fatal	Injury	PDO	Total
69	ETOWAH	RAINBOW CI	S-77	141	448	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	NA	NA	0	6	19	25
71	CHILTON	CLANTON	S-3	18	35	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	224.47	225.23	0	9	16	25
72	JEFFERSON	HOOVER	S-150	10133	15987	NO DESCRIPTION AVAILABLE	NO DESCRIPTION AVAILABLE	8.09	8.61	0	5	20	25
73	JEFFERSON	HOOVER	S-150	15139	15978	INTERSTATE 459 at SR-150 INTERCHANGE	BESSEMER CUT-OFF RD at SHADES CREST RD	8.09	8.7	0	5	20	25

APPENDIX F

CRASH RATES ON INDIVIDUAL SEGMENTS

APPENDIX F
CRASH RATES ON CANDIDATE SEGMENTS

Sl No	State Route, City, County		AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT	# Days in a year	Total # of veh	Seg ln (mi)	# Crashes on the segment	CRASH RATE
1	**S53, Madison Rural, Madison**		10070	10450	11240	11070	12760	13500	13380	13340	13400	13870	123080	365	44924200	2.8	134	**1.07**
2	**S13, Northport, Tuscaloosa**		8220	8360	8720	9530	9290	9400	8890	9900	10430	10290	93030	365	33955950	0.32	75	**6.90**
3	**S16, Mobile Rur, Mobile**		6280	6470	6540	6880	7260	7180	7330	6950	7550	7410						
			9440	9630	10040	10550	11030	10810	11180	10620	10960	10930						
			12010	12360	12930	13540	14090	13920	14140	13790	13410	13540						
			14770	15300	16040	16740	17360	17280	17290	16510	15960	16310						
			26450	27220	27280	28130	28960	29250	29170	28120	24660	28520						
			29990	30440	31440	32290	33190	31360	31390	30300	28610	28370						
			29370	29010	27740	28750	29600	28770	29010	30470	31300	32120						
		Average AADT	18330	18633	18859	19554	20213	19796	19930	19537	18921	19600	193373	365	70581093	9.5	59	**0.09**
4	**S261, Pelham, Shelby**		13420	14250	14620	16360	13790	17760	18340	17120	18410	18280	162350	365	59257750	1.84	59	**0.54**
5	**S4, Jasper, Walker**		0	0	0	0	0	0	0	0	10390	10520	20910	365	7632150	0.42	57	**17.78**
6	**S7, Fort Payne, Dekalb**		5630	5760	5380	5380	6170	6160	6260	6240	6410	6410	59800	365	21827000	0.36	54	**6.87**
7	**S157, Cullman, Cullman**		7580	10760	11150	11350	11940	11700	11570	11630	12270	11810	111760	365	40792400	0.06	56	**22.88**
8	**S42, Mobile Rur, Mobile**		18290	17710	17440	16730	16980	16840	16750	16830	16570	17110	171250	365	62506250	3.9	52	**0.21**

