A BENEFIT/COST ANALYSIS OF PAVED SHOULDER INSTALLATION ON HIGH PRIORITY ROAD SEGMENTS ON TWO-LANE RURAL HIGHWAYS IN ALABAMA

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Renee´ Danielle Ayala

Certificate of Approval:

Robert L. Vecellio
Associate Professor
Civil Engineering

Rod E. Turochy, Chair
Associate Professor
Civil Engineering

David H. Timm
Associate Professor
Civil Engineering

George T. Flowers
Interim Dean
Graduate School

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Renee´ Danielle Ayala

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Renee´ Danielle Ayala

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Date of Graduation

VITA

Renee´ Danielle (Cunningham) Ayala, daughter of Kenneth Allen and Adele (Hurtado) Cunningham, was born September 17, 1979, in Escondido, California. She graduated from Orange Glen High School in June, 1997. She joined the U.S. Army in August, 1997, and served at the U.S. Army Marksmanship Unit until August, 2001. She married Armando Ayala, son of Ernesto and Eva (Urias) Ayala, on June 7, 1999. She attended Columbus State University, Georgia, for one year, then entered Auburn University in August, 2002, and graduated magna cum laude with a Bachelor of Science degree in Biosystems Engineering in May, 2006. As an undergraduate student she participated in the Co-operative Education Program, Auburn University, where she worked as an Engineering Aide for the U.S. Forest Service, Auburn, Alabama. She entered Graduate School, Auburn University, in May, 2006. Her daughter Mila Cecilia Ayala was born September 16, 2006 at Fort Benning, Georgia.

THESIS ABSTRACT

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Renee´ Danielle Ayala

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There are currently more than 40,000 deaths a year that occur as the result of motor vehicle traffic accidents, which have been ranked among the leading causes of death for Americans. In addition, a reported 55% of all roadway fatalities are the result of roadway departures. In an effort to reduce the number of accidents that occur on two-lane rural highways the Alabama Department of Transportation established a new policy in 2006 to begin installing 2-ft of paved shoulders on both sides of the highways during resurfacing and reconstruction projects. This type of countermeasure provides an additional recovery area for vehicles that have veered out of the traveled way as well as a reduction in accidents.

Since the policy that ALDOT established in 2006 has only been in effect for two years, a before-and-after study to quantify the benefits of installing 2-ft paved shoulders was not possible. However, a hypothetical benefit/cost analysis was needed to evaluate the potential benefits and lay the foundation for future research in this area. As part of this analysis a detailed methodology was created to assist in the identification of high priority segments that could experience a significant reduction in accidents if this treatment were implemented. The CARE 8 software program that has been developed and maintained by the University of Alabama CARE Research and Development Laboratory was used to conduct a high accident analysis. Based on this analysis, two different lists of high priority segments were created which contained accident and location information for the top 5% of the road segments that were identified based on two criteria: crash rate and severity.

The economic benefits associated with the installation of paved shoulders at these locations were calculated based on a range of crash reduction factors. The cost of installing 2-ft paved shoulders was determined based on 41 projects that had already been let to bid by ALDOT. The resulting benefit/cost ratios for the high priority segments in each of the criteria ranged from 0.08:1 to 2.20:1 for the segments identified based on crash rate and 1.22:1 to 8.18:1 for those segments identified based on severity. The results of this preliminary analysis indicated that the installation of 2-ft paved shoulders on two-lane rural highways in Alabama is a cost effective countermeasure that has the potential to significantly reduce accidents and improve safety.

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Style manual used: Publication Manual of the American Psychological Association, Fifth Edition

Computer software used: Microsoft Word, Microsoft Excel, CARE 8

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CHAPTER ONE

INTRODUCTION

1.1 Background

Motor vehicle accidents have been reported by the Center for Disease Control's (CDC) National Center for Health Statistics (NCHS) as one of the leading causes of death in the United States (Kochanek et al., 2004). In this report by the NCHS, motor vehicle accidents were all categorized under unintentional injuries. As a result, the National Highway Traffic Safety Administration (NHTSA) conducted its own study to further examine the proportion of deaths that occur from motor vehicle accidents. NHTSA's National Center for Statistics and Analysis (NCSA) "determined that motor vehicle traffic crashes were the leading cause of death for every age 3 through 33" and were the cause of 44,065 deaths in 2002 (NHTSA, 2005a)." Furthermore, it was determined to be the cause of more than 50% of the deaths that resulted from unintentional injuries as well as the leading external cause of death for both males and females in the U.S. (NHTSA, 2005b).

It has also been shown that the highest proportions of fatal crashes occur in the southeastern portion of the U.S., defined here as eight states including Alabama (Dixon, 2005). These states collectively contribute over 26% of the nation's fatal motor vehicle crashes annually and exceed the national average by "30 fatalities per million vehicle miles traveled" (MVMT) (Dixon, 2005). More than 40% of fatal motor vehicle crashes occur in rural areas and approximately 60% of them are the result of a roadway departure (NHTSA, 2005b and FHWA, 2006). In addition, there are fewer vehicle miles of travel in rural areas and as a result the crash rates are often higher than those of urban areas. Crashes in rural areas have also been shown to be more severe, cause greater injuries, and result in more fatalities (NHTSA, 2005b).

Many studies of countermeasures that can be implemented to reduce the number and severity of motor vehicle accidents that occur on rural two-lane highways have been conducted. The findings of several different studies have identified shoulder paving or widening as an effective measure in reducing accidents and accident severity on two-lane rural highways (Heimbach et al., 1974; Ogden, 1997; Rogness et al., 1982; Turner et al., 1981, Zegeer et al., 1988, and Zegeer et al., 1995). This countermeasure provides vehicles with an additional recovery area that has been shown to effectively reduce run-off-the-road and head-on crashes. It is thought to be most effective where shoulder edge drop offs are eliminated by the addition or widening of paved shoulders (NCHRP, 2003, AAA Foundation for Traffic Safety, 2005).

The Alabama Department of Transportation (ALDOT) established a new policy in 2006 to reduce the number of run-off-road crashes. As a result ALDOT has been installing 2-ft of paved shoulders as part of their resurfacing and reconstruction projects for two-lane rural highways throughout the state.

1.2 Objectives

The objectives of this research include the development of a procedure that could be used by ALDOT to identify high priority road segments that have either high crash rates or severity. These segments could potentially have the greatest reduction in run-off-road crashes as a result of the installation of 2-ft paved shoulders. In addition a benefit/cost analysis was conducted in an attempt to quantify the potential benefits of adding 2-ft of paved shoulders to high priority segments on two-lane rural highways in Alabama.

1.3 Scope

This project was conducted for the Alabama Department of Transportation as part of a preliminary analysis to quantify the potential benefits of installing 2-ft paved shoulders on two-lane rural highways within the state. Pavement widening is often used as a countermeasure against lane departures which have been shown to result in high severity accidents. The widening of paved shoulders on two-lane rural roads can provide errant vehicles with an additional recovery area that can reduce accident frequency and severity.

This study established a methodology that ALDOT could use to identify high priority sections of roadway based on crash rate and severity. These segments were then used in a hypothetical benefit/cost analysis to determine the potential benefits that could be obtained by installing 2-ft paved shoulders on these segments. Since ALDOT's shoulder paving policy has been in place for only 2 years, a hypothetical analysis was conducted in the absence of sufficient data after installation. Common practice is to have a minimum of three years of after data when conducting a before-and-after analysis.

The potential benefits were calculated based on the number of accidents that could be prevented if this shoulder treatment had been applied to the identified segments. The per-mile-cost of adding paved shoulders was calculated based on 41 projects that had been let to bid within the past two years. The mean value of these project costs was used in this analysis which limits the results of this study to the State of Alabama.

1.4 Outline

This thesis begins with background information regarding the need for this project, a list of the objectives, as well as how and where the research will be applied; which is presented in chapter one. Chapter two contains an extensive literature review which consists of a summary of the studies that have been conducted to determine and analyze the effects that paved shoulders can have on accident rates and safety. Included are publications examining the impacts of shoulder widening as well as comparisons between the accident rates experienced on similar roadways with different shoulder widths. Following the examination of the relationship between paved shoulders on rural two-lane highways and accident occurrence, there is a synopsis of associated crash reduction factors (CRFs) currently being recommended for use by the U.S. Department of Transportation (DOT), National Cooperative Highway Research Program (NCHRP), and other state DOTs. Finally, a section examining the economic costs incurred as a result of motor vehicle accidents was included. In this section, a brief discussion regarding the rating scale that is used to characterize different levels of injury severity and a breakdown of their associated costs were outlined.

Chapter three contains the methodologies used to identify the high priority road segments as well as the details of the benefit/cost analysis. The first section of this chapter provides a detailed outline of the methodology that was used during data collection. Section two contains the methodology used during data analysis to identify the high priority segments and to determine an appropriate range of CRF values that were used to estimate the reductions in accidents that may be obtained from the installation of paved shoulders. The final three sections of this chapter give the details of the determination of the potential benefits and costs associated with the installation of 2-ft paved shoulders on two-lane rural highways in Alabama. The results of which were used in the hypothetical benefit/cost analysis to determine the potential benefits of implementing this countermeasure at the locations that were identified as high priority segments.

The final two chapters of this thesis present the results and conclusions of this study. In chapter four, the results of the high priority identification process based on the two criteria: crash rate and severity, were examined. Consequently the use of these segments in the calculation of potential benefits and costs were also discussed. The ranges of potential economic benefits that can result from the application of the shoulder treatment were identified. These calculated benefits were based on the selected range of CRF values selected in the methodology section. The construction costs associated with the installation of paved shoulders were also identified and used in the determination of the benefit/cost ratios for these two criteria. Chapter five expands on these results and discusses the recommendations for the application of the outlined methodology for identifying high priority segments as well as recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

In an attempt to reduce accidents, the Alabama DOT has been installing 2-ft paved shoulders on each side of two-lane rural highways during resurfacing and reconstruction projects for the past two years. Many related articles and publications were reviewed to quantify the potential accident reductions that may be obtained from this countermeasure. Of particular interest were publications that examined the effects that the installation or presence of paved shoulders have been shown to have on accident rates. Consequently, studies that have examined the relationship between different paved shoulder widths and accident rates or reductions were also reviewed. In addition, a state-of-the-practice approach was followed to determine the crash reduction or accident modification values that were currently being recommended for use regarding the installation or widening of paved shoulders. Finally, publications that quantified the economic costs associated with accidents were used to determine the value of an injury, fatality, and property damage.

2.1 Effects of Paved Shoulders and Shoulder Widths on Accident Rates

Two different types of studies were reviewed to gain an understanding of the relationship between paved shoulders and accident rates. The first type, were those that examined the presence of paved shoulders. Seven studies were reviewed that compared the accident rates of road segments with paved shoulders with those that had unpaved shoulders. Each of these studies established a methodology of characterizing road segments in an attempt to isolate the effects of paved shoulders on accident rates. The second type of study followed a similar methodology in their evaluations of the accident rates on similar road segments that had different shoulder widths.

2.1.1 Comparisons between Paved Shoulders and Unpaved Shoulders

In 1974 a study was published which examined the cost-effectiveness of paving the shoulders of rural highways in North Carolina (Heimbach et al., 1974). During this study the accident rates of road segments with paved shoulders were compared to those with unpaved shoulders. The accident data included the number of accidents, fatalities, injuries, and property damage from 1966 to 1969.

The accident data were initially grouped into two categories based on the presence or absence of paved shoulders and rated according to nine characteristics. All sections of roads that contained an object that may change speed, flow, or in some way alter the traffic pattern were eliminated. This included road segments that contained intersections, bridges, as well as varying roadway and shoulder widths. This preliminary analysis resulted in the selection of 817 sections of roadway that had paved shoulders and roughly 3,100 sections with unpaved shoulders.

An extensive classification system was then employed to ensure that the road segments used in the analysis would be similar in all aspects except shoulder treatment. However, when the researchers attempted to group the road segments according to the rating system they found only a few roads to be similar. As a result, an analysis of covariance was conducted to determine which of the variables used in the classification process were actually significant. From this test it was determined that only five of the original nine variables were found to have a statistically significant relationship with the number of accidents: average daily traffic (ADT), access control, speed limit, number of lanes, and lane width. Once the number of variables used in the classification system was reduced, 141 sections that had paved shoulders were paired against 985 sections that had unpaved shoulders.

The accident data that were used in this study included only four years of information. If the year of construction fell within this range, then the entire year of accident data was omitted resulting in only three years of before and after data combined. After the two sets of data were established, a statistical analysis was conducted to determine if there was a “difference in accident experience between highway sections alike in all respects, except for the shoulder construction” (Heimbach et al, 1974). The Chi-square test that was conducted showed there to be a statistically lower accident experience as well as accident severity on roadways with paved shoulders than roadways with unpaved shoulders. The conclusion of this analysis was limited to highway road segments that had 3-ft to 4-ft of paved shoulders and ADT values between 2,000 and 10,000 vehicles per day (vpd).

One of the major drawbacks to this study is that only four years of accident data were available. As a result, there was an inconsistent amount of data available for the time periods before and after shoulder construction. The shoulder widths of the road segments studied also varied, although, the majority were reported to be between 3-ft and 4-ft. Another point that should be considered when examining the findings of this study is that many of the road segments that were classified as unpaved did have shoulder treatments such as rock or gravel.

The Texas State Department of Highways and Public Transportation conducted two studies that both had similar results to the Heimbach et al. (1974) study (Turner et al., 1981 and Rogness et al., 1982). The purpose of the first study was to determine the effect that paved shoulders had on accident rates. During this study they compared rural two-lane highways that had full width paved shoulders with similar roads without paved shoulders.

The accident data set used in this study was for the three years from 1975 to 1977. The accident data were reviewed and the accidents that were the result of a condition that was not normally characteristic of the road were eliminated. Some examples include accidents that occurred in construction areas, or near railroad crossings. The accident data were then divided into two categories: all accidents and non-intersection accidents.

Road data for these locations were also collected. Segments that contained divided roadways, major intersections, or other objects that may influence accident rates were eliminated. Road segments with shoulders that were paved but less than 6-ft were also classified as not having a paved shoulder. As a result, the analysis was conducted using 85 sections of similar roadways that were classified as either full-width paved shoulders or no shoulders. The road characteristics that were initially created divided the road data for paved and unpaved shoulders into three categories based on three ADT ranges: 1,000 to 3,000, 3,000 to 5,000, and 5,000 to 7,000. The researchers had originally intended to have ten sites in each ADT range. However, the ADT range of

5,000 to 7,000 consisted of only eight sites that met the criteria of being five or more miles in length with similar characteristics.

From a regression analysis, it was determined that two-lane highways with full width paved shoulders had lower accident rates over all three ADT ranges than those without full width paved shoulders. This was found to be true regardless of the presence of intersections. They also concluded that “two-lane highways without paved shoulders are very sensitive to intersection accidents, especially at high traffic volumes” (Turner et al., 1981). The road sections with shoulders were also observed to have lower fatality rates, hit-other-car, run-off-road, and fixed-object accidents.

The second study conducted by the Texas State Department of Highways and Public Transportation focused on the effect that the installation of full width shoulders had on accident frequency (Rogness et al., 1982). During this before and after study the comparison was made between the number and type of accidents that occurred on a road segment before the installation of full width shoulders with those that occurred after construction was completed.

