FINAL REPORT

Investigation of Fatal Motor Vehicle Crashes on Two-Lane Rural Highways in Georgia

By:

Simon Washington, Ph.D.

Karen Dixon, Ph.D., P.E.

David White

and

Chi-Hung E. Wu, Ph.D

The Georgia Institute of Technology

July 2002

Prepared for the Georgia Department of Transportation

TECHNICAL REPORT STANDARD TITLE PAGE

1.Report No.: FHWA-GA-02-9905	2. Government Accession No.:	3. Recipient's Catalog No.:

4. Title and Subtitle:
Investigation of Fatal Motor Vehicle Crashes on Two- Lane Rural Highways in Georgia

5. Report Date:
July 2002

6. Performing Organization Code:

7. Author(s):
Simon Washington, Ph.D.
Karen Dixon, Ph.D., P.E.
David White
Chi-Hung E. Wu, Ph.D.

8. Performing Organ. Report No.:
9905

9. Performing Organization Name and Address:
Georgia Institute of Technology
School of Civil & Environmental Engineering
Atlanta, Georgia 30332-0355

10. Work Unit No.:

11. Contract or Grant No.:

12. Sponsoring Agency Name and Address:
Georgia Department of Transportation
Office of Materials and Research
15 Kennedy Drive
Forest Park, Georgia 30297-2599

13. Type of Report and Period Covered:
Final; June 1999-August 2001

14. Sponsoring Agency Code:

15. Supplementary Notes:
Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract:
The objective of this study was to determine why a disproportionate number of fatal crashes occur on Georgia two-lane rural highways and identify possible countermeasures (from a host of feasible roadway or roadside improvements) that are the most effective for reducing these fatal crashes. To understand the nature of the crashes, researchers evaluated 150 randomly chosen fatal crashes from 1997. The observed crash characteristics were divided into human, vehicle, roadway, or environmental related characteristics. In an effort to determine potentially effecive countermeasures, researchers combined past knowledge of countermeasure effectivenes with new knowledge gained from engineering evaluations of approximately 30 roadway and roadside countermeasures asessed for the 150 fatal crashes. Through this approach, several countermeasures (under specific conditions) were found to be potentially effective in minimizing crash severity. The report concludes with short-term and long-term safety investment strategies for Georgia.

17. Key Words:
fatal crashes, safety improvements, rural highways

18. Distribution Statement:

19. Security Classification (of this report): Unclassified	20. Security Classification (of this page): Unclassified	21. Number of Pages: 204	22. Price:

Form DOT 1700.7 (8-69)

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ABSTRACT

Fatal crashes nationwide on two-lane rural highways, the largest single class of highways in the United States, comprised 19,680 in 1997, with 751 of those occurring in Georgia. When faced with a number of highway safety projects and working with a limited budget, transportation safety managers choose projects that result in the greatest reduction of fatalities, injuries, and property damage resulting from motor vehicle crashes. Prior to the implementation of any given safety countermeasure a safety manager would be best served to know, with the highest degree of certainty possible, the expected effect of a countermeasure on highway safety. The options currently available to the safety manager for managing road safety investments can make decision-making difficult and safety managers clearly benefit from a repeatable and objective process that facilitates the evaluation of a number of safety countermeasures at the same time, while providing with greater confidence an estimate of the expected effect on highway safety in their local jurisdiction.

This research includes an evaluation of 150 randomly selected fatal crashes for public two-lane roads in Georgia—including both state and non-state maintained facilities. Two-lane rural roads are the focus of this research due to an over-representation of fatal crashes on this type of highway. The intent of this research is to identify engineering countermeasures that will be most beneficial in the state of Georgia, and to identify and describe conditions under which fatal crashes have been occurring in the state.

The technical approach presented in this paper and undertaken in this research involves Bayesian techniques. This methodology is an advanced analytical technique for assessing countermeasures in regional safety programs and combines crash reconstruction analysis with statistical results from past studies to determine countermeasures from a host of feasible roadway or roadside improvements that are the most effective for reducing fatal crashes on two-lane

rural highways in Georgia, and to prioritize them with respect to the highest expected number of lives saved.

Five recommended countermeasures are presented as a product of this analysis. In addition, two safety investment strategies (short-term and long-term) are recommended to the Georgia Department of Transportation (GDOT).

1.0 EXECUTIVE SUMMARY

The objective of this research was to determine why a disproportionate number of fatal crashes occur on Georgia two-lane rural highways, and identify possible countermeasures (from a host of feasible roadway or roadside improvements) that are the most effective for reducing these fatal crashes. This executive summary presents the key findings of this research. Throughout this executive summary references to supporting details later in the document are provided.

To determine the best way to reduce the number or severity of crashes, the nature of these crashes must first be understood. For this effort, the research team evaluated 150 randomly chosen fatal motor vehicle crashes for 1997.

The observed crash characteristics can be generally divided into human, vehicle, roadway, or environmental related characteristics. In general, the 150 crashes were characterized by the following:

- Human Related Characteristics:
  - 71% of the involved drivers were male,
  - 11 pedestrians were involved (8 fatally injured),
  - Approximately one-third of the crashes were directly associated with drivers under the influence of alcohol (also, toxicology results were not available for 20% of the 150 crashes, so alcohol involvement was conceivably much greater),
  - Approximately 20% of the crashes were due to driver error or inattention, and
  - Almost 50% of the people involved in the crash did not use safety restraints.
- Vehicle Related Characteristics:
  - Approximately 41% of the crashes occurred between two moving vehicles, 35% occurred when a vehicle impacted a roadside object, and 17% of the crashes resulted in overturned vehicles (generally due to roadside conditions),

- 66% of the at-fault vehicles were single-occupant vehicles, and
- 55% of the involved vehicles were passenger cars and 24% were pickup trucks.

➢ Roadway Related Characteristics:

- 59% of the crashes occurred on state routes, and 41% occurred on county or local roads,
- 49% of the crashes occurred at horizontal curve locations (more than half of these curves were sharp enough to require speed reduction),
- About two-thirds of the crashes occurred at roads with lane widths of 11' or less,
- Only 29% of the crash sites had either a paved shoulder or a raised curb adjacent to the road,
- Only 12% of the sites had traversable roadside conditions suitable for the driver of an errant vehicle to correct the path of the vehicle,
- Almost 77% of the crashes occurred on roads with speed limits of 55 mph, and
- Almost 98% of the crashes occurred on roads with average daily traffic volumes of 10,000 vehicles per day or less.

➢ Environmental Related Characteristics:

- 54% of the crashes occurred during daylight conditions, and
- 81% of the crashes occurred on dry days (no inclement weather).

In an effort to determine potentially effective countermeasures, the research team undertook a technical approach that combined past knowledge of countermeasure effectiveness with new knowledge gained from engineering evaluations of approximately 30 roadway and roadside countermeasures assessed for the 150 fatal crashes.

Through this approach several countermeasures (under specific conditions) were found to be potentially effective in minimizing crash severity, with the recommended countermeasures summarized as:

1. Addition of advisory speed signs or other speed controls,
2. Geometric alignment improvements,
3. Widening of lanes/pavement widths,
4. Adding and/or widening graded/stabilized shoulders, and
5. Widening/improvement of clear zones.

Appendix E contains the “Countermeasure Handbook” developed for this study with more specific information about the individual countermeasures and their placement.

Addition of advisory speed signs or other speed controls are applicable at sharp curve locations or locations where reduced operating speed is prudent, for example locations where sight distance is restricted.

Geometric alignment improvements include potential improvements to either horizontal and vertical alignment or both, such as increasing curve radius or length. These improvements should be considered when other less costly countermeasures are not effective, and when the current roadway geometric design can significantly benefit from alignment improvements.

Widening of lanes/pavement widths specifically relates to the roadway lane or pavement width and excludes consideration of paving the shoulder. The lanes should not be widened at the expense of eliminating an existing paved shoulder.

Adding and/or widening graded/stabilized shoulders specifically relates to graded or stabilized shoulders and excludes consideration of paving the shoulder. Shoulders are not widened at the expense of an existing paved shoulder. It also suggests that problems such as edge-rutting, commonly seen at rural road locations with roadside mailboxes, would be addressed with this countermeasure.

Widening/improvement of clear zones is associated with improving the survivability of run-of-road type crashes. It may involve flattening the side slopes, removal of roadside obstacles such as trees, rocks, and increasing available stopping distance adjacent to the road.

The authors identified these countermeasures and the specific conditions under which they are effective (see Table 25) as the most beneficial roadway and/or roadside improvements for reducing fatal motor vehicle crashes on two-lane rural roads in Georgia.

The report concludes with a short-term and long-term safety investment strategy to guide the Georgia Department of Transportation (GDOT) with making safety improvement decisions. These strategies are discussed in detail in Section 5 (see pages 57-64).

2.0 BACKGROUND

Fatal crashes nationwide on two-lane rural highways, the largest single class of highways in the United States, comprised 19,680 in 1997, with 751 of those occurring in Georgia (NHTSA, 1999). When faced with a number of highway safety projects and working with a limited budget, transportation safety managers choose projects that result in the greatest reduction of fatalities, injuries, and property damage resulting from motor vehicle crashes. Prior to the implementation of any given safety countermeasure a safety manager would be best served to know, with the highest degree of certainty possible, the expected effect on highway safety. The options currently available to the safety manager include locally funded research, an extensive literature review to identify and locate similar studies transferable to local jurisdictions, and less formal techniques such as anecdotal "lessons learned."

These approaches for managing road safety investments can make decision-making difficult. First, past studies may only provide insight into the effects of a single countermeasure, may have been conducted on roadways with significantly different features, roadside environment, or driving population, or may be conflicting. Anecdotal evidence is hard to support publicly, while conducting new lengthy studies is costly and time consuming, and usually does not provide timely information for immediate safety investment decisions.

Safety managers clearly benefit from a repeatable and objective process that facilitates the evaluation of a number of safety countermeasures at the same time, while providing with greater confidence an estimate of the expected effect on highway safety in their local jurisdiction.

This research aims to evaluate the nature of fatal crashes on rural two-lane highways in Georgia, determine recommended countermeasures for minimizing these crashes, and provide a robust decision-making tool for safety managers to help identify which countermeasures to select. The technical approach presented in this paper and undertaken in this research involves Bayesian techniques and is termed the Bayesian Safety Analysis Framework (B-SAF) (Hauer, 1997; Harlow, Mulaik, & Steiger, 1997; Greene, 1990). This methodology is an advanced analytical technique for assessing countermeasures in regional safety programs. Bayesian approaches, in general, combine "objective" prior expert knowledge or information such as literature reviews, with "subjective" current information such as engineering evaluations to derive meaningful "posterior" information on probability distributions of Crash Reduction Factors (CRF's). To apply Bayes' theorem in the B-SAF methodology, prior and current estimates of CRF's are combined to obtain posterior estimates of CRF's. In general, Bayesian statistical philosophy asserts that useful information can be learned about specific observable events through subjective, expert evaluation or insight. It is thought that past information can always be updated with current information, and the process of research is iterative. A fundamental element in the Bayesian framework is the requirement for useful and meaningful 'subjective' or 'prior' expert information. This element is critical for the process to be informative. In fact the most significant criticism of the Bayesian philosophy is the manner in which subjective information is obtained. In the B-SAF methodology, subjective information is obtained from engineering evaluation of crashes and countermeasures, termed *Iterative Countermeasure Analysis Technique, A Microscopic Analysis Method,* discussed in detail in a companion paper.

There is a considerable interpretive advantage of Bayesian statistical inference because posterior estimates of CRF's reflect different probabilities than do classical confidence or prediction intervals (Hauer, 1983; Pruzek, 1997). In other words, the most likely value of a CRF for a specific countermeasure is obtained from B-SAF, whereas classical statistical methods, such as regression and ANOVA, provide the probability that a CRF lies within a range of values—a considerable philosophical and practical difference.

This methodology also combines crash reconstruction analysis, which is based purely on engineering and physics principles and logic, with statistical results from past studies. It is this combination of information that provides faith to the safety management engineer that countermeasure effectiveness estimates are grounded in engineering fundamentals, while relying also on past empirical studies that have been conducted to assess countermeasure effectiveness.

While this approach has considerable advantages over alternative approaches for assessing countermeasures, it is subject to some shortcomings, none of which are new to the field of road safety. For example, it is not known precisely how much weight to give to past study results (in conventional studies zero weight is given)—in our study we tried to give equal weight to engineering evaluations and past research findings. However, by conducting careful analysis by highly experienced and trained professionals, the B-SAF methodology offers a sound theoretical and practical framework for assessing safety-related countermeasures.

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3.0 DATA DESCRIPTION

This section describes the fatal crashes used for this research.

INTRODUCTION TO CRASH DATABASE

In the State of Georgia, the GDOT acquires and maintains information on all reported traffic crashes (including fatal, injury, and property-damage-only crashes) in a comprehensive database. In the following sections, the "GDOT crash database" denotes this comprehensive crash database.

The Georgia Department of Public Safety initially constructed this crash database on the basis of the Georgia Uniform Motor Vehicle Accident Report Form (police crash report) and provided this data to GDOT who, in turn, coordinated the database with the Road Characteristic (RC) data file (a statewide roadway inventory database). In the GDOT crash database, traffic crashes are categorized by six main classifications: crash, commercial vehicle (if commercial vehicles were involved), occupant, roadway, ramp (if the crash occurred on ramp), and driver and vehicle related information. All of the crash-related information in any of these six major categories can be retrieved using Microsoft Access.

CRASH DATA SAMPLING PROCEDURE

This section describes the data sampling process that generated the selected sample crash database developed for this study. As mentioned previously, the research is limited to the study of fatal crashes occurring on rural two-lane highways. Per the GDOT crash database, in 1997 there were 640 fatal crashes on rural two-lane highways in the state of Georgia. These 640 fatal crashes make up the target crash database of interest in this study, and were used to provide the data for the engineering evaluations. Due to time and budget limitations, 150 fatal crashes from the crash database were randomly selected. This sample represents approximately 23.7% of the total fatal crashes observed in the Georgia database.

First, the research team collected basic information on the target crashes using the 1997 Fatal Analysis Reporting System (FARS) database. The FARS system was created by the United States Department of Transportation (U.S. DOT) National Highway Traffic Safety Administration (NHTSA) in 1975 in order to improve traffic safety and record keeping. The research team downloaded the target crash database by specifying those fatal crashes occurring on rural two-lane highways without median separation in the state of Georgia.

Next, the research team employed a random number generator to create a shortened list of 175 crash cases. Researchers cross-referenced the 175 FARS fatal crashes on rural two-lane highways from the GDOT crash database. Due to apparent discrepancies between the GDOT and FARS database, six out of the 175 FARS crashes were not displayed in the retrieved data set from the GDOT crash database, resulting in 169 successful matches. After checking these 'missing' crashes, researchers found that in these six cases, one of them was mis-recorded in its roadway functional classification, two were mis-recorded with respect to the number of lanes, and three of them had an unknown number of lanes. Therefore, the research team added these 6 cases into the "target" crash database. GDOT provided copies of the police reports for these 175 pre-selected fatal crashes.

For the next analysis step, the research team checked each of these pre-selected fatal crashes to verify complete crash data information, successfully matched conditions (e.g. rural two-lane highways), etc. The research team identified 12 cases with mismatched information or unavailable/incomplete police reports, and replaced them with randomly selected crash cases from the remainder of the target crash database.

Next, the Georgia Tech (GT) team prepared a site data collection form and performed field surveys for approximately 75% of these 175 pre-selected fatal crashes, in particular those sites with a non-state route as at least one of the intersecting roadways. An example of the data collection form is provided in the example crash file contained in Appendix A. The research team utilized the GDOT video library for the remaining 25% state-route sites to obtain site-related information such as direction of curve, cross-section, roadside hazard rating, etc. At this stage, the research team removed several incomplete crash cases from this 175 pre-selected crash database. This left the sample size at 159 crashes. The research team utilized the random generator again to select 150 crash cases out of these 159 crash cases. These 150 final selected fatal crashes account for 23.4% of the target database.

Finally, the research team created a detailed crash database on the basis of this 150-case final selected crash database, supplementing it with original police reports, crash site investigation reports, and crash site photos. Figure 1 shows the data sampling procedure used in the study.

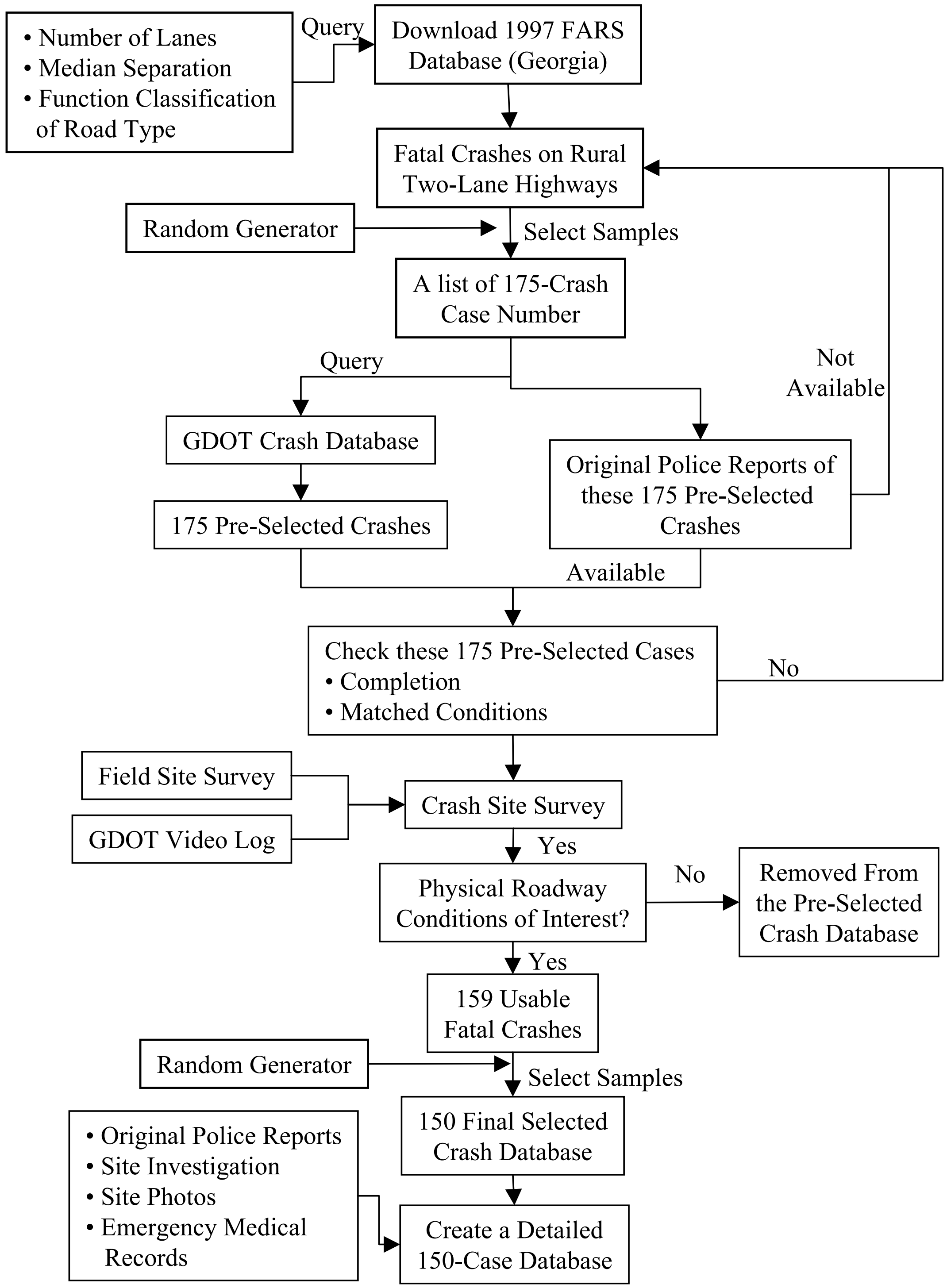

Figure 1: Data Sampling Procedure

4.0 DESCRIPTION OF FATAL CRASH DATA

In the 150 studied fatal crashes, the crash reports indicated 350 people and 235 involved vehicles. Out of these 235 vehicles, 3 were parked vehicles that were struck by at-fault drivers. In addition, 11 of the involved people were pedestrians (coded on crash reports as a second vehicle). Therefore, the number of actual moving vehicles involved in the 150 fatal crashes is 221 vehicles.

The 150 crashes actually included only 347 people (3 “drivers” eliminated since 3 parked vehicles did not actually have drivers in the vehicles when the crashes occurred). Two drivers included in the remaining 347 people fled the crash scenes. Due to insufficient information regarding these two drivers, they are not included in driver specific statistics. One of the two drivers fled the crash scenes on foot (left the vehicle on scene) and one drove away with the vehicle involved in the crash. Therefore, in the crash database, the information regarding this missing vehicle is incomplete. As a result, the remaining number of people and vehicles add up to 345 and 220, respectively.

Out of these 150 fatal crashes, 80 (53.3%) were single-vehicle crashes, 62 (41.3%) crashes involved multiple vehicles, and 8 (5.4%) crashes involved pedestrians. Of the 345 people in the final crash database, 219 were drivers, 115 were passengers, and 11 were pedestrians.

Table 1 shows the perceived primary causes for the 150 fatal crashes of which more than one-third (58) were related to DUI and more than one-fifth (32) were caused by driver error.

Table 2 depicts the reported most harmful event for the 150 fatal crashes. “Impact moving vehicles” (41.3%), “impact roadside obstacle” (34.7%), and “overturned vehicle” (16.7%) account for the majority of most harmful events.

Table 1: Distribution of Contributing Crash Cause in the Study's Crashes

Contributing Cause	Frequency	Percent
DUI- Alcohol & Drugs	58	38.7%
Driver Error	32	21.3%
Driver Condition (Fatigue/Drowsy)	12	8.0%
Too Fast for Weather	11	7.3%
Speeding	9	6.0%
Horizontal Curve	8	5.3%
Driver Inexperience	5	3.3%
Pedestrian Related	5	3.3%
Foreign Object in Road	4	2.7%
Drinking (Not Legally Impaired)	3	2.0%
In-Vehicle Distraction	1	0.7%
Environment Related	1	0.7%
Vehicle Related	1	0.7%
Total	150	100%

Table 2: Distribution of Most Harmful Event in the Study's Crashes

Most Harmful Event	Frequency	Percent
Impact Moving Vehicle	62	41.3 %
Impact Roadside Obstacle	52	34.7 %
Overturned Vehicle	25	16.7 %
Injured in Vehicle	5	3.3 %
Immersion	2	1.3 %
Fell From Vehicle	2	1.3 %
Impact Parked Vehicle	1	0.7 %
Fire	1	0.7 %
Total	150	100%

HUMAN-RELATED CHARACTERISTICS

Injury Severity

Out of the 345 people involved in the fatal crashes, 173 (50.1%) were killed, 39 (11.3%) suffered incapacitating injuries, 60 (17.4%) had non-incapacitating injuries, 29 (8.4%) were possibly incapacitating injuries, and 44 (12.8%) people were not injured. Of these 345 people, 226 (65.5%) were male and 119 (34.5%) were female. A total of 156 of the 219 drivers (71.2%) were male. Similarly, 64 of the 115 involved passengers (55.7%) were male, and 6 of the 11 pedestrians (54.5%) were male.