Sl No	State Route, City, County		AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT	# Days in a year	Total # of veh	Seg ln (miles)	# Crashes on the segment	CRASH RATE
9	**S6 Autaga, Autaga Rural**		4600	5400	5010	4780	4990	5300	5230	6010	5970	5950						
			6010	6880	6410	6370	6620	6120	6100	7150	7100	7070						
			4180	4270	4410	4400	4890	5270	4980	5440	5480	5580						
			5910	5960	6250	6240	6770	7150	7090	7960	8010	7370						
			10370	10400	10530	10510	11320	12200	12660	14580	15460	14500						
			10660	10660	11110	11390	12560	13490	14000	15650	14630	13830						
		Average AADT	6955	7262	7287	7282	7858	8255	8343	9465	9442	9050	81198	365	29637392	10.2	46	**0.15**
10	**S157, Cullman, Cullman**		7580	10760	11150	11350	11940	11700	11570	11630	12270	11810	111760	365	40792400	0.12	45	**9.19**
11	**S3, Montgomery, Montgomery**		15240	16400	16430	16530	16680	15890	15700	15240	15490	14670	158270	365	57768550	0.74	44	**1.03**
12	**S204, Calhoun Rur, Calhoun**		4360	4380	4570	4650	5010	5030	5300	5140	5080	5350	48870	365	17837550	1.88	43	**1.28**
13	**S261, Pelham, Shelby**		13420	14250	14620	16360	13790	17760	18340	17120	18410	18280	162350	365	59257750	0.38	42	**1.87**
14	**S 25, Moody,Saint Claire**		16480	16760	16850	17290	18470	18680	18670	18320	18350	18650	178520	365	65159800	0.93	42	**0.69**
15	**S 119, Shelby Rur,Shelby**		6590	7790	8180	9370	9990	9830	11970	12230	11780	12760						
			10200	11500	12070	13040	13410	13240	15680	15900	15330	18900						
		Average AADT	8395	9645	10125	11205	11700	11535	13825	14065	13555	15830	119880	365	43756200	2.8	41	**0.33**
16	**S 16,Mobile Rur, Mobile**		6280	6470	6540	6880	7260	7180	7330	6950	7550	7410						
			9440	9630	10040	10550	11030	10810	11180	10620	10960	10930						
			12010	12360	12930	13540	14090	13920	14140	13790	13410	13540						
			14770	15300	16040	16740	17360	17280	17290	16510	15960	16310						
		Average AADT	12073	12430	13003	13610	14160	14003	14203	13640	13443	13593	134160	365	48968400	5	40	**0.16**

Sl No .	State Route, City, County		AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT	# Days in a year	Total # of veh	Seg In (miles)	# Crashes on the segment	CRASH RATE
17	**S1, Celeburne Rur, Celeburne**		5280	5450	5550	5550	5790	5830	5880	6270	6190	6430						
			5500	5600	5840	5830	6250	6140	6190	5070	6590	6710						
			5390	5525	5695	5690	6020	5985	6035	5670	6390	6570						
		Average AADT	5390	5525	5695	5690	6020	5985	6035	5670	6390	6570	58970	365	21524050	7.8	37	**0.22**
18	**S 22, Chilton Rur, Chilton**		3000	3180	2990	3180	3400	3470	3360	3650	3190	3780						
			4180	4400	4000	4420	4580	4720	4640	4960	4550	5190						
		Average AADT	3590	3790	3495	3800	3990	4095	4000	4305	3870	4485	39420	365	14388300	4.3	36	**0.58**
19	**S 8, Russel Rur, Russel**		7650	7880	7850	7820	7960	8070	8130	8160	8250	8500						
			12650	12750	13250	13250	13390	13270	13440	13500	13430	13830						
		Average AADT	10150	10315	10550	10535	10675	10670	10785	10830	10840	11165	106515	365	38877975	5.6	36	**0.17**
20	**S 217, Mobile Rur, Mobile**		8060	8790	8710	9270	9690	9860	9800	10800	10790	10940	96710	365	35299150	2	36	**0.51**
21	**S 245, Greenville, Butler**		8070	8570	8870	9570	9850	9510	9210	9060	9310	8740	90760	365	33127400	0.37	34	**2.77**
22	**S 38, Coosa Rur, Coosa**		13580	14460	13500	13050	14400	14520	14630	15100	15330	15560	144130	365	52607450	1.5	33	**0.42**
23	**S 3, Autaga Rur, Autaga**		5660	6280	6430	6830	7470	7810	7760	7760	7940	8310	72250	365	26371250	2	33	**0.63**