The same classification system and a similar set of criteria were used to evaluate the road data and accident data as in the previous study by Turner et al. (1981). Road segments for this study were selected based on whether two years of before and after accident data were available. As an additional requirement, there could not have been any other alterations or construction conducted on the road segment within this four year period. Accidents that were not considered to be associated with roadway type were also excluded from the accident data even though the classification of all accidents and non-intersection accidents were maintained. In addition, some road segments were included even though they were less than five miles in length due to a small sample size in the 3,000 to 5,000 and 5,000 to 7,000 ADT ranges.

Rogness et al. (1982) concluded that for the frequency analysis the total number of accidents decreased after the installation of full width paved shoulders for both the all-accident and non-intersection classifications. They also conducted a paired t-test on the before and after data for each ADT range to determine if there was a statistically significant difference in either the type of accident or the severity. From this analysis they concluded that there was no significant change in accident type. However, there appeared to be a decrease in accident severity for the two lower ADT ranges and an increase in accident severity for the higher ADT range.

In 1988, an article was published that again found there to be a reduction in accidents after shoulder widening of paved and unpaved shoulders (Zegeer et al., 1988). This study was conducted using road and accident data from seven different states. The emphasis of the study was on the effects that certain road treatments had on safety. One of the primary objectives of the study was to develop a model that would explain the relationship between accidents and different road characteristics. In addition, the comparison was again made between the accident rates that occurred on road segments with paved and unpaved shoulders.

Accident data were obtained from each of the seven states. Several modifications were then made to the data sets to account for the different reporting measures of each state. Five years of data were obtained for most of the sites. There were a few sites in which accident data were available for only two to three years. The researchers then reduced the accident data set by including only those that they felt were the result of the specific road conditions of interest. This was accomplished by conducting a Chi-square analysis on the different types of accidents and the selected roadway features. Three types of single-vehicle accidents and four types of multi-vehicle accidents were found to be significant.

Along with the accident data, road data were also obtained from the appropriate state agencies. The road segments that were selected from rural areas varied in length from one to ten miles. The length of each section was determined by significant changes in ADT, as well as lane and shoulder width, and several other factors that could affect traffic flow. The important road characteristics were recorded and then analyzed using several statistical methods to determine whether they had a significant impact on the designated types of accidents. Thirteen variables were identified and found to be significant based on a Chi-square, regression, and analysis of variance and covariance.

A model was then developed based on the known variables and used to predict the number of accidents that would occur at specific shoulder widths. The model was also used to develop accident reduction factors. The percent of accident reduction that could be expected from adding a specified number of feet of paved shoulder was then calculated based on the predicted values of before and after accident data generated by the model.

Zegeer et al. (1988) concluded from this study that unpaved shoulders were not as effective in reducing accidents in the specified categories as paved shoulders. The percent reduction in accidents that could be expected from the addition of two, four, and six-ft of shoulder widening were 16%, 29%, and 40% reduction in accidents, respectively. Although adding unpaved shoulders to both sides of the road did not reduce accident rates as much, they still reported reductions of 13%, 25%, and 35%, respectively.

Although the results of this study are similar to those previously reviewed, it is difficult to make a direct comparison. First, this study used road and accident data from several different states. Secondly, the percent reduction in accident rates that were reported in this study were based on simulated before and after data. Therefore, the results of this study were based on the model's ability to accurately predict accident occurrence. Any direct comparisons between the accident data that were collected and the simulated data were not discussed. Different models were developed for each accident type with reported R^2 values that ranged between 0.39 and 0.46. Although many road characteristics were analyzed to determine their statistical significance, it is not possible to account for all of them. Finally, the compounding effects that some of these characteristics may have when they occur together were not assessed.

A study that was later conducted in Victoria, Australia, examined the benefits and costs of paving the shoulders of two-lane rural roads (Ogden, 1997). The road segments selected for the study were all part of resealing projects that included the addition of a paved shoulder. The paved shoulder that was added had to be at least 600-mm or 2-ft wide to be included in the study. A corresponding control segment was also selected for each road segment and was required to be the same length, on the same highway, with the same speed limit, having similar geometric design, traffic volume, and preferably the same vehicular traffic. In total, thirty-six road segments with corresponding control segments were selected.

As part of this study a statistical analysis of the effects of paved shoulders was conducted by comparing the number of accidents that occurred on the treated segments, which had paved shoulders, with the accidents that occurred on the control segments without paved shoulders. Accident data before and after the construction period were collected for both the treatment and control sites. The financial year in which the road construction was conducted was eliminated from the analysis. From this study Ogden concluded "that paved shoulders have a positive effect on accidents on two-way rural highways" (1997). Based on the results of a Chi squared test, he also concluded that there was a 41% reduction in casualty accidents per vehicle kilometer.

However, some care should be taken when examining the results of these data because the rural roads in Australia that do not have paved shoulders also lack edge lines. In some instances raised reflective pavement markers were also added along with the edge lines and paved shoulders. The lack of edge lines as well as the addition of the reflective pavement markers may have independently had an effect on the number of accidents that occurred before and after shoulder widening.

There were two studies that found there to be no difference in the accident rates of road segments with paved shoulders when compared to unpaved shoulders. The first study to come to this conclusion was published by Zegeer et al. in 1994. Unlike the other studies, this study only examined data for low-volume roads having less than 2,000 vpd. During this study, an analysis of covariance was used to determine if there was a statistically significant relationship between accident rates of a certain type and shoulder width. The only two that were found to have a significant relationship on low-volume two-lane roads were the single-vehicle accidents and opposite-direction accidents. When a covariance model was used to compare unpaved shoulders with paved shoulders they concluded that there was no significant difference in the accident rates (Zegeer et al., 1994).

In 1999, a study was published for the Alabama Department of Transportation in which a safety effectiveness evaluation was conducted on two-lane rural roads (Bowman and Abboud, 1999). There were a total of 57 road segments that were analyzed that had either a 2-ft or 4-ft paved shoulder installed where there had been none previously. The accident rate and accident frequency for each segment were determined using three years of accident data before and after construction of the shoulders. Control factors were developed based on county crash statistics for each location to help identify trends in the accident data. Only three types of accidents were considered during this analysis: single vehicle, multiple vehicle same direction, and multiple vehicle opposite direction.

A statistical analysis was conducted to determine whether there was a statistically significant difference in the accident rates per 100 million vehicle miles of travel before and after shoulder construction. A paired t-test analysis showed that there were no statistically significant differences between the actual and expected crash rates as well as severity rates for either of the shoulder conditions. However, “there was a reduction in single vehicle and total crashes for both the two and four-foot shoulder installations” (Bowman and Abboud, 1999). In addition, a two sample t-test was conducted to determine if there was a statistically significant difference in crash rate or severity rate between the two and four foot shoulder installations. When compared at a significance level of five percent it was again concluded that there was no statistically significant difference between the crash rates associated with the two different shoulder widths. This was found to be true for single vehicle, multiple vehicle, and total accidents.

Although five of the seven studies reviewed had similar findings, i.e. that roads with paved shoulders have lower accident rates than roads with unpaved shoulders (Heimbach et al., 1974; Ogden, 1997; Rogness et al., 1982; Turner et al., 1981; and Zegeer et al., 1988) the lack of continuity between these studies makes comparing their findings difficult. Several key elements of the studies were different: width of shoulders evaluated, ADT values, classification system of roadway elements, and the statistical analyses used to determine the results. The length of road segments evaluated varied not only between studies but often within a study as well. Furthermore, each of the studies utilized a different set of criteria to evaluate the accident and road data.

Most of the studies compared accident rates of roads with paved and unpaved shoulders by selecting roads based on an established set of criteria and using accident data for specific years (Heimbach et al., 1974; Turner et al., 1981; Zegeer et al., 1988; and Zegeer et al., 1994). However, the number of years varied between studies, and sometimes even between sites within a study (Zegeer et al., 1988 and Zegeer et al., 1994). In contrast, three of the studies chose to conduct before and after analyses based on accident data for a specified number of years before and after the installation of paved shoulders (Rogness et al., 1982, Ogden, 1997, and Bowman and Abboud, 1999).

Many of the unpaved shoulders evaluated in the studies had received some type of treatment such as gravel or rock but were obviously not paved. Alternatively, in the studies conducted by Turner et al. (1981) and Rogness et al. (1982), road segments with a paved shoulder of less than 6-ft were classified as unpaved. Although the results of these two studies were similar to the findings of the other studies, the criteria selected for shoulder classification makes them difficult to compare. The 6-ft of paved shoulder may have influenced the number of accidents as well as their severity when compared to studies that examined entirely unpaved shoulders.

Despite the differences in the studies, they all concluded that in general, rural roads with paved shoulders appear to be safer than rural roads with unpaved shoulders. The studies also suggest that paved shoulders reduce the number of accidents and the severity of the accidents that occurred on the roads they examined. The two exceptions were the studies conducted by Zegeer et al. (1994) and Bowman and Abboud (1999), in which there was found to be no statistically significant reduction or difference in accident rates. However, it should be noted that although not statistically significant, there were reported reductions in single vehicle and total crashes as the result of the installation of paved shoulders during the Bowman and Abboud study (1999).

2.1.2 Examination of the Effects of Shoulder Width

Several other studies have also been conducted to determine whether a relationship exists between different shoulder widths and accident rates. One of the earlier studies was conducted by the Connecticut State Highway Department during which the relationship between accident rates and shoulder widths was examined

(Perkins, 1956). Four years of accident data from 1951-1954 were divided into categories based only on the paved shoulder width. An analysis of the data was conducted which led to the conclusion that there was “no significant relationship between accident rate and shoulder width” (Perkins, 1956). However, there was no mention of the type of statistical analysis that was conducted to reach this conclusion.

A study that was published just prior to the Perkins (1956) study was conducted in California by Belmont (1954). His analyses included an examination of both paved and treated shoulders that were divided into three categories based on shoulder width. The road segments were separated into shoulder width classifications of less than 6-ft, 6-ft, and greater than 6-ft. Belmont proceeded to conduct a regression analysis which generated three different regression equations to explain the relationship between the three categories of shoulder widths and accident rates. He concluded that 6-ft shoulders were safer than shoulders that were narrower than 6-ft, and shoulders wider than 6-ft when traffic volumes exceeded 5,000 vpd.

Another study that found a similar relationship between paved shoulder width and accident frequency was conducted by the Oregon State Highway Department (Blensly and Head, 1960). The majority of the road segments had ADT values that were less than 5000 vpd, and they were categorized in increments of 1,000 vpd. Two different statistical analyses were conducted to try and determine if there was a relationship between paved shoulder widths and personal injury, property damage, and total accidents.

First, the relationship between accident frequency and the width of paved shoulders was examined using correlation procedures. Blensly and Head concluded that there was a “statistically reliable tendency toward an increase in accident frequency as paved shoulder width increased” (Blensly and Head, 1960). However, the results of the partial correlation method that was conducted found that the 2,000 to 2,999 ADT range was the only one that showed there to be a significant relationship between accident frequency and paved shoulder width.

In order to conduct the second set of analyses the data were sub-divided into two different categories: narrow paved shoulders and wide paved shoulders. The narrow shoulder classification was given to all road segments that had paved shoulders of 4-ft and less, and the wide shoulder classification was assigned to segments that had paved shoulders of 8-ft or wider. Then analyses of variance and co-variance procedures were used to assess whether there was a tendency for there to be an increase in any of the three types of accidents when shoulders were either narrow or wide. The results of the analysis of variance “found that without control over the effect of ADT there was a statistically reliable tendency for sections with wide shoulders to have a higher mean number of property damage and total accidents than sections with narrow paved shoulders” (Blensly and Head, 1960). There were similar findings in their analysis of variance, where they concluded that when the road segments had wide shoulders there were higher incidents involving property damage and total accidents.

The findings of the Zegeer et al. (1981) study were contradictory to the results of the correlation procedures conducted by Blensly and Head (1960) and the regression analysis of Belmont (1954). Zegeer et al. (1981) conducted a comparative analysis that found there to be a decrease in run-off-road and opposite-direction accidents as shoulder widths were increased from zero to 9-ft. However, this study also determined that there was an increase in these types of accidents for shoulder widths from 10-ft to 12-ft. It was also concluded that there were little changes or slight increases in accident rates for other types of accidents as the shoulder widths increased on these same road segments.

The studies that examined the potential relationship between shoulder widths and accident rates all had substantially different conclusions. Belmont (1954) concluded that two-lane rural roads with shoulder widths of 6-ft were safer than road segments that had either narrower or wider shoulders. A study with similar findings that accident frequency increases as shoulder width increases was conducted by Blensly and Head (1960). However, they also concluded that only one ADT range in their study showed a statistically significant relationship between accident occurrence and shoulder width. Finally, the Zegeer et al. studies conducted in 1981 and 1988 contradicted the findings of both of the previous studies when they concluded that accident rates decreased as shoulder widths increased from zero to 9-ft. However, the 1981 study also showed that when shoulder widths increased to 10-ft and12-ft there was a slight increase in accident rates (Zegeer et al., 1981). In addition, at least two studies found there to be no statistically significant relationship between shoulder width and accident rates (Perkins, 1956 and Bowman and Abboud, 1999).

Although the findings of the studies were contradictory, several considerations should be made. Each of the studies was conducted in a different state where the methods of reporting and recording accident information may differ. Some of the studies included treated shoulders as well as paved shoulders which may have affected the number and types of accidents that occurred. The studies also had different types of accidents that were examined rather than overall accidents. Many of these studies separated the road segments into different classifications based on traffic volume and shoulder width. Finally, each study used a different methodology for analyzing the data which may have contributed to the differences in their findings.

2.2 Crash Reduction/Modification Factors

A crash reduction factor (CRF) is a value that represents the expected percent reduction in crashes as a result of the implementation of a treatment or program. These values are generally based on the quantitative results of research studies. They are often used to determine the safety effectiveness of implementing geometric improvements or new countermeasures. Formally, a CRF "is the expected number of crashes with an action, divided by the expected number of crashes had the action not been taken (Gross and Jovanis, 2007). This information can also be expressed as an accident modification factor (AMF) or crash modification factor (CMF), which is simply the expected reduction of crashes if the improvement or treatment is installed (Equation 2-1).

$$\text{AMF} = \text{CMF} = 1\text{-CRF} \tag{2-1}$$

The first attempt at assigning an AMF value to changes in shoulder width and shoulder type was determined based on an extensive literature review by a panel of experts (NCHRP, 2005). In total, this panel determined AMF values and assigned a level of predictive certainty value (LOPC) to 100 different treatments. The LOPC value was used to indicate to the reader the panel's level of confidence in the AMF value assigned to each treatment. This value was influenced by the type, amount, and credibility of the research that was reviewed.

The accident modification function that was given for shoulder width and type is shown in Equation 2-2 (NCHRP, 2005).

$$AMF = (AMF_{WRA}AMF_{TRA}-1.0)P_{RA}+1.0 \qquad (2\text{-}2)$$

The accident modification factor for related accidents based on shoulder width, AMF_{WRA}, and shoulder type, AMF_{TRA}, can be obtained from the tables provided with the equation (Appendix A). Both of these values were “calculated by dividing the AMF for the after improvement condition by the AMF for the before condition” (NCHRP, 2005). The P_{RA} value is the proportion of total accidents that will be reduced. This equation is capable of producing an accident modification factor that accounts for shoulder width as a function of ADT and shoulder type. The function was also assigned a “medium-high” LOPC rating indicating that the panel had a high level of confidence in the function’s predictive ability. However, it should be noted that the reasons for the rating were not given.