Table 3: Severity Distribution for Different Type of People

Severity Type	Driver	Passenger	Pedestrian	Total
Killed (K)	126 (57.5%)	39 (33.9%)	8 (72.7%)	173 (50.1%)
Nonfatal Injury, Incapacitating (A)	16 (7.3%)	22 (19.1%)	1 (9.1%)	39 (11.3%)
Nonfatal Injury, Non-incapacitating (B)	31 (14.2%)	27 (23.5%)	2 (18.2%)	60 (17.4%)
Nonfatal Injury, Possible (C)	18 (8.2%)	11 (9.6%)	0 (0.0%)	29 (8.4%)
Not Injury (O)	28 (12.8%)	16 (13.9%)	0 (0.0%)	44 (12.8%)
Total	219*	115	11	345

* Note: Two drivers fled the crash scenes.

Of these 219 drivers, 126 (57.5%) did not survive the crashes, 65 (29.7%) were injured, and 28 (12.8%) were not injured. Among these 115 passengers, 39 (33.9%) were killed during the crashes, 60 (52.2%) were injured, and 16 (13.9%) were not injured. Unfortunately, 8 out of 11 involved pedestrians (72.7%) did not survive the crashes. The 3 surviving pedestrians were all survivors of multi-pedestrian crashes.

Age Distribution

Among the 345 people involved in the crashes, their ages were randomly distributed between 0 and 92 years old.

There were 4 drivers (1.8%) under the age of 16 years old. Of these 4 drivers, one 15-year-old driver was driving a large van, one 11-year-old driver was driving a go-cart, one 11-year-old driver was driving a 4-door sedan, and one 15-year-old was driving a 4-door sedan.

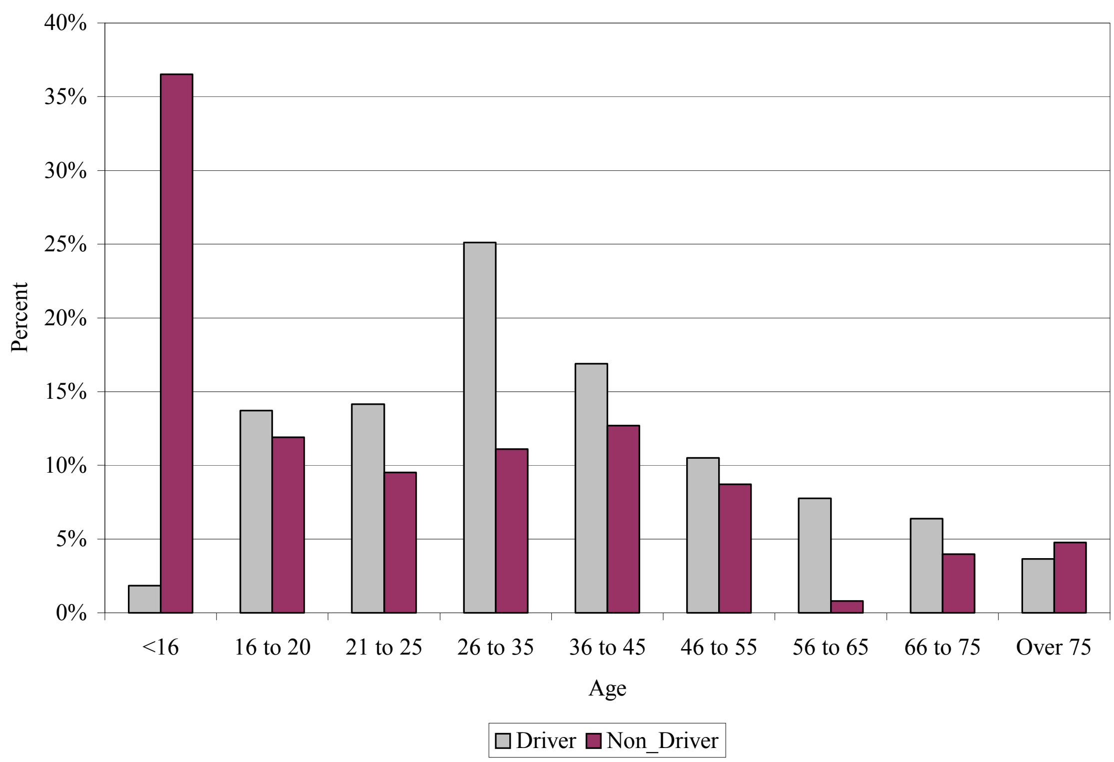

Figure 2: Age Distribution of Drivers and Non-Drivers in the Study Crashes

Figure 2 shows the age distribution of drivers and non-drivers of the 345 involved people. Essentially, the driver ages were distributed in a “bell” shape. The average driver age was 37.3 year-old and the standard deviation was 17.4. The highest frequency (55 drivers) occurred between age 26 and 35 years old and the second highest frequency was between age 36 and 45 years old. Generally speaking, the distribution of driver age is skewed to the right. For 30 young drivers aged between 16 and 20 years old and 31 aged between 21 and 25 years old, this study shows that the probability of young driver involvement in fatal crashes is very high as compared to the bell shaped “normal” curve of the other drivers. In addition, among these 219 drivers, 8 (3.7%) were aged over 75 years old and 14 (6.4%) drivers were aged between 66 and 75 years old. These figures indicate that senior drivers are less likely to survive serious crashes than the healthier, less fragile younger driving population.

A total of 46 out of 126 of the non-driving passengers (36.5%) were younger than 16 years old. The age distribution is skewed to the right and follows an exponential distribution. The average non-driver age was 27.5 years old with a standard deviation of 21.2 years. For those non-drivers aged between 26 and 55, the number of people involved in fatal crashes was evenly distributed.

Seating Position

As previously indicated, 219 of the 345 involved people were drivers, 115 were passengers, and 11 were pedestrians. Out of the 115 passengers, 6 (5.2%) were seated in the front center, 71 (61.7%) were in the front right, 15 (13.0%) were in the second-row-left, 10 (8.7%) in the second-row-center, 10 (8.7%) in the second-row-right seats, and 3 (2.6%) in the unenclosed or cargo areas.

Table 4 demonstrates that in the study crashes, drivers experienced a probability of approximately 57.5% of being killed and an 87.2% of injury. For people seated in the front middle seats, the probability of fatal injury was zero but the chance of injury was 83.8%. The likelihood that the front-right passengers might be fatally injured was 43.7% with a 90.1% likelihood of injury. For passengers seated in the second-row, the right-side passengers had a 30.0% probability of fatal injury and an 80.0% chance of injury, while passengers seated on the left-side experienced a 20.0% probability that they would not survive the crash and a 73.3% likelihood that they would be injured. This disproportionate survival rate is based on a small total sample size of 6 fatally wounded passengers. The fatality ratio for the 11 pedestrians was 72.7% with an unfortunate injury ratio of one hundred percent.

Table 4: Association between Seating Position and Type of Severity

Seating Position	Not Injured	Injured	Killed	Total	Fatal Ratio	Injury Ratio
Driver Seat	28	65	126	219	57.5%	87.2%
Front Middle	1	5	0	6	0.0%	83.3%
Front Right	7	33	31	71	43.7%	90.1%
Second-Row Left	4	8	3	15	20.0%	73.3%
Second-Row Middle	1	8	1	10	10.0%	90.0%
Second-Row Right	2	5	3	10	30.0%	80.0%
Cargo Areas	1	1	1	3	33.3%	66.7%
Pedestrian	0	3	8	11	72.7%	100.0%
Total	44	128	173	345	50.1%	87.2%

In general, if a crash occurred, pedestrians had the highest risk of severe injury or fatality of any person involved in a crash. For front seat drivers or passengers, the likelihood that they would not survive the crash or they would be injured was higher than the odds of second-row passengers. In addition, the chance that passengers seated in the middle would be fatally injured was lower than for passengers seated on both-sides (immediately adjacent to a car door and prospective point of impact).

Safety Restraint System Usage

As shown in Table 5, 167 of the 345 involved people did not use any safety restraints. Approximately 31% of the vehicle occupants properly used a shoulder and lap belt or safety seat. Since the State of Georgia has a primary seat belt law, this observed non-compliance of the law is a significant factor in evaluating driver responsibility to occupant severity.

Table 5: Distribution of Safety Restraint System Usage

Restraint System Usage	Frequency	Percent
Non-Used	167	48.4%
Shoulder Belt Only	5	1.4%
Lap Belt Only	11	3.2%
Shoulder and Lap Belt	102	29.6%
Child Safety Seat	5	1.4%
Helmet Used	3	0.9%
Unknown	41	11.9%
Not Applicable	11	3.2%
Total	345	100.0%

There were 68 of the 345 involved people (19.7%) trapped inside their vehicles, 3 (0.9%) who were extricated by mechanical means. Further, 49 (14.2%) people were totally ejected from their vehicles and 24 (7.0%) were partially ejected from their vehicles during crashes as shown in Table 6. Approximately 71% of the people totally ejected from their vehicles did not use any restraint system. Out of the 24 people who were partially ejected from their vehicles, 19 (79.2%) did not use any restraint system and it was not known if 5 people used any restraint system during crashes. For the 272 people who were not ejected from their vehicles, 41.5% were not using any safety equipment when the crash occurred, and 37.1% wore both shoulder and lap belts. Table 6 illustrates that even though the motorcyclists and bicyclists were wearing helmets during crashes, they were totally ejected from their vehicles and did not survive the crash.

Table 6: The Association between Safety Restraint System Usage and Ejection

Restraint System Usage	Not Ejected	Totally Ejected	Partially Ejected	Total
Non-Used	113	35	19	167
Shoulder Belt Only	5	0	0	5
Lap Belt Only	11	0	0	11
Shoulder and Lap Belt	101	1	0	102
Child Safety Seat	5	0	0	5
Helmet Used	0	3	0	3
Unknown	26	10	5	41
Not Applicable	11	0	0	11
Total	272	49	24	345

Driving Under the Influence of Alcohol or Drugs

Two drivers left the crash scenes. One of the drivers was considered an at-fault driver and the other was not at-fault. Therefore, in the study crashes, there are 149 at-fault drivers (including 5 at-fault pedestrians) and 75 not at-fault drivers. As shown in Table 7, of these 149 at-fault drivers, 56 (37.6%) were not under any influence of alcohol or drugs when crashes occurred and 30 (20.3%) were in unknown condition. According to the police reports, 63 (42.3%) at-fault drivers were driving under the influence (DUI) of alcohol and/or drugs.

Table 7: Distribution of Alcohol/ Drug Involvement

Alcohol/ Drug Involvement	Type of People			
	At-Fault Driver or Pedestrian		Not-At-Fault Driver or Pedestrian	
	Frequency	Percent	Frequency	Percent
Non-DUI	56	37.6%	39	52.0%
DUI-Alcohol	44	29.5%	2	2.7%
DUI-Drugs	13	8.7%	2	2.7%
DUI-Alcohol and Drugs	6	4.0%	0	0.0%
Unknown	30	20.1%	32	42.7%
Total	149	100.0%	75	100.0%

For not at-fault drivers, 39 (52.0%) of them were not under the influence when the crash occurred. The crash information did not definitively indicate the condition for 32 (42.7%) drivers. There were only 4 not-at-fault drivers (5.4%) who were under the influence of alcohol or drugs when the crashes occurred.

Among the 11 pedestrians involved in the 150 study fatal crashes, 5 were considered to be at-fault. Of the 11 pedestrians, 2 were under the influence of alcohol, 1 was under the influence of both alcohol and drugs, and the impairment condition of the remaining 8 was not known.

In summary, in spite of the drivers whose condition was not known, impaired drivers clearly have a higher likelihood of being at-fault, or responsible for the occurrence of crashes. Therefore, DUI drivers can be considered as one of the causal factors to traffic crashes.

Driver Condition

As mentioned previously, there were 149 at-fault and 75 not-at-fault vehicle drivers (including 5 pedestrians) involved in the 150 crashes. Of the total 219 involved drivers and 5 pedestrians, almost half (48.7%) of them were not impaired physically or mentally (deemed to be in normal condition). There were 67 (29.9%) drivers or pedestrians known to be under the influence of alcohol and/or drugs, 5 (2.2%) were asleep or fatigued, and 3 (1.3%) suffered some physical impairment or health condition. Table 8 shows the summary of driver conditions for at-fault and not-at-fault pedestrians and drivers involved in the study crashes.

Table 8: Summary of Driver Conditions

Driver Condition	At-Fault Driver or Pedestrian		Not At-Fault Driver or Pedestrian		Total	
	Frequency	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Normal	57	38.3%	52	69.3%	109	48.7%
Physical Impairment	3	2.0%	0	0.0%	3	1.3%
Fell Asleep, Fainted, Fatigued	5	3.4%	0	0.0%	5	2.2%
DUI	63	42.3%	4	5.3%	67	29.9%
Other	2	1.3%	1	1.4%	3	1.3%
Unknown	19	12.8%	18	24.0%	37	16.5%
Total	149	100.0%	75	100.0%	224	100.0%

VEHICLE-RELATED CHARACTERISTICS

Of the 220 vehicles involved in the 150 fatal crashes, 145 vehicles were considered at-fault. Out of the 145 at-fault vehicles, 95 (65.5%) were single-occupant. For the not at-fault vehicles, 50 (66.7%) were single-occupant. Overall, there were 145 (65.9%) single-occupant vehicles in the study crashes.

Table 9: Vehicle Type Distribution in the Study's Crashes

Type of Vehicle	At-Fault		Not-At-Fault		Total	
	Freq.	Percent	Freq.	Percent	Freq.	Percent
2 Door Sedan/HT/ Coupe	29	20.0%	12	16.0%	41	18.6%
4 Door Sedan/ HT	50	34.5%	17	22.7%	67	30.5%
Station Wagon	1	0.7%	0	0.0%	1	0.5%
Compact Sport Utility	9	6.2%	9	12.0%	18	8.2%
Large Sport Utility	2	1.4%	0	0.0%	2	0.9%
Minivan	2	1.4%	1	1.3%	3	1.4%
Large Van	8	5.5%	8	10.7%	16	7.3%
Compact Pickup	21	14.5%	7	9.3%	28	12.7%
Standard Pickup	14	9.7%	4	5.3%	18	8.2%
Truck/ Tractor	6	4.1%	9	12.0%	15	6.8%
Heavy Single Unit Truck	2	1.4%	4	5.3%	6	2.7%
Motorcycle	1	0.7%	1	1.3%	2	0.9%
Farm Equipment	0	0.0%	1	1.3%	1	0.5%
Others	0	0.0%	2	2.7%	2	0.9%
Total	145	100.0%	75	100.0%	220	100.0%

Vehicle Type

Table 9 shows the specific type of vehicles for the 220 study vehicles. Of the 145 at-fault vehicles, 34.5% were four-door sedans, 24.1% were pickup trucks, 20.0% were two-door sedans, 7.6% were sport utility vehicles, 6.9% were vans, 4.1% were combination trucks, and 1.4% were heavy single unit trucks. Out of the 75 not at-fault vehicles, 22.7% were four-door sedans, 16.0% were two-door sedans, 14.7% were pickup trucks, 12.0% were combination trucks, 12.0% were sport utility vehicles, 12.0%)were vans, and 5.3% were heavy single unit trucks.

For at-fault rates, the research team compared the number of at-fault vehicles and the totals for each type of vehicle and found that the at-fault rates for station wagons and large utility trucks are the highest for the 150 crash sample at one hundred percent. However, the sample sizes for these two vehicle types are very small (1 station wagon and 2 large utility trucks). In general, the at-fault rates of pickup trucks (76.1%) and passenger cars (73.1%) are high. The at-fault rates of sport utility vehicles and vans are also over 50%, with the at-fault rate of motorcycles at 50%. For this study, the at-fault rate of heavy vehicles (38.1%) is less than that of passenger cars (73.1%). The distribution of at-fault rates for different types of vehicles is shown in Figure 3.

Vehicle Age

Out of these 220 studied vehicles, two were not included in the calculation of vehicle age in this study because they were a bike and a go-cart. Therefore, the actual number of vehicles analyzed was 218 vehicles. Of the 218 vehicles, the average vehicle age was approximately 8.9 years and the standard deviation was 6.1 years. For at-fault vehicles, the average vehicle age was 9.0 years old and the standard deviation was 6.6 years old. For not at-fault vehicles, the average vehicle age was 8.5 years old and the standard deviation was 5.1 years old.

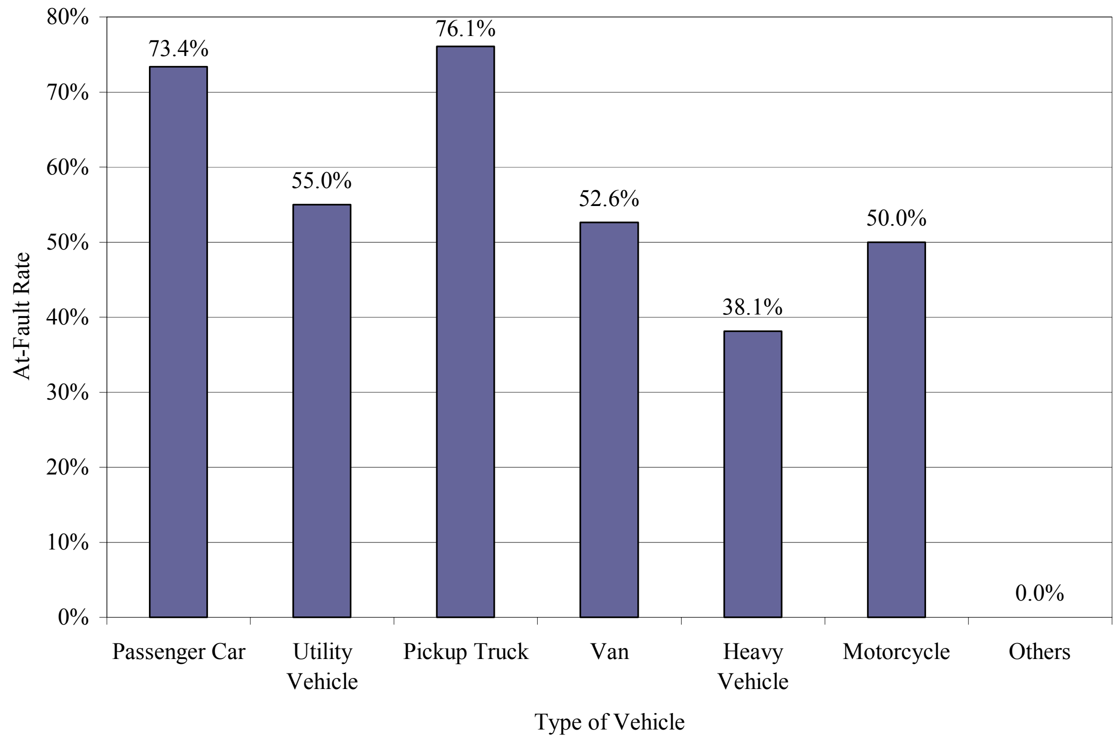

Figure 3: At-fault Rates by Types of Vehicles in the Study's Crashes

In summary, the average vehicle age of those vehicles driven by at-fault drivers was older than the average vehicle age of the not-at-fault vehicles. In addition, the standard deviation of the at-fault vehicles was greater than the not-at-fault vehicles.

ROADWAY-RELATED CHARACTERISTICS

The analyzed crashes all occurred on public roads, including 88 (58.7%) that occurred on state routes, 61 (40.7%) on county routes, and 1 (0.6%) occurred on a city street.

Horizontal Alignment

A total of 74 of the 150 crash locations (49.3%) occurred at horizontal curves and 76 (50.7%) at straight sections. At the 74 horizontal curve crash locations, 40 (54.1%) were on curves to the right sections and 34 (45.9%) were on curves to the left sections. In addition, 41 (55.4%) out of the 74 horizontal curve locations had sharp curves (radius < 820') and 33 (44.6%) had mild curves (radius > 820'). Another way to understand how a curve is considered to be sharp is if the driver should feel that he or she needs to reduce the vehicle operating speed to safely traverse the curve. No speed adjustment is perceived as required for a mild curve. The relationship between curves and lane widths is discussed on p. 32 of the report.

Table 10 shows the association between the horizontal alignment and the estimated radius of these 150 crash locations. Of 41 sharp-curved crash locations, 22 (53.7%) were curving to the right and 19 (46.3%) were curving to the left. Out of the 33 mild-curve crash locations, 18 (52.9%) were curving to the right and 15 (44%) were curving to the left.

Table 10: Association between Horizontal Alignment and Estimated Curve Radius

Estimated Radius	Curve to Right	Curve to Left	Tangent	Total
Sharp	22	19	0	41
Mild	18	15	0	33
Flat	0	0	76	76
Total	40	34	76	150

Table 11 depicts the relationships between crash locations, direction of curves, and estimated curve radius. Among these 22 locations with sharp curves to the right, 20 (90.9%) crashes occurred on the outside of curves; only 2 (9.1%) were on the inside of curves. Further, the research team determined that of these 22 crashes on sharp curves to the right, 9 were head-on crashes and one was an angle collision. All of these 10 crashes occurred on the outside of curves. This observation indicates that for those cross-over vehicles, before the drivers responded and steered back to the travel lane, their vehicles impacted approaching vehicles. Of the remaining 12 vehicles, 2 ran off the road on the inside of the curves and 10 crashed on the outside of the curves. This observation indicates that on the sharp-curved sections, even though cross-over vehicles may avoid hitting approaching vehicles, the majority of vehicles losing control and crashing on the outside of the curves still do not have adequate time to steer back to the appropriate travel lane.

Table 11: Distribution of Crash Locations, Direction of Curves, and Curve Radius

Crash Location	Direction of Curve				Total
	Curve to Right		Curve to Left		
	Sharp	Mild	Sharp	Mild	
Inside of Curve	2	6	11	8	27
Outside of Curve	20	10	8	6	44
Unknown	0	2	0	1	3
Total	22	18	19	15	74

Of the 18 crashes at mild curves to the right, 10 (55.6%) crashes occurred on the outside of curves, 6 (33.3%) were on the inside of curves, and 2 were unknown. Among these 18 crashes, one vehicle hit a pedestrian, one was a rear-end crash on the inside of the curve, 5 were head-on collisions on the outside of the curves, and 4 were angle collisions (3 occurred on the inside of the curves and 1 on unknown location). For the remaining 7 of the 18 crashes, 2 were side swipe collisions with approaching vehicles, 1 vehicle ran off the road and crashed on the inside of the curve and 4 crashed on the outside of the curves. These figures indicate that on mild-curved road sections, cross-over vehicles have a higher probability of hitting approaching vehicles. However, drivers who lose control have a higher likelihood of steering their vehicles back to their traveling lane in comparison to those vehicles on sharp-curved sections. Nevertheless, approximately one-third of the drivers appear to be over-correcting their vehicles and crash on the inside of the curves.

Of the 19 locations with sharp curves to the left, 11 (57.9%) crashes occurred on the inside of the curves and 8 (42.1%) were on the outside of the curves. Among these crashes, 3 were head-on collisions on the inside of the curves, 2 were angle collisions on the inside of the curves, 6 ran off road and crashed on the inside of the curves, and 8 crashed on the outside of the curves. These statistics show that on the curving to the left sections, more than 50% of drivers who lose control of their vehicles steer back to the travel lane. With limited perception-reaction time, most of the drivers over-correct their vehicles and cross over the centerline. Thus, they have a higher probability of hitting the approaching vehicles or running off the road on the inside of the curves.

Among the 15 mild curve to the left crash locations, 8 (53.3) were on the inside of the curves and 6 (40.0%) on the outside of the curves. Out of these crashes, 1 was a head-on collision on the inside of the curve, 1 angle collision was on the inside of the curve, 1 angle-collision was at an unknown location, and 1 was a same direction side-swipe collision on the outside of the curve. In addition, 6 vehicles ran off the road and crashed on the inside of the curve as well as 5 on the outside of the curves. Those crash locations show us that on mild curves to the left, only one-third of vehicles ran off the road in the tangent direction, steering back to the travel lane. Most of these drivers apparently attempted to steer their out-of-control vehicles back to the travel lane but over-corrected and crossed the centerline where they either hit approaching vehicles or ran off the road on the inside of the curves.