Sl No	State Route, City, County		AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT	# Days in a year	Total # of veh	Seg In (miles)	# Crashes on the segment	CRASH RATE
25	**S 3, M'Gmry Rur, M'gmry**		2600	2740	2550	3120	3160	3940	3520	3290	3050	3160						
			3660	3800	3690	4250	4300	5010	5070	4080	4270	4060						
			4210	4350	4210	4920	4970	5670	5690	4840	5140	4630						
			6350	6370	6200	6950	7010	7640	7610	7540	7980	7980						
			5340	5500	5530	5870	6270	6370	6280	6030	7540	7240						
			5210	5400	5430	6110	6540	6670	6550	6420	6570	6500						
			21350	21060	21100	21870	22570	22850	22650	22600	23130	23570						
			20030	20050	20090	17640	18270	16210	16040	17250	16940	13780						
		Average AADT	8594	8659	8600	8841	9136	9295	9176	9006	9328	8865	89500	365	32667500	13.9	31	**0.07**
27	**S 53, St. Claire, St. Claire**		6500	6840	6980	7210	7130	7260	7960	8600	8760	9060						
			3040	3140	3300	3450	3430	3590	3590	4040	3970	4180						
		Average AADT	4770	4990	5140	5330	5280	5425	5775	6320	6365	6620	56015	365	20445475	5.5	31	**0.28**
28	**S 41, Dallas Rur, Dallas**		9460	8800	9400	9540	9730	10670	9780	9300	8740	8880						
			4680	4450	4580	4930	5050	4870	4780	4500	4550	4610						
		Average AADT	7070	6625	6990	7235	7390	7770	7280	6900	6645	6745	70650	365	25787250	2.65	31	**0.45**
29	**S 16, Mobile Rur, Mobile**		9440	9630	10040	10550	11030	10810	11180	10620	10960	10930						
			12010	12360	12930	13540	14090	13920	14140	13790	13410	13540						
			14770	15300	16040	16740	17360	17280	17290	16510	15960	16310						
			26450	27220	27280	28130	28960	29250	29170	28120	24660	28520						
			29990	30440	31440	32290	33190	31360	31390	30300	28610	28370						
			29370	29010	27740	28750	29600	28770	29010	30470	31300	32120						
		Average AADT	20338	20660	20912	21667	22372	21898	22030	21635	20817	21632	213960	365	78095400	8.4	31	**0.05**
30	**S 87, Pike Rur, Pike**		1780	1970	1980	1990	2120	2160	2160	2030	2120	2270						
			2030	2230	2240	2250	2400	2470	2470	2350	2450	2650						
			6580	6730	6910	6610	7020	7920	7920	6820	6920	7420						
		Average AADT	4305	4480	4575	4430	4710	5195	5195	4585	4685	5035	47195	365	17226175	7.4	30	**0.24**

Sl No	State Route, City, County		AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT	# Days in a year	Total # of veh	Seg In (miles)	# Crashes on the segment	CRASH RATE
31	**S 22, Coosa Rur, Coosa**		2500	2520	2600	2810	2900	2930	2630	2580	2420	2400	26290	365	9595850	4.3	30	**0.73**
32	**S 6, Tuscaloosa Rur, Tuscaloosa**		11020	11190	12060	12060	13680	13320	13410	13650	13200	13300						
			9660	9820	10460	10460	11590	13020	13110	13170	12950	12700						
		Average AADT	10340	10505	11260	11260	12635	13170	13260	13410	13075	13000	121915	365	44498975	4.7	30	**0.14**
33	**S 52, Geneva Rur, Geneva**		4420	4330	4270	4260	4350	4580	4480	4180	4120	411						
			7470	6850	6730	6840	6980	7420	7290	7240	7230	6930						
			6660	6210	5980	5940	6060	6390	6040	5950	6010	5690						
			4890	4510	4320	4440	4520	4800	4500	4420	4470	4170						
		Average AADT	5860	5475	5325	5370	5478	5798	5578	5448	5458	4300	54088	365	19741938	5.8	30	**0.26**
34	**S 13, Northport, Tuscaloosa**		8220	8360	8720	9530	9290	9400	8890	9900	10430	10290	93030	365	33955950	0.52	29	**1.64**
35	**S 257, Walker Rur, Walker**		7280	7510	7400	7600	7910	8000	7890	7310	8710	9210	78820	365	28769300	2.7	29	**0.37**
36	**S 6, Autaga Rur, Autaga**		4600	5400	5010	4780	4990	5300	5230	6010	5970	5950						
			6010	6880	6410	6370	6620	6120	6100	7150	7100	7070						
			4180	4270	4410	4400	4890	5270	4980	5440	5480	5580						
			5910	5960	6250	6240	6770	7150	7090	7960	8010	7370						
			10370	10400	10530	10510	11320	12200	12660	14580	15460	14500						
			10660	10660	11110	11390	12560	13490	14000	15650	14630	13830						
		Average AADT	6955	7262	7287	7282	7858	8255	8343	9465	9442	9050	81198	365	29637392	2.55	29	**0.38**