The “Desktop Reference for Crash Reduction Factors” that was published in September 2007 by FHWA, provided several different crash reduction factors associated with shoulder widening (Bahar et al., 2007). This technical report was again based on an extensive literature review that obtained most of its values from publications previously discussed. The CRF values and functions that can be obtained from this document include countermeasures such as: changes in shoulder type and/or width, installation of shoulders, stabilization of shoulders, varying outside shoulder width, widening of shoulders, and widening of paved shoulders. The values given for the widening of paved shoulders show an increase in CRF with increasing shoulder width (Table 2-1).

Table 2 - 1 Paved shoulder widening CRF values (Bahar et al., 2007)

Widen Paved Shoulder	Crash Type	Crash Severity	Crash Reduction Factor (%)
0 to 2 ft	Fixed object & ROR	All	16
0 to 4 ft	Fixed object & ROR	All	29
0 to 6 ft	Fixed object & ROR	All	40
0 to 8 ft	Fixed object & ROR	All	49

Several different CRF values were obtained from publications produced for state DOTs. The Ohio and Oregon DOTs both recommended the use of the AMF function given in Equation 2-2 (Monsere et al., 2006 and Zwahlen and Suravaram, 2007). Both of these state DOTs reported that the AMF function was obtained from an extensive literature review. The decision to use this function was determined by each state's DOT in conjunction with an expert panel. The remaining values reportedly used by the state DOTs ranged from 12% to 20% (Table 2-2).

Table 2 - 2 CRF values used by State DOTs

State DOT	Recommended CRF Value
Alabama	20%
Arizona	12%
Kentucky	15%
New York	17%
North Carolina	18%
South Dakota	20%

The Arizona DOT reported the lowest value for shoulder widening which was 12% for fatal and nonfatal injuries combined (Arizona DOT, 2004). This recommended value was obtained from a 1996 Annual Report published by FHWA in which a value of 21% reduction in accident rates was also reported for fatal crashes (FHWA, 1996). The Arizona DOT also provided accident reduction factors based on their own accident data that were significantly higher than the FHWA recommended values. The percent reduction in accident rates that they reported to be potentially attainable from shoulder widening was 57% (Arizona DOT, 2004). This value was reported to be a statistically significant reduction for all types of accidents and injuries.

A study was conducted for the Kentucky DOT that consisted of a survey of CRF values that were currently being used within the state as well as by other state DOTs for different treatments and improvements (Agent et al., 1996). Shoulder widening values were examined as part of the construction/reconstruction category for several different shoulder treatments. A range of CRF values were obtained for each of the treatments (Table 2-3 and 2-4).

Table 2 - 3 CRF values obtained from within the state of Kentucky (Agent et al., 1996)

Treatment	No. of Values	Range of Values (%)	Average Value (%)
Shoulder Widening	18	5 – 50	19
2 to 4-ft	2	15 – 32	24
Paved Shoulder	3	10 – 25	18

Table 2 - 4 CRF values obtained from other State DOTs (Agent et al., 1996)

Treatment	No. of Values	Range of Values (%)	Average Value (%)
Shoulder Widening	17	8 – 57	20
2 to 4-ft	2	15 – 16	15
Paved Shoulder	1	20	20

Based on this examination of reported CRF values, the Kentucky DOT recommended the following values be used within their state: shoulder widened to a width of less than 4-ft, 20% reduction, shoulder was stabilized or a shoulder drop off eliminated, 25% reduction, and if a paved shoulder was installed, 15% reduction in accidents (Agent et al., 1996). However, there is no recommendation given for determining a CRF value for the combined effects of these shoulder treatments.

The New York DOT reported only one CRF value for shoulder widening on two-lane roads, 17% (NYSDOT, 2000). This expected reduction in accidents was for the widening of existing shoulders only. No additional information as to the determination of this value was given. Similarly, the North Carolina DOT reported a CRF for total crashes on rural 2-lane roads to be 18% (North Carolina DOT, 2007). This value was followed by recommended values for fatal crashes, non-fatal injury crashes, and PDO crashes of 48%, 8%, and 23%, respectively. These values were referenced from a meeting handout and no additional information was given.

The value that was reportedly used by South Dakota's DOT was based on an extensive literature review as well as a review panel that evaluated CRF values that were obtained from accident data. The average CRF value that was reported for shoulder widening by this state DOT was a 20% reduction (Tople, 1998). This was the same value that the Alabama DOT was currently using and the highest reported value that was found.

Extreme caution should be exercised when using CRF values to determine when and where shoulder widening could be beneficial. The user should be aware of how and where the CRF was developed. The validity of a CRF when it is transferred from one location to another is not known. The most accurate CRF values are obtained from before and after studies (Bahar et al., 2007, Gross and Jovanis, 2007, and NCHRP, 2005). However, the accuracy of the study or analysis process could still result in biased data that will in turn produce an inaccurate CRF value (NCHRP, 2005). Although there are several sources for obtaining a CRF for shoulder widening or paved shoulder installation, the use and applicability to the desired project may be limited. Consideration should also be given to any additional comments, information, or ratings that were assigned to the published CRF.

2.3 Economic Evaluation of Accidents

When motor vehicle accidents occur many people are affected and the costs associated with these traffic accidents are far reaching. There are costs associated directly with the medical care that is received such as insurance premiums, medical expenses, and the cost of emergency services rendered. There are many indirect costs to not only the individuals involved in the traffic accident but to society as well. These costs include legal fees, lost wages, travel delay, property damage, and many others. To determine the costs associated with an automobile accident several factors need to be taken into consideration. Several examples include how many people were injured or killed, the extent of the injuries, and how much property damage resulted from the incident.

A rating system has been produced by the Association for the Advancement of Automotive Medicine (AAAM) to pair the severity of an injury with an identification number. This system is known as the Abbreviated Injury Scale (AIS) which assigns a value from 0 to 6 to indicate the threat-to-life that results from a particular injury (Zaloshnja et al., 2004). The value of 0 represents the lowest level, or uninjured rating. The highest rating that can be received is a 6, indicating a fatal injury. The AIS rating system is often used to determine the costs associated with automobile accidents (FHWA, 2005, NHTSA, 2002, and Zaloshnja et al., 2004).

In 1982, research was conducted by the FHWA to provide a cost scheme that could be used during economic evaluations of highway improvements. The cost values were calculated to "reflect the amount individuals are willing to pay to reduce the number and severity of accidents" (FHWA, 1994). Later in 1985, the FHWA sponsored another research initiative that determined the comprehensive costs associated with injuries, fatalities, and property damage that resulted from motor vehicle crashes (FHWA, 1994). These analyses resulted in dollar values being assigned to the AIS rating system (Table 2-5).

These comprehensive costs consist of eleven different components that encompass the individual and societal costs associated with the severity of an injury. The values in Table 2-5 were reportedly obtained in accordance with FHWA departmental guidance which recommended that the Gross Domestic Product (GDP) implicit price deflator be used to update the dollar amounts (FHWA, 1994). Following this procedure the 1988 dollar values were inflated by 18% and reported in terms of a 1994 dollar amount.

Table 2 - 5 Comprehensive costs of police reported crashes (FHWA, 1994)

Severity	Cost Per Injury (1994 Dollars)
AIS 1	$5,000
AIS 2	$40,000
AIS 3	$150,000
AIS 4	$490,000
AIS 5	$198,000
AIS 6	$2,600,000

In 2004 a study was published by Zaloshnja et al. which updated the crash cost estimates based on the 1990 version of the AIS codes (AIS90). During this study an evaluation of the effects of using cost data that were based on the 1985 edition of the AIS codes to injuries that had been classified using the 1990 edition as applied during a highway crash cost analysis were examined. From this study, it was concluded that adjusting the AIS85 costs based solely on inflation for injuries classified using the AIS90 scale generally resulted in the overestimation of benefits.

The AIS90 scale was assigned different severity codes than the AIS85 scale, and as a result, the error in the benefit calculations can be significant (Zaloshnja, 2004). In addition, the costs associated with the AIS85 scale predated managed care in the U.S. which has greatly impacted health care services. Managed care has changed the way care is administered. In general managed care has reduced the length of hospitalization after an accident which has subsequently affected the cost of care.

The most current documentation of the economic costs associated with motor vehicle crashes was published by NHTSA in 2002. It was reported that in 2000 the total cost of motor vehicle crashes in the U.S. was $230.6 billion (NHTSA, 2002). This is the present value of the total economic costs associated with all police-reported and unreported accidents that occurred in 2000. In this publication a dollar amount was assigned to each of the six AIS90 codes as well as a value for incidents that resulted in property damage only (PDO) (Appendix B). These unit costs were calculated in terms of the U.S. dollar in the year 2000 and included values for both injury and non-injury components (Table 2-6). A breakdown of the number of police-reported and unreported accidents that occurred in 2000 were also given (Appendix B).

Table 2 - 6 Total unit costs of injuries on the AIS 90 scale (NHTSA, 2002)

Severity	Cost (2000 Dollars)
PDO	$2,532
MAIS 0	$1,962
MAIS 1	$10,562
MAIS 2	$66,820
MAIS 3	$186,097
MAIS 4	$348,133
MAIS 5	$1,096,161
Fatal	$977,208

2.4 Summary of Findings

The literature review that was conducted yielded several key findings. When the publications regarding the impacts that paved shoulders had on accidents and accident rates were examined in detail, there was found to be a considerable amount of variability between studies. Inconsistencies in the evaluation criteria for accident and road data including shoulder classification, segment length, and shoulder width were found. Furthermore, the methodologies and statistical analyses used to determine the effects that the presence or absence of paved shoulders had on accidents and accident rates varied considerably. Despite all of these differences, it was concluded, that in general, road segments with paved shoulders appeared to have fewer accidents and lower accident rates than segments without paved shoulders.

There was an overall lack of consensus among the findings of the studies that examined the effects that shoulder widths have on accident rates. One study concluded that shoulders that were 6-ft wide were safer than those that were wider or narrower (Belmont, 1954). Another study concluded that accident frequency increases as shoulder width increases (Blensly and Head, 1960). While two others concluded that the opposite was true, accident rates decreased as shoulder widths increased (Zegeer et al., 1981 and Zegeer et al., 1988). The final two studies concluded that there were no statistically significant differences in the accident rates of different shoulder widths (Perkins 1956 and Bowman and Abboud, 1999). Again there were a considerable number of differences in the way these studies were conducted, the shoulder widths examined, the methodologies followed, and ultimately their results and conclusions.

In the third section of this literature review a synopsis of CRF values that were currently being recommended for use was presented. The CRF values from seven different state DOTs were identified and ranged from 12% to 20% (Table 2-2). In addition, an equation that can be used to calculate an AMF value based on the shoulder width and shoulder materials was also examined (Equation 2-2) (NCHRP, 2005).

Finally, an evaluation of the economic costs associated with automobile accidents was conducted. These costs can be broken down into two categories: direct and indirect costs. Direct costs can include tangible expenses such as medical costs, emergency services rendered, and legal fees. Indirect costs however, may include expenses associated with travel delay and lost productivity. Each of these categories are equally important when evaluating the economic implications that an accident may cause to both the individuals involved in the accident as well as society as a whole. A unit cost was obtained for each level of injury severity on the AIS90 rating scale as well as for property damages (NHTSA, 2002). These values were reported in terms of 2000 dollar amounts (Table 2-6).

CHAPTER THREE

METHODOLOGY

The project funds that can be used by a state DOT to install paved shoulders are often limited. The development of a detailed process that could assist a state DOT in identifying road segments that could benefit from the installation of 2-ft paved shoulders could be useful. The widening of paved shoulders can reduce the number of run-off-road crashes and provide a recovery area for errant vehicles. If this treatment were installed at the appropriate locations there could possibly be a significant reduction in accident occurrence and severity. These potential reductions can be converted to economic savings in terms of the amount of money that is saved when an accident or injury is prevented. A benefit/cost analysis can then be conducted to assess the locations that would benefit most from this treatment. The greatest benefits are obtained at those locations that are able to maximize public safety in terms of reducing accidents and saving lives at a lower cost to the state DOT.

The main objectives of this study were to identify high priority segments based on crash rate and severity and conduct a hypothetical benefit/cost analysis to determine the potential benefits of adding 2-ft of paved shoulders to these segments. This required a detailed methodology to assist ALDOT in the identification of high priority segments that would benefit most from the shoulder treatment.

The initial accident data set was obtained from the CARE 8 program and contained accident and location information for the years 2003 through 2006 (CRDL, 2007). CARE is a computer software program that can be used to conduct statistical analyses and inquiries of accident data. During this study the CARE 8 program was also used to create a filter to identify two-lane rural roads with unpaved shoulders and conduct a “high accident analysis.” Many of the locations that were identified by this analysis were within close proximity of another “hotspot.” In response, a decision rule was developed and used to combine segments that were within 0.5-mile of one another.

This new data set was then used to identify high priority segments based on two criteria: crash rates and accident severity. Once these segments were identified, a hypothetical benefit/cost analysis was conducted to evaluate the potential benefits of installing 2-ft paved shoulders at these locations. The actual benefits were not quantifiable since this would require several sections of roadway to have been fully operational for a minimum of three years after paved shoulder installation. However, a preliminary evaluation of the potential benefits of applying this treatment to high priority segments can be beneficial to the decision making process.

To calculate these potential benefits, a range of CRF values for each of the criteria was selected. The benefits were calculated in terms of the number of accidents that could potentially be prevented as well as their associated costs. The costs of installing 2-ft paved shoulders as part of resurfacing and reconstruction projects on two-lane rural highways were obtained from ALDOT and evaluated to determine an appropriate cost value to be used in the benefit/cost analysis. After careful consideration the mean per-mile cost of the projects that had been bid over a two year period from 2006 to 2008 was selected. Finally, a hypothetical analysis of the benefits and costs of adding paved shoulders to these locations was conducted.

3.1 Data Collection

The CARE program was developed and is maintained by the University of Alabama CARE Research and Development Laboratory (CRDL, 2007). This software package was used to access the accident database for the state of Alabama, which contains information regarding the type, severity, location, as well as road characteristic data associated with each accident. Four years of accident data were obtained from the CARE 8 database and used to identify high priority segments of two-lane rural highways.

3.1.1 Filter Creation and Implementation

The original data set contained over 571,000 accident records and needed to be reduced to include only the accidents that occurred specifically on two-lane rural highways without paved shoulders. To accomplish this task a filter was created and checked in accordance with the CARE 7 User Manual and the CARE 8 Individualized Training Manual (CRDL, 2007) (Appendix C). The filter consisted of several lines of code that facilitated the identification of accidents that occurred on road segments that met specific criteria. The filter was created based on three primary criteria: two-lane rural roads, ALDOT maintained highways, unpaved shoulders of any condition. Using the created filter, the original data set was reduced to 17,814 accident records.