In summary, regardless of the direction of the horizontal curves, sharp curves generally have higher crash occurrence than mild curves. Due to the limited perception-reaction time on sharp curves, the probability that errant vehicles will run off the road and crash on the outside of the curves is higher. On mild-curved sections, drivers have a better likelihood of steering their vehicles back to the active travel lane but with a high probability that they may over-correct their vehicle and crash on the inside of the curves. The influence of the direction of curves, as indicated by the statistics, appears to support the conclusion that out-of-control vehicles have a higher probability of hitting vehicles approaching from the opposite direction. On the curves to the left drivers have more reaction time and buffer space to steer their vehicles back to the appropriate active travel lane; however, a high percentage of drivers over-correct their vehicles so they cross the centerline and hit the vehicles approaching from the opposite direction or run off the road on the inside of the curves.

Of the investigated crashes, 65 (87.8%) were superelevated, 33 (44.6%) had signing, 73 (98.6%) were striped, and 69 (93.2%) had shoulders as shown in Table 12. Of the curves' striping 58 (78.4%) had complete striping (centerline, solid double yellow, and edgeline) present, 15 (20.3%) had no edgelines present, and 1 (1.4%) had no striping present. The distribution of the curves' shoulders were 47 (63.5%) graded, 1 (1.4%) paved, 21 (28.4%) combination of paved and graded, and 5 (6.8%) had no shoulders present.

Table 12: Distribution of Location, Curve Direction, Shoulder, and Striping

		Shoulder Type and Direction								
		Graded		Paved		Combined		No Shoulder		Total
		Left	Right	Left	Right	Left	Right	Left	Right	
Inside of Curve	Complete Striping	7	6	0	0	7	2	0	0	22
	No Edgelines	5	0	0	0	0	0	0	0	5
	No Striping	0	0	0	0	0	0	0	0	0
Outside of Curve	Complete Striping	8	10	0	1	3	8	1	2	33
	No Edgelines	1	8	0	0	0	0	0	1	10
	No Striping	0	0	0	0	0	0	1	0	1
Unknown	Complete Striping	0	2	0	0	1	0	0	0	3
	No Edgelines	0	0	0	0	0	0	0	0	0
	No Striping	0	0	0	0	0	0	0	0	0
Total		21	26	0	1	11	10	2	3	74

Vertical Alignment

Out of the 150 fatal crashes, 44 (29.3%) occurred at level roadway sections without noticeable vertical grade, 48 (32.0%) were at uphill locations, and 58 (38.7%) were at downhill locations. Of the 48 uphill crash locations, 31 sites had mild grades (approximately +2% to +6%) and 17 occurred at grades of approximately +1%. Among the downhill crash locations, 4 were on steep downgrades (steeper than -6%), 32 were on mild downgrades (around -2% to -6%), and 20 were on level grades (about -1%). The vertical alignment characteristics of the 150 crash locations are summarized in Table 13. Of the 48 uphill crash locations, 15 (31.3%) were located at crest vertical curves. Eight out of the 15 crashes occurred during daylight conditions and 7 occurred when it was dark at roads with no supplemental lighting.

Table 13: Characteristics of Vertical Alignment of Crash Locations

Estimated Percent of Slope (g)	Direction of Slope			Total
	Up	Down	Flat	
Level (|g| = 1%)	17	20	—	37
Mild (2% < |g| < 6%)	31	32	—	63
Steep (6% < |g|)	0	4	—	4
Not Applicable	0	2	44	46
Total	48	58	44	150

Among the 58 downhill crash locations, 7 (12.1%) were at crest vertical curves and 4 (6.9%) occurred at sag vertical curves locations. Of the 7 crashes occurring at crest vertical curves, 6 occurred during daylight conditions and 1 occurred when it was dark at a roadway section with no supplemental lighting. For the 4 crashes at sag vertical curves, 2 occurred during daylight conditions, 1 at dawn, and 1 during dark conditions at a location with no supplemental lighting.

Lane Width

Table 14 shows the distribution of the lane widths for the studied 150 crash locations. Of the 150 crash locations, the lane widths ranged from 8 to 13 feet, with 41 (27%) crashes occurring at locations with 10 feet lane widths, 37 (25%) collisions located on facilities with 11 feet lanes, and 51 (34%) crashes locations on 12 feet lane roadways.

Table 14: Lane Width Distribution for 150 Fatal Crashes

Lane Width (feet)	Crash Frequency	Percent
8	2	1%
9	15	10%
10	41	27%
11	37	25%
12	51	34%
13	3	2%
NA	1	1%
Total	150	100%

To sum up, only approximately one-third of the 150 crash locations had lane widths greater than 11 feet. The majority of crashes therefore occurred on narrow lanes.

The relationship between horizontal alignment and lane width, as discussed on page 26 and shown in Table 15, identified 40 horizontal curves to the right for which 18 (45.0%) locations had lane widths between 10 and 11 feet, and 13 (32.5%) locations had greater than 11 feet lanes. Of the 34 identified horizontal curves to the left, 14 (41.2%) locations had lane widths between 10 and 11 feet, and 13 (38.2%) locations had greater than 11 feet lanes. Of the 76 tangent locations, 39 (51.3%) sites had lane widths between 10 and 11 feet, and 26 (34.2%) sites had lane widths greater than 11 feet.

Table 15: Lane Width Distribution for Different Horizontal Alignments

Lane Width (feet)	Curve to Right	Curve to Left	Tangent	Total
< 10	9	7	11	27
10 to 11	18	14	39	71
> 11	13	13	26	52
Total	40	34	76	150

Figure 4 demonstrates the 95% confidence intervals for different horizontal alignments at the 150 studied crash locations. On average, the lane widths on the curve to the right crash locations were narrower than on the curve to the left sections or the tangent sections. The average lane width on tangent sections was the widest and the standard deviation was the smallest. These observations indicate that on the horizontal curve to the right locations, the fatal crashes were more likely to occur on narrower lanes. In other words, when the road curves to the right and a driver loses control, the likelihood that the driver will steer the vehicle back to the travel lane will be greater on a wider lane. On the curve to the left sections, the average lane width was wider than on the curve to the right sections and the standard deviation was greater as well. The standard deviation of lane width for roads with horizontal curves to the left was greater. In comparison, the average lane width at tangent crash locations was wider and the standard deviation was smaller. One possible explanation may be that the driving task is simpler on tangent sections even though the design speed on tangent sections is higher.

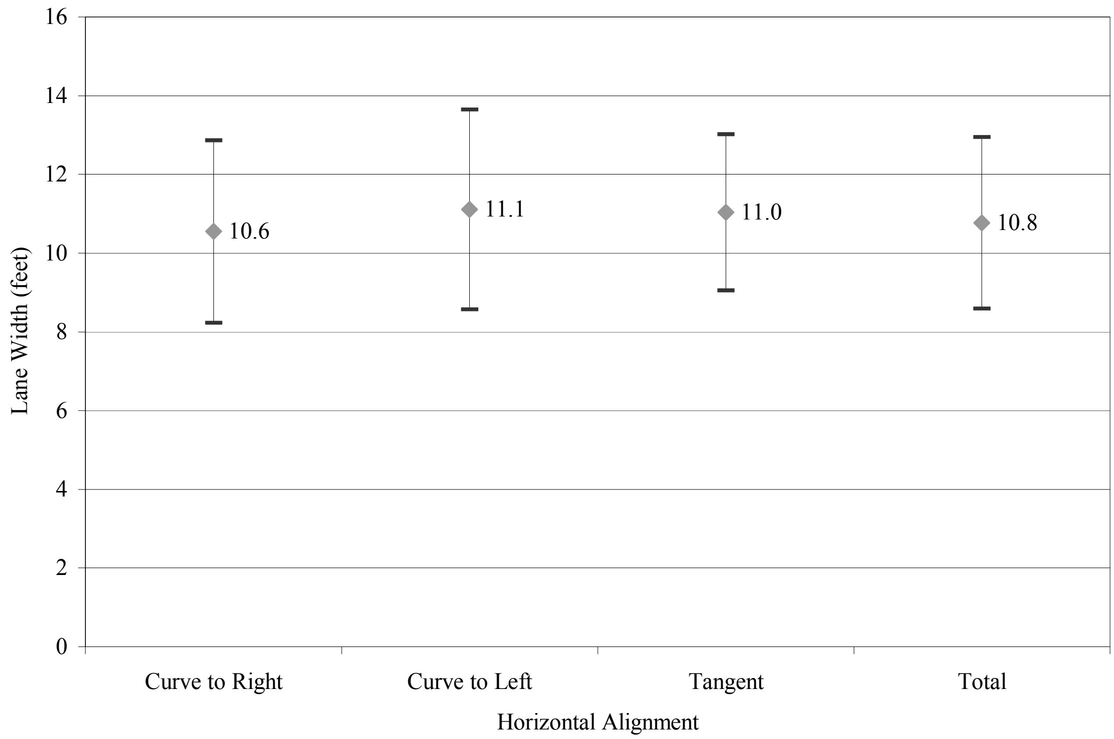

Figure 4: Comparison of Mean and 95% Confidence Intervals on Lane Widths

Shoulder Type and Shoulder Width

Figure 5 shows the shoulder type distribution for the studied 150 crash locations. Out of 150 fatal crashes, 9 (6.0%) occurred on roadway sections without any available shoulders, 5 (3.3%) on roads with paved shoulders, 98 (65.3%) at locations with only graded shoulders, 37 (24.7%) at sites with a combination of paved and graded shoulders, and only one crash occurred at a raised curb roadway section.

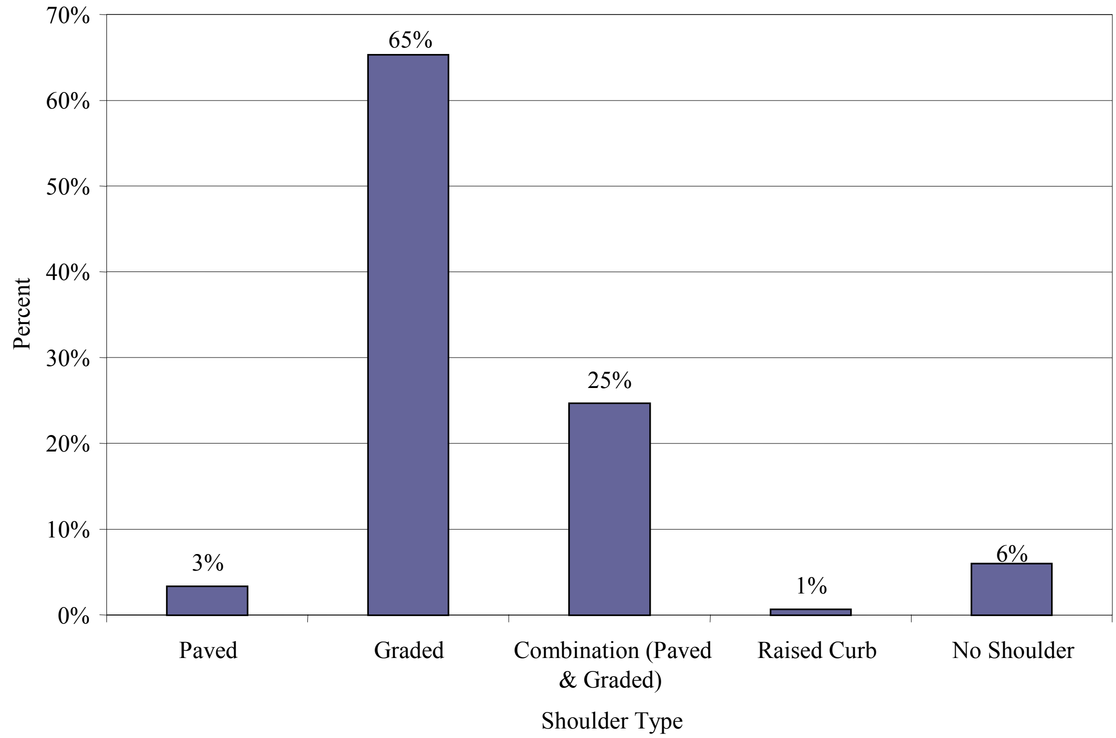

Figure 5: Shoulder Type Distribution

Table 16 shows the average lane width for the different shoulder types. The crash locations where the shoulders were a combination of paved and graded conditions were also characterized by the widest lanes. The narrowest lanes were located at the locations without any available shoulders.

For crash evaluation purposes, shoulder types were defined as follows:

- Paved – region adjacent to edge stripes for use by disabled vehicles to safely exit the road;
- Graded – no paved shoulder adjacent to edge stripe (except perhaps a 6 inch buffer), but shoulder graded to permit a disabled vehicle to pull off of the road;
- Combination (Paved and Graded) – only a 2 to 4 feet of paved shoulder adjacent to the edge stripe but adjacent terrain graded for shoulder use to permit a disabled vehicle to safely pull off of the road;

- Raised Curb – no graded shoulder present but a vertical concrete curb (approximately 6 inch in height) was located adjacent to the active travel lanes;
- No Shoulder – terrain adjacent to the road was not suitable for a disabled vehicle to safely exit the active travel lanes.

Table 16: The Average Lane Width for Different Types of Shoulders

Shoulder Type	Observation		Average Lane Width	Standard Deviation
	Frequency	Percent		
Paved	5	3.3%	10.6	0.9
Graded	98	65.3%	10.5	1.1
Combination, Paved and Graded	37	24.7%	11.6	0.6
Raised Curb, Barrier	1	0.7%	12.0	0.0
No Shoulder	9	6.0%	9.8	1.2
Total	150	100.0%	10.8	1.1

For the 5 locations with paved shoulders, the actual shoulder widths ranged from 2 to 5 feet with an average shoulder width of 3.2 feet, and a standard deviation of 1.3 feet. Of the 98 crash locations with graded shoulders, the shoulder widths ranged from 2 to 10 feet. The average shoulder width was 5.6 feet and the standard deviation was 2.2 feet. Among the 37 locations with combined shoulders, the shoulders were between 2 and 20 feet wide. The average shoulder width was 7.6 feet and the standard deviation was 3.1 feet. Of these 37 crash locations with combined paved and graded shoulders, the paved shoulder widths were between 1 and 6 feet and the graded shoulder widths were between 1 and 16 feet. Basically, for the 150 fatal crashes, the graded shoulder widths were wider than the paved shoulders.

Type of Roadway Junction

Figure 6 shows that of the 150 crash locations, 101 (67.3%) occurred at roadway sections without intersections proximate to the crash location, 17 (11.3%) occurred at four-way intersections, 29 (19.3%) were at T-intersections, 2 (1.3%) were at Y-intersections, and 1 (0.7%) was at a railway grade crossing.

Among the 49 intersections sites, 2 four-way intersections had flashing traffic control signals, and one railway grade crossing had a flashing beacon that was not active at the time of the crash because a train was not present. The remaining intersections in the study crashes were unsignalized with stop controlled regulatory signs.

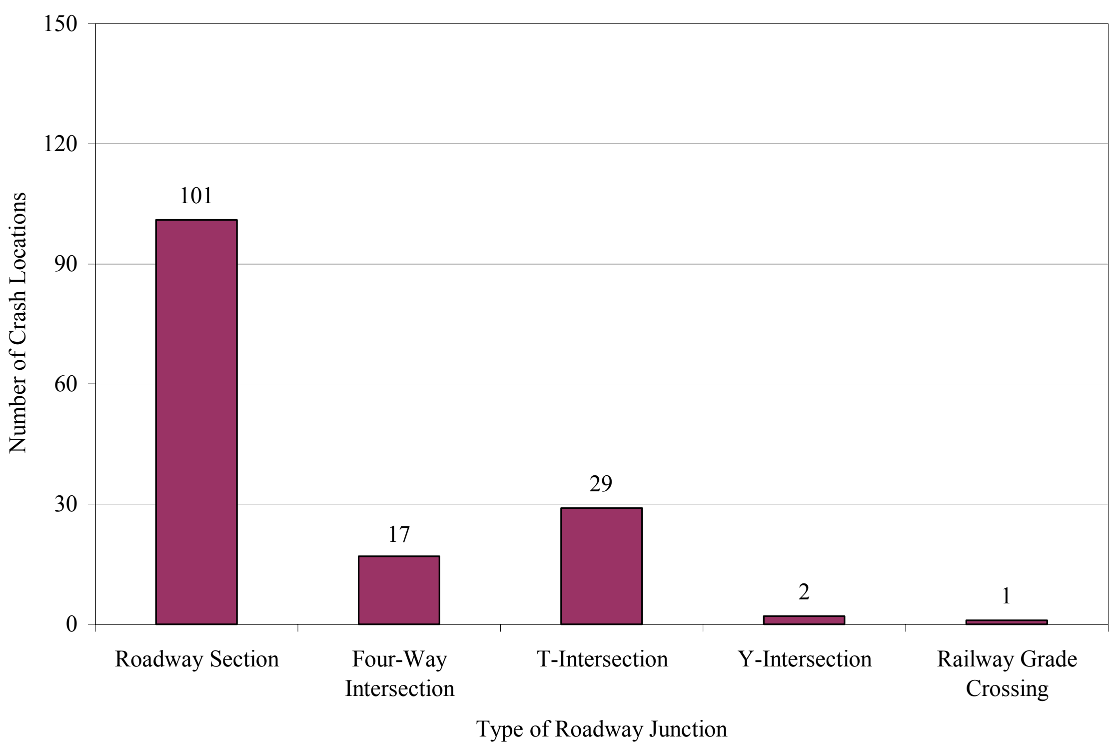

Figure 6: Distribution of Types of Roadway Junction of Crash Locations

Roadside Hazard Rating

Figure 7 shows the distribution of roadside hazard ratings for the 150 crash locations. The roadside hazard ratings (RHR) are determined from a seven point pictorial scale describing the roadside condition with one being less hazardous to seven being most hazardous (Zegeer et al., 1988). A recoverable side slope is a relatively flat side slope (1 foot vertical to 4 feet horizontal or flatter) for which the driver of an errant vehicle may correct the path of the vehicle and "recover" from a potential crash. A non-recoverable slope is traversable but vehicles cannot stop or return easily to the roadway (slopes steeper than recoverable and up to approximately 1 foot vertical to 3 feet horizontal). A critical side slope is steep and a vehicle will likely overturn while attempting to traverse it (AASHTO, 2002).

The side slope at 18 crash locations (12.0%) was recoverable (RHR = 1 or 2), and 91 sites (60.7%) had marginally recoverable (RHR = 3 or 4) side slopes. In addition, 34 out of 150 (22.7%) crash locations had non-recoverable (RHR = 5 or 6) side slopes, while 7 (4.7%) had critical (RHR = 7) roadside conditions.

Of 40 sites with horizontal curves to the right, 22 (55.0%) locations also had marginally recoverable roadside conditions, 4 had recoverable roadside conditions, 12 (30.0%) locations were non-recoverable, and 2 were at critical roadside conditions. Out of 34 sites with horizontal curves to the left, 18 (52.9%) had marginally recoverable roadside conditions, 6 (17.6%) had recoverable roadside conditions, and 9 (26.5%) exhibited non-recoverable roadside conditions. Among the 76 tangent crash locations, 51 (67.1%) locations were characterized by marginally recoverable conditions, 8 (10.5%) had recoverable roadside conditions, 13 (17.1%) exhibited non-recoverable roadside conditions, and 4 had critical roadside conditions. Table 17 contains the summary of roadside hazard ratings at different horizontal alignment crash locations.

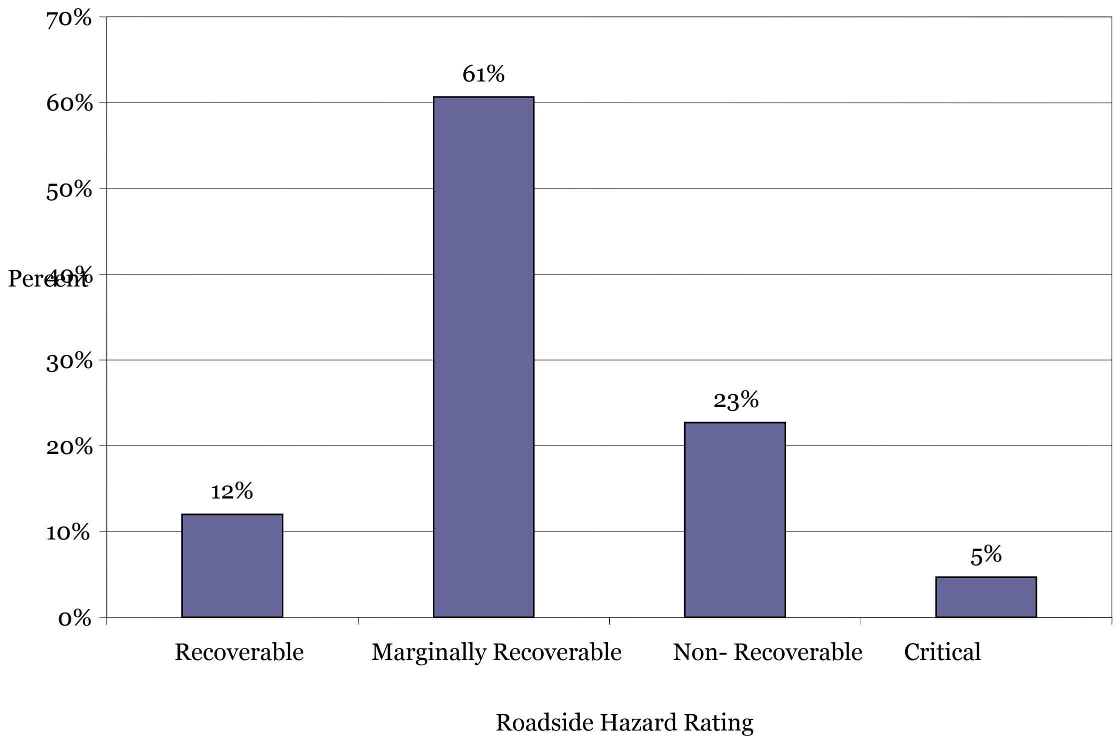

Figure 7: Distribution of Roadside Hazard Rating

Table 17: Summary of Roadside Hazard Rating at Crash Locations

Roadside Hazard Rating	Curve to the Right	Curve to the Left	Tangent	Total
Recoverable	4	6	8	18
Marginally Recoverable	22	18	51	91
Non-Recoverable	12	9	13	34
Critical	2	1	4	7
Total	40	34	76	150

Speed Limit

Vehicle speed is a critical factor to crash severity; however, the Georgia standard police report for crashes does not include estimated vehicle speed. As a result, the speed limit is often used as a surrogate indicator of speed. For example, it is unlikely a vehicle will travel at 55 mph on a road with a 15 mph speed limit. Similarly, roads with higher speed limits will rarely have vehicles traveling at 15 or 20 mph. The roadway design speed is generally considered to be 5 to 15 mph above the speed limit, but for this study the precise design speed at each location is unknown. As a result, this report summarized speed limit conditions as indicators of possible road conditions. These speed limits should not be assumed to reflect vehicle operating speeds.

Of the 150 studied crash locations, 5 (3.3%) locations had speed limits less than 35 mph, 12 (8.0%) locations had 35 mph speed limits, and 2 (1.3%) had 40 mph speed limits. In addition, 16 (10.7%) locations had 45 mph speed limits and 115 (76.7%) had 55 mph limits. Figure 8 shows the distribution of speed limits for the studied crash locations, and Table 18 shows the specific relationship between speed limit and lane width.