Sl No	State Route, City, County		AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT	# Days in a year	Total # of veh	Seg ln (miles)	# Crashes on the segment	CRASH RATE
37	**S 69, Walker Rur, Walker**		4690	5070	4830	4870	5150	5550	5110	4970	5120	5110						
			4440	4620	4590	4660	4930	5420	5120	4930	5090	5080						
		Average AADT	4565	4845	4710	4765	5040	5485	5115	4950	5105	5095	49675	365	18131375	4.7	29	**0.34**
38	**S 9, M'gmry Rur, M'gmry**		6900	7290	7720	7240	6890	6750	6220	6470	6110	6080						
			7690	8050	8630	8260	7920	7530	7080	7060	6660	7060						
			7690	8050	8630	8410	8110	7730	7010	7220	6650	7080						
			4820	5320	5660	5130	4940	4820	4560	4830	4210	4430						
		Average AADT	6775	7178	7660	7260	6965	6708	6218	6395	5908	6163	67228	365	24538038	4.43	29	**0.27**
39	**S7 Fort Payne, Dekalb**		5630	5760	5380	5380	6170	6160	6260	6240	6410	6410	59800	365	21827000	0.46	30	**2.99**
40	**S 14, Elmore Rur, Elmore**		5410	5720	6720	6680	6750	7580	7850	7220	7800	7890						
			6510	7030	8150	8570	8740	9680	10030	9210	9820	10380						
		Average AADT	5960	6375	7435	7625	7745	8630	8940	8215	8810	9135	78870	365	28787550	4.4	28	**0.22**
41	**S 179, Etowah Rur, Etowah**		2220	2480	2310	2540	2510	2470	2550	2290	2140	2220	23730	365	8661450	2.6	28	**1.24**
42	**S 1, Russel Rur, Russel**		8050	7990	7580	7670	8070	9170	10020	10410	10620	10560						
			6960	6610	6550	6510	7050	9160	8690	9310	9410	9610						
			7690	7020	7010	6960	7580	9100	8640	9140	9140	9790						
		Average AADT	7567	7207	7047	7047	7567	9143	9117	9620	9723	9987	84023	365	30668517	6.7	28	**0.14**
43	**S 53, Madison Rur, Madison**		10070	10450	11240	11070	12760	13500	13380	13340	13400	13870	123080	365	44924200	2.8	28	**0.22**
44	**S 3, Montgomery Rur, Montgomery**		3660	3800	3690	4250	4300	5010	5070	4080	4270	4060						
			4210	4350	4210	4920	4970	5670	5690	4840	5140	4630						
			6350	6370	6200	6950	7010	7640	7610	7540	7980	7980						
		Average AADT	4740	4840	4700	5373	5427	6107	6123	5487	5797	5557	54150	365	19764750	8.44	28	**0.17**