3.1.2 High Accident Analysis

Once the filter had been applied to the original data set, a narrower data set was created. This new data set was then used during a “high accident” analysis that was conducted using the CARE 8 software package (CRDL, 2007). This analysis subsequently produced a list of “hotspots” that were defined as 0.5-mile segments of roadway that had a minimum of 5 crashes of any type occur within the designated four year period. This minimum value of 5 crashes was the lowest value that could be selected within the CARE program. The “high accident” analysis resulted in the identification of 1,305 hotspots that occurred on 116 different routes within the state of Alabama (Appendix D). The data set that was produced included location information as well as accident, annual average daily traffic (AADT), million vehicle miles of travel (MVMT), crash rate (C/MVMT), and severity values for each location.

3.1.3 Verification of Traffic Data

Thirty hotspot locations were randomly selected from the data set of 1,305 highway segments using the sampling function in the program Microsoft Excel to verify the reported AADT, MVMT, and crash rate values. This was done using traffic data obtained from ALDOT’s traffic statistics website to ensure that the reported values from CARE were reliable and sound (ALDOT, 2008a). An example of the traffic data verification process can be seen in Tables 3-1 and 3-2. First, location data from one of the randomly selected segments, ID #40, were taken and used to identify the three closest traffic counting stations on ALDOT’s website.

Table 3 - 1 Example data from actual road segment

ID # 40	Beg MP	End MP	AADT	Total Crashes	MVMT	C/MVMT
	145.3	145.8	5130	5	3.74	1.34

The traffic counting station located at mile post 142.975 is located approximately 2.3-mi before the beginning of the ID #40 road segment. The traffic counting station located at mile post145.665 is located within the segment, and the traffic counting station located at 148.26 is approximately 2.5-mi after the end of the ID #40 road segment (Table 3-2).

Table 3 - 2 Example of ALDOT's traffic data

ALDOT	Before
Mile Post	142.975
AADT 2006	5200
AADT 2005	5110
AADT 2004	4900
AADT 2003	5310
Average	5130

ALDOT	In
Mile Post	145.665
AADT 2006	5220
AADT 2005	5130
AADT 2004	4900
AADT 2003	5270
Average	5130

ALDOT	After
Mile Post	148.26
AADT 2006	6680
AADT 2005	6590
AADT 2004	6320
AADT 2003	6890
Average	6620

Initially, the average AADT value was calculated for the years 2003 through 2006 using the traffic data at each of ALDOT's counting station locations (Table 3-2). These average values were then compared to the CARE 8 values which were found to be exactly the same as at least one of the data collection points for 28 of the 30 locations that were examined. The AADT values that were calculated for the two remaining locations were within five percent of the average AADT values found on ALDOT's website (ALDOT, 2008a). The five percent difference was determined to be sufficient for this analysis.

Once the AADT values of the randomly selected hotspots were determined to be acceptable, the MVMT and crash rate values were checked using equations 3-1 and 3-2, respectively. All of the calculated MVMT and crashes per MVMT values were found to be exactly the same as the values obtained from the CARE 8 program (Table 3-1).

$$\text{MVMT} = \frac{(\text{AADT} * 365 \text{ days/yr} * 4 \text{ yr} * 0.5 \text{ mi})}{(1{,}000{,}000)} \tag{3-1}$$

$$\text{C/MVMT} = \frac{\text{Total Crashes}}{\text{MVMT}} \tag{3-2}$$

3.1.4 Combining Road Segments

Once the data had been checked for errors, it was visually examined as part of the preliminary analyses. It was noted that many of the “hotspot” locations were located on the same routes and were often within close proximity of another “hotspot”. Since the road segment length was originally defined to be 0.5-mile during the high accident analysis, it was not possible to get a segment of greater length even if it was a continuous segment of roadway. The data set also contained consecutive segments in which one or two sections had a substantially lower number of crashes occur within them when compared to the others around them.

One such example is shown in Table 3-3, in which the total number of crashes that occurred on the road segment ID #22 was much lower than the three consecutive road segments before and after it. In practice, this entire section would likely receive the same treatment. In addition, paving projects are generally greater than 0.5-mile in length so a decision rule was needed to determine the greatest distance that two 0.5-mile road segments could be apart and still be combined into the same segment.

Table 3 - 3 Comparison of consecutive road segments

ID #	City	Route	Beginning MP	Ending MP	Distance To Next Segment (mi)	Total Crashes
19	Dallas	S-14	117.6	118.1	0	17
20	Dallas	S-14	118.1	118.6	0	16
21	Dallas	S-14	118.6	119.1	0	16
22	Dallas	S-14	119.1	119.6	0.1	5
23	Dallas	S-14	119.7	120.2	0	12
24	Dallas	S-14	120.2	120.7	0	10
25	Dallas	S-14	120.7	121.2		15

In order to develop a decision rule, a histogram was created to show the frequency and cumulative frequency distributions of the distances between the ending and beginning milepost markers of all of the consecutive 0.5-mile road segments (Appendix E). The distances between two road segments on the same route were obtained by subtracting the beginning milepost marker of the latter road segment from the previous road segment (Table 3-4).

Table 3 - 4 Determination of the distance between consecutive segments

City	Route	Beginning MP	Ending MP	Length (mi)	Distance To Next Segment (mi)
Pickens	S-14	11.7	12.2	0.5	25.9
Greene	S-14	38.1	38.6	0.5	1.3
Greene	S-14	39.9	40.4	0.5	2.8
Greene	S-14	43.2	43.7	0.5	4.1
Greene	S-14	47.8	48.3	0.5	0.5
Greene	S-14	48.8	49.3	0.5	4.4

Figure 3-1 shows the same frequency distributions as Appendix E, however, only the road segments that were within 2.1-miles of one another were examined to determine a decision rule. From Figure 3-1, it can be seen that a large number of segments had 0.1-mile or less between them. It was determined through visual inspection, that any two road segments that were equal to or less than 0.5-mile apart would be considered the same segment of road for the rest of the analysis. This breakpoint was selected based on the frequency distribution which showed a reduction in the number of segments that had distances of greater than 0.5-mile between them (Figure 3-1). This trend is also shown in the reduction of the slope of the line on the cumulative frequency distribution between the 0.5 and 0.6-mile segments. From the cumulative frequency distribution it can also be shown that approximately 60% of the segments are within 0.5-mi of the next closest hotspot location.

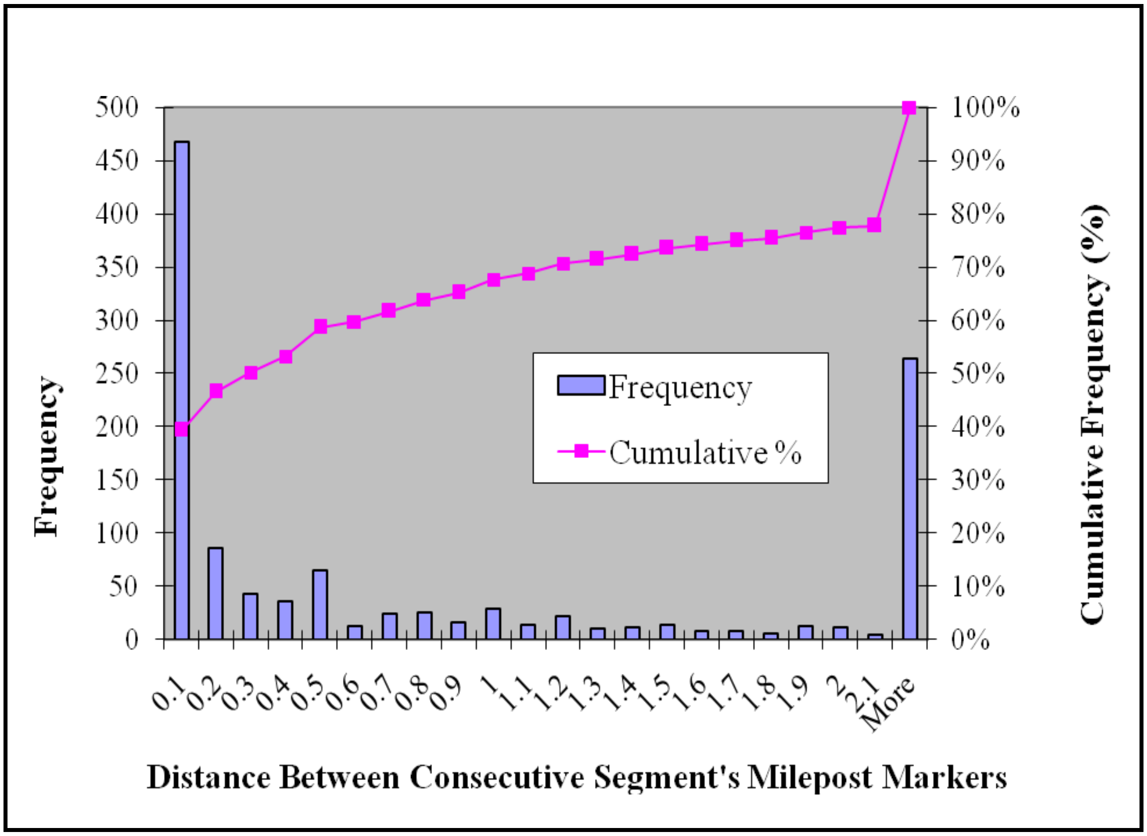

Figure 3 - 1 Frequency and cumulative frequency distributions of road segments less than 2.1-miles apart

Based on this decision rule, the data set was then reconfigured to reflect this change. When road segments were combined, the values for length, total crashes, crash rate, and severity were recalculated. Following this procedure the segments were reduced from 1,305 segments that were all 0.5-mile in length to 607 segments of varying lengths.

3.2 Data Analysis

During the data analysis portion of this project a methodology for identifying high priority segments was established based on two criteria: crash rate and severity. In addition, a hypothetical analysis of the potential benefits associated with the installation of 2-ft paved shoulders on the identified segments was conducted. This analysis required a range of CRF values to be used to estimate the potential reductions in accidents if the shoulder treatment were to be implemented. Finally, a methodology to evaluate the potential economic benefits associated with these reductions was also developed.

3.2.1 Determination of High Priority Segments

A chart containing a frequency and cumulative frequency distribution was created to identify high priority road segments for each of the criteria (Figures 3-2 and 3-3). These segments were defined as those that were greater than the 95th percentile for either crash rate or severity. This analysis resulted in the identification of 31 high priority segments based on crash rate and 41 based on severity (Tables 3-5 and 3-6). The locations that were classified as high priority segments were located on a State Highway Map to further examine the location and to check the proximity to any urban areas.

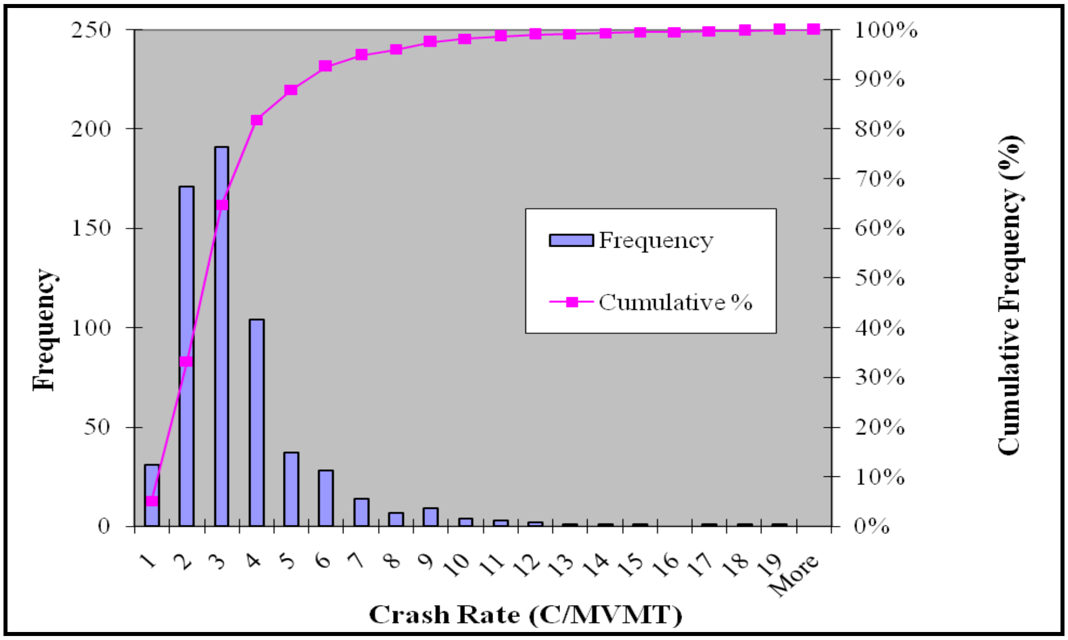

Figure 3 – 2 Frequency and cumulative frequency distributions used in high priority segment identification based on crash rate

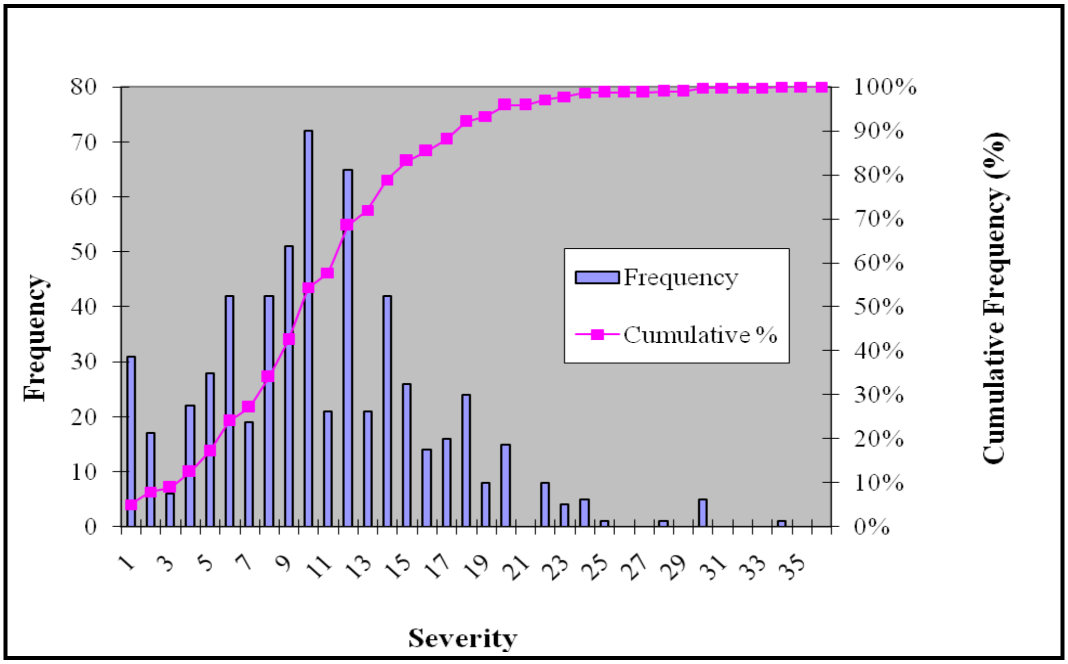

Figure 3 – 3 Frequency and cumulative frequency distributions used in high priority segment identification based on severity