Of the 27 locations with lane width less than 10 feet, 15 (55.6%) had speed limits of 55 mph. Of the locations with lane widths between 10 and 11.5 feet, 58 (76.7%) locations had 55 mph speed limits. Among the 48 crash locations with lane widths equal to or greater than 12 feet, 42 (87.5%) had speed limits of 55 mph.

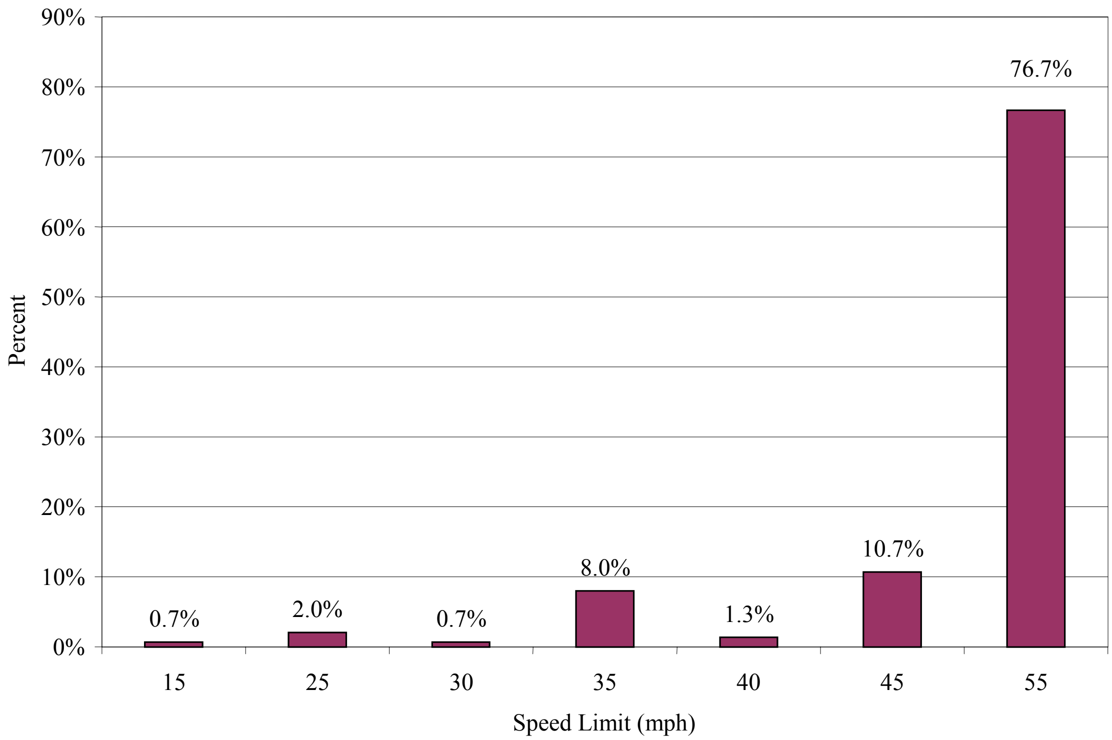

Figure 8: Distribution of Speed Limits

Table 18: Distribution of Speed Limits and Lane Widths

Speed Limit (mph)	Lane Width (feet)			
	<10	10-11.5	≥12	Total
15	1	0	0	1
25	0	2	1	3
30	0	1	0	1
35	3	8	1	12
40	2	0	0	2
45	6	6	4	16
55	15	58	42	115
Total	27	75	48	150

In summary, as shown in Figure 9, when the lane widths were narrower, the average speed limit was lower and the standard deviation was greater. Figure 9 demonstrates that the wider the lane width, the higher the speed limit. This observation supports the assumption that a higher design standard is associated with higher speed limits.

The average speed limit at tangent crash locations was 51.8 mph, and the average speed limit on curving sections (with no regulatory speed limit reductions) was 50.4 mph.

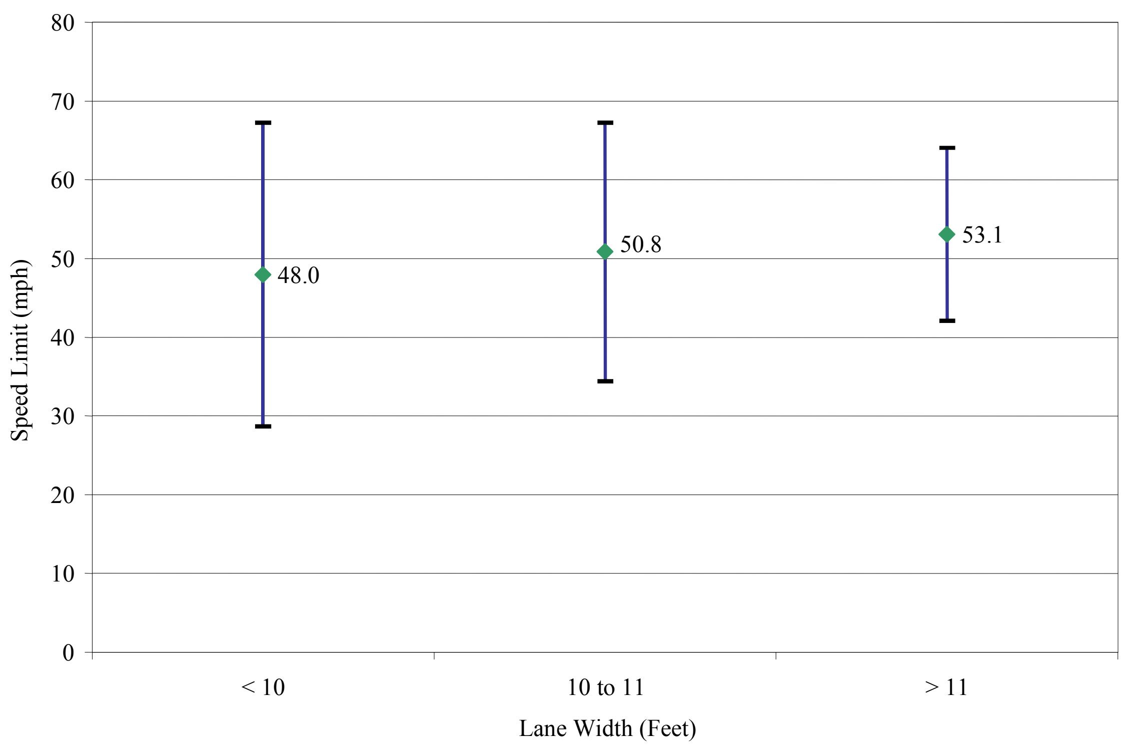

Figure 9: Comparison of Mean and 95% Confidence Intervals on Speed Limits

Average Daily Traffic Volume

Of the 150 crashes, 9 locations had unknown average daily traffic (ADT) volumes. For the remaining 141 locations, the majority (97.9%) of them had an ADT of less than 10,000 vehicles per day. The average ADT for these 141 locations was 2938 vehicles per day and the standard deviation was 2925 vehicles per day.

Figure 10 shows the ADT distribution for the 150 crash locations. Of these 150 crashes, 46 occurred at sites with an ADT of less than 1,000 vehicles per day, 27 with an ADT between 1,000 and 2,000 vehicles per day, 15 with ADT values between 2,000 and 3,000 vehicles per day, and 16 between 3,000 and 4,000 vehicles per day. Basically, the ADT distribution is skewed to the right and follows an exponential distribution.

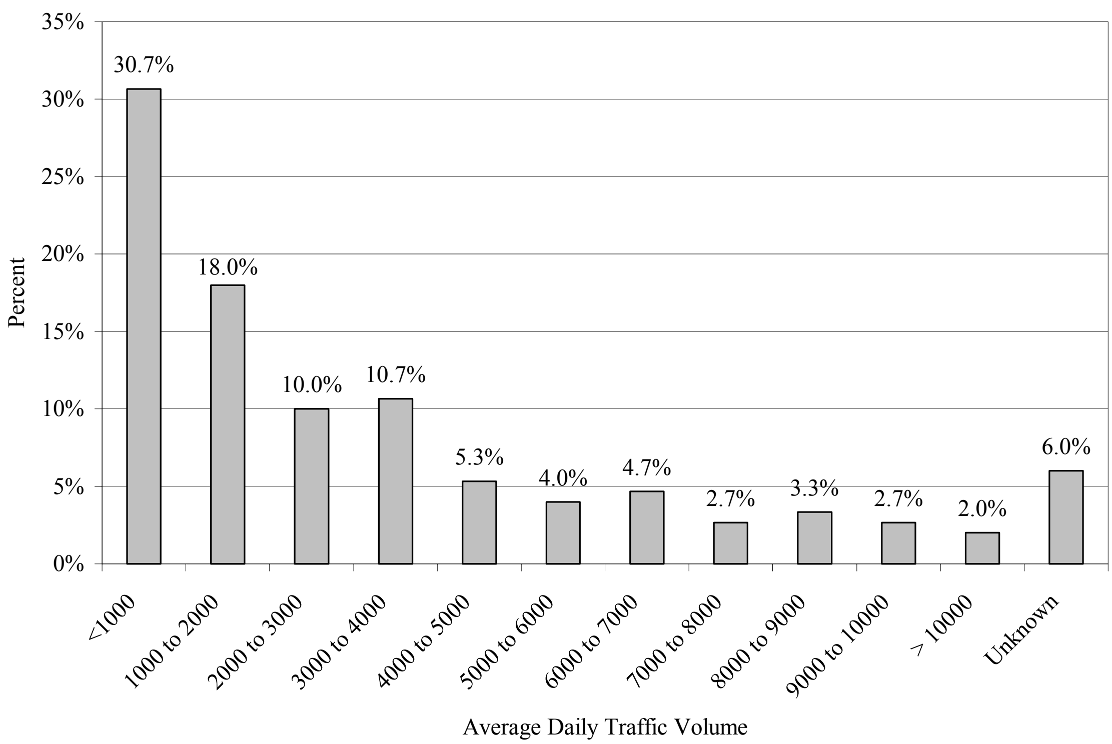

Figure 10: Distribution of Average Daily Traffic Volume

ENVIRONMENT-RELATED CHARACTERISTICS

Day of Week

Of these 150 fatal crashes in the study, 33 (22.0%) occurred on Saturday, while 29 (19.3%) were on Sunday. The lowest frequency is 14 (9.3%) occurring on Monday and the second lowest is on Wednesday (15 crashes, 10.0%). The research team also noted that 67 of the 150 crashes (44.7%) occurred on the weekend (from Friday 6:00 p.m. to Monday 6:00 a.m.).

Weather Conditions

Out of the 150 fatal crashes, 124 (82.7%) occurred on clear days, 21 (14.0%) were on rainy days, 3 (2.0%) were on cloudy days, and 2 (1.3%) were on foggy days. Among these crashes, 121 (80.7%) occurred on dry pavement and 29 (19.3%) were on wet pavement.

Lighting Conditions

The crash reports indicated that 81 (54.0%) crashes occurred during daylight hours, 2 (1.3%) occurred at dusk and 1 crash occurred at dawn. For the nighttime of crashes, only 1 occurred at a dark but lit roadway section, while 65 (43.3%) occurred at locations without supplemental street lighting.

5.0 COUNTERMEASURE EVALUATION

INTRODUCTION

Recall that the objective of this research was to identify effective engineering countermeasures for two-lane rural roads in Georgia, ranked from most to least effective. Effectiveness is measured using theta (θ), the ratio of "safety" before to "safety" after application of a given countermeasure. Safety, in this evaluation method, refers to the number of fatal crashes. The reader should note that a theta value equal to or greater than unity (1.0) means that a countermeasure is not deemed to be effective.

As discussed previously, the Georgia Tech research team applied a meta-analysis to past safety related literature, and performed engineering evaluations for the prospective countermeasures shown in Table 19. A five-member panel performed the engineering evaluations and included Dr. Karen Dixon, P.E., Jennifer Ogle, Dr. Simon Washington, David White, and Dr. Chi-Hung Wu. Each participant had earned at least a Masters Degree in Transportation Engineering and possessed varying experience in the area of transportation safety (ranging from practical to academic applications). The goal of the meta-analysis was to summarize the current state of knowledge of safety research regarding the effectiveness of these countermeasures. The objective of the engineering evaluations was to assess the anticipated impact on two-lane rural roads in the state of Georgia. The independent engineering evaluation results were then averaged to determine the "objective evaluation" theta values.

ANALYSIS PROCEDURE

The analysis procedure reported in this section consists of:

- Summary results of meta-analysis and engineering evaluations
- Reduction of meta-analysis results
- Identification of "effective" countermeasures
- Identifying candidate road sections in Georgia

Table 19: Countermeasure List

Number	Category	Countermeasure	
1	*Pavement Markings*	Add/Upgrade Edgeline	
2		Add/Upgrade Centerline	
3		Add/Upgrade No-Passing-Zone Lines	
4		Add Raised Pavement Markings (RPMs)	
5	*Traffic Signs*	Warning Signs	
6		Advisory Speed Signs	
7		Chevron Alignment Sign	
8		Post Delineator	
9	*Roadway Improvements*	Modify Geometric Alignment (Horizontal, Vertical, Separation)	
10		Modify Superelevation/Cross Slope	
11		Improve Sight Distance without Geometric Realignment	
12		Widen Lanes/Pavement Width	
13		Add Turn Lane	
14		Improve Longitudinal Shoulder	Add/Widen Graded/Stabilized Shoulder
15			Pave Existing Graded Shoulder of Suitable Width
16			Widen and Pave Existing Paved Shoulder
17		Add Rumble Strips	
18		Improve Roadway Access Management	
19	*Roadside Improvements*	Install/Upgrade Guardrail	
20		Upgrade Guardrail End Treatment/Add Impact Attenuator	
21		Clear Zone Improvements	Widen Clear Zone
22			Flatten Side Slope
23			Relocate Fixed Object
24			Remove Fixed Object
25			Convert Object to Breakaway
26			Construct Traversable Drainage Structure
27	*Lighting*	Add Segment Lighting	
28		Add Intersection Lighting	
29		Upgrade Segment/Intersection Lighting	
30	*Regulations*	Enforce Speed Limits	

INITIAL RESULTS

Table 20 shows a summary of results from the meta-analysis. Approximately 67% of investigated countermeasures resulted in no significant or clear published results from the literature search. Another 20% of investigated countermeasures produced fewer than three studies. The vast majority of studies examined the effects of lane width, shoulder width, and geometric alignment on crashes. The variance of the effectiveness of countermeasure 9, modification of geometric alignment, was considerably larger than the others and can be attributed to any number of reasons including the failure to include, quantify, and correct for study artifacts. Artifacts refer to errors resulting from imperfect research and can be manifest as selection bias, incorrect data recording or transcription, model misspecification, etc. The negative signs attributed to both weighted means and variances are due to the prescribed computation method of the previous research efforts evaluated. This format differs from conventional methods, particularly for the variance calculation that is computed as the mathematical difference between two other variances.

The engineering evaluations were performed by the panel of transportation safety experts, and then were consolidated into a single Microsoft® Excel worksheet. From the worksheet, summary statistics were gleaned for all pertinent countermeasures. Table 21 shows a summary of the engineering evaluation results.

Table 20: Countermeasure List for Meta-Analysis

Countermeasure	Number of Studies[1]	Unit of measure[2]	Weighted Mean CRF[3]	Variance of CRF
1. Edgeline	0	Present/Absent	N/A	
2. Centerline	0	Present/Absent	N/A	
3. No-Passing Zone	0	Present/Absent	N/A	
4. Raised Pvmt. Markings	0	Present/Absent	N/A	
5. Warning Signs	0	Present/Absent	N/A	
6. Advisory Speed Signs	2(6)	MPH	0.0082	0.0005
7. Chevron Signs	0	Present/Absent	N/A	
8. Post Delineator	0	Present/Absent	N/A	
9. Geometric Modification	24(36)	Current/Modified	0.0258	29.6752
10. Change Cross Slope	1	Feet/Feet	0.5860	0.0014
11. Improve Sight Dist.	0	Feet	N/A	
12. Widen Lanes/Road	11(15)	Feet	0.3306	1.4033
13. Add Turn Lane	0	Present/Absent	N/A	
14. Improve Graded Shld.	17(27)	Feet	0.7025	1.4053
15. Pave Graded Shld.	2	Feet	0.1608	0.0002
16. Widen & Pave Shld.	0	Feet	N/A	
17. Rumble Strips	0	Present/Absent	N/A	
18. Access Management	2	Intersections/mile	0.2585	0.0002
19. Guardrail	0	Present/Absent	N/A	
20. Attenuation Devices	0	Present/Absent	N/A	
21. Widen Clear Zone	4	Feet	0.4567	0.2423
22. Flatten Side Slope	1	Feet/Feet	3.4607	5.5E-05
23. Relocate Fixed Object	1	Yes/No	1.9048	0.0014
24. Remove Fixed Object	1	Yes/No	1.9048	0.0014
25. Breakaway Object	0	Yes/No	N/A	
26. Traversable Drain.	0	Yes/No	N/A	
27. Segment Lights	0	Present/Absent	N/A	
28. Intersection Lights	0	Present/Absent	N/A	
29. Upgrade Lights	0	Present/Absent	N/A	
30. Enforce Speeds	0	Present/Absent	N/A	

See Table 19 for expanded definitions of the countermeasures shown.

[1] Number in parentheses represents the total quantity of analysis results. Some reports examined more than one countermeasure within a single study.
[2] Some countermeasures have no units of measure and others have nominal values; i.e. the countermeasure is either present or absent, which answers the question whether a countermeasure needs to be added or not.
3 Crash Reduction Factor (CRF) refers to the crash reduction per unit improvement for each countermeasure, the computation method is presented in 10.0 APPENDIX C: Meta-Analysis Process.

Table 21: Countermeasure Theta List for Engineering Evaluation

Countermeasure	Sample Size	Mean Score[4]	Median Score	Mode Score	Variance
1. Edgeline	145	0.9681	1.00	1.00	0.0092
2. Centerline	145	0.9818	1.00	1.00	0.0042
3. No-Passing Zone	48	0.9758	1.00	1.00	0.0094
4. Raised Pvmt. Markings	75	0.9384	1.00	1.00	0.0153
5. Warning Signs	61	0.8972	1.00	1.00	0.0219
6. Advisory Speed Signs	44	0.8838	1.00	1.00	0.0235
7. Chevron Signs	76	0.8196	0.75	0.67	0.0301
8. Post Delineator	146	0.9219	1.00	1.00	0.0201
9. Geometric Modification	149	0.8991	1.00	1.00	0.0235
10. Change Cross Slope	144	1.0000	1.00	1.00	0.0000
11. Improve Sight Dist.	150	0.9802	1.00	1.00	0.0070
12. Widen Lanes/Road	150	0.9129	1.00	1.00	0.0227
13. Add Turn Lane	60	0.9388	1.00	1.00	0.0547
14. Improve Graded Shld.	147	0.9527	1.00	1.00	0.0136
15. Pave Graded Shld.	131	0.8951	1.00	1.00	0.0311
16. Widen & Pave Shld.	36	0.9217	1.00	1.00	0.0261
17. Rumble Strips	45	0.8861	1.00	1.00	0.0285
18. Access Management	148	0.9899	1.00	1.00	0.0024
19. Guardrail	41	0.8384	1.00	1.00	0.0407
20. Attenuation Devices	4	1.0000	1.00	1.00	0.0000
21. Widen Clear Zone	149	0.8858	1.00	1.00	0.0232
22. Flatten Side Slope	150	0.9161	1.00	1.00	0.0247
23. Relocate Fixed Object	56	0.9087	1.00	1.00	0.0207
24. Remove Fixed Object	54	0.8774	1.00	1.00	0.0345
25. Breakaway Object	34	0.9806	1.00	1.00	0.0046
26. Traversable Drain.	49	0.8914	1.00	1.00	0.0423
27. Segment Lights	138	0.9079	1.00	1.00	0.0211
28. Intersection Lights	60	0.9339	1.00	1.00	0.0187
29. Upgrade Lights	5	0.9340	1.00	1.00	0.0218
30. Enforce Speeds	149	0.8876	1.00	1.00	0.0341

See Table 19 for expanded definitions of the countermeasures shown.

[4] Scores are thetas (θ) representing: 0: would prevent crash; 0.33: would reduce crash severity; 0.67: may reduce crash severity; and ≥ 1: ineffective in reducing crashes and their severity.

As shown in Table 21, countermeasures 10 (modify cross slope) and 20 (upgrade guardrail end treatments) received theta value assignments equal to 1.0. This means the safety experts did not rate these countermeasures as effective for the specific crashes evaluated. The sample sizes for countermeasures 20 and 29 (upgrade existing lighting) were too small (<30) to warrant further analysis. All other countermeasures were potentially effective and therefore included in further analysis.

REDUCTION OF COUNTERMEASURE LIST

Following completion of the initial literature review and examination of the results, the research team decided that only previous research reports based upon data collected from 1977 onwards would be considered for inclusion in future data analysis. The justification for this time restriction was that studies older than two decades prior to the analysis year (1997) would likely contain more selection bias, and are possibly of poorer methodological quality than the current evolved techniques. In addition, where explicit fatal crash data were not reported, the fatal national crash data were used to prorate the reported crash data for that year. For instance, say a study on the influence of lane width on crashes on two-lane rural roads was conducted across 2 years with a sample size of 200 *total* crashes. To determine the number of fatal crashes per year from this number we first divide the total number of crashes (200) by the number of years (2), hence we now have 100 total crashes per year. Assuming that 10% of total crashes per year across the analysis period were fatal crashes, then the effective analysis sample size is assumed to have been 10 fatal crashes. Finally, after careful consideration of the wide fluctuations (large variance) in reported results, the research team determined that a minimum sample size of five studies is appropriate for a countermeasure to be included and meaningful in the meta-analysis process. Adhering to the above criteria, the results of the meta-analysis process are presented in Table 22.

Table 22: Reduced "Effective" Countermeasure List from Meta-Analysis

Countermeasure	Description
6	Advisory Speed Signs
9	Modify Geometric Alignment
12	Widen Lanes/Pavement Width
14	Add/Widen Graded/Stabilized Shoulders
21	Widen Clear Zone

IDENTIFICATION OF EFFECTIVE COUNTERMEASURES

The goal during this stage of analysis was to identify road sections and traffic conditions that lend themselves to effective application of the countermeasures identified in Table 22. The overall challenge throughout this analysis was development of a method to identify a sufficiently small number of road sections worthy of improvement. A constant concern while conducting the analyses was that there would be many road-sections that would share common characteristics of "improveable" sections, and that the number of lane-miles requiring improvement using this method would be too large to enable targeted expenditures of safety improvement dollars. This concern ultimately required modification to the analysis methodology originally proposed. We describe this analysis procedure here and conclude with the impact of these analysis decisions in this section.

The procedure incorporated the use of classification and regression trees (CART's) and the engineering evaluations to identify roadway characteristics and traffic conditions where countermeasures can be effectively applied to increase safety (see Appendix D).

The CART procedure identified predictor variables that appeared to be important to a particular countermeasure's effectiveness based on ADT, posted speed limit, RHR and lane width and Table 23 presents the conditions under which they were considered most effective.