Sl No	State Route, City, County		AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT	# Days in a year	Total # of veh	Seg ln (miles)	# Crashes on the segment	CRASH RATE
45	**S3, Montgomery, Montgomery**		19730	20870	22200	23140	21650	21420	20620	20450	19510	18960	208550	365	76120750	0.55	27	**0.64**
46	**S 15, Lee Rur, Lee**		4140	4250	4350	4530	4960	5260	5310	5140	5230	5200						
			4610	4740	4930	4760	5310	5190	5220	4990	5120	5130						
		Average AADT	4375	4495	4640	4645	5135	5225	5265	5065	5175	5165	49185	365	17952525	18.8	27	**0.08**
47	**S14, Pratville, Autaga**		9720	9380	9180	9320	9130	8570	8740	8590	8440	8570						
			10370	9850	9570	10250	10050	9460	9730	9390	9200	9360						
			22060	21930	23150	24310	23880	21610	20420	21570	22310	21820						
		Average AADT	14050	13720	13967	14627	14353	13213	12963	13183	13317	13250	136643	365	49874816.7	3	27	**0.18**
48	**S 38, Lee Rur, Lee**		9340	9290	9420	9600	9720	10770	11780	11470	12310	12110						
			7700	7140	7290	7350	7460	7780	8600	8340	9120	8870						
			8750	8550	9170	9400	9520	9860	10260	10490	11310	11610						
			6170	5760	6540	6560	6650	7740	7640	8090	9190	9000						
		Average AADT	7990	7685	8105	8227.5	8337.5	9037.5	9570	9597.5	10483	10398	89430	365	32641950	11.4	**27**	**0.07**
49	**S 188, Mobile Rur, Mobile**		5730	6300	5670	5790	5790	7140	6580	7080	6740	6610	63430	365	23151950	2.5	26	**0.45**
50	**S 157, Cullman,Cullman**		7580	10760	11150	11350	11940	11700	11570	11630	12270	11810	111760	365	40792400	0.98	26	**0.65**
51	**S 42, Baldwin Rur, Baldwin**		7730	7770	8130	8130	8570	8770	8940	9390	10130	9970						
			7410	7450	7490	7490	7570	7810	7620	7570	8380	8340						
			8020	8030	8210	8430	8920	9180	8420	8340	8570	8790						
			8530	8750	9390	9610	10170	10450	10490	10340	10620	10900						
			8260	8520	8200	8420	8830	9030	8910	8910	9150	9390						
			7350	7630	7870	8090	8390	8500	8470	8560	8790	9020						
		Average AADT	7883	8025	8215	8362	8742	8957	8808	8852	9273	9402	86518	365	31579192	14	26	**0.06**

Sl No	State Route, City, County		AADT 1994	AADT 1995	AADT 1996	AADT 1997	AADT 1998	AADT 1999	AADT 2000	AADT 2001	AADT 2002	AADT 2003	Total AADT	# Days in a year	Total # of veh	Seg ln (miles)	# Crashes on the segment	CRASH RATE
51	**S 9, Cherokee Rur, Cherokee**		3890	4370	4530	4330	4450	4630	4800	4510	4380	4050						
			4870	5370	5620	5510	5770	5780	5860	5880	6030	5580						
		Average AADT	4380	4870	5075	4920	5110	5205	5330	5195	5205	4815	50105	365	18288325	4.7	25	**0.29**
52	**S 3, Blount Rur, Blount**		3050	3240	3580	3820	3980	3800	3770	3310	3500	3290	35340	365	12899100	3.1	25	**0.63**
53	**S 219, Perry Rur, Perry**		900	920	980	900	970	970	980	970	1100	980	9670	365	3529550	4.25	25	**1.67**
54	**S 14, Dallas Rur, Dallas**		7320	7690	7680	7040	7700	7550	7950	8320	7860	7790	76900	365	28068500	2.25	25	**0.40**
55	**S 3, Clanton, Chilton**		8380	8620	8990	8640	9020	8830	9250	8260	8700	9740	88430	365	32276950	0.76	25	**1.02**