Table 3 – 5 List of high priority segments based on crash rate

ID #	Division	City	Route	Length (mi)	Beg MP	End MP	C/MVM	CRF (%)
16	5	Perry	S-14	0.5	93.7	94.2	19	2.8
1285	5	Fayette	S-107	0.5	7.4	7.9	18	2.0
1282	1	Cherokee	S-273	0.5	8.6	9.1	16	2.2
1296	6	Bullock	S-239	0.5	14.1	14.6	15	2.1
525	5	Hale	S-25	0.5	66	66.5	14	2.0
912	4	Tallapoosa	S-49	0.5	6.6	7.1	13	3.0
1273	7	Coffee	S-189	0.5	22.8	23.3	12	3.4
950	2	Lawrence	S-101	0.5	6.7	7.2	11	5.0
1248	5	Chilton	S-191	0.5	7.8	8.3	11	3.3
1288	7	Barbour	S-130	0.5	12.6	13.1	11	2.3
1238	7	Geneva	S-103	0.5	1.0	1.5	10	3.7
1137	7	Dale	S-105	1.0	8.9	9.9	10	3.5
911	4	Tallapoosa	S-49	0.5	5.4	5.9	10	2.5
1274	7	Crenshaw	S-189	0.5	31.2	31.7	10	2.5
1224	5	Greene	S-39	1.3	14.7	16.0	9	3.6
522	5	Hale	S-25	0.5	40.8	41.3	9	4.1
1113	7	Covington	S-12	0.5	119.6	120.1	9	5.3
938	7	Coffee	S-27	0.5	32.8	33.3	9	5.3
949	7	Henry	S-27	0.5	64.4	64.9	9	3.1
1240	7	Geneva	S-103	0.5	12.0	12.5	9	3.1
526	5	Bibb	S-25	0.5	80.8	81.3	8	2.8
923	4	Tallapoosa	S-49	1.3	36.7	38.0	8	3.3
1135	7	Dale	S-105	1.0	6.5	7.5	8	4.9
1031	7	Coffee	S-87	0.5	19.5	20.0	8	3.3
924	4	Clay	S-49	0.5	77.6	78.1	8	3.4
1304	7	Dale	S-92	0.5	3.3	3.8	8	3.4
1225	5	Greene	S-39	0.5	21.4	21.9	8	3.0
523	5	Hale	S-25	0.5	42.8	43.3	7	4.3
1249	5	Chilton	S-191	0.5	9.4	9.9	7	4.4
1242	7	Pike	S-125	1.3	19.7	21.0	7	3.6
1190	5	Perry	S-219	0.5	32.1	32.6	7	3.2

Table 3 – 6 List of high priority segments based on severity

ID #	Division	City	Route	Length (mi)	Beg MP	End MP	S/MVM	CRF (%)
926	7	Barbour	S-51	0.5	28.5	29.0	34	4.5
803	7	Geneva	S-167	0.5	9.9	10.4	30	5.3
349	8	Monroe	S-21	0.5	51.9	52.4	30	5.3
1185	2	Winston	S-195	0.5	37.6	38.1	30	5.3
1181	2	Colbert	S-184	0.5	7.5	8.0	30	5.3
444	5	Chilton	S-3	0.5	225.0	225.5	30	5.3
487	6	Bullock	S-6	0.5	195.3	195.8	28	5.3
1279	4	Coosa	S-259	0.5	2.7	3.2	25	4.0
335	4	Randolph	S-22	0.5	151.1	151.6	24	5.3
1280	4	Tallapoosa	S-259	0.5	11.2	11.7	24	4.9
14	5	Hale	S-14	0.5	70.5	71.0	24	5.0
90	6	Montgomery	S-9	0.5	74.6	75.1	24	5.3
6	5	Greene	S-14	1.5	47.8	49.3	23	5.3
645	6	Bullock	S-15	0.5	138.6	139.1	23	5.3
1094	5	Fayette	S-18	0.5	36.0	36.5	23	5.3
1155	1	Morgan	S-157	1.2	23.6	24.8	23	5.3
66	6	Elmore	S-14	1.5	185.3	186.8	22	5.3
1176	3	Shelby	S-145	0.5	22.3	22.8	22	5.3
555	5	Hale	S-69	0.5	104.7	105.2	22	5.3
1003	7	Crenshaw	S-10	0.5	137.1	137.6	21	5.2
953	2	Lawrence	S-101	0.5	21.6	22.1	21	5.3
81	7	Crenshaw	S-9	0.5	58.6	59.1	21	5.3
523	5	Hale	S-25	0.5	42.8	43.3	21	4.3
854	4	Tallapoosa	S-50	1.6	2.5	4.1	21	4.1
351	6	Lowndes	S-21	0.5	103.8	104.3	20	4.1
1211	7	Dale	S-123	0.5	34.6	35.1	20	4.2
639	7	Covington	S-15	0.5	28.7	29.2	20	4.0
1299	4	Russell	S-26	0.5	8.5	9.0	20	5.3
925	7	Barbour	S-51	0.5	26.8	27.3	20	4.5
133	4	Calhoun	S-9	0.5	237.6	238.1	20	5.3
1175	3	Shelby	S-145	0.5	17.2	17.7	20	5.3
1226	5	Hale	S-60	0.5	1.2	1.7	20	5.3
875	7	Coffee	S-134	0.5	18.0	18.5	20	5.3
979	4	Lee	S-169	0.5	17.9	18.4	20	5.3
870	7	Coffee	S-134	0.5	7.4	7.9	20	5.3
403	4	Calhoun	S-21	0.5	276.1	276.6	20	5.3
1152	1	Morgan	S-157	0.5	20.0	20.5	20	5.3
575	1	Cullman	S-69	0.5	231.7	232.2	20	5.3
773	5	Tuscaloosa	S-171	2.3	8.7	11.0	19	5.3

If a segment was considered to be in close proximity to a large urban area, or in an area that may have higher volumes of traffic it was located using aerial photography available from the Internet site, Google Earth (Google, 2008). Each of the segments was examined to confirm that it was located on a rural two-lane highway. This procedure was conducted to identify any segments that may have been widened during the four year analysis period. One of the segments identified during the severity analysis was eliminated because it was located on a four-lane road. This was considered to be the best alternative since the year that the widening was conducted was not known.

3.2.2 Determination of CRF Values

Once the two lists of high priority segments were located and visually examined using the Google Earth software, a range of CRF values were selected for each of the two criteria. There were two primary reasons that a range of CRF values were selected rather than a single value. First, the literature review had yielded a wide range of CRF values which were currently being recommended for use by different state and federal organizations. Although no effective date was given, it was also known that ALDOT was planning to reduce their current CRF value from 20% down to 16% for shoulder paving projects conducted in the future (Sonya Baker, personal communication, May 28, 2008).

The range of CRF values were determined by first calculating the CRF values for the individual segments on each of the corresponding lists, Tables 3-5 and 3-6, using Equations 2-1 and 2-2 (NCHRP, 2005). These values were used to determine the lower limit CRF values which ranged from 2.0 to 5.3% for the segments that were selected based on crash rate and 4.0 to 5.3% for the high severity segments. The lower limit CRF value for each of the criteria was set at the lowest calculated CRF value of the individual segments within it. The upper limit was then set at 20% which was the highest value found in the literature, and the value that ALDOT was currently using.

Once a range of CRF values was established, they were then applied to the total number of crashes that occurred on the high priority segments for each of the two criteria: crash rate and severity (Tables 3-7 and 3-8). This was done to determine the potential reductions in accidents. Tables 3-7 and 3-8 show the total number of crashes that occurred on all of the identified segments during the four-year analysis period based on each of the two criteria, which coincidentally happened to be 274 for both. The lower and upper limit CRF values were then applied to the total number of crashes to determine the number of accidents that could be expected if the shoulder treatment were applied to all of the identified segments. This process resulted in a lower and upper limit value for the number of expected crashes which ranged from 219 to 269 based on crash rate and 219 to 263 based on severity.

The upper limit actually has a lower number of crashes due to the upper limit CRF value. This is because the higher CRF value corresponds to a greater reduction in accidents if 2-ft paved shoulders were to be installed at these locations. The segments that were identified based on severity also show that there is potential to have 3 fewer accidents occur on these segments when compared to the segments identified based on crash rate. This is due to the 2% higher lower limit value that was calculated from Equations 2-1 and 2-2 (NCHRP, 2005).

Table 3 - 7 CRF values and expected number of crashes based on crash rate

High Priority Segments by Crash Rate	
Total Crashes	274
CRF Lower Limit (LL)	2%
CRF Upper Limit (UL)	20%
Expected Crashes (LL)	269
Expected Crashes (UL)	219

Table 3 – 8 CRF values and expected number of crashes based on severity

High Priority Segments by Severity	
Total Crashes	274
CRF Lower Limit (LL)	4%
CRF Upper Limit (UL)	20%
Expected Crashes (LL)	263
Expected Crashes (UL)	219

3.3 Economic Evaluation of Potential Benefits

To determine the potential benefits of adding 2-ft of paved shoulders to the high priority segments, the costs associated with each accident and injury were calculated. Initially, the reported values of the unit costs of an accident based on its severity were obtained from the 2002 NHTSA publication entitled *The Economic Impact of Motor Vehicle Crashes* (Table 2-6). However, the injury data that was obtained from the CARE 8 program only provided the number of injuries, fatalities, and reported property damages. Since the unit costs in the NHTSA report were assigned for each level of the most current version of the abbreviated injury scale, AIS90, a weighted average of cost for the 1 through 6 ratings was calculated based on the total number of police-reported injury crashes that occurred in each category (Appendix B). This resulted in the unit costs of each property damage, injury, and fatality in terms of a 2000 dollar amount, which were \$2,532, \$18,160, and \$977,208 respectively.

Once these unit costs were determined, they were adjusted using the gross domestic product (GDP) implicit price deflator to determine their average value over the four-year analysis period, 2003 through 2006. The GDP is the dollar value of all services and goods that are produced within a country during an established period of time. The implicit price deflator measures the year to year percent change in inflation or deflation with respect to the GDP.

There were several factors that were taken into consideration when selecting an appropriate price index for this analysis. It was important to select an index that would in some way account for the constant changes within the medical field to include pharmaceutical expenses, as well as goods and services rendered. Since medical costs were only one contributor to the overall expense of an accident, it was equally important to select an index that would be representative of the other contributing expenses and their changes as well. The GDP was selected based on the recommendations of the FHWA publication, *Motor Vehicle Accident Costs* (1994) and because it takes into account any new expenditure patterns within the country's economy. The GDP does this by accounting for not only the final goods and services produced, but their market value during a specific time period as well.

Once a price index was selected, the inflation of the U.S. dollar from the year 2000 to the average value over the analysis years, 2003 through 2006, was calculated. The GDP implicit price deflator values were obtained using Bloomberg Professional® service software for each quarter of every year from 2000 through 2006 (Bloomberg, 2008) (Appendix F). Several steps were followed to calculate the appropriate inflation value to apply to the unit cost data. First the average value for each year was obtained. Next, the average inflation value for the years 2003 through 2006 was calculated and then applied to each of these years, respectively. Then the sum of these average values was determined for the years 2001 through 2006 (Equation 3-3).

$$\text{Percent Inflation} = \sum \text{average GDP implicit price deflator value for each year} \qquad (3-3)$$

As a result, the inflation value to convert the unit cost data from 2000 dollars to the average value of the dollar over the four year analysis period was calculated to be 16%. When this inflation value was applied to the 2000 unit cost data it resulted in cost values of $2,937 per PDO, $21,065 per injury, and $1,133,561 per fatality. These new unit costs were then used to determine a range of values for the total costs of the accidents and related injuries that occurred on the high priority segments (Tables 3-9 and 3-10).

The total number of PDOs, injuries, and fatalities that occurred over the four-year analysis period for each of the criteria are shown in Tables 3-9 and 3-10. In addition, the expected number incidences at these locations after the installation of 2-ft paved shoulders are also shown. These expected values were calculated using the CRF upper and lower limit values that were presented in section 3.2.2. The costs of each PDO, injury, and fatality were then used to determine the total cost of these incidences on all of the segments combined based on the two criteria: crash rate and severity. The results were a total combined cost that ranged from approximately $8,600,000 to $10,400,000 for the crash rate high priority segments and $41,400,000 to $49,300,000 for the severity high priority segments (Tables 3-9 and 3-10).

Table 3 - 9 Total costs of accidents and injuries on crash rate high priority segments

	Total	Expected based on CRF lower limit	Expected based on CRF upper limit
Total PDOs	172	169	138
Total Cost: PDOs	$ 505,185	$ 496,373	$ 405,323
Total Injuries	150	147	120
Total Cost: Injuries	$ 3,159,785	$ 3,096,589	$ 2,527,828
Total Fatalities	6	6	5
Total Cost: Fatalities	$ 6,801,368	$ 6,801,368	$ 5,667,806
Total Cost on the Segments	**$10,466,337**	**$10,394,330**	**$ 8,600,957**

Table 3 - 10 Total costs of accidents and injuries on severity high priority segments

	Total	Expected based on CRF lower limit	Expected based on CRF upper limit
Total PDOs	73	71	59
Total Cost: PDOs	$ 214,410	$ 208,536	$ 173,290
Total Injuries	295	284	236
Total Cost: Injuries	$ 6,214,244	$ 5,982,527	$ 4,971,395
Total Fatalities	39	38	32
Total Cost: Fatalities	$44,208,890	$43,075,329	$36,273,961
Total Cost on the Segments	**$50,637,544**	**$49,266,391**	**$41,418,646**

3.4 Costs of Shoulder Paving

The costs of installing 2-ft paved shoulders vary from project to project. This is primarily due to the variety in road geometry and site conditions that exist before construction begins. In some locations there could be a severe pavement edge drop off that has to be reconstructed before the shoulder can be paved. In other locations there may be a well-maintained gravel shoulder that requires a minimal amount of additional work other than paving.

ALDOT has had a total of 41 resurfacing and reconstruction projects that have included the addition of 2-ft paved shoulders on two-lane rural highways from March

2006 through February 2008. The locations, project numbers, and percentage of the project funds that were designated for shoulder paving were provided by ALDOT (Clay McBrien, personal communication, June 9, 2008). The bid amounts for 41 of the projects were obtained online from ALDOT's Project Letting website (ALDOT, 2008b). The road segments were located in 32 different counties and were of varying lengths, 2.04-miles to 15.94-miles, and bid amounts, approximately $512,000 to $4,360,000 (Appendix G). The cost of the shoulder paving portion of each project was calculated by multiplying the percentages provided by ALDOT by the total project amount. These values were then divided by the length of the road segment to obtain the cost-per-mile for the shoulder treatment, which ranged from approximately $17,900 to $140,500 (Table 3-11).

Table 3 – 11 Statistical values used in cost determination

Per-mile Cost		Percentage of Project Cost	
Mean	$44,901	Mean	19.4
Median	$44,500	Median	18.0
Standard Deviation	$22,666	Standard Deviation	7.4
Maximum	$140,516	Maximum	38
Minimum	$17,912	Minimum	7

Since the cost-per-mile of installing 2-ft paved shoulders varied substantially, a frequency and cumulative frequency distribution was created to help determine an appropriate cost value to use in the analyses (Figure 3-4). From the distributions it was shown that the majority of the projects fell within the $20,000 to $70,000 range with only three projects exceeding these cost-per-mile amounts. The three projects that had a cost-per-mile in excess of $70,000 were greater than 1 standard deviation away from the mean and were therefore eliminated from the dataset before any other cost analyses were conducted.