Table 23: Reduced "Effective" Countermeasures List from CART (based on Engineering Evaluations)

Countermeasure	Effectiveness	CART Identified Predictor Variables
1. Edgeline	0.67	350 ≤ ADT < 450, Speed ≥ 55mph
2. Centerline	0.835	ADT < 450, Speed ≥ 55mph, RHR 5-7
4. Raised Pvmt. Markings	0.67	ADT < 450, Speed ≥ 55mph, RHR 5-7
5. Warning Signs	0.67	ADT < 1650, RHR 5-7
	0.67	ADT ≥ 5960, RHR 1-4
	0.67	550 ≤ ADT < 750, RHR 1-4
6. Advisory Speed Signs	0.67	ADT < 600, RHR 5-7
7. Chevron Signs	0.67	ADT < 650, RHR 5-7
	0.67	ADT < 650, Speed ≥ 55mph, RHR 1-4
8. Post Delineator	0.67	ADT < 850, Speed ≥ 55mph, RHR 5-7
9. Geometric Modification	0.67	ADT < 550, Speed < 55mph, RHR 5-7
	0.67	ADT ≥ 5200, Speed < 55mph
	0.67	550 ≤ ADT <1300, Speed ≥ 55mph, RHR 5-7
	0.67	6950 ≤ ADT < 8300, Speed ≥ 55mph, RHR 1-4
11. Improve Sight Dist.	0.835	ADT < 450, Speed < 55mph, RHR 5-7
12. Widen Lanes/Road	0.835	ADT < 1800, Speed < 55mph, RHR 5-7, Lane Width < 12 feet
	0.67	1350 ≤ ADT < 1800, Speed ≥ 55mph, RHR 1-4, Lane Width < 12 feet
14. Improve Graded Shld.	0.835	3250 ≤ ADT < 4800, Lane Width < 12 feet
15. Pave Graded Shld.	0.67	ADT<450, Speed ≥ 55mph, RHR 5-7
16. Widen & Pave Shld.	0.835	ADT < 1900
17. Rumble Strips	0.835	2900 ≤ ADT < 4100
	0.835	ADT < 650
	0.67	1900 ≤ ADT < 2900
19. Guardrail	0.67	Speed ≥ 55mph, RHR 5-7

Table 23: Reduced "Effective" Countermeasures List from CART (continued)

Countermeasure	Effective-ness	CART Identified Predictor Variables
21. Widen Clear Zone	0.67	ADT < 250, Lane Width < 12 feet
	0.67	250 ≤ ADT < 450, Speed < 55mph, Lane Width < 12 feet
	0.67[a]	3600 ≤ ADT < 4700, RHR 1-4, Lane Width ≥ 12 feet
	0.835	3250 ≤ ADT < 5200, Lane Width < 12 feet
	0.67	650 ≤ ADT < 850, Lane Width < 12 feet
22. Flatten Side Slope	0.67	550 ≤ ADT < 750, RHR 1-4
	0.67	2850 ≤ ADT < 4800, RHR 5-7
	0.67	ADT<550, Speed ≥ 55mph, RHR 5-7
23. Relocate Fixed Object	0.67	ADT<3350, Speed < 55mph, RHR 5-7
	0.67	ADT < 600, RHR 1-4
	0.67	1800 ≤ ADT < 3350, RHR 1-4
24. Remove Fixed Object	0.67	1650 ≤ ADT < 3350
	0.67	450 ≤ ADT < 1100
26. Traversable Drain.	0.67	380 ≤ ADT < 5550
27. Segment Lights	0.67	ADT ≥ 2550, Speed ≥ 55mph, Lane Width < 12 feet
28. Intersection Lights	0.67	500 ≤ ADT < 2900, RHR 5-7
30. Enforce Speeds	0.67	ADT < 950, Speed < 55mph

a: Considered ideal lane width and RHR.

See Table 19 for expanded definitions of the countermeasures shown.

When combining the 5 “effective” countermeasures from the meta-analysis process (Table 22) with the 26 “effective” countermeasures from the CART analysis (Table 23), the research team observed that both analysis results—the meta-analysis and the engineering evaluation CART analysis—had the following “effective” countermeasures in common (where effective is defined as theta less than 1.0):

- Addition of Advisory Speed Signs,
- Modification of Geometric Alignment,
- Widening of Lanes/Pavement Width,
- Adding/Widening Graded/Stabilized Shoulders, and
- Widening Clear Zones.

When identifying candidate improvement roadway sections, consideration should be given to application of the above 5 common “effective” countermeasures before consideration should be granted to the other noted countermeasures in Table 23, since the engineering evaluation process only identifies predictor variables as opposed to confirming actual countermeasure effectiveness.

IDENTIFYING CANDIDATE IMPROVEMENT LOCATIONS IN GEORGIA

The Fatality Analysis Reporting System (FARS) database and the GDOT Road Characteristics Database (RCFILE) were queried for the CART identified predictor variables or surrogates to determine the number of fatalities and the number of roadway sections, respectively, that would potentially be affected by installing countermeasures at these sites. Unfortunately, the ADT attribute was only present in the RCFILE, while the RCFILE variable SURFACE_U, which describes the width and type of pavement surface for undivided highways, represented "lane width", and varied in value from 15 feet to 23 feet. Some FARS query conditions, for particular countermeasures, could not be comprehensively or accurately investigated due to the lack of representative or closely related attributes for those measured in the field. The results of the database queries are displayed in Table 24.

Table 24 contains the estimates of the number of roadway section, and aggregate roadways, that if upgraded can reduce the number of fatal crashes on two-way rural roads. While the predictor variables indicate specific RHR cohorts the above results include roadways with any type of RHR, thus the number of roadway sections with RHR 5-7 will be less. For example, say we use the RCFILE variable R_SHOULDER_U which describes the width and type of shoulder on the right side or an undivided highway as a surrogate for RHR of 5-7. This variable ranges in value from zero to five feet for various shoulder compositions (see appendix B). The results produced with this variable included in the query for countermeasure 2 are 15,987 roadway sections (1491 aggregate roadways), a reduction of more than 50% of roadway sections from the query for all RHR types with values of 34,282 roadway sections (2441 aggregate roadways). Further analysis could be done on the RCFILES roadway sections to determine the length of roadways that these sections represent, which would immensely aid the benefit-cost analysis process.

Table 24: Georgia Candidate Roadway and Sections

Counter-measure	Predictor Variables	RCFILE Roadway Sections[1]	RCFILE Roadways[1]	Fatal Crashes [2]
1. Edgeline	350 ≤ ADT < 450, Speed ≥ 55	2600	354	CND[3]
2. Centerline	ADT < 450, Speed ≥ 55, RHR 5-7	34282	2441	CND
4. Raised Pvmt. Markings	ADT < 450, Speed ≥ 55, RHR 5-7	34282	2441	CND
5. Warning Signs	ADT < 1650, RHR 5-7	71915	4556	CND
	ADT ≥ 5960, RHR 1-4	7637	283	CND
	550 ≤ ADT < 750, RHR 1-4	4723	513	CND
6. Advisory Speed Signs	ADT < 600, RHR 5-7	51336	3282	CND
7. Chevron Signs	ADT < 650, RHR 5-7	53649	3470	CND
	ADT < 650, Speed ≥ 55, RHR 1-4	37959	2796	CND
8. Post Delineator	ADT < 850, Speed ≥ 55, RHR 5-7	41529	3063	CND
9. Geometric Modification	ADT < 550, Speed < 55, RHR 5-7	14985	1419	30[a]
	ADT ≥ 5200, Speed < 55	4719	264	30[a]
	550 ≤ ADT <1300, Speed ≥ 55,RHR 5-7	10127	1003	104[a]
	6950≤ADT < 8300, Speed≥55,RHR 1-4	1038	65	104[a]
11. Improve Sight Dist.	ADT < 450, Speed < 55, RHR 5-7	14293	1298	CND
12. Widen Lanes/Road	ADT < 1800, Speed < 55, RHR 5-7, Lane Width < 12 feet	11667	1613	CND
	1350 ≤ ADT < 1800, Speed ≥ 55, RHR 1-4, Lane Width < 12 feet	1125	137	CND
14. Improve Graded Shld.	3250 ≤ ADT < 4800, Lane Width < 12 feet	810	111	CND
15. Pave Graded Shld.	ADT<450, Speed ≥ 55, RHR 5-7	34282	2441	5[b]
16. Widen & Pave Shld.	ADT < 1900	73960	4613	CND
17. Rumble Strips	2900 ≤ ADT < 4100	6842	357	CND
	ADT < 650	53649	3470	CND
	1900 ≤ ADT < 2900	8519	530	CND
19. Guardrail	Speed ≥ 55, RHR 5-7	68945	3905	CND
21. Widen Clear Zone	ADT < 250, Lane Width < 12 feet	18068	1762	CND
	250 ≤ ADT < 450, Speed < 55, Lane Width < 12 feet	999	185	20[c]
	3600 ≤ ADT < 4700, RHR 1-4, Lane Width ≥ 12 feet	5296	302	CND
	3250 ≤ ADT < 5200, Lane Width < 12 feet	1016	131	CND
	650 ≤ ADT < 850, Lane Width < 12 feet	3332	407	CND

Table 24: Georgia Candidate Roadway and Sections (continued)

Counter-measure	Predictor Variables	RCFILE Roadway Sections[1]	RCFILE Roadways[1]	Fatal Crashes [2]
22. Flatten Side Slope	$550 \le$ ADT < 750, RHR 1-4	4723	513	CND
	$2850 \le$ ADT < 4800, RHR 5-7	9537	434	CND
	ADT<550, Speed $\ge$ 55, RHR 5-7	36270	2654	CND
23. Relocate Fixed Object	ADT<3350, Speed < 55, RHR 5-7	26527	2379	20[c]
	ADT < 600, RHR 1-4	51336	3282	CND
	$1800 \le$ ADT < 3350, RHR 1-4	12530	663	CND
24. Remove Fixed Object	$1650 \le$ ADT < 3350	13469	695	CND
	$450 \le$ ADT < 1100	15015	1519	CND
26. Traversable Drain.	$380 \le$ ADT < 5550	6931	342	CND
27. Segment Lights	ADT $\ge$ 2550, Speed $\ge$ 55, Lane Width < 12 feet	822	113	CND
28. Intersection Lights	$500 \le$ ADT < 2900, RHR 5-7	33739	2184	CND
30. Enforce Speeds	ADT < 950, Speed < 55	17508	1708	CND

See Table 19 for expanded definitions of the countermeasures shown.

1: RCFILE Roadway Sections and Roadways represent the number of roadway segments and their respective continuous roadways in the Georgia RCFILE that were found to be candidate sites for each specific countermeasure.
2: Source FARS 1997
3:Could Not Determine

a: Curved alignment related crashes
b: Shoulder related crashes
c: Crashes related to trees, utility poles, highway/traffic signs/posts, other poles/posts/fixed object/support.

IMPLEMENTATION OF COUNTERMEASURES FOR SAFETY IMPROVEMENT IN GEORGIA: SHORT-TERM STRATEGY

Installing individual effective countermeasures at candidate locations is a sound long-term safety investment strategy, but the implementation procedure will take substantial resources dedicated to inventory, analysis, and evaluation activities before implementation can begin. In the following section, we outline a short-term strategy that can be implemented by GDOT more swiftly.

The guiding principal of the short-term strategy is as follows:

> Sites with multiple opportunities for countermeasure application (say 4 or more) represent increased driver risk relative to those sites with few countermeasure improvement opportunities (say one or two safety countermeasure opportunities). The increased risk arises from the increased 'difficulty' or 'complexity' involved with successfully negotiating the segment of road.

It follows from this guiding principal that GDOT could identify sites with multiple opportunities for countermeasure application, and then apply a reasonable set of countermeasures from those determined to be effective from this research.

The engineering evaluations of the sample of 150 crashes revealed the following number of identified roadways, the expected theta for the conditions, and the conditions under which the countermeasures were effective for the five identified most effective countermeasures.

Table 25 depicts those locations where the five countermeasures can be effectively applied. In the short-term safety investment strategy, one should note that the applicable conditions listed in the table represent locations identified where that specific countermeasure would be effective. For instance, there are 1762 road segments identified where widening the clear zone may be effective. These segments all have ADT < 250 and lane widths less than 12 feet. A subset of these locations may also be ideal candidates for speed controls, and widening of lanes, etc. The objective of the short-term safety investment strategy is to identify locations where multiple countermeasure investment opportunities exist.

Table 25: "Most Promising" Countermeasure List

"Effective" Countermeasure	Potential Roadways	Applicable Conditions
Advisory Speed Signs	3282	ADT<600, RHR 5-7
Modify Geometric Alignment	1419	ADT<550, Speed<55, RHR 5-7
	264	ADT≥5200, Speed<55
	1003	550≤ADT<1300, Speed ≥ 55, RHR 5-7
	65	6950≤ADT<8300, Speed ≥ 55, RHR 1-4
Widen Lanes or Pavement Width	1613	ADT<1800, Speed<55, RHR 5-7, Lane Width<12 feet
	137	1350≤ADT<1800, Speed ≥ 55, RHR 1-4, Lane Width<12 feet
Add/Widen Graded/Stabilized Shoulder	111	3250≤ADT<4800, Lane Width<12 feet
Widen Roadside Clear Zone	1762	ADT<250, Lane Width<12 feet
	185	250≤ADT<450, Speed<55, Lane Width<12 feet
	302	3600≤ADT<4700, RHR 1-4, Lane Width ≥ 12 feet
	131	3250≤ADT<5200, Lane Width<12 feet
	407	650≤ADT<850, Lane Width<12 feet

Table 26: Fatal Crashes' Relationship to "Effective" Countermeasures

"Effective" Countermeasures	Crashes	Percent
4+	74	49.3%
3	22	14.7%
2	18	12%
1	20	13.3%
0	16	10.7%
Total:	150	100.0%

Table 26 shows the number of Georgia study fatal crashes in 1997 (including crashes on both state and non-state maintained facilities) that were studied and subsequently identified as candidates for safety investment opportunities. For instance, 74 out of 150 crashes received "effective" ratings for four or more countermeasures. This table gives an indication of the number of noted potential countermeasure improvements that could be implemented for improving crash locations. So, more than half of the 150 crashes could receive multiple countermeasures to mitigate fatal crashes. This finding suggests that a considerable number of crash sites have multiple safety deficiencies, and perhaps these sites can be identified as "more serious" as compared to sites with 1 countermeasure improvement opportunity. Table 26 depicts the fatal crash data in a manner that compliments information provided by the effectiveness of specific countermeasures as applied in isolation.

It is interesting and important to note that of the 150 investigated crashes; approximately 11% would not be affected by any of the countermeasures listed in Table 19. Also, the analysis process considered each countermeasure independently and did not consider possible countermeasure interactions. Add this to the uncertainty surrounding the expected effectiveness of identified countermeasures, and there remains a significant portion of crashes that could not be eliminated or benefit from a severity reduction as a result of implementation of these engineering-based countermeasures.

The recommended short-term safety investment procedure for GDOT as a result of these findings is as follows:

1. Search the roadway inventory for instances where three or more countermeasure investment opportunities exist. This will require a current comprehensive roadway database and sorting capability that accurately identifies locations with multiple opportunities and their associated "effective" countermeasures;
   OR
   Compile a list of crash site locations on two-lane rural roads in Georgia (state and non-state maintained) over the past several years and systematically determine which sites are candidates for multiple countermeasure investment opportunities.

2. Implement improvements based upon the type of countermeasure investment opportunities, the expected benefits (theta) for the countermeasures of the sites, and an engineering analysis of the nature of crashes at the sites.
3. Prioritize sites based on steps 1 and 2 above (using cost-benefit analysis or a similar defensible prioritization strategy), make safety investments, and monitor the safety record at improved sites over several years.

IMPLEMENTATION OF COUNTERMEASURES FOR SAFETY IMPROVEMENT IN GEORGIA: LONG-TERM STRATEGY

Recall that the overall objective of this research is to prioritize and rank the effectiveness of various countermeasures for two-lane rural roads in Georgia, so that safety investments can be made wisely and with maximum benefit.

A long-term strategy is required due to the difficulty in correlating roadside and traffic operations features with the GDOT RCFILE and NHTSA FARS databases. For instance, the RHR, which has been shown to be effective in gauging the level of risk associated with roadside hazards, is not present in the RCFILE or FARS. This omission makes it difficult to correlate a RHR obtained through site investigations with a meaningful measure in either FARS maintained by NHTSA or the RCFILE maintained by GDOT. Similarly, traffic volumes are not consistently measured across databases. As a result, it is not feasible for the researchers to precisely identify the specific sites for candidate improvements (other than at the observed crash site locations). Instead, the researchers have identified CONDITIONS UNDER WHICH effective countermeasures may be applied. It then remains for the GDOT professional staff to analyze, sort, inventory, and finally implement safety improvements.

Thus, as a long-term strategy for making safety investments, and requiring resources to analyze, sort, and inventory data, the GDOT could follow the described implementation steps:

1. Determine the number of roadway miles (or intersections) that are "ideal" with respect to countermeasure application (see Table 23). Recall that a good starting point is to identify sites where the most effective countermeasures could be applied and whose application is justified (see Table 19). This will require archiving the roadway inventory (state and non-state maintained) that has specific characteristics. It will also probably require the help of local jurisdictions for identification of these facilities. On those identified roadway sections/intersections, determine the number of fatal crashes averaged over the past several years (3 years is a target).
2. Examine crash records at "candidate" sites and identify sites with below average safety records (i.e. sites with number of crashes greater or equal to the average plus one standard deviation).
3. As an alternate, step 2 could be conducted first to identify 'sites with promise', and then the characteristics of those sites could be determined as described in step 1.
4. Estimate the expected reduction in fatal crashes as a result of countermeasure application at candidate sites. This reduction can be calculated as:

   (number of fatal crashes in previous 3-year period) x (fatalities/fatal crash) x (1 – theta),

   where theta is the combined value of theta obtained from the meta-analysis process (see Table 20) and the engineering evaluations (see Table 23).

For example, assume that there were 12 fatal crashes on two-lane rural roads with ADT < 1800, Speed < 55mph, RHR 5-7, and Lane Width < 12 feet over the past 3 years (locations where widening of lanes is an ideal countermeasure). We collect information from the meta-analysis results and from the engineering evaluations and are comfortable using a theta of 0.835. That is, the engineers feel that local conditions (engineering evaluations) are the dominant factor for determining the effectiveness of widening of lanes.

With theta equal to 0.835, and assuming a hypothetical 1.25 fatalities per crash occurred during the study years, the calculation yields: (12)(1.25)(1 - 0.835) = 2.475 expected reduction in fatalities at those sites over future periods.

This estimate represents the most probable number of fatalities saved by widening lanes to 12 feet at those sites, all else being equal (i.e. traffic stays constant, no major influencing factors, etc.).

5. This same procedure is conducted for each countermeasure identified with the site-related characteristics and most probable estimates of theta obtained from Tables 19 and 22.

6. The cost per application of implementing each countermeasure should be combined with the expected benefits to determine the most effective applicable countermeasures. It is during this step that the expected effectiveness will be combined with costs to re-order the countermeasures. In other words, the priority according to theta alone will probably be changed when costs are added to the analysis. It may turn out that some countermeasures with lower effectiveness (say around 0.95) may on a cost per life saved be a more effective strategy than countermeasures with expected thetas of 0.70.

7. GDOT could then apply countermeasures using safety investment and improvement resources and closely monitor the safety performance of these improvements over time. The improvement may not be immediate, since changes to roadways and intersections may initially bring about unfamiliarity to regular roadway users.

6.0 CONCLUSIONS

The objective of this research was to determine roadway or roadside improvements countermeasures that are most effective for reducing fatal crashes on two-lane rural highways in Georgia, and to prioritize them with respect to the highest expected number of lives saved. To accomplish this objective, the research team evaluated 150 randomly selected fatal crashes for 1997. In general, these crashes were characterized by human, vehicle, roadway, and environmental features that contributed to the crash.

The research team undertook a technical approach that combined past knowledge of countermeasure effectiveness with new knowledge gained from engineering evaluations of approximately 30 roadway and roadside countermeasures assessed on the 150 fatal motor vehicle crashes. Through this approach several countermeasures (under specific conditions) were found to be effective, with the recommended countermeasures summarized as:

- Addition of advisory speed signs or other speed controls,
- Geometric alignment improvements,
- Widening of lanes/pavement widths,
- Adding and/or widening graded/stabilized shoulders, and
- Widening/improvement of clear zones.

The authors identified these countermeasures and the specific conditions under which they are effective as the most beneficial roadway and/or roadside improvements for reducing fatal motor vehicle crashes on two-lane rural roads in Georgia.

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8.0 APPENDIX A -- SAMPLE CRASH FILE

Case #71070077
Date: 5/4/97
County: Heard

Sequence of Events:

1. A male driver (17 years old, residence in Lagrange, Georgia) of vehicle #1 (passenger car) was traveling southbound on State Route 1 at approximately 6:25 p.m. on Sunday, May 4, 1997. Pavement conditions were dry and lighting conditions were daylight at the time of the crash. The driver was the only vehicle occupant, was wearing both a lab and shoulder belt, and was not under the influence of drugs or alcohol. A male driver (61 years old, residence in Carrollton, Georgia) of vehicle #2 (passenger car) was traveling in the northbound direction. In addition to the driver, a 37 year-old male passenger was seated in the front passenger seat. It is unknown if either vehicle occupant utilized safety restraints. The driver was not tested for drug or alcohol usage. Neither vehicle was equipped with an airbag system. The road at this location has one southbound lane and one northbound lane for a total paved road width of approximately 24'. There is approximately a 2' paved shoulder and a 4' graded shoulder adjacent to the road. At the location of the crash the road is curved to the right for the southbound direction of travel and on grade. The posted speed limit is 55-mph.

2. Vehicle #1 was traveling southbound and, as the driver attempted to negotiate a mild horizontal curve to the right, the driver entered the opposing travel lane and impacted vehicle #2 head-on. Following impact, vehicle #1 rotated counter clockwise and came to rest 32' from the point of impact. Vehicle #1 was facing north in the southbound lane at this location. Vehicle #2 rotated clockwise and traveled 35' down the east embankment. Vehicle #2 then caught fire.

3. The driver of vehicle #1 was visibly injured, trapped in the vehicle, extricated from the vehicle, and was transported for medical treatment. The driver of vehicle #2 was also trapped in the vehicle, extricated from the vehicle, and determined to be dead at the crash scene. The passenger of vehicle #2 was visibly injured and transported for medical treatment. Emergency Medical Services were notified at 6:26 p.m., arrived at the scene at 6:35 p.m., and arrived at the hospital at 7:40 p.m.

Crash Number: 71070077 Evaluator: KKD

Crash Date: 5/4/97

County: Heard

Sequential Occurrence Factors (events/factors contributing to cause):

Horizontal Curve (mild curve to right)

Driver Error (wrong side of road)

Impact Moving Vehicle

Severity Occurrence Factors (events/factors contributing to severity):

Safety Restraints

Fire

Was Road a Contributing Factor to Crash Cause?

Yes No

Was Road a Contributing Factor to Crash Severity?

Yes No

Was Roadside Environment a Contributing Factor to Crash Cause?

Yes No

Was Roadside Environment a Contributing Factor to Crash Severity?