APPENDIX G

SEGMENT PRIORITIZATION BY CRASH RATE

APPENDIX G
SEGMENT PRIORITIZATION BY CRASH RATES

Sl. No	Segment #	County	City	State Route	Seg ln (miles)	Crash rate
1	7	Cullman	Cullman	S-157	0.06	22.88
2	6	Walker	Jasper	S-4	0.42	17.78
3	14	Cullman	Cullman	S-157	0.12	9.19
4	2	Tuscaloosa	Northport	S-13	0.32	6.90
5	8	Dekalb	Fort Payne	S-7	0.36	6.87
6	39	Dekalb	Fort Payne	S-7	0.46	2.99
7	27	Butler	Greenville	S-245	0.37	2.77
8	49	Limestone	Athens	S-127	0.61	2.01
9	17	Shelby	Pelham	S-261	0.38	1.87
10	67	Perry	Perry Rural	S219	4.25	1.67
11	44	Tuscaloosa	Northport	S13	0.52	1.64
12	16	Calhoun	Calhoun Rural	S204	1.88	1.28
13	53	Etowah	Etowah Rural	S 179	2.6	1.24
14	1	Madison	Madison Rural	S53	2.8	1.07
15	15	Montgomery	Montgomery	S3	0.74	1.03
16	71	Chilton	Clanton	S3	0.76	1.02
17	40	Coosa	Coosa Rural	S 22	4.3	0.73
18	18	Saint Claire	Moody	S25	0.93	0.69
19	62	Cullman	Cullman	S157	0.98	0.65
20	57	Montgomery	Montgomery	S3	0.55	0.64
21	31	Autaga	Autaga Rural	S3	2	0.63
22	66	Blount	Blount Rural	S3	3.1	0.63
23	23	Chilton	Chilton Rural	S 22	4.3	0.58
24	5	Shelby	Pelham	S261	1.84	0.54
25	25	Mobile	Mobile Rural	S 217	2	0.51
26	36	Dallas	Dallas Rural	S 41	2.65	0.45
27	61	Mobile	Mobile Rural	S 188	2.5	0.45
28	29	Coosa	Coosa Rural	S 38	1.5	0.42
29	68	Dallas	Dallas Rural	S14	2.25	0.40
30	46	Autaga	Autaga Rural	S 6	2.55	0.38
31	45	Walker	Walker Rural	S 257	2.7	0.37
32	47	Walker	S 69 Walker Rural	S 69	4.7	0.34
33	59	Autaga	Pratville	S14	3	0.34
34	20	Shelby	Shelby Rural	S119	2.8	0.33
35	65	Cherokee	Cherokee Rural	S9	4.7	0.29

Sl. No	Segment #	County	City	State Route	Seg ln (miles)	Crash rate
36	35	St. Claire	St. Claire	S53	5.5	0.28
37	48	M'gmry	Montgomery Rural	S-48	4.43	0.27
38	43	Geneva	Geneva Rural	S-52	5.8	0.26
39	38	Pike	Pike Rural	S-87	7.4	0.24
40	55	MadiSon	Madison Rural	S-53	2.8	0.22
41	50	Elmore	Elmore Rural	S-14	4.4	0.22
42	22	Celeburne	Celeburne Rural	S-1	7.8	0.22
43	10	Mobile	Mobile Rural	S-42	3.9	0.21
44	56	Montgomery	Montgomery Rural	S-3	8.44	0.17
45	24	Russel	Russel Rural	S-8	5.6	0.17
46	21	Mobile	Mobile Rural	S-16	5	0.16
47	12	Autaga	Autaga Rural	S-6	10.2	0.15
48	41	Tuscaloosa	Tuscaloosa Rural	S-6	4.7	0.14
49	54	Russel	Russel Rural	S-1	6.7	0.14
50	4	Mobile	Mobile Rural	S-16	9.5	0.09
51	58	Lee	Lee Rural	S-15	18.8	0.08
52	60	Lee	Lee Rural	S-38	11.4	0.07
53	34	Montgomery	Montgomery Rural	S-3	13.9	0.07
54	63	Baldwin	Baldwin Rural	S-42	14	0.06
55	37	Mobile	Mobile Rural	S-16	8.4	0.05
				Total miles =	**224.67**	