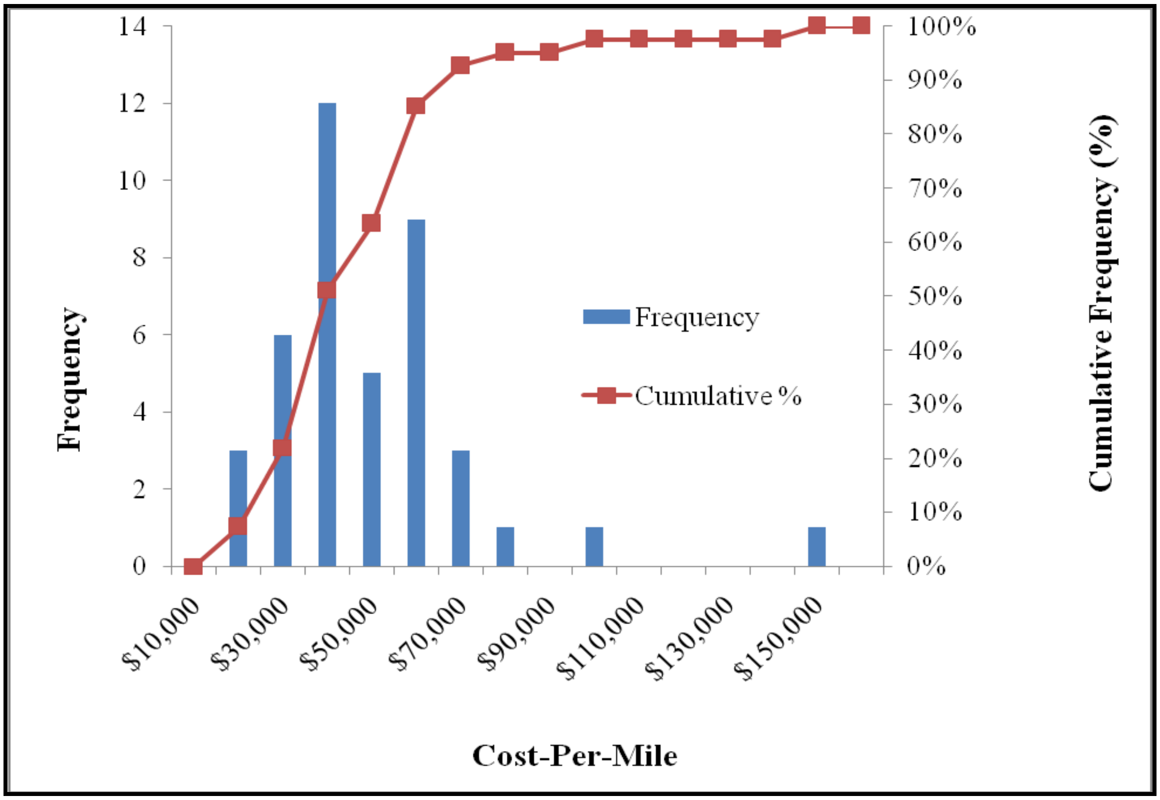

Figure 3 – 4 Frequency and cumulative frequency distributions for shoulder paving costs-per-mile

Next, a statistical analysis was conducted to determine a single value that could be used during the benefit/cost analysis. The mean cost-per-mile value of $44,900 was considered to be representative of the projects based on several considerations. The sample size was considered to be large enough to encompass a broad range of projects and conditions. The projects were also dispersed throughout the state and were representative of most locations. Finally, with the exception of 3 projects, the per-mile cost of shoulder paving on the remaining 38 projects fell within the range of $20,000 to

$70,000. Furthermore, the median value of this range was $45,000, which is close to the calculated mean of $44,900 (Table 3-11).

3.5 Benefit/Cost Analysis

The benefit/cost ratio is calculated by dividing the total benefits by the total costs. In this hypothetical benefit/cost analysis the benefits were defined in terms of the economic costs that would potentially be saved through accident prevention. Since the cost to install the treatment varied, and the exact number of accidents that would be prevented if the shoulder treatment were installed on each of the high priority segments was not known, the calculated range of values for the benefits and the mean value for the associated costs were used. A range of benefits was selected rather than a single value due to the broad range of CRF values that were reviewed.

CHAPTER FOUR

RESULTS

It has been shown that lane departure accidents are among the most severe and often result in run-off-the-road and head-on crashes. Since a large percentage of fatal motor vehicle accidents have been shown to occur in rural areas, ALDOT established a new policy to install 2-ft of paved shoulders on two-lane rural highways throughout the state. This type of shoulder treatment provides an additional recovery area for vehicles that leave the travel lane, and reduces the chances of overcorrection that often result in head-on collisions and roll-over accidents.

A limited number of projects that have included the installation of 2-ft paved shoulders on two-lane rural highways have been initiated over the last two years. As a result, a before and after study to quantify the actual reductions in accidents and severity in response to this shoulder treatment was not possible. Since funding for improvements such as shoulder paving can be limited and the cost of such projects can be significant, a preliminary benefit/cost analysis was conducted to determine the potential benefits of the treatment. This hypothetical analysis was based on the identification of high priority segments that could possibly benefit the most from the installation of 2-ft paved shoulders.

4.1 Identification of High Priority Segments

During this study, high priority segments were defined as those that had either a high crash rate or severity. The two lists of high priority segments contained approximately the top 5% of the segments that were originally obtained from the high accident analysis conducted using the CARE 8 software program. There were a total of 31 road segments identified based on crash rate and 40 based on severity (Tables 3-5 and 3-6). Only one of the identified segments appears on both lists, ID # 523, which is located on State Route 25 in Hale County.

4.2 Calculated Benefits

To quantify the potential benefits of widening the shoulders of the high priority segments, the economic savings in terms of the number of accidents prevented by the treatment were calculated. A range of CRF values were used in this analysis to calculate the hypothetical number of accidents that would be prevented if this shoulder treatment were installed on all of the high priority segments. The savings that would be obtained from the prevention of all of the associated injuries, fatalities, and PDOs were calculated on each segment. These values along with the segment length were utilized to determine a per-mile savings. The total lengths of the segments designated by each of the criteria were 18.90-mi for those identified based on crash rate and 25.10-mi for the severity segments. The total savings for each criteria and CRF limit were divided by the total length of all of the segments within each of the criteria to get a savings per-mile value ($1,865,380/18.90-miles = $98,697/mile) (Tables 4-1 and 4-2).

Table 4 - 1 Potential savings if shoulder treatment is implemented on high priority segments based on crash rate

	Expected based on CRF lower limit	Expected based on CRF upper limit
Total PDOs	3	34
Total Savings: PDOs	$ 8,811	$ 99,862
Total Injuries	3	30
Total Savings: Injuries	$ 63,196	$ 631,957
Total Fatalities	0	1
Total Savings: Fatalities	$ -	$ 1,133,561
Total Savings on the Segments	$ 72,007	$ 1,865,380
Total Savings per mile	**$ 3,810**	**$ 98,697**

Table 4 - 2 Potential savings if shoulder treatment is implemented on high priority segments based on severity

	Expected based on CRF lower limit	Expected based on CRF upper limit
Total PDOs	2	14
Total Savings: PDOs	$ 5,874	$ 41,120
Total Injuries	11	59
Total Savings: Injuries	$ 231,718	$ 1,242,849
Total Fatalities	1	7
Total Savings: Fatalities	$ 1,133,561	$ 7,934,929
Total Savings on the Segments	$ 1,371,153	$ 9,218,897
Total Savings per mile	**$ 54,628**	**$ 367,287**

It can be seen in Table 4-1 that, applying the CRF upper limit would result in a total expected reduction of 34 PDO crashes, 30 injuries, and 1 fatality when applied to the high priority segments that were identified based on crash rate. The expected savings associated with the prevented PDOs, injuries, and fatalities were, $99,862, $631,957, and $1,133,561, respectively (Table 4-1). It should also be noted that the injury value was calculated based on the weighted average of injury severity from police-reported accidents that occurred within the U.S. in the year 2000. As a result, these dollar amounts may be conservative since it has been shown that the types of accidents that are generally prevented by installing paved shoulders tend to be more severe. The calculated total savings-per-mile ranged from approximately $3,800 to $98,700 based on crash rate and $54,600 to $367,300 based on severity.

4.3 Calculated Costs

There were a total of 41 ALDOT projects that included the installation of 2-ft paved shoulders that had been let to bid since 2006 for which cost data were available. The cost-per-mile for the shoulder installation on these projects ranged from approximately $17,900 to $140,500 (Appendix G). Since such a broad range of values existed, a statistical analysis was conducted and the mean cost-per-mile value of $44,900 was selected for use in the benefit/cost analysis.

4.4 Benefit/Cost Analysis

The benefit/cost analysis determined the associated benefits in terms of the economic savings associated with accidents, injuries, and fatalities that would be expected to be prevented by the installation of 2-ft paved shoulders. The ratio of benefits to costs for the range of economic savings values ranged from 0.08 to 2.20 for the high priority segments that were identified based on crash rate, and 1.22 to 8.18 for the segments that were identified based on severity (Tables 4-3 and 4-4).

The hypothetical results of the benefit/cost analyses indicate that the implementation of the shoulder treatment on either set of high priority segments would be beneficial to ALDOT as well as the traveling public. However, it appears that the greatest benefit will result from the installation of 2-ft paved shoulders on the high priority segments that were selected based on severity. The midpoint values for each of the criteria were 1.14:1 and 4.70:1, for the crash rate and severity respectively.

Table 4 - 3 Benefit/Cost ratios for high priority segments based on crash rate

	Expected based on CRF lower limit	Expected based on CRF upper limit
Total Savings per mile	$ 3,810	$98,697
Mean cost per mile	$44,900	$44,900
Benefit/Cost ratio	0.08	2.20

Table 4 - 4 Benefit/Cost ratios for high priority segments based on severity

	Expected based on CRF lower limit	Expected based on CRF upper limit
Total Savings per mile	$54,628	$367,287
Mean cost per mile	$44,900	$44,900
Benefit/Cost ratio	1.22	8.18

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The overall results showed that the installation of 2-ft paved shoulders on two-lane rural highways in the State of Alabama has the potential to greatly reduce accidents. However, the results and conclusions of this study were based on a hypothetical analysis of the potential benefits since the new policy to install this type of shoulder treatment was only implemented by ALDOT in 2006. Although further research has been recommended to help quantify the results of this study, a minimum of three years of after data is needed. In addition, the methodology given in this study could also be used in the identification of high priority segments for this future research.

5.1 Conclusions

The high priority segments that were identified based on crash rates and severity both yielded positive benefits that ranged from a total savings-per-mile of approximately \$3,800 to \$98,700 and \$54,600 to \$367,300, respectively. These hypothetical savings reflect the total dollar amounts that could be saved through the prevention of property damage, injuries, and fatalities on these segments. Utilizing the mean cost-per-mile of \$44,900 for the installation of 2-ft paved shoulders resulted in benefit/cost ratios that ranged from 0.08:1 to 2.20:1 based on crash rate, and from 1.22:1 to 8.18:1 based on severity

5.2 Recommendations for ALDOT

The methodology that was used to identify high priority segments based on the two criteria, crash rate and severity, appears to be a useful tool in selecting road segments to receive this type of shoulder treatment. The hypothetical analysis revealed that there are potential savings that can be obtained if 2-ft paved shoulders are applied to road segments that fall within the top 5% based on the established criteria. ALDOT could use this analysis to further expand either list of locations beyond the top 5%. The methodology provided in this study can also be used to examine a different analysis period that may be of particular interest to ALDOT. It is also recommended that road segments with high severity crashes should be given extra consideration for this treatment since the results of the hypothetical evaluation suggest that they will experience the greatest benefits in terms of accident prevention.

5.3 Recommendations for Future Research

After sufficient time has passed, minimum three years from completion of construction, it is recommended that a before-and-after study be conducted to quantify the reductions or changes in accidents, injuries, and property damages that resulted from the installation of 2-ft paved shoulders. A before-and-after study could also be used to determine a more accurate range of CRF values. In the future it would be beneficial to apply the treatment to several of the high priority segments that were identified during this analysis to determine whether the benefit/cost ratios fall within the calculated ranges.

A life-cycle cost analysis is also recommended since this study only examined the savings based on a four-year analysis period and the initial construction costs. It is suspected that the savings over the lifetime of the pavement when compared to the installation and maintenance costs could potentially yield an even higher benefit/cost ratio. This type of analysis could also be useful in determining long term savings.

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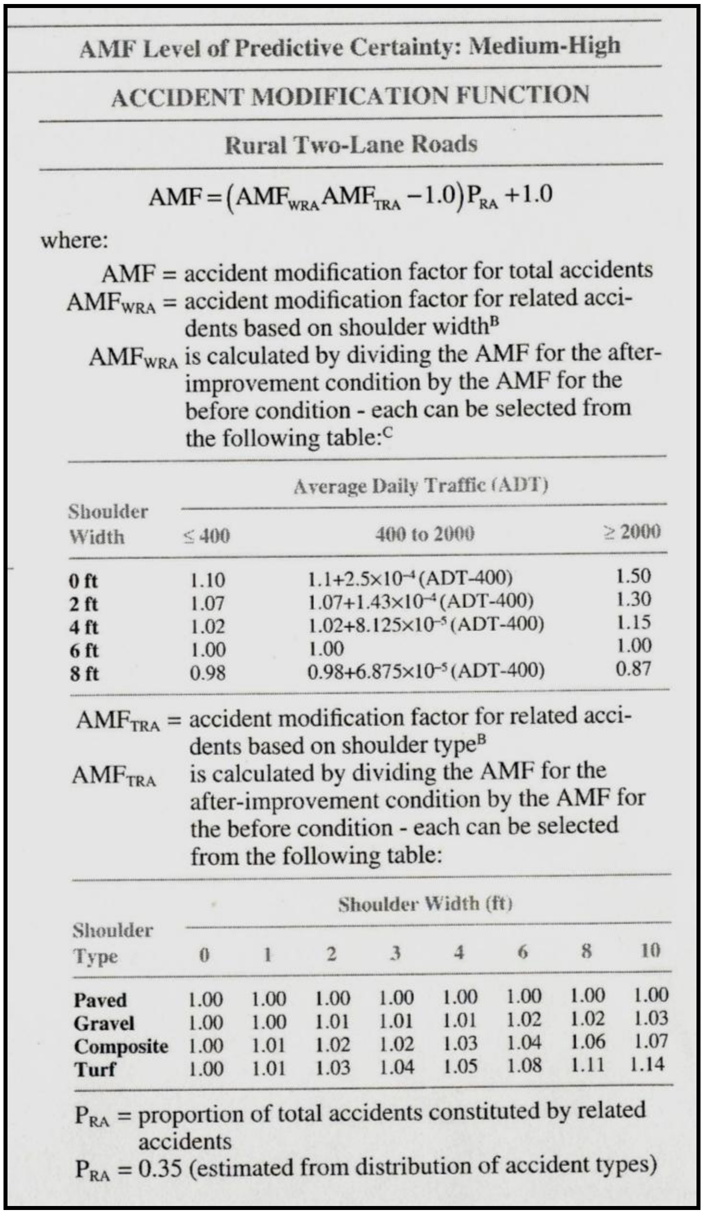
APPENDIX A