Yes No

Accident Summary

Case #: 71070077

Date/Time:	5/4/97 6:25:00 PM
Day:	Sunday
County:	Heard
Road:	State Route 0001
Nearest Intersecting Road:	0000
City:	

Number of people involved:	3
Number of fatalities:	1
Number of Injuries:	2
Serious:	0
Visible:	2
Complaints:	0
Time EMS notified	5/4/97 6:26:00 PM
Time EMS Arrived	5/4/97 6:35:00 PM
Time EMS at hospital:	5/4/97 7:40:00 PM

Atmospheric Conditions:

Weather/ Temp:	Clear
Ambient Light:	Daylight
Road Surface Condition:	Dry

Accident Location:	On Roadway
Road Character Description:	Straight On Grade
Road Comp Description:	Black Top
Road Defects:	No Defects
Manner of Collision:	Head On
First Harmful Event:	Motor vehicle in Motion

Page 1 of 4

#1

Driver Summary

Case #: 71070077

Drivers License State: GA
State of Vehicle Tag: GA
Driver Age: 17
Driver DOB: 8/25/79
Driver Sex: M
Driver Condition Description: Not Drinking

Alcohol Test given, type: Yes Blood
Drug Test given, type: Yes Blood
Alcohol test results: 00 *Drug test results:* NEG

Driver Cited N
Ejection/Injury: Trapped / Visible
Extriction required? Y
Safety Equipment: Lap and Shoulder Belt
Air bag No Air Bag in Vehicle

Total Occupants: 01
Direction of travel: South
Vehicle Maneuver: Straight
Initial Contact Location: Front Left
Traffic Control Description: No Passing Zone
Obscured vision: Not Obscured

Contributing Factors Description:

Wrong Side of the Road
No Contribution Factors
No Contribution Factors
No Contribution Factors

Driver #2 Summary

Case #: 71070077

Drivers License State:	GA
State of Vehicle Tag:	GA
Driver Age:	61
Driver DOB:	5/27/35
Driver Sex:	M
Driver Condition Description:	Not Known if UI
Alcohol Test given, type:	No
Drug Test given, type:	No
Alcohol test results:	*Drug test results:*
Driver Cited	N
Ejection/Injury:	Trapped / Killed
Extriction required?	Y
Safety Equipment:	Unknown
Air bag	No Air Bag in Vehicle

Total Occupants:	02
Direction of travel:	North
Vehicle Maneuver:	Straight
Initial Contact Location:	Front Left
Traffic Control Description:	No Passing Zone
Obscured vision:	Not Obscured

Contributing Factors Description:

No Contribution Factors
No Contribution Factors
No Contribution Factors
No Contribution Factors

Roadway Characteristics:

Case # 71070077

Federal Eligibility Description:	NHS
Functional Class Description:	R-Principle Arterial
Speed Limit:	55
ADT	3500
Number of travel lanes, left:	1
Number of travel lanes, right:	1
Divided Highway?	N
Divided Median Width:	0

Driver and Occupant Information

Case # 71070077

Vehicle Number: **01**

Occupant number: 01

Age	Sex	Injury?	Taken for Treatment?	Ejected?	Safety Equipment:	Extriction?	Air bag?	Location:
17	M	Visible	Y	Trapped	Lap and Shoulder Belt	Y	No Air Bag in Vehicle	Driver

Vehicle Number: **02**

Occupant number: 01

Age	Sex	Injury?	Taken for Treatment?	Ejected?	Safety Equipment:	Extriction?	Air bag?	Location:
61	M	Killed	N	Trapped	Unknown	Y	No Air Bag in Vehicle	Driver

Occupant number: 02

Age	Sex	Injury?	Taken for Treatment?	Ejected?	Safety Equipment:	Extriction?	Air bag?	Location:
37	M	Visible	Y	Not Ejected	Unknown	N	No Air Bag in Vehicle	Front Right Passenger

SE Fatal Crash Study
Site Data Collection Form

Site Reviewer	Crash State	Crash Case Number (state specific)
SATISH C MUSUNURU	❑ 01 Alabama ❑ 12 Florida ☑ 13 Georgia ❑ 21 Kentucky ❑ 28 Mississippi ❑ 37 North Carolina ❑ 45 South Carolina ❑ 47 Tennessee	71070077
Date of Site Review VIDEO 3/96 5 / 22 / 00		Source (police report, state DOT, etc.): GDOT
Time of Site Review 7 : 30 AM PM		Sequential Case Number (i.e., GA103) GA259

Crash Site Information for Major Roadway

Horizontal Alignment			
General Alignment	Direction of Curve	Estimated Curve Radius	Crash Location
❑ Straight ☑ Curved	❑ Not Applicable ☑ Right ❑ Left	❑ Not Applicable ❑ Sharp Curve (requires driver speed adjustment) ☑ Mild/Gentle Curve	❑ Not Applicable ❑ Inside of Curve ☑ Outside of Curve

Grade			
Direction of Slope	Estimate of the Percent of Slope	Crest Vertical Curve	Sag Vertical Curve
☑ Up ❑ Down ❑ Flat	❑ Not Applicable ❑ Level (1% ±) ☑ Mild Slope (2-6% ±) ❑ Steep Slope (>6% ±)	❑ Not Applicable ☑ Yes ☒ No	❑ Not Applicable ❑ Yes ☑ No

Cross-Section	National Highway System	Functional Classification of Roadway
❑ Typical Rooftop 1-2% ☑ Superelevated ❑ Other: ______	☑ Yes ❑ No ❑ Unknown **NHS Route Number** US 27	☑ Principal Arterial ❑ Minor Arterial ❑ Major Collector ❑ Minor Collector ❑ Local ❑ Unknown

Roadside Barrier		
☑ None ❑ 3-Strand Cable ❑ W-Beam (weak-post)	❑ Thrie-Beam (weak-post) ❑ Box Beam (weak-post) ❑ Blocked-out W-Beam (strong-post) ❑ Blocked-out Thrie-Beam (strong-post) ❑ Modified Thrie-Beam	❑ Self-Restoring Barrier ❑ Steel-Backed Wood Rail ❑ Concrete Safety Shape ❑ Stone Masonry Wall ❑ Other______

1

Lanes	
0	Number of turning lanes in addition to the two main lanes
0	Number of passing lanes in addition to the two main lanes
0	Number of emergency lanes in addition to the two main lanes

Lane Width

12 Feet

- [ ] Not Applicable

Driveways/Intersections

1	Number of driveways within 250 ft each side of crash site
0	Number of inter-sections within 250 ft each side of crash site

Nature of Adjacent Influences

- [ ] Billboards
- [x] Driveways, residential
- [x] Driveways, commercial
- [ ] Driveways, industrial
- [ ] Other, list below

______

Roadside Illumination

- [x] No illumination fixtures
- [ ] Spot illumination
- [ ] Continuous illumination

Roadway Shoulder

Shoulder Type

- [ ] Paved
- [ ] Graded
- [x] Combination Paved and Graded
- [ ] Raised Curb, Transversable
- [ ] Raised Curb Barrier
- [ ] No Shoulder

Paved Shoulder Width

02 Feet

- [ ] Not Applicable

Graded Shoulder Width

04 Feet

- [ ] Not Applicable

Bridge/Railroad

Bridge/Railroad Involvement

- [x] Not Applicable
- [ ] Bridge
- [ ] Railroad
- [ ] Bridge and Railroad

Bridge/Structure Identification Number

______

- [x] Not Applicable

Railroad Crossing Identification Number

______

- [x] Not Applicable

Bikeway

- [x] No Bikeway
- [ ] Bicycle Route (signed only)
- [ ] Bicycle Lane (striped) - right only
- [ ] Bicycle Lane (striped) - both sides
- [ ] Bicycle Lane (striped) - left only
- [ ] Separate Bicycle Path/Trail
- [ ] Unknown

Speed Limit

Speed Limit Type

- [x] Regulatory
- [ ] Warning

Posted Speed Limit

55 mph

Surface Type

- [ ] Concrete
- [x] Blacktop/Asphalt
- [ ] Brick or block
- [ ] Slag, gravel or stone
- [ ] Dirt
- [ ] Unknown
- [ ] Other, list below

______

2

Pavement Markings	**Raised Pavement Reflectors**	**Delineators**
☐ Centerline, skip-dash, yellow ☐ Centerline, solid, yellow ☑ Centerline, solid double, yellow ☐ No passing barrier, right or left, yellow ☐ Lane line, skip-dash, white ☐ Lane line, solid, white ☐ Edge line, left, yellow ☑ Edge line, right, white ☐ Left turn lane lines, combination of solid and skip-dash, yellow ☐ Turn arrow symbols, right, through, left, or combination ☐ Unknown	☑ Yes ☐ No	**Delineator Presence** ☑ None ☐ Delineators, right ☐ Delineators, left ☐ Delineators, both sides ☐ Unknown **Type of Delineator** ☑ Not Applicable ☐ Directional Chevron Signs ☐ Mounted Reflectors

Roadside Parking	**Roadside Hazard Rating**	**Terrain**
☑ No Roadside Parking ☐ Parallel Parking ☐ Head-in Parking ☐ Unknown	3 (1-7) Based on 7 point rural pictorial scale clear zone ≈ 3m, Marginally recoverable	☐ Flat ☑ Rolling ☐ Mountainous

Traffic Control Devices		**Average Daily Traffic**
Highway Traffic Signals ☑ Not Applicable ☐ Traffic control signal (operating green, yellow, red) without pedestrian signal ☐ Traffic control signal (operating green, yellow, red) with pedestrian signal ☐ Traffic control signal (operating green, yellow, red) pedestrian signal not known ☐ Flashing traffic control signal ☐ Flashing beacon ☐ Flashing highway traffic signal, type unknown, or other ☐ Lane use control signal ☐ Unknown highway traffic signal ☐ Other highway traffic signal, list below	**Regulatory Signs** ☑ Not Applicable ☐ Stop Sign ☐ Yield Sign ☐ Unknown type (regulatory) ☐ Other regulatory sign, list below **School Zone Signs** ☑ Not Applicable ☐ School speed limit sign ☐ School advance or crossing sign ☐ Unknown type (school zone) ☐ Other school related sign, list below Warning Sign – Indicate Type ☑ Not Applicable	**ADT or AADT** ☑ Average Daily Traffic (ADT) ☐ Annual Average Daily Traffic (AADT) **Daily Traffic Count** 3500 **Length of Count** ☐ Hours ☐ Days ☐ Months ☐ Years **Date Collection Began** (mm/dd/yyyy) / / **Counts obtained from:** ☑ Actual Roadway ☐ Similar Roadway

3

QV

DEPARTMENT OF TRANSPORTATION
STATE OF GEORGIA

INTERDEPARTMENTAL CORRESPONDENCE

OFFICE *Thomaston Traffic Operations*
DATE *June 18, 1997*

FROM *Joe B. Street, District Engineer*

TO *Marion G. Waters, III, P.E., State Traffic Operations Engineer*

SUBJECT *SAFETY ENHANCEMENT REVIEW*

ACCIDENT INVESTIGATION

Attached for your further handling is a Safety Enhancement Review Report for the below listed accident:

County: *Heard*

State Route: *1*

Milepost: *~~18/11~~* 18.10

Date of Accident: *5-4-97*

Date of Study: *5-7-97*

Names of Injured Parties:
(note show (F) fatality or (I) if non Fatality)

Available for Review: 35mm film and accident #3 on video #64

**Area Engineers copy available at the Thomaston D.O.T. District Office.*

KBR:KWW:mlw
attachment

SAFETY ENHANCEMENT REVIEW REPORT

COUNTY: HEARD

	ROAD	MILELOG	SPEED LIMIT	ADT
PRIMARY ROAD (P):	SR 1	18/11 18.10 18.0	55	3305
INTERSECTING ROAD (I):	—	7.15		

OTHER LOCATION INFORMATION:

DIVIDER TYPE
P I
1 1 CONCRETE BARRIER
2 2 GUARDRAIL/FENCE
3 3 RAISED ISLAND (CONCRETE OR GRASS)
4 4 GRADED WITH SWALE OR DITCH
5 5 GRASS/EARTH
6 6 PAINTED OR MARKED
7 7 DOES NOT APPLY

AUXILIARY LANES
P
1 LEFT TURN
2 RIGHT TURN
3 TWLTL
4 PASSING

PAVEMENT MARKINGS (CHECK ALL APPLICABLE)
P I
0 0 NONE
1 1 BROKEN YELLOW LINE
2 2 BROKEN YELLOW LINE & SOLID YELLOW LINE
3 3 DOUBLE SOLID YELLOW LINES
4 4 BROKEN WHITE LINE
5 5 SOLID YELLOW LINE
6 6 SOLID WHITE LINE
7 7 EDGE LINES
8 8 RAISED PAVEMENT MARKERS
9 9 PRE-LINE (TEMPORARY LINES)

TRAFFIC CONTROLS
P I
0 0 NO CONTROLS
1 1 TRAFFIC SIGNAL
2 2 FLASHING RED SIGNAL
3 3 FLASHING YELLOW SIGNAL
4 4 STOP SIGN
5 5 YIELD SIGN
6 6 RR FLASHING LIGHTS SIGNALS & GATES
7 7 RR CROSSBUCK WITH ADVANCE WARNING SIGN
8 8 RR CROSSBUCK WITHOUT ADVANCE WARNING SIGNS
9 9 SCHOOL ZONE SIGN
10 10 NO PASSING ZONE
11 11 OTHER TRAFFIC CONTROL

ACCESS CONTROL
P
1 INTERSTATE
2 OTHER LIMITED ACCESS
3 CONTROLLED ACCESS
4 UNCONTROLLED
5 MEDIAN CROSSOVER

ADJACENT LAND DEVELOPMENT
1 RESIDENTIAL
2 COMMERCIAL
3 INDUSTRIAL
4 WOODS/FIELDS
5 SCHOOL
6 OTHER

GEOMETRICS OF ROADWAY/SHOULDERS (PRIMARY ROAD):

ROADWAY
CURVATURE 2°±
GRADE +3.5% (S.S.)
SUPERELEVATION 4.3%
DIVIDED YES NO
MEDIAN WIDTH —
TOTAL NO. THRU LANES (BOTH DIR.) 2
LANE WIDTH 12'±
CURB PROVIDED YES NO

SHOULDERS
MATERIAL:
1 - GRASS
2 - CONCRETE
3 - BITUMINOUS
4 - GRAVEL
5 - SURFACE TREATMENT
6 - OTHER

HEIGHT: Flush
WIDTH: ① ③
OUTSIDE 4.5' 2'±
INSIDE —
(IF DIVIDED)

ACCIDENT EXPERIENCE
(LATEST COMPLETE YEAR)
FROM 1-1-95 TO 12-31-95

(INTERSECTION OR 0.10 MILE EACH SIDE OF MILELOG)
ACCIDENTS 0 INJURIES 0 FATALITIES 0

DATE OF LATEST FATAL ACCIDENT (within past 2 years): 5/4/97

NAME Kevin W. Wood DATE OF REVIEW 5/7/97

SPECIFIC INVOLVEMENT

SPEEDING	YES	NO	SUS	UNK	
DUI	YES	NO	SUS	UNK	
PED. UI	YES	NO	SUS	UNK	N/A
SCHOOL BUS	YES	NO	___	___	
RAMP	YES	NO	___	___	
BRIDGE	YES	NO	___	___	

CONSTRUCTION/MAINTENANCE

	CONST.	MAINT.
NOT ZONED	0	0
ZONED-ACTIVITY		
IN PROGRESS	1	5
IDLE	2	6
NOT STARTED	3	7
STATUS UNKNOWN	4	8

IF IN CONSTRUCTION ZONE, GIVE PROJECT NO.________________________

RR GRADE CROSSING ID NO.________________________

IS LOCATION DESCRIPTION ON POLICE REPORT CORRECT? YES____ NO ✓

IF "NO", COMPLETE AND ATTACH CORRECTED DESCRIPTION BLOCK FORM.

NOTES:

Accident Number 24-560-97 | Agency NCIC No. GAGSP2400 | GEORGIA UNIFORM MOTOR VEHICLE ACCIDENT REPORT | County HEARD | Date Rec. By DPS

Date 050497 | Day Of Week: [X] Sun M T W Th F S | Time 1825 | Off. Arrived 1855 | Total Number Of: Vehicles 2 Injuries 2 Fatalities 1 | Inside City Of:

Road of Occurrence GA. 1 — 1 ☐ Interstate 2 [X] Lowest St. Rt. 3 ☐ Co. Road 4 ☐ City St. | At Its Intersection With — 1 ☐ Interstate 2 ☐ Lowest St. Rt. 3 ☐ Co. Road 4 ☐ City St. | Corrected Report Yes ☐

Not At Its Intersection But 774 ☐ Miles [X] Feet 1 ☐ North 2 [X] South 3 ☐ East 4 ☐ West Of: West Ferry Rd. — 1 ☐ Interstate 2 ☐ Lowest St. Rt. 3 [X] Co. Road 4 ☐ City St. 5 ☐ Co. Line | Suppl. To Original Yes ☐

And Continuing in the Direction Checked Above The Next Reference Point is Glenloch Rd. — 1 ☐ Interstate 2 ☐ Lowest St. Rt. 3 [X] Co. Road 4 ☐ City St. 5 ☐ Co. Line

Driver # 1	Driver # 2
Last Name / First / Middle; Ped ☐	Last Name / First / Middle; Ped ☐
City Lagrar	City Car
Driver's License No. Class C State Ga [X] Male ☐ Female	Driver's Lic. Class C State Ga [X] Male ☐ Female
Posted Speed 55 Insurance Co. Policy No.	Posted Speed Insurance Co. Policy No.
Trailer Tag # State County Year	
[X] Same as Driver Owner's Last Name First Middle	[X] Same as Driver Owner's Last Name First Middle
Address	Address
City State Zip	City State Zip
Removed By Holcomb's ☐ Request [X] List	Removed By Meacham's ☐ Request [X] List
Alcohol Test 1 Type 1 Results Pend; Drug Test 1 Type 1 Results Pend	Alcohol Test 2 Type Results No Test; Drug Test 2 Type Results No Test
Driver Condition 2; Direction of Travel 2 SB; Vision Obscured 1; Contributing Factors 7 Wrong Side	Driver Condition 2; Direction of Travel 1 NB; Vision Obscured 1; Contributing Factors 1 None
Vehicle Condition 1; Vehicle Maneuver 5 Straight; Pedestrian Maneuver	Vehicle Condition 1; Vehicle Maneuver 5 Straight; Pedestrian Maneuver
Most Harmful Event 11 Veh; Vehicle Class 1; Vehicle Type 1 Car	Most Harmful Event 2 Fuel; Vehicle Class 1; Vehicle Type 1 Car
Traffic Control No Pass 6; Device Inoperative? ☐ Yes [X] No	Traffic Control No Pass 6; Device Inoperative? ☐ Yes [X] No

Injured Taken To Tanner Medical Center By: Heard Co. EMS

EMS Notified Time 1826 | EMS Arrival Time 1835 | Hospital Arrival Time 1940 | Photos Taken: [X] Yes ☐ No By: County Coroner

Report By: SGT. K.M. Pyron #321 | Department GSP Newnan | Report Date 05/06/97 | Checked By: | Date Checked 5-6-97

Witness(es): Name None Located at scene | Address | City | State | Zip Code | Telephone No.

DPS MICROFILM NUMBER (DO NOT WRITE IN THIS SPACE)

COMMERCIAL VEHICLES ONLY

Carrier Name Vehicle #	Carrier Name Vehicle #
Address	Address
City State Zip	City State Zip
Number of Axles; G.V.W.R.; Fed. Reportable 1 ☐ Yes 2 ☐ No; Cargo Body Type	Number of Axles; G.V.W.R.; Fed. Reportable 1 ☐ Yes 2 ☐ No; Cargo Body Type
Vehicle Config.; I.C.C.M.C. #; U.S. D.O.T. #; Interstate ☐ Intrastate ☐	Vehicle Config.; I.C.C.M.C. #; U.S. D.O.T. #; Interstate ☐ Intrastate ☐
C.D.L.? 1 ☐ Yes 2 ☐ No; C.D.L. Suspended? 1 ☐ Yes 2 ☐ No	C.D.L.? 1 ☐ Yes 2 ☐ No; C.D.L. Suspended? 1 ☐ Yes 2 ☐ No
Vehicle Placarded? 1 ☐ Yes 2 ☐ No; Hazardous Materials? 1 ☐ Yes 2 ☐ No; Released? 1 ☐ Yes 2 ☐ No	Vehicle Placarded? 1 ☐ Yes 2 ☐ No; Hazardous Materials? 1 ☐ Yes 2 ☐ No; Released? 1 ☐ Yes 2 ☐ No
If YES, Name or 4 Digit Number from Diamond or Box: 1 Digit Number from Bottom of Diamond:	If YES, Name or 4 Digit Number from Diamond or Box: 1 Digit Number from Bottom of Diamond:
__ Ran Off Road __ Down Hill Runaway __ Cargo Loss Or Shift __ Separation of Units	__ Ran Off Road __ Down Hill Runaway __ Cargo Loss Or Shift __ Separation of Units

DPS-523 (2/94)

MAIL TO: GEORGIA DEPARTMENT OF PUBLIC SAFETY, ACCIDENT REPORTING UNIT, P.O. BOX 1456, ATLANTA, GEORGIA, 30371-2303

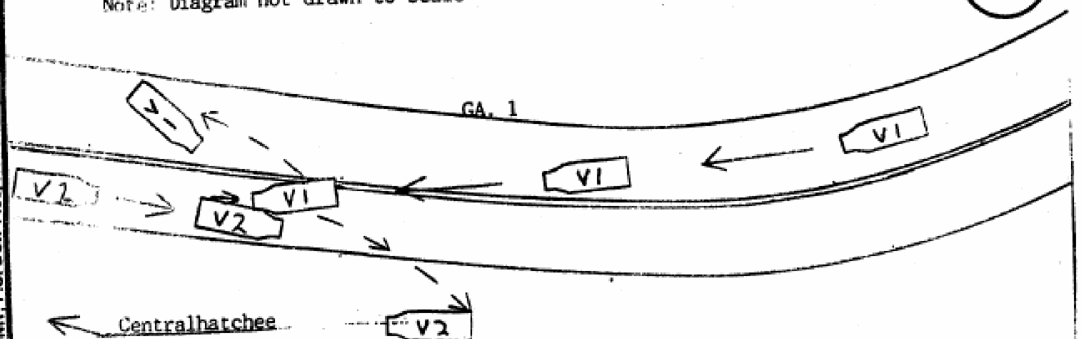
REMARKS

Vehicle 1 was traveling so[illegible] on Ga. 1. Vehicle 2 was trave[illegible]ng north. Vehicle 1 crossed centerline and struck Vehicle 2 head-on. The area of imp[illegible] was 6 feet and 5 inches from the center of Ga. 1 in the northbound lane as determined by skidmarks from Vehicle 2 and after impact gouge marks from both vehicles. Vehicle 1 rotated counter-clockwise and came to rest 32 feet from the A.O.I. facing north in the southbound lane. Vehicle 2 rotated clockwise and traveled 35 feet down an embankment. Vehicle 2 then caught on fire and burned. An autopsy is to be performed on driver 2 by the G.B.I. Crime Lab. All measurements made with 100 ft. steel tape and Lidar.