APPENDIX H

BENEFIT TO COST RATIO CALCULATIONS

APPENDIX H
BENEFIT TO COST RATIO CALCULATIONS

								BENEFITS							
				Number of crashes on Segments without a countermeasure				Expected # of crashes prevented with 14% reduction	(14% reduction across all crash types)			SAVINGS IN CRASH COSTS			
SI No.	County	City	Link	Fatal	Injury	PDO	Total		Fatal	Injury	PDO	Fatal	Injury	PDO	Total
1	MADISON	MADISO RURAL	S-53	1	27	106	134	19	0	4	15	339697.04	167164.35	61002.82	567864.21
2	TUSCALOOSA	NORTHPORT	S-13	0	13	62	75	11	0	2	9	0.00	80486.54	35680.89	116167.43
3	MOBILE	MOBILE RURAL	S-16	0	11	48	59	8	0	2	7	0.00	68103.99	27623.92	95727.91
4	SHELBY	PELHAM	S-261	0	5	54	59	8	0	1	8	0.00	30956.36	31076.91	62033.27
5	WALKER	JASPER	S-4	0	6	51	57	8	0	1	7	0.00	37147.63	29350.41	66498.05
6	CULLMAN	CULLMAN	S-157	0	9	47	56	8	0	1	7	0.00	55721.45	27048.42	82769.87
7	DEKALB	FORT PAYNE	S-7	0	10	44	54	8	0	1	6	0.00	61912.72	25321.92	87234.65
8	MOBILE	MOBILE RURAL	S-42	1	16	35	52	7	0	2	5	339697.04	99060.35	20142.44	458899.84
9	AUTAUGA	AUTAUGA RURAL	S-6	1	14	31	46	6	0	2	4	339697.04	86677.81	17840.45	444215.30
10	CULLMAN	CULLMAN	S-157	0	7	38	45	6	0	1	5	0.00	43338.91	21868.93	65207.84
11	MONTGOMERY	MONTGOMERY	S-3	0	9	35	44	6	0	1	5	0.00	55721.45	20142.44	75863.89
12	CALHOUN	CALHOU RURAL	S-204	1	14	28	43	6	0	2	4	339697.04	86677.81	16113.95	442488.81
13	SHELBY	PELHAM	S-261	0	10	32	42	6	0	1	4	0.00	61912.72	18415.94	80328.67
14	SAINT CLAI	MOODY	S-25	0	11	31	42	6	0	2	4	0.00	68103.99	17840.45	85944.44
15	SHELBY	SHELBY RURAL	S-119	0	5	36	41	6	0	1	5	0.00	30956.36	20717.94	51674.30
16	MOBILE	MOBILE RURAL	S-16	0	12	28	40	6	0	2	4	0.00	74295.27	16113.95	90409.22
17	CLEBURNE	CLEBUR RURAL	S-1	1	19	17	37	5	0	3	2	339697.04	117634.17	9783.47	467114.69
18	CHILTON	CHILTO RURAL	S-22	1	8	27	36	5	0	1	4	339697.04	49530.18	15538.45	404765.68
19	RUSSELL	RUSSELL RURAL	S-8	4	12	20	36	5	1	2	3	1358788.18	74295.27	11509.97	1444593.41
20	MOBILE	MOBILE RURAL	S-217	0	11	25	36	5	0	2	4	0.00	68103.99	14387.46	82491.45
21	BUTLER	GREENVILLE	S-245	0	6	28	34	5	0	1	4	0.00	37147.63	16113.95	53261.58
22	COOSA	COOSA RURAL	S-38	0	13	20	33	5	0	2	3	0.00	80486.54	11509.97	91996.50
23	AUTAUGA	AUTAUG RURAL	S-3	0	9	24	33	5	0	1	3	0.00	55721.45	13811.96	69533.41
24	MONTGOMERY	MONTGO RURAL	S-3	2	6	23	31	4	0	1	3	679394.09	37147.63	13236.46	729778.18
25	SAINT CLAIRE	ST. CLAIR	S-53	0	7	24	31	4	0	1	3	0.00	43338.91	13811.96	57150.86