ACCIDENT MODIFICATION FUNCTION (NCHRP, 2005)



AMF Level of Predictive Certainty: Medium-High

ACCIDENT MODIFICATION FUNCTION

Rural Two-Lane Roads

$$AMF = \left(AMF_{WRA} AMF_{TRA} - 1.0\right) P_{RA} + 1.0$$

where:

AMF = accident modification factor for total accidents

AMF_{WRA} = accident modification factor for related accidents based on shoulder width[B]

AMF_{WRA} is calculated by dividing the AMF for the after-improvement condition by the AMF for the before condition - each can be selected from the following table:[C]

Shoulder Width	Average Daily Traffic (ADT)		
	≤ 400	400 to 2000	≥ 2000
0 ft	1.10	$1.1+2.5\times10^{-4}$(ADT-400)	1.50
2 ft	1.07	$1.07+1.43\times10^{-4}$(ADT-400)	1.30
4 ft	1.02	$1.02+8.125\times10^{-5}$(ADT-400)	1.15
6 ft	1.00	1.00	1.00
8 ft	0.98	$0.98+6.875\times10^{-5}$(ADT-400)	0.87

AMF_{TRA} = accident modification factor for related accidents based on shoulder type[B]

AMF_{TRA} is calculated by dividing the AMF for the after-improvement condition by the AMF for the before condition - each can be selected from the following table:

Shoulder Type	Shoulder Width (ft)							
	0	1	2	3	4	6	8	10
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.03
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06	1.07
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11	1.14

P_{RA} = proportion of total accidents constituted by related accidents

$P_{RA} = 0.35$ (estimated from distribution of accident types)

APPENDIX B

ECONOMIC COSTS OF ACCIDENTS AND TOTAL POLICE-REPORTED INCIDENCES (NHTSA, 2002)

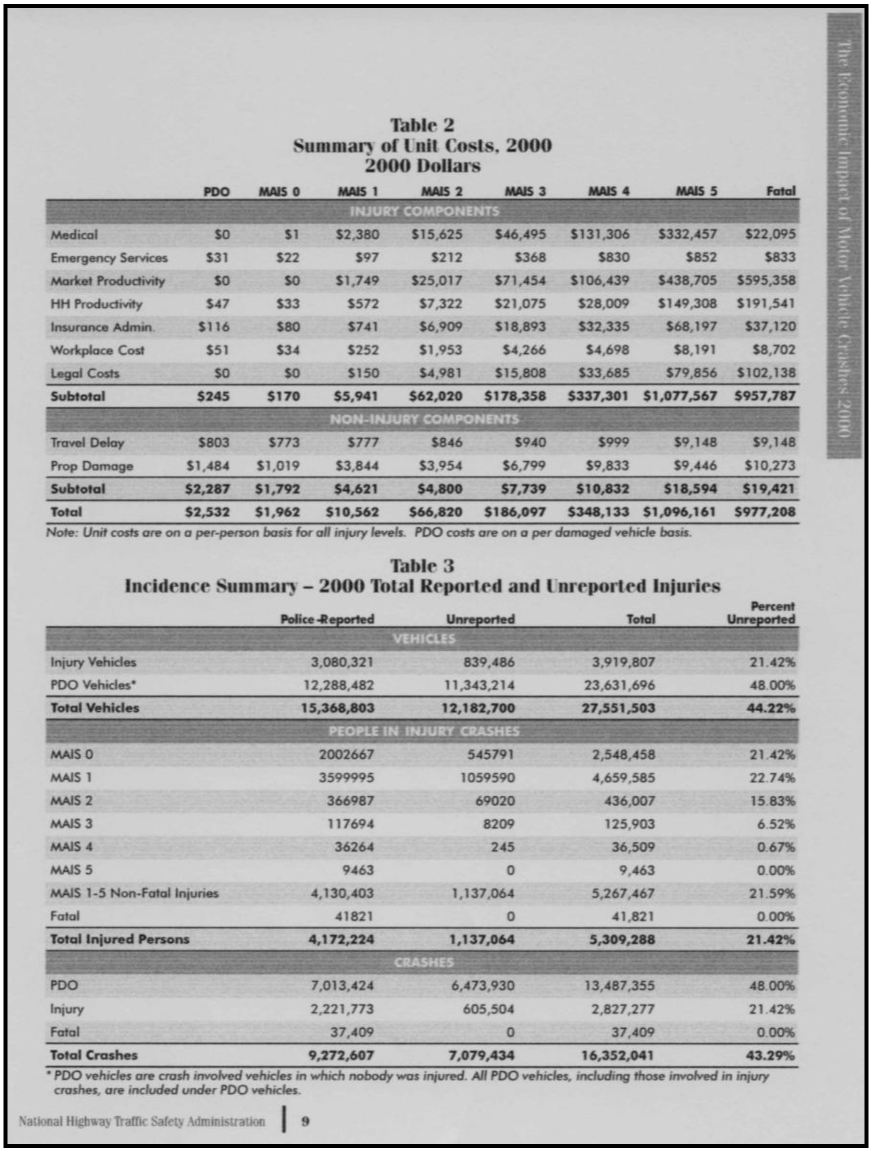


Table 2
Summary of Unit Costs, 2000
2000 Dollars

	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.

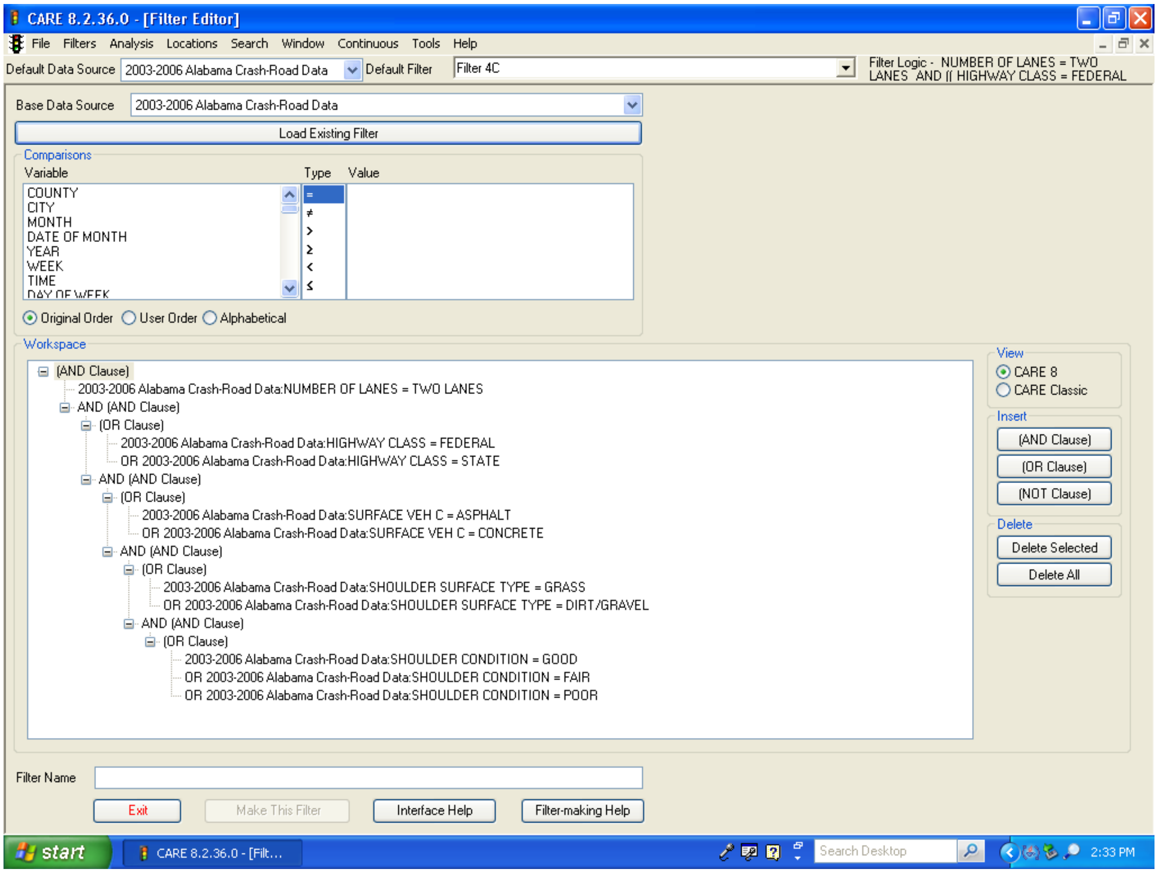
Table 3
Incidence Summary – 2000 Total Reported and Unreported Injuries

	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.*

APPENDIX C

FILTER CREATION CARE 8 (CRDL, 2007)