INDICATE ON THIS DIAGRAM WHAT HAPPENED

INDICATE NORTH

Note: Diagram not drawn to scale



Accident Investigation Site?	CITATIONS - VEHICLE # 1	CITATIONS - VEHICLE # 2
☐ Yes ☒ No Site Number:	Pending	None

First Harmful Event	Traffic Way Flow	Weather	Surface Cond.	Light Condition	Manner Of Collision	Location At Area Of Impact	Road Comp.	Road Defects	Road Character
11		1 Clear	Dry 1	Day 1	2	1	2	1	2

	VEH. # 1	VEH. # 2
Number of Occupants	1	2
Point Of Initial Contact	11	11
Damage To Vehicles	4	5

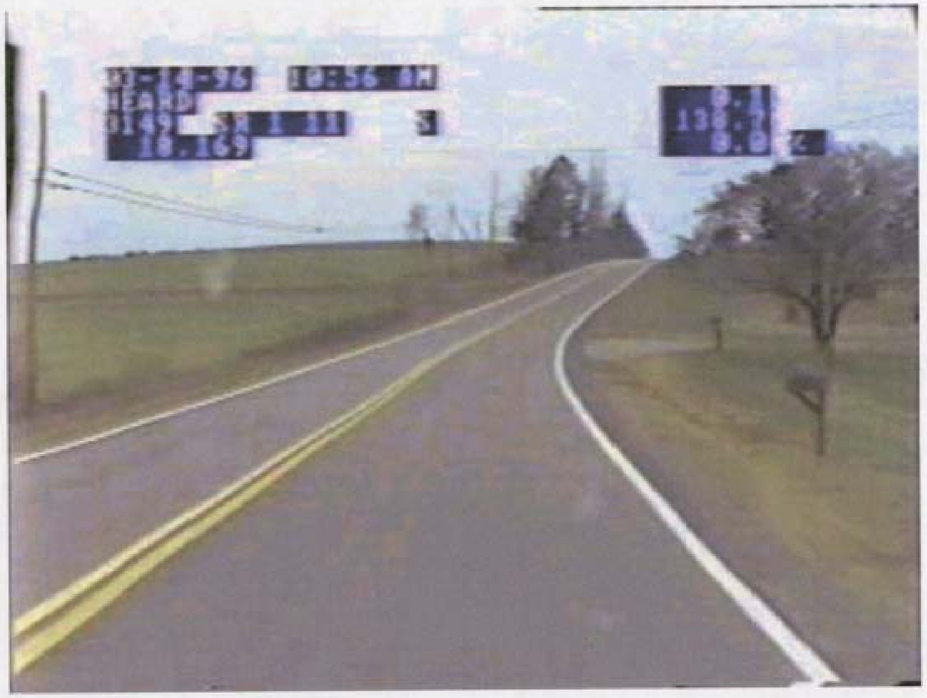
SKID DISTANCE BEFORE IMPACT: 0 VEH. 1; 30 ft. VEH. AFTER: 0 VEH. 1; 0 VEH.

Width Of Road: 25 ft.

Damage Other Than Vehicle: Owner:

Occupants	AGE	SEX	VEH NO.	POS.	INJURY	TAKEN FOR TREAT.	EJECT	SAFETY EQUIP.	EXTRIC.	AIR BAG
Driver # 1 Or Pedestrian #	[redacted]				3	1 N	2	3	1 Y	0
Driver # 2 Or Pedestrian #					1	2 Y	2	8	1 Y	0
Address City State Zip	37	M	2	3	3	1 N	1	8	2 N	0

HEARD COUNTY
GA CASE #71070077



SR 1 Southbound

HEARD COUNTY
GA CASE #71070077

SR 1 Northbound

9.0 APPENDIX B -- DATA DICTIONARY FOR GDOT RCFILE

Table 27. Data Dictionary for R C File

Event Item	Item Definition	Event Type (feature type)	Event Definition	Event Domain Values
RCLINK	10,10,C	N/A	GDOT Route Identification Number. Provides relational link between Route features and the RCFILE. Each route in the system has a unique link value	Alphanumeric GDOT route Identification Numbers are composite of the following codes: Positions 1-3 - County FIPS Code Position 4 - GDOT Route Type 0- Unknown Road 1- State Route 2- County Route 3- City Route 4- Col Route 5- Unofficial Route 6- Ramp/Interchange 7- Private Road 8- Public Road 9- Collector-Distributor Roads Position 5-10 - GDOT Route Number (Unique within a given county inventory collection area. Positions 5-8 code the actual number of the road. Positions 9-10 code the following designations: 10- State Route or County Route, none of the following NO- North, SO- South EA- East, WE- West AL- Alternate BY- Bypass SP- Spur CO- Connector LO- Loop TO- Toll DU- Dual Mileage AD- Alternate Dual BD- Business Dual BC- Bypass Connector CD- Connector Dual SD- Spur Dual NN- City Suffix Number

Table 27. Data Dictionary for R C File (continued)

MILEPOINT	7,7,N,2	Point	Mile measurement along Route field collected and recorded to 1/100th of a mile. Use this item as the measurement item for mapping point events using Dynamic Segmentation	Milepoint
FROM	7,7,N,2	Point	Milepoint along Route demarking the beginning milepoint for linear events, measured as a distance from the Route 0 milepoint	Milepoint
TO	7,7,N,2	Point	Milepoint along Route demarking the ending milepoint for linear events, measured as a distance from the Route 0 milepoint	Milepoint
DESCRIPTION	20,20,C	Point	Milepoint along Route demarking the ending milepoint for linear events, measured as a distance from the Route 0 milepoint	Milepoint
DISTRICT	2,2,C	Linear	GDOT District responsible for the inventory and collection of route characteristics	GDOT district number

Table 27. Data Dictionary for R C File (continued)

DESIG_TRUCK	1,1,C	Linear	Route sections officially designated by the FHWA and GDOT for use by large trucks	1. Single and twin trailers and singles 2. Single Trailers only 3. Twins only 4. Original interstate routes L- Access limits from interstate routes N- Access limits from other than interstate routes T- Other than original interstate (T's are now A's)
SPEED_LIMIT	2,2,1	Linear	Actual standard speed limit in miles per hour	Integer value between 5 and 70
FA_FAS_RT_NUM	5,5,C	Linear	Actual FA/FAS route number with Spur or Loop if any	5 Character Federal Identification Number
ST_RT_SEQ	2,2,1	Linear	Sequence of counties in which a state route traverses	0-99
INV_YEAR	2,2,1	Linear	Last two digits of the year of actual inventory	00-99
ACCESS	1,1,C	Linear	Control of traffic access to a route	U- Free access to the road at grade P- Access at grade are intersecting roads F- Access is gained only at interchanges or rest areas
OPERATION	1,1,1	Linear	Direction of traffic flow along route	0- Can never be used 1- One way (non restricted) 2- Two way (non-restricted) 3- Reversable 4- One-way during school hours 5- One-way (with truck restrictions) 6- Two-way (with truck restrictions) 7- Through trucks restricted
TRAVEL_LANES	2,2,C	Linear	1 character num. Left, 1 character num. right. Representing the number of lanes along the route	Combinations of 1-9 on both character positions representing the actual number of lanes

Table 27. Data Dictionary for R C File (continued)

L_SHOULDER_D	3,3,C	Linear	Describes width and type of shoulder on left of a divided highway	First 2 characters code shoulder width in feet, 3rd character codes shoulder composition as follows: G- Grass or sod S- Gravel or stone F- Bituminous Surface treatment (low) I- Bituminous concrete (high) J- Portland cement (high) C- Curb and gutter (always coded '00C') N- No shoulder or curb D- Gutter only O- Bituminous concrete (high) with curb and gutter P- Bituminous surface treatment (low) with curb and gutter
SURFACE_D	3,3,C	Linear	Describes the width and type of pavement surface of a divided route	First 2 characters code pavement width in feet, 3rd character codes surface type as follows: A- Primitive road B- Unimproved road C- Graded and drained (natural earthen materials) D- Soil-surfaced road E- Gravel or stone road F- Bituminous surfaced treated (road of any type to which a bituminous surface layer which <1" thick) G- Mixed bituminous (<7" combined thickness of surface and base materials, surface alone is >1" thick) I- High flexible (>7" combined thickness J- High rigid (Portland cement concrete pave-ments with or without bituminous surface if < 1") K- Brick L- Block (consisting of stone, asphalt, wood and other block, steel or wood with <1" surface thickness)

Table 27. Data Dictionary for R C File (continued)

R_SHOULDER_D	3,3,C	Linear	Describes width and type of a shoulder on right of a divided highway	See L_SHOULDER_D event domain values
MEDIAN	4,4,C	Linear	Describes width and type of median and barrier	First 2 characters code barrier and median combined width in feet, 3rd character code median type as follows: 0- Undivided road 1- Grass 2- Soil, Stone 3- Park, Business 4- Couplet (2 paralled solid pained lines 4,8 or 10 ft wide center area) 5- Concrete 6- Other 7- Roadway separated by barrier only (use 4' median width) 4th character codes barrier type as follows: 0- No barrier 1- Curb 2- Guardrail 3- Curb and guardrail 4- Fence 5- New Jersey Concrete barrier 6- Cable 7- Other
L_SHOULDER_U	3,3,C	Linear	Describes width and type of shoulder on left side of an undivided highway	See L_SHOULDER_D event domain values
SURFACE_U	3,3,C	Linear	Describes the width and type of pavement surface of the undivided route	See SURFACE_D event domain values

Table 27. Data Dictionary for R C File (continued)

R_SHOULDER_U	3,3,C	Linear	Describes width and type of shoulder on the right side of an undivided highway	See L_SHOULDER_D event domain values
AUX_LANES_L	3,3,C	Linear	Auxiliary lanes of different types located on the left side of the route	First 2 characters code auxiliary lane width, 3rd character codes type of lane as follows: A- Left turn B- Right turn C- Left and right turn D- Left-left lane in center of road E- Passing or climbing lane F- Parking lane (must be striped or posted) G- Angle parking H- Left turn and parking I- Left left lane in center of road and parking J- Left-left lane in center of road and right turn K- Marked of striped median in center of road, undivided roads only L- Left turn and other M- Striped median in center and other N- Right turn and other, must be marked with an arrow O- All additional non-through roadway width not listed P- Parking and other Q- Left-left turn and other R- Left turn, right turn and other T- Transition lane
AUX_LANES_R	3,3,C	Linear	Auxiliary lanes of different types located on the right side of the route	See AUX_LANES_L event domain values

Table 27. Data Dictionary for R C File (continued)

FUNC_CLASS	2,2,1	Linear	Code for functional classification, see Value list	Rural 1. Interstate principal arterial 2. Principal arterial 6. Minor Arterial 7. Major collector 8. NFA Minor Collector 9. Local Urban 11- Interstate Principal arterial 12- Urban freeway and expressway 14- Urban principal arterial 16- Minor arterial street 17- Collector street 19- Local
R_W	4,4,C	Linear	Right of way in feet	First 3 character code the right of way in feet, 4th character codes as follows: A. Actual width E. Estimated width
SIDEWALKS	2,2,C	Linear	1 character alpha left, 1 character alpha right, Indicates existence of sidewalk on left or right side of route	S- Exists
SIGNALS	1,1,C	Point	Code defining the type of traffic signal along route	S- Traffic control device (red, amber, green) P. Traffic control w/ pedestrian signalization A-Stop sign F-Flasher, other than overhead beacon L-Traffic control device with left turn arrow B-Beacon, overhead flashing number R-Beacon, overhead flashing red C-Stop, all directions Y- Yield sign W-Yield sign, opposite direction of inventory O-Stop sign, opposite direction of inventory

Table 27. Data Dictionary for R C File (continued)

INTERSECTION	20,20,C	Point	Intersecting junction of two or more routes See JUNCTION feature	The following codes where nnnnnnn is the route number and the (L, R) is the side of the route SRX - State route cross-road CRX- County route cross-road CSX- City route cross-road SRT- State route T intersection CRT- County route T intersection CST- City route T intersection SRY- State route Y intersection CRY- County route Y intersection CSY- City route Y intersection COM- route becomes common to the specified route EXC- Route exists the county and re-enters RPT- Ramp T intersection RPX- Ramp Cross road RPY- Ramp Y intersection CDT- Collector distributor T intersection CDX- Collector distributor cross road CDY- Collector distributor Y intersection
STRUCTURES	19,19,C	Point	See BRIDGE feature	
CUL_DE_SAC	1,1,1	Point	See CUL_DE_SAC feature	
UNDERPASS	19,19,C	Point	See UNDERPASS feature	
REST_SITES	19,19,C	Point	See REST SITES feature	

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10.0 APPENDIX C -- META-ANALYSIS PROCESS

Highway safety is an important aspect of highway planning and design with highway safety research extending over many decades. Motor vehicle crashes on rural highways involve multiple factors that include the driver, motor vehicle, and the environment. The environmental factors include not only the weather and time of day but also the condition of the roadway and roadside. Researchers have attempted, with some success, to identify the most pertinent factors related to the roadway and roadside environment with the intent to better design these factors and reduce the number of fatalities, injuries, and property damage claims resulting from motor vehicle crash occurrences. These roadway factors include highway geometric design, pavement markings, traffic signs, and roadside features with the roadway factors proving the most flexible to control in relation to highway safety. This research has produced many results, some conflicting, regarding the best approach to the problem of rural highway crashes.

INTRODUCTION

This current research attempts to complement the prevailing body of work with insight that will guide future design policy regarding rural highways. This appendix presents the method used to critically examine the body of available relevant literature and glean integral study results for statistical analysis towards integrating the results. This method is known as meta-analysis and is commonly termed the analysis of analyses.

Meta-analysis is a departure from traditional causal narrative literature reviews as it permits quantitative review and synthesis of research literature. In research, the task of integrating numerous study findings can be complex and the traditional procedures of integrating conflicting results across large numbers of studies are sometimes inadequate. This underscored the need for methods to integrate existing study results, from which patterns of invariable relationships can be identified. Meta-analysis applies statistical procedures to accumulated individual study empirical findings with the express purpose of integrating, synthesizing, and gleaning useful information from them. Meta-analysis brings a technical and statistical approach to traditional causal narrative literature reviews with the findings of voluminous research treated as a complex data set requiring statistical analysis. Each individual study is considered a single data point in any analysis as opposed to traditional research studies that consider individual subjects for analysis.

The purpose of meta-analysis is to elucidate the vast amount of already documented study results and the meta-analysis process can both support the existing body of knowledge and provide directions towards lacking needed research. Research questions are seldom answered by single studies or designed experiments in transportation engineering, however, progress can be made from the accumulation and refinement of large bodies of work by discovering underlying trends and principles. Though literature reviews of empirical research are integral to summarizing and clarifying the state of engineering at any instance in time, traditional narrative literature reviews are found lacking from their dependence on subjective judgment, reviewer's biases, and disparate definitions, variables, procedures, and samples of the original researchers. Also, study conclusions are often contradictory or inconclusive, and study results are often misinterpreted. Safety research reports are gathered and each report is examined and evaluated by individuals who note pertinent information regarding its characteristics and quantitative results. An analysis of the resulting data is then conducted using statistical techniques to describe the findings in the selected studies.

There are many methods, other than meta-analysis, to aggregate and investigate selected research reports, but this process plays an important role. Meta-analysis is only applicable on empirical research studies, only applies to research that produced quantitative findings, hence disqualifying qualitative forms of research, and is a technique for encoding and analyzing research reports' summary statistics results. In the event that the complete original data sets for the study are available, it is recommended that more appropriate conventional methods be used for analysis rather than the meta-analysis process. In addition, because aggregation and comparison of various research study results are the basis of a meta-analysis, these results must be able to be compared effectively. Hence, the findings must address similar relationships and be statistically similar. Each safety study's findings are represented in the form of safety effect sizes in a meta-analysis process. The critical qualitative information from each pertinent safety study finding is encoded in the safety effect size statistic. Safety effect size statistics generally vary depending on the type of study findings.

The body of research included in a meta-analysis must reflect comparable research designs and it is imperative that the meta-analyst develops a rationale for either the inclusion or exclusion of safety studies from the process. A significant problem remains regarding integrating results into a database for meaningful analysis given a set of quantitative research results. These safety studies, for example, rarely use the same measurement procedures for applicable variables. This problem is addressed through the concept of standardization and involves the various safety effect size statistics used in encoding numerous quantitative study results. The statistical standardization of the safety study results, produced by the safety effect size statistics, results in the numerical values being consistently interpretable across applicable variables and measures. The key to meta-analysis is defining a safety effect size statistic representative of the quantitative results of a body of research in a standardized form that then permits meaningful analysis across the research. Of the many possibilities, the safety effect size statistics that record a relationship's magnitude and direction are more greatly desired. A meta-analyst should seek a safety effect size statistic for any scrutinized research that facilitates adequate standardization.

The meta-analysis process addresses potential problems from traditional causal narrative literature reviews including: (1) selective study inclusion through quality of study reviewer bias; (2) subjective weighting of different studies; (3) misinterpretation of study results; (4) failure to examine studies' characteristics as potential causes for varying or consistent studies results; and (5) the effect of moderator variables on the investigated relationship.

Generally, the meta-analysis process involves the following steps:

1. For each available study identify and determine the desired descriptive statistic, then calculate the average across studies.
2. Calculate the variance of that statistic.
3. Correct the variance for sampling error (sampling error is usually large because the sample size is determined by the number of studies as opposed to the number of subjects in a study).
4. Correct the mean and variance for artifacts other than sampling error.
5. Compare the corrected standard deviation (considered an overestimate of the true standard deviation) to the mean to assess the magnitude of the variation in results across studies.

PROBLEM SPECIFICATION AND STUDY RETRIEVAL

Study Overview

Upon determination of the comprehensive study's goals and objectives, conduct a cursory literature search to identify as many pertinent articles related to the general subject area as possible.

Combining Research Results

For this Georgia study, the research team and GDOT representatives identified several prospective safety countermeasures and conducted a thorough search to locate and retrieve all literature germane to the subject area. This search included books, journals, theses, and unpublished work. Upon completion of this task, all relevant statistics from the retrieved literature were extracted and tabulated. This included data such as sample size, duration of study, regression parameters, t-statistics, etc.

Identify Artifacts and Associated Attenuation Factors

The database developer next determined what, if any, study artifacts could alter the recorded measures and noted these studies for further analysis. To correct for the effect of an artifact, information about the size and nature of the artifact is required. For each available study artifact, an analyst rated the degree of attenuation with a score lying between the limits of 0 and 1.0 in 0.1 increments. A score of 1.0 means there was no error in measurement while a score close to 0 means the score was largely due to error. These scores were appended to the table and the GT team computed the compound artifact attenuation factor by determining the product of each separate factor.

<u>Attenuation factor for safety study duration (year)</u>

During analysis, the GT researchers developed an attenuation factor for safety study duration. The rationale behind these scores is based on the assumption that roadway characteristics and conditions would remain relatively unchanged over shorter periods of time. Safety studies conducted across longer periods of time are susceptible to variation in the roadway characteristics and a lack of adequate documentation of those changes. Hence, shorter safety study duration resulted in a higher attenuation factor scores than longer safety study duration. Safety study duration ranged from a minimum of one year to as much as six years. The attenuation scores ranged from 1.0 through 0.5 respectively.

<u>Attenuation factor for selection bias</u>

The GT researchers also developed a selection bias attenuation factor. The reasoning behind these scores relates to the method by which study states, crash sites, crash duration, crash types, etc. were selected. Higher attenuation factor scores were awarded to safety studies that used random selection as judiciously as possible; whereas, safety studies that presented little or no evidence of randomness received low attenuation scores. The range of attenuation factor scores ranged from a high of 1 down through 0.5.

Attenuation factor for omitted variables

The research team also developed a third attenuation factor representing omitted variables. The rationale behind these scores relates to the kind of crashes (dependent variables) that were modeled and the independent variables included in the model. Say, we were examining the relationship between head-on crashes on two-lane rural roads. We would expect independent variables such as lane width, shoulder width, access points, vertical alignment, horizontal curvature, and other related roadway variables to be considered as possible crash predictors. As such, the more comprehensive the list of included independent variables, the higher will be the attenuation factor score. This applies to all modeled crash types, i.e. single-vehicle run-off road crashes, truck crashes, curve crashes, etc.

It should be noted that the meta-analysis process cannot correct for any artifact where no information exists. Unfortunately, no safety study contains complete information on all artifacts. Hence, a fully corrected meta-analysis cannot correct for all artifacts.

Determine the appropriate weight for each safety study

Weighting is necessary to account for the differences inherent to each safety study resulting from both sample sizes and artifacts. The authors expected results from larger sample size safety studies to have more influence over the meta-analysis process than results from relatively smaller sample safety studies. Each safety study was weighted according to the product of its sample size and square of its compound artifact attenuation factor.

Measuring safety effect size

In an effort to approximate the safety effect size of a study, each applicable safety study statistic was converted to a similar metric. Next, each study safety effect size was weighted and summed across all studies. Finally, the previous sum is divided by the sum of the weights to produce the average corrected countermeasure safety effect size (mean).

After correction of each applicable safety study statistic for artifacts and weighting assignment, the authors computed three meta-analysis averages using the corrected safety effect: the mean corrected safety effect, the mean variance of the corrected safety effect, and the mean sample error variance for the corrected safety effect. The corrected variance of corrected safety effect is computed as the difference between variance attributed to sampling error and variance attributed to error of measurement. Negative values present in some meta-analysis results conceptually reflect the indirect effect that countermeasure has on crash occurrences, i.e. if we increase lane width or shoulder width we should expect a decrease in the number of crashes or their severities. Negative signed variances are considered as zeros as they are determined by the difference of two other variances.

The following titled columns (see Table 28) describe each component of the meta-analysis process in detail:

1. **Study number:** refers to the individual safety study included in the process.
2. **Author(s):** The author(s) of each safety study.
3. **Sample Size:** The total number of crashes.
4. **Years:** The time period across which the safety study crash data were collected.
5. **Accident Type:** Identifies the specific crash type(s) examined by the safety study.
6. **Analysis Approach:** Identifies the modeling methodology applied to the data.
7. **Safety effect size:** Identifies the safety study model coefficient associated with the applicable countermeasure, including the appropriate sign. This is noted as the uncorrected effect.
8. **Year Factor:** Artifact that affects the recorded measure over time.

9. **Selection Bias:** Artifacts that affect the recorded measure due to prejudice.
10. **Omitted Variables:** Artifacts that affect the recorded measure through omission.
11. **(Compound) Attenuation Factor:** The product of 8, 9, and 10.
12. **Corrected Effect:** The quotient of the safety effect size and the compound attenuation factor. This corrects the observed safety study coefficient for the reduction caused by artifacts.
13. **Study Weight:** A function of the sample size and the attenuation factor.
14. **Ave(rage) Effect:** Product of safety study weight and corrected effect. The sum across the total number of safety studies divided by the sum of the total safety study weights. This represents the mean coefficient corrected for individual known artifacts.
15. **Theta:** Quotient of average effect and sample size.
16. **Var(iance) Effect:** The mean variance of the corrected effect.
17. **Error Variance:** The sampling error variance of the uncorrected effect.
18. **Sample Error Variance:** Quotient of error variance and the square of the (compound) attenuation factor. This is noted as the sampling error variance of the corrected effect.
19. **Weighted Error Variance:** Product of simple error variance and safety study weight. The sum across the total number of safety studies divided by the sum of the total safety study weights. This represents the variance of the corrected mean coefficient.

Common criticism of application of meta-analysis to safety includes: (1) safety studies with disparate measuring techniques, variable definitions, and subjects that cannot be compared and aggregated to any logical conclusions; (2) combining results from "good" designed safety studies with results from "poorly" designed safety studies cannot produce relevant meta-analysis results; (3) meta-analysis results are biased as a result of biased published research (only significant results); and (4) incorporation of multiple results from the same safety study can invalidate meta-analysis results through lack of independence.

Examining and Reducing Bias

Both qualitative and quantitative literature reviews can, in many ways, result in biased analyses or conclusions. A meta-analysis may produce biased conclusions through inclusion of published positive results and the omission of negative results. Also bias can occur by applying equal weights to the results of all safety studies examining the same research questions, though clear qualitative differences exist between them. Similarly, including many tests on a hypothesis from one safety study will induce statistical bias. These issues present difficult problems for the meta-analyst. Though numerous potential strategies exist for addressing these issues, there is still no consensus on a definitive approach. In all likelihood, a literature review rarely uncovers every safety study conducted on a specific hypothesis. Because of the tendency for safety studies resulting in support of the null hypothesis of no significance to be stored away in file drawers, this is commonly called the "file drawer problem." With the tendency for safety studies to be abandoned if it appears that statistically significant results are futile, published research tends to be biased towards positive outcomes. Replications of previous statistically significant safety studies that result in non-significant results are rarely published, which is generally justified by the number of statistically significant safety study results editors receive for publication. Separate analyses for published and unpublished safety studies are often performed by many meta-analysts to determine if any differences in safety effect size are present and can be attributed to the safety study source. It has been proposed that this problem be addressed analytically by determining the number of safety studies supporting the null hypothesis needed to reverse a conclusion of the existence of a significant relationship.