								BENEFITS							
				Number of crashes on Segments without a countermeasure				Expected number of total crashes prevented with 14% reduction	(14% reduction across all crash types)			SAVINGS IN CRASH COSTS			
Sl No.	County	City	Link	Fatal	Injury	PDO	Total		Fatal	Injury	PDO	Fatal	Injury	PDO	Total
26	DALLAS	DALLAS RURAL	S-41	1	5	25	31	4	0	1	4	339697.04	30956.36	14387.46	385040.86
27	MOBILE	MOBILE RURAL	S-16	0	7	24	31	4	0	1	3	0.00	43338.91	13811.96	57150.86
28	PIKE	PIKE RURAL	S-87	0	8	22	30	4	0	1	3	0.00	49530.18	12660.96	62191.14
29	DEKALB	FORT PAYNE	S-7	1	4	25	30	4	0	1	4	339697.04	24765.09	14387.46	378849.59
30	COOSA	COOSA RURAL	S-22	0	14	16	30	4	0	2	2	0.00	86677.81	9207.97	95885.78
31	TUSCALOOSA	TUSCAL RURAL	S-6	0	11	19	30	4	0	2	3	0.00	68103.99	10934.47	79038.46
32	GENEVA	GENEVA RURAL	S-52	0	12	18	30	4	0	2	3	0.00	74295.27	10358.97	84654.23
33	TUSCALOOSA	NORTHPORT	S-13	0	8	21	29	4	0	1	3	0.00	49530.18	12085.46	61615.64
34	WALKER	WALKER RURAL	S-257	0	6	23	29	4	0	1	3	0.00	37147.63	13236.46	50384.09
35	AUTAUGA	AUTAUG RURAL	S-6	1	11	17	29	4	0	2	2	339697.04	68103.99	9783.47	417584.51
36	WALKER	WALKER RURAL	S-69	1	16	12	29	4	0	2	2	339697.04	99060.35	6905.98	445663.38
37	MONTGOMERY	MONTGO RURAL	S-9	0	9	20	29	4	0	1	3	0.00	55721.45	11509.97	67231.41
38	LIMESTONE	ATHENS	S-127	0	8	20	28	4	0	1	3	0.00	49530.18	11509.97	61040.14
39	ELMORE	ELMORE RURAL	S-14	0	6	22	28	4	0	1	3	0.00	37147.63	12660.96	49808.60
40	ETOWAH	ETOWAH RURAL	S-179	0	13	15	28	4	0	2	2	0.00	80486.54	8632.47	89119.01
41	RUSSELL	RUSSELL RU	S-1	0	7	21	28	4	0	1	3	0.00	43338.91	12085.46	55424.37
42	MADISON	MADISO RURAL	S-53	0	3	25	28	4	0	0	4	0.00	18573.82	14387.46	32961.27
43	MONTGOMERY	MONTGO RURAL	S-3	0	5	23	28	4	0	1	3	0.00	30956.36	13236.46	44192.82
44	MONTGOMERY	MONTGOMERY	S-3	0	8	19	27	4	0	1	3	0.00	49530.18	10934.47	60464.64
45	LEE	LEE RURAL	S-15	0	10	17	27	4	0	1	2	0.00	61912.72	9783.47	71696.19
46	AUTAUGA	PRATTVILLE	S-14	1	11	15	27	4	0	2	2	339697.04	68103.99	8632.47	416433.51
47	LEE	LEE RURAL	S-38	0	5	22	27	4	0	1	3	0.00	30956.36	12660.96	43617.32
48	MOBILE	MOBILE RURAL	S-188	1	14	11	26	4	0	2	2	339697.04	86677.81	6330.48	432705.34
49	CULLMAN	CULLMAN	S-157	0	4	22	26	4	0	1	3	0.00	24765.09	12660.96	37426.05
50	BALDWIN	BALDWI RURAL	S-42	0	5	21	26	4	0	1	3	0.00	30956.36	12085.46	43041.82
51	CHEROKEE	CHEROK RURAL	S-9	1	14	10	25	4	0	2	1	339697.04	86677.81	5754.98	432129.84
52	BLOUNT	BLOUNT RURAL	S-3	1	11	13	25	4	0	2	2	339697.04	68103.99	7481.48	415282.52

								BENEFITS							
				Number of crashes on Segments without a countermeasure				**Expected number of total crashes prevented with 14% reduction**	**(14% reduction across all crash types)**			**SAVINGS IN CRASH COSTS**			
Sl No.	**County**	**City**	**Link**	**Fatal**	**Injury**	**PDO**	**Total**		**Fatal**	**Injury**	**PDO**	**Fatal**	**Injury**	**PDO**	**Total**
53	PERRY	PERRY RURAL	S-219	0	13	12	25	4	0	2	2	0.00	80486.54	6905.98	87392.52
54	DALLAS	DALLAS RURAL	S-14	0	9	16	25	4	0	1	2	0.00	55721.45	9207.97	64929.42
55	CHILTON	CLANTON	S-3	0	9	16	25	4	0	1	2	0.00	55721.45	9207.97	64929.42
	TOTALS											6793940.90	3126592.43	824113.54	10744646.87

Total cost of instllation @ $0.55/ L.F. (C)= 652441.68

Total cost saved in terms of crashes
prevented ($) or Benefit (B) =

B/C = 16.47

It is assumed that crash severity does not change on a segment, across the ten years (1994 to 2003) and across the crash types for the entire analysis period