Default Data Source: 2003-2006 Alabama Crash-Road Data

Default Filter: Filter 4C

Filter Logic - NUMBER OF LANES = TWO LANES AND ((HIGHWAY CLASS = FEDERAL

Base Data Source: 2003-2006 Alabama Crash-Road Data

```
(AND Clause)
    2003-2006 Alabama Crash-Road Data:NUMBER OF LANES = TWO LANES
    AND (AND Clause)
        (OR Clause)
            2003-2006 Alabama Crash-Road Data:HIGHWAY CLASS = FEDERAL
            OR 2003-2006 Alabama Crash-Road Data:HIGHWAY CLASS = STATE
        AND (AND Clause)
            (OR Clause)
                2003-2006 Alabama Crash-Road Data:SURFACE VEH C = ASPHALT
                OR 2003-2006 Alabama Crash-Road Data:SURFACE VEH C = CONCRETE
            AND (AND Clause)
                (OR Clause)
                    2003-2006 Alabama Crash-Road Data:SHOULDER SURFACE TYPE = GRASS
                    OR 2003-2006 Alabama Crash-Road Data:SHOULDER SURFACE TYPE = DIRT/GRAVEL
                AND (AND Clause)
                    (OR Clause)
                        2003-2006 Alabama Crash-Road Data:SHOULDER CONDITION = GOOD
                        OR 2003-2006 Alabama Crash-Road Data:SHOULDER CONDITION = FAIR
                        OR 2003-2006 Alabama Crash-Road Data:SHOULDER CONDITION = POOR
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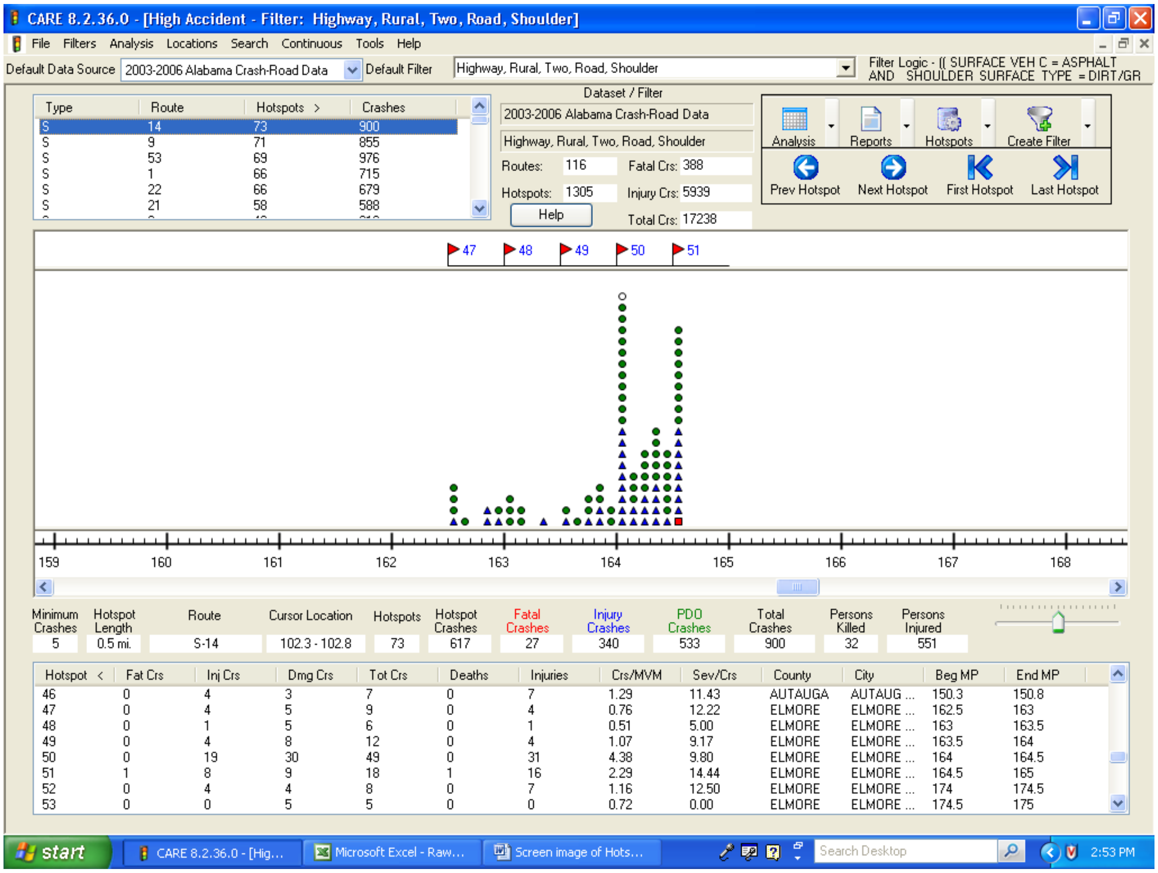
Filter Name:

APPENDIX D

HIGH ACCIDENT ANALYSIS CARE 8 (CRDL, 2007)



CARE 8.2.36.0 - [High Accident - Filter: Highway, Rural, Two, Road, Shoulder]

Default Data Source: 2003-2006 Alabama Crash-Road Data

Default Filter: Highway, Rural, Two, Road, Shoulder

Filter Logic - ((SURFACE VEH C = ASPHALT AND SHOULDER SURFACE TYPE = DIRT/GR

Type	Route	Hotspots >	Crashes
S	14	73	900
S	9	71	855
S	53	69	976
S	1	66	715
S	22	66	679
S	21	58	588

Dataset / Filter

2003-2006 Alabama Crash-Road Data

Highway, Rural, Two, Road, Shoulder

Routes: 116

Fatal Crs: 388

Hotspots: 1305

Injury Crs: 5939

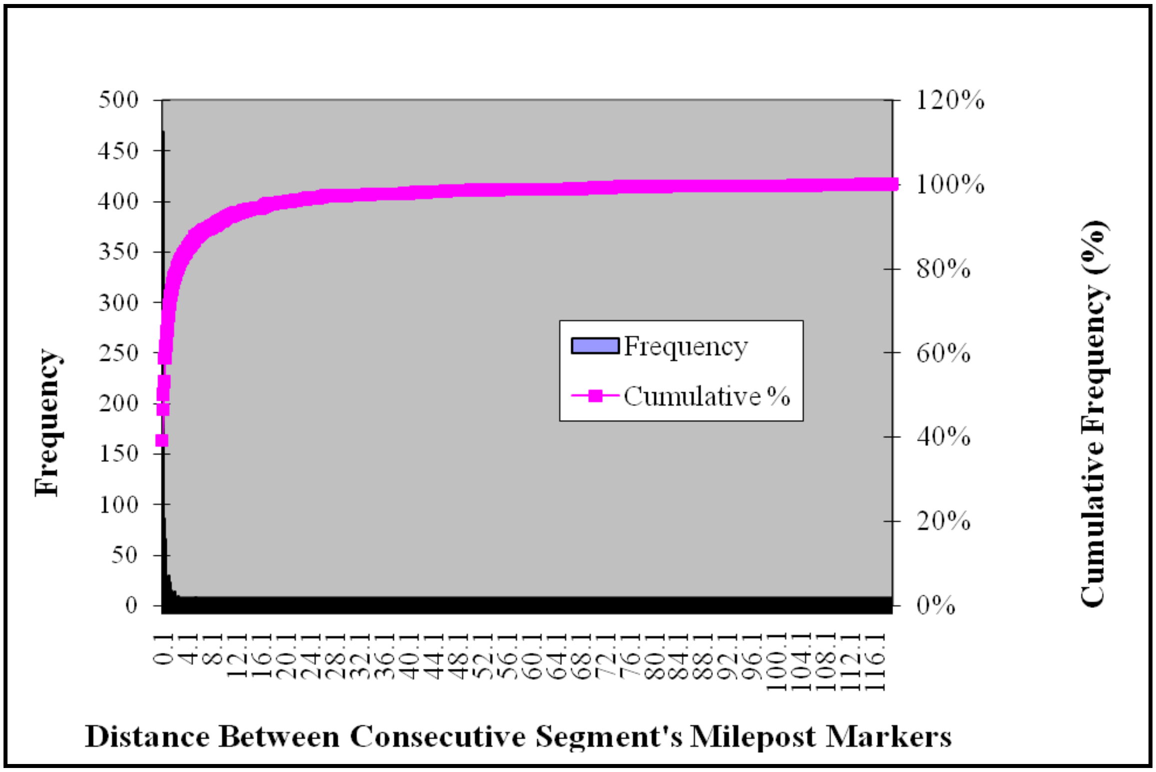
Total Crs: 17238

Minimum Crashes	Hotspot Length	Route	Cursor Location	Hotspots	Hotspot Crashes	Fatal Crashes	Injury Crashes	PDO Crashes	Total Crashes	Persons Killed	Persons Injured
5	0.5 mi.	S-14	102.3 - 102.8	73	617	27	340	533	900	32	551

Hotspot <	Fat Crs	Inj Crs	Dmg Crs	Tot Crs	Deaths	Injuries	Crs/MVM	Sev/Crs	County	City	Beg MP	End MP
46	0	4	3	7	0	7	1.29	11.43	AUTAUGA	AUTAUG ...	150.3	150.8
47	0	4	5	9	0	4	0.76	12.22	ELMORE	ELMORE ...	162.5	163
48	0	1	5	6	0	1	0.51	5.00	ELMORE	ELMORE ...	163	163.5
49	0	4	8	12	0	4	1.07	9.17	ELMORE	ELMORE ...	163.5	164
50	0	19	30	49	0	31	4.38	9.80	ELMORE	ELMORE ...	164	164.5
51	1	8	9	18	1	16	2.29	14.44	ELMORE	ELMORE ...	164.5	165
52	0	4	4	8	0	7	1.16	12.50	ELMORE	ELMORE ...	174	174.5
53	0	0	5	5	0	0	0.72	0.00	ELMORE	ELMORE ...	174.5	175

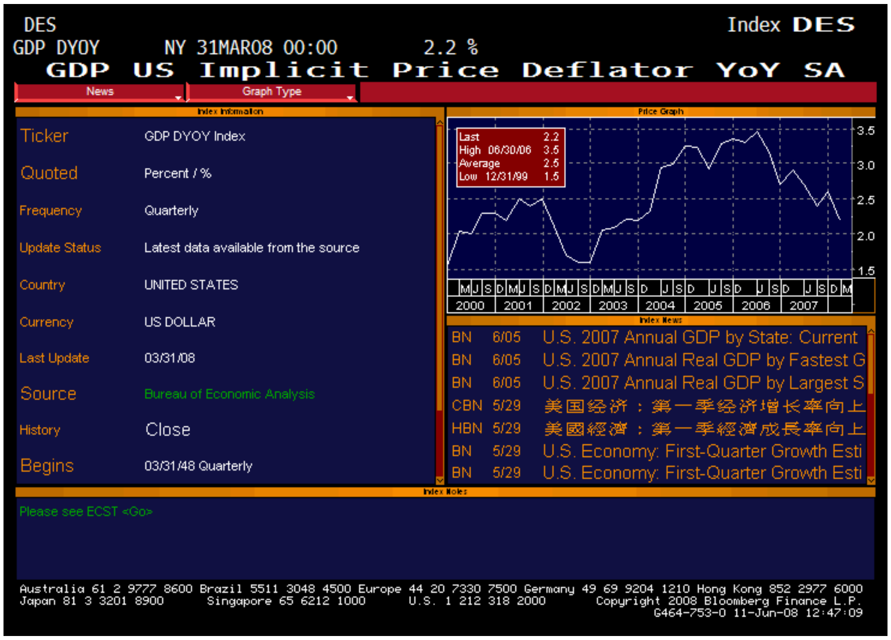
APPENDIX E

DECISION RULE FREQUENCY AND CUMULATIVE FREQUENCY DISTRIBUTIONS



APPENDIX F

GDP IMPLICIT PRICE DEFLATOR TRENDS AND VALUES (Bloomberg, 2008)



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 DES                                                        Index DES
GDP DYOY       NY 31MAR08 00:00        2.2 %
   GDP US Implicit Price Deflator YoY SA
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Ticker GDP DYOY Index
Quoted Percent / %
Frequency Quarterly
Update Status Latest data available from the source
Country UNITED STATES
Currency US DOLLAR
Last Update 03/31/08
Source Bureau of Economic Analysis
History Close
Begins 03/31/48 Quarterly

BN	6/05	U.S. 2007 Annual GDP by State: Current
BN	6/05	U.S. 2007 Annual Real GDP by Fastest G
BN	6/05	U.S. 2007 Annual Real GDP by Largest S
CBN	5/29	美国经济：第一季经济增长率向上
HBN	5/29	美國經濟：第一季經濟成長率向上
BN	5/29	U.S. Economy: First-Quarter Growth Esti
BN	5/29	U.S. Economy: First-Quarter Growth Esti

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Australia 61 2 9777 8600 Brazil 5511 3048 4500 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900       Singapore 65 6212 1000       U.S. 1 212 318 2000            Copyright 2008 Bloomberg Finance L.P.
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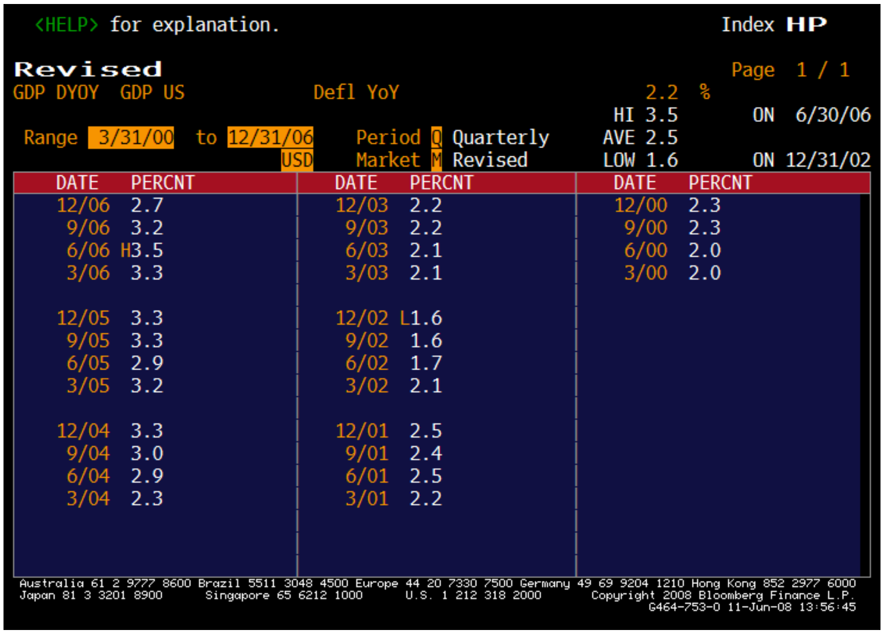

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Revised                                                       Page  1 / 1
GDP DYOY  GDP US             Defl YoY             2.2  %
                                                HI 3.5       ON  6/30/06
 Range  3/31/00  to 12/31/06    Period Q Quarterly  AVE 2.5
                         USD    Market M Revised   LOW 1.6       ON 12/31/02
    DATE    PERCNT          DATE    PERCNT          DATE    PERCNT
    12/06   2.7             12/03   2.2             12/00   2.3
     9/06   3.2              9/03   2.2              9/00   2.3
     6/06 H3.5               6/03   2.1              6/00   2.0
     3/06   3.3              3/03   2.1              3/00   2.0

    12/05   3.3             12/02 L1.6
     9/05   3.3              9/02   1.6
     6/05   2.9              6/02   1.7
     3/05   3.2              3/02   2.1

    12/04   3.3             12/01   2.5
     9/04   3.0              9/01   2.4
     6/04   2.9              6/01   2.5
     3/04   2.3              3/01   2.2

Australia 61 2 9777 8600 Brazil 5511 3048 4500 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900       Singapore 65 6212 1000       U.S. 1 212 318 2000            Copyright 2008 Bloomberg Finance L.P.
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APPENDIX G

ALDOT SHOULDER WIDENING PROJECTS

Letting Date	Projects in Contract	Project Length (mi)	Low Bid	Percentage	Widening Cost	Per-mile Cost
3/31/06	STPSA-0006(518) 99-307-036-006-601	8.143	$1,957,472	17	$332,770	$40,866
3/31/06	STPSA-0036(500) 99-302-402-036-601	2.75	$511,788	22	$112,593	$40,943
3/31/06	STPSA-0176(501) 99-301-253-176-601	13.67	$2,539,434	17	$431,704	$31,580
4/28/06	STPSA-0007(511) 99-305-323-007-601	7.875	$1,514,114	20	$302,823	$38,454
4/28/06	STPSA-0014(512) 99-306-015-014-601	14.719	$1,837,189	16	$293,950	$19,971
4/28/06	STPSA-0034(500) 99-303-582-034-611	4.622	$1,057,505	11.22	$118,652	$25,671
4/28/06	STPSA-0036(501) 99-301-521-036-602	5.25	$1,064,375	17	$180,944	$34,465
4/28/06	STPSA-0139(501) 99-305-114-139-602	3.458	$704,092	10	$70,409	$20,361
4/28/06	STPSA-0147(501) 99-304-093-147-601	4.18	$1,139,020	20	$227,804	$54,499
4/28/06	STPSA-0172(500) 99-302-473-172-601	5.139	$1,315,008	7	$92,051	$17,912
4/28/06	STPSA-0139(500) 99-305-044-139-601	9.126	$2,020,803	15	$303,120	$33,215

Letting Date	Projects in Contract	Project Length (mi)	Low Bid	Percentage	Widening Cost	Per-mile Cost
5/26/06	STPSA-0253(500) 99-302-473-253-601	5.866	$1,086,158	10	$108,616	$18,516
6/30/06	STPSA-0048(500) 99-304-144-048-601 STPSA-0048(501) 99-304-564-048-601	15.489	$3,375,620	25	$843,905	$54,484
6/30/06	STPSA-0204(513) 99-304-082-204-601	9.29	$2,196,101	30	$658,830	$70,918
7/28/06	STPSA-0001(528) 99-301-285-001-603	7.11	$2,210,367	12.2	$269,665	$37,928
7/28/06	STPSA-0025(510) 99-308-462-025-606	5.484	$1,333,912	24.5	$326,808	$59,593
7/28/06	STPSA-0019(503) 99-302-302-019-601	3.56	$985,596	8	$78,848	$22,148
7/28/06	STPSA-0025(511) 99-303-595-025-617	8.08	$1,595,567	12.22	$194,978	$24,131
7/28/06	STPSA-0021(512) 99-306-434-021-601	11.16	$1,636,319	18	$294,537	$26,392
8/25/06	STPSA-0015(512) 99-306-062-015-601	6.396	$1,584,405	13	$205,973	$32,203
11/3/06	STPSA-0245(500) ST-007-245-001 99-306-074-245-601	2.044	$992,342	13	$129,004	$63,114
12/1/06	STPSA-0091(502) 99-301-224-091-703	12.97	$2,768,234	16.79	$464,786	$35,836
1/12/07	STPSA-0015(514) 99-306-442-015-701	14.536	$2,633,906	18	$474,103	$32,616
1/12/07	STPSA-0079(505) 99-301-484-079-708	10.44	$1,835,240	17.3	$317,497	$30,412
1/12/07	STPSA-0001(529) 99-301-285-001-705	6.37	$1,597,510	9	$143,776	$22,571

Letting Date	Projects in Contract	Project Length (mi)	Low Bid	Percentage	Widening Cost	Per-mile Cost
2/28/07	STPSA-0021(515) 99-306-434-021-701	10.929	$1,677,728	24	$402,655	$36,843
2/28/07	STPSA-0185(500) 99-306-074-185-701	7.249	$1,297,203	32	$415,105	$57,264
3/28/07	STPSA-0140(500) 99-306-245-022-701 99-306-245-140-701	13.825	$2,761,286	25	$690,322	$49,933
3/28/07	HSIP-0069(512) 99-308-134-069-708 99-508-134-069-715	7.074	$2,088,546	20	$417,709	$59,049
3/28/07	STPSA-0025(513) 99-308-462-025-703 99-308-662-025-702	4.579	$1,296,533	22	$285,237	$62,292
3/28/07	STPSA-0089(500) 99-308-663-089-706	3.135	$671,467	27	$181,296	$57,830
4/27/07	HSIP-0026(500) 99-304-576-026-701	14.545	$3,871,216	34	$1,316,213	$90,493
11/2/07	HSIP-0021(518) 99-308-503-021-802	5.95	$1,620,960	24	$389,030	$65,383
11/2/07	HSIP-0047(501) 99-308-503-047-804	5.23	$1,174,571	23	$270,151	$51,654
1/18/08	HSIP-0005(518) 99-305-044-005-801	6.434	$1,638,500	18	$294,930	$45,839
1/18/08	HSIP-0025(515) 99-305-335-025-801	11.782	$4,356,727	38	$1,655,556	$140,516
1/18/08	HSIP-0107(500) 99-305-291-107-801	15.944	$3,281,717	24	$787,612	$49,399
1/18/08	HSIP-0028(504) 99-308-692-028-806	6.281	$1,522,572	24	$365,417	$58,178
2/29/08	HSIP-0134(502) 99-307-234-134-801	6.833	$1,577,698	15	$236,655	$34,634
2/29/08	HSIP-0051(501) 99-307-162-051-801	5.762	$1,047,532	32	$335,210	$58,176
2/29/08	STPSA-0141(501) 99-307-162-141-802 STPSA-0166(500) 99-307-162-166-803	7.169	$1,552,237	16	$248,358	$34,643