Problem Specification and Safety Study Retrieval

Quantitative research results are presented in various forms to the meta-analyst and can be correlation coefficients, regression coefficients, etc. A coding process using a safety effect size statistic must be used on the results for the meta-analysis problem. In any meta-analysis process the same safety effect size statistic must be utilized in coding all the results for both consistency and comparison purposes. It is therefore incumbent on the meta-analyst to identify and procure all pertinent research results to ensure that a common safety effect size statistic can be used. Meta-analysts have yet to fully develop safety effect size statistics that adequately represent results from multivariate analysis (due to their complexity).

Safety Study Eligibility Criteria

Upon definition of the meta-analysis topic and determination of the appropriate research type, the next research step included identification of safety research reports to include in the meta-analysis. For a study to qualify for inclusion in the meta-analysis, it must next adhere to a detailed list of specification criteria. These include categories such as (a) distinguishing features, (b) key variables, (c) research design/method, (d) time frame, and (e) publication type. The following discusses each of these categories:

(a) Distinguishing Features.
This explored the aspect of a safety study that legitimized its inclusion in the meta-analysis process. In addressing fatal crashes on two-lane rural highways we include motor vehicle crashes of all types, i.e. passenger cars, trucks, sport utility vehicles (SUVs), etc., pedestrian crashes, crashes that occurred at both intersections and on roadway segments, and on tangents and curves. We excluded safety studies from crashes involving the roadway surface, and the weather.

(b) Key Variables.
For inclusion in the analysis, a safety study must include any variable related to the list of crash countermeasures. In addition, a safety study should possess, at a minimum, adequate statistical information for the estimation of a safety effect size statistic or any other necessary information germane to the meta-analysis

process. The quality of research methodology reporting in the safety study literature is severely wanting. It is almost impossible for the meta-analyst to determine what transpired during the course of a safety study as most reports either do not record, or ambiguously report, the methods and procedures employed during the study. As such, the quality of research methodology is very subjective but, through appropriate coding, allows the analyst an opportunity to determine the influence that different methods have on research results.

(c) Research Design/Method.

Most highway safety studies are of the before-after (B-A) type, with and without control groups, followed by a smaller number of cross-sectional studies. Selection bias is prevalent through the selection of facilities with high crash frequencies. Some safety research studies omit important variables necessary for a more comprehensive evaluation of a crash scenario. While some or all of the above conditions compromise the meta-analysis process, none are deemed serious enough to disqualify a safety study from the meta-analysis process. The onus is on the analyst to recognize these sources of error or bias, make a note of the source, and account for them in the meta-analysis process.

(d) Time Frame.

This investigation evaluated all safety studies irrespective of when they were conducted. We were mindful of changes that may occur on a highway facility that would affect traffic flow, and the enactment of legislation that may affect driver safety such as seat belt mandatory use laws, speed limit increases or decreases, air bags, etc. With that in mind, we placed more confidence in results produced from safety studies either with data collected across a shorter time span or investigated over a shorter period of time. These were coded accordingly.

(e) Publication Type

The GT team sought to include all report types in the meta-analysis process (especially unpublished safety studies, as their exclusion will probably introduce an upward safety effect size bias). However, restrictive eligibility criteria would allow the meta-analysis process to include only the best safety studies. This would limit the quality and quantity of eligible studies. This includes published journal articles, books, Doctoral dissertations, technical reports, unpublished manuscripts, conference proceedings, etc. It also proved markedly harder to get research reports from foreign countries.

IDENTIFYING, LOCATING, AND RETRIEVING RESEARCH REPORTS

The eligibility criteria define the meta-analyst's study populations, and the analysis effort included every attempt to identify and retrieve each safety study. The research team developed a record keeping system to detail the progress in identifying potential reports, the search status, and outcome. This record keeping system includes information on each potential report such as authors, title, publication type and duration of safety study. Eligible reports were noted and recorded as active for the meta-analysis process.

Finding References

This process was two pronged: first, the potentially eligible safety studies were located, and second, copies of the studies were obtained to check for eligibility and inclusion in the meta-analysis process. The former task proved more challenging than the latter, as it entailed multiple sources. These sources included review articles, safety study's references, computerized bibliographic databases, journals, conference proceedings, experts in the area of interest, and government agencies as summarized below:

(i) Review articles are great first sources as they provide references on the subject, though not necessarily in-depth study information.

(ii) Study's references are included in retrieved eligible safety studies. They are cited along with other similar safety studies. They serve to identify unknown potential eligible studies.

(iii) Computerized bibliographic databases facilitate reference retrieval through keyword searches. The databases available for searches included, Georgia Tech Library catalogue (GTEC), Engineering Index (ENGI), Transportation Research Information Service (TRIS), National Technical Information Service (NTIS), ERIC, Dissertation Abstract Online, and Dialog.

(iv) Certain journals are more prevalent in their contributions to the potential list, as such. Since identified journals publish the research topic area, they may possibly contain undisclosed articles that do not appear in a general database search. The GT team performed a cursory check of all volumes' table of contents to identify potential articles.

(v) Conference proceedings from professional organizations provided useful information about papers and authors. This permitted direct contact with an author and possible access to research topic related material they may possess.

(vi) Experts may have intimate knowledge on undiscovered studies and material. A request for assistance often produces material or information leading to additional research worthy of consideration.

(vii) Research oriented federal government agencies provided an excellent source for the meta-analyst as they have records on funded research projects including current ongoing research. Also, state and local government agencies provided a valuable resource.

Retrieving Research Reports

Once a study has been identified and deemed possibly eligible for inclusion, the meta-analyst initiates the retrieval process. This involves journal articles, books, Doctoral dissertations, and microfiche in the library, in addition to copies of material from other libraries through the interlibrary loan service. Also, external dissertations are available from Dissertation Abstract International, and government reports from the Government Printing Office. After the studies were retrieved copies of all reports for the meta-analysis process are archived. The analysts exercised due diligence in retrieving all pertinent research reports as omissions could create potential selection bias.

Table 28. Sample Meta-Analysis Table

Study Number	Sample Size	Years	Analysis Approach	Effect Size (ft)	Corrected Effect	Year factor	Selection Bias	Omitted Variables	Attenu-ation Factor	Study Weight	Ave Effect	Theta	Var Effect	Error Var	Sample Error Var	Weighted Error Var
1	234	3	Discriminant	-0.0074	-0.0220	0.80	0.60	0.70	0.336	26.4	-0.582	-0.002	2.52	0.0042	0.0379	1.002
2	6483	5	Non-linear	-0.1294	-0.2996	0.60	0.80	0.90	0.432	1210.0	-362.499	-0.056	1.16	0.0002	0.0008	0.998
3	190	4	Regression	-0.0323	-0.0942	0.70	0.70	0.70	0.343	22.4	-2.105	-0.011	1.25	0.0053	0.0446	1.003
	190	4	Non-linear	-0.0294	-0.0858	0.70	0.70	0.70	0.343	22.4	-5.194	-0.027	0.22	0.0053	0.0449	1.003
	190	4	Regression	-0.0797	-0.2324	0.70	0.70	0.70	0.343	22.4	-3.998	-0.021	0.52	0.0053	0.0449	1.003
	190	4	Non-linear	-0.0613	-0.1788	0.70	0.70	0.70	0.343	22.4	-53.478	-0.281	95.03	0.0053	0.0449	1.003
4	71	5	-ve Binomial	-0.9187	-2.3924	0.60	0.80	0.80	0.384	10.7	-25.047	-0.353	44.51	0.0143	0.0967	1.012
5	2425	5	Non-linear	-0.0223	-0.0515	0.60	0.80	0.90	0.432	452.5	-23.301	-0.010	35.25	0.0004	0.0022	0.998
6	6483	5	Non-linear	-0.1755	-0.4064	0.60	0.80	0.90	0.432	1210.0	-491.670	-0.076	6.95	0.0002	0.0008	0.998
7	8528.5	2	-ve Binomial	0.0478	0.0843	0.90	0.70	0.90	0.567	2741.8	231.082	0.027	471.90	0.0001	0.0004	0.998
8	5584	1	Log-linear	-0.1469	-0.1469	1.00	1.00	1.00	1.000	5584.0	-820.290	-0.147	188.40	0.0002	0.0002	0.998
9	5764	3	Logistic	-1.1640	-3.4643	0.80	0.60	0.70	0.336	650.7	-2254.130	-0.391	6389.70	0.0002	0.0015	0.998
10	1135	3	Poisson	-0.4941	-1.4706	0.80	0.60	0.70	0.336	128.1	-188.437	-0.166	166.53	0.0009	0.0078	0.999
	1608	3	Poisson	-1.3672	-4.0690	0.80	0.60	0.70	0.336	181.5	-738.525	-0.459	2536.62	0.0006	0.0055	0.998
11	420	5	Log-linear	4.0707	10.6009	0.60	0.80	0.80	0.384	61.9	656.528	1.563	7400.62	0.0024	0.0161	1.000
	38925			-0.0340					0.423	12346.8	-0.331	-0.027	1.40		0.3494	0.001
Effect Mean	-0.3306											Var(effect) =	1.403			
Effect Var.	1.4033											s.d. =	1.185			

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11.0 APPENDIX D – CLASSIFICATION AND REGRESSION TREE (CART) PROCESS

Classification and regression trees (CART's) were used with the engineering evaluations to identify roadway and traffic conditions where countermeasures can be effectively applied to increase safety. CART's are non-parametric statistical procedures that can be used to classify a response variable based on one or more predictor variables. In this application of CART, roadway characteristics and traffic conditions are used to classify different levels of countermeasure effectiveness. Advantages of tree based models include: ease of interpretation when predictors include both numeric variables and factors, treatment of missing values, and modeling of factor response variables with more than two levels. Also, tree based models capture interactions without explicit specification. When growing a tree, a binary partitioning algorithm recursively splits each node's data until either the node becomes homogenous or contains too few observations (compared to a pre-specified size limitation). The resulting subsets from this process are called terminal nodes.

The engineering evaluation ratings, from the 150 fatal crashes, were appended with data on traffic volume (ADT), posted speed limit, roadside hazard rating (RHR), and lane width, as these predictor variables, or surrogate variables, were present in both the CART and RCFILE databases and provided the means by which these databases could be matched to produce estimates of the desired fatal crashes and affected roadways This process required the matching of each fatal crash with its respective case number to aid in site characteristic identification. The research team then examined the newly created database to determine the presence of non-informative data records (i.e. empty data records). Next, we factored posted speed limit data into 2 groups; less than 55 miles per hour (< 55 MPH) or 55 MPH and greater (≥ 55 MPH). Also, the analysis team factored RHR data into 2 groups; ratings of 1 through 4 (1-4) considered safe, and ratings of 5 through 7 (5-7) considered less safe. Similarly the procedure divided the data into two groups for lane width: less than 12 feet, and equal to or greater than 12 feet. To assure consistency, the research team rounded the ADT to the nearest 100 vehicles, and verified and, if possible, corrected each incomplete crash record based on archived field data. Finally, the research team imported the newly created database into S-Plus 2000® and converted each column of data to the correct data type for the CART analysis.

The CART procedure identified predictor variables that appeared to be important to a particular countermeasure's effectiveness. Countermeasures 3 (add/upgrade no-passing-zone lines), 13 (add turn lane), 18 (improve access management), and 25 (convert roadside objects to breakaway) proved ineffective for the crashes studied. This means they resulted in predictor variables with thetas equal to one. The remaining countermeasures queries were based on ADT, posted speed limit, RHR and lane width that proved most productive, and the conditions under which they were considered most effective are presented in Table 23. ADT was the identified predictor variable for countermeasures 16 (widen and pave existing paved shoulder), 17 (add rumble strips), 24 (removed fixed object), and 26 (construct traversable drainage structure). Also, ADT, posted speed, RHR, and lane width were the identified predictor variables for only one countermeasure: widen lanes/pavement width (countermeasure 12).

Figure 11 shows the results of the tree-growing procedure for countermeasure 22. The roadways in the root node are first split on RHR 1-4 (Node 2), and RHR 5-7 (Node 3). This process coincides with the maximum reduction in variability of the dependent variable. If the RHR 5-7 condition exists, they are split again for ADT < 4800. Subsequent splits for ADT < 2850, posted speed ≥ 55mph, and ADT < 550 resulted in a predicted theta of 0.67. This tree has 21 terminal nodes. This shows that overall, road sections with roadside hazard ratings between 5 and 7, with posted speed limits of 55 mph and greater, and ADT less than 550 vehicles are important variables in predicting the effectiveness of flattening side slopes on fatal crashes for two-way rural roads. This also shows that overall, road sections with roadside hazard ratings between 5 and 7, and ADT between 4800 and 2850 vehicles (in addition to road sections with roadside hazard ratings between 1 and 4, and ADT between 750 and 550 vehicles) are important variables in predicting the effectiveness of flattening side slopes on fatal crashes for two-way rural roads. When growing a tree the result may be more complex than necessary to describe the data.

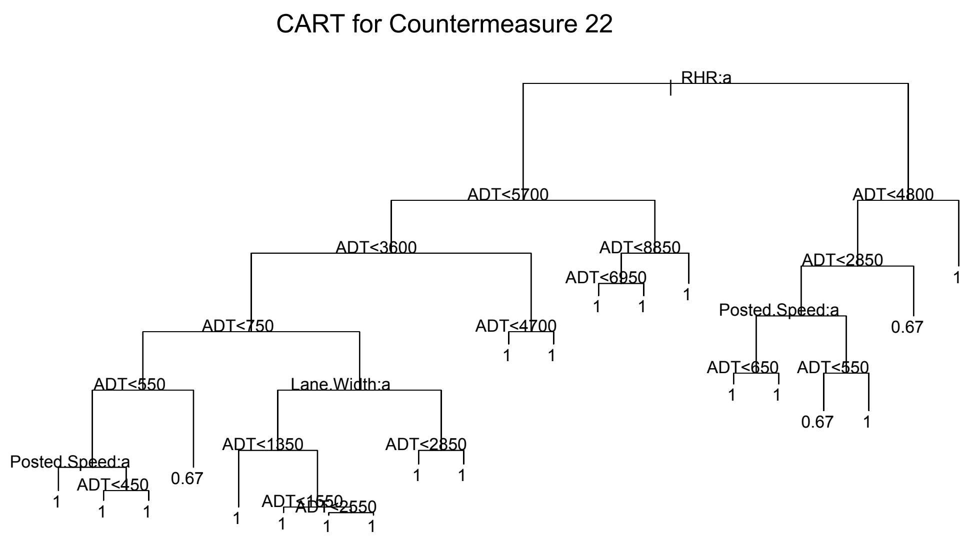

Figure 11: CART for Countermeasure 22

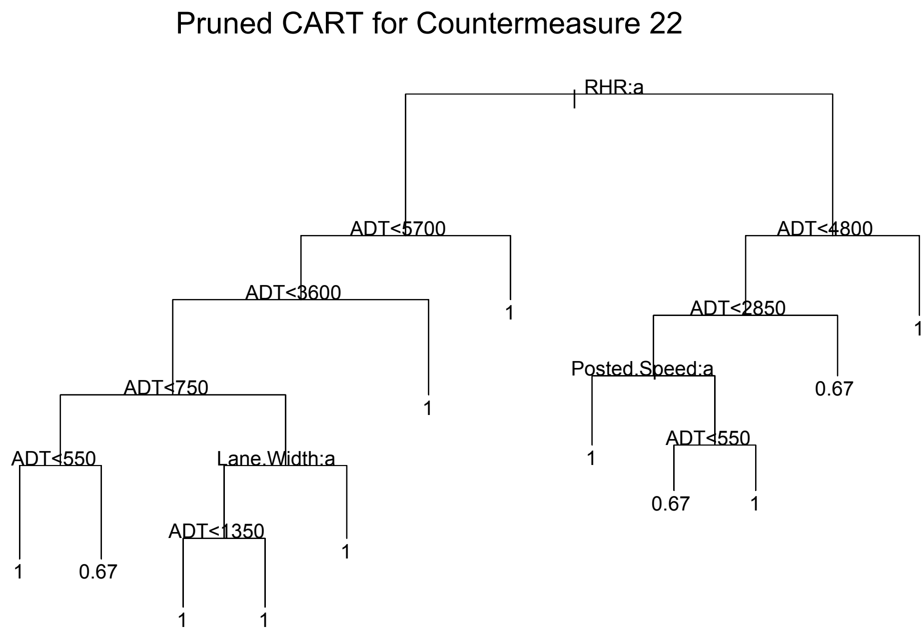

Figure 12: Pruned CART for Countermeasure 22

Pruning is a process that reduces the nodes on a tree by successively removing the least important splits. The resulting pruning process, when applied to countermeasure 22, is displayed in Figure 12. Again, following one terminal node, the split on roadside hazard rating partitions the 146 observations (the result of 4, out of 150, numeric predictor ADT variables with no recorded data values not being considered) into RHR 1-4 (Node 2, 107 observations), and RHR 5-7 (Node 3, 39 observations), with respective deviance's of 149.70 and 87.16. The group at node 3 is then partitioned into groups of 33 and 6 individuals (nodes 6 and 7) dependent on whether ADT < 4800 or ADT ≥ 4800. Again, the group at node 6 is further partitioned into groups of 27 and 6 individuals (nodes 12 and 13) dependent on whether ADT < 2850 or ADT ≥ 2850. The group at node 12 is then partitioned into groups of 12 and 15 individuals (nodes 24 and 25) dependent on whether posted speed < 55 mph or posted speed ≥ 55 mph. Finally, the group at node 25 is divided dependent on whether ADT < 550 or ADT ≥ 550.

There is no further division of subgroups. This results in a predicted theta of 0.67. This tree has 12 terminal nodes.

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12.0 APPENDIX E – COUNTERMEASURE HANDBOOK

Countermeasure Handbook

Prepared for the Georgia 1997 Fatal Crash Study

Prepared by:
Georgia Institute of Technology
School of Civil and Environmental Engineering
Atlanta, GA 30332-0355

For Information Regarding Handbook Contact:
Karen K. Dixon, Ph.D., P.E.
Telephone: (404) 894-5830
Fax: (404) 894-2278
E-Mail: karen.dixon@ce.gatech.edu

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Countermeasure List of Tables

I. INTRODUCTION

Research team members at the Georgia Institute of Technology developed this Countermeasure Handbook as a supplemental guide to be used in the State of Georgia fatal crash study portion of a Federal Highway Administration (FHWA) pooled fund study. The countermeasure list is not all-inclusive, but rather represents feasible engineering-based improvements that can be implemented. As a result, several viable countermeasures such as education and stricter driving laws were not candidates for the handbook.

The Georgia study includes a subjective analysis by which each individual crash is evaluated by qualified traffic engineering experts in an effort to determine feasibility and/or effectiveness of the application of a countermeasure for a specific crash. This countermeasure evaluation departs from a common countermeasure evaluation method where a crash type is paired with feasible countermeasures. By evaluating the individual countermeasures at a microscopic level, the research team hopes to identify realistic countermeasure applications. For example, often a run-off-road crash may end when the errant vehicle impacts a tree adjacent to the roadside. The countermeasure suggested for this type of crash would be to remove the obstacle (in this case the tree) and widen the clear zone. Clearly improving the clear zone is a good candidate countermeasure. If the individual crash is evaluated, however, the reviewer may determine that an impaired driver exited the road after crossing an opposing lane (somehow managing to avoid a head-on collision) and then traversed a considerable distance well beyond a reasonable clear zone before impacting the tree. In this example, it is probable that no countermeasure would have prevented the crash. This is the type of detail the Georgia Tech research team seeks to identify and evaluate supplemented by the use of this Countermeasure Handbook.

II. COUNTERMEASURES

Numerous feasible engineering countermeasures may be considered for reduction of crashes or crash severity. During the early stages of this research project, Georgia Tech representatives met with representatives of the Georgia Department of Transportation (GDOT) to identify reasonable countermeasures for inclusion in this study. Table 1 includes a list of the countermeasures summarized in this handbook. In addition, Appendix A provides supplemental information regarding past research on each specific countermeasure.

Table 1 also includes a column that suggests (based on past research and engineering judgement) suitable conditions for applying the countermeasures. In addition, the subjective analyses proposed for this research includes an effectiveness scale. Two of the evaluation categories are “No Effect” and “Not Applicable.” During a pilot study to assure repeatability of results using numerous reviewers, the distinction between these two categories confused the analysts. As a result, Table 1 includes a third column that discusses conditions where the countermeasure is not applicable.

Table 1. Countermeasure Analysis Summary

Countermeasures (General / Specific)	Suitable Conditions for Applying Countermeasure	Conditions under which Countermeasure is Not Applicable
A. Pavement Marking		
1. Add/Upgrade Edgeline	• Improve nighttime visibility of roadway edgeline • Improve visibility during wet conditions • Run-off-road crash where driver is alert	• Edgeline in place and in good condition
2. Add/Upgrade Centerline	• Improve nighttime or poor visibility conditions • Improve visibility during wet conditions • Crashes where the driver crossed into the opposing lane of travel	• Centerline in place and in good condition
3. Add/Upgrade No-Passing-Zone Lines	• Install where passing maneuvers are not safe under horizontal and/or vertical alignment • Applicable for restricted sight-distance conditions and intersections • Crashes where the driver attempted to pass a vehicle at an inappropriate location	• No-passing-zone pavement marking in good condition
4. Add Raised Pavement Markings (RPM's) to Centerline	• Install where painted centerlines provide inadequate delineation and alert driver crossed centerline	• RPMs already exist and are in good condition

B. Traffic Signs		
1. Warning Sign	• Location where driver advisory sign is needed: Extreme curves, animals, pedestrians, school zone, curve warning, etc. and this perceived hazard contributed to the crash	• Signage already exists, or additional signage is not appropriate for specific location
2. Advisory Speed Sign	• Sharp high speed curves where the driver should reduce speed to safely traverse road geometry • Locations where reduced operating speed is warranted (like at work zones)	• Low speed roads • Tangent sections or mild curve locations • Locations where an advisory speed sign already exists and is in good condition
3. Chevron Alignment Sign	• Sharp horizontal curves (radius < 820') where alert driver may have experienced difficulty in identifying the curve (particularly suitable for night or inclement weather) • Intersections with a change of horizontal alignment	• Tangent sections of road with good visibility • Mild horizontal curve locations with good visibility • Locations where chevron alignment signs already exist and are in good condition
4. Post Delineator	• Horizontal curves (radius > 820') where alert driver may have experienced difficulty in identifying the curve (particularly suitable for night or inclement weather) • Unexpected road features such as land reductions that can benefit from supplemental delineation	• Tangent sections of road with good visibility • Mild horizontal curve locations with good visibility • Locations where post delineators already exist and are in good condition with proper placement

C. Roadway Improvements		
1. Geometric Realignment (Horizontal, Vertical, Intersection)	• Horizontal or vertical alignment is substandard, e.g. sharp curves, crest curves, limited sight distance conditions and this alignment condition contributed to the crash	• Horizontal or vertical alignment is acceptable
2. Modify Superelevation / Cross Slope	• Location where the pavement cross-slope or superelevation is not compatible with the horizontal alignment and this contributed to the crash • Drainage inadequate during inclement weather	• Superelevation or cross slope is compatible with the horizontal alignment
3. Improve Sight Distance without Geometric Realignment	• Limited sight distance at horizontal curves due to static obstructions, e.g. trees, signs, billboards, etc. and these obstructions contributed to the crash	• No sight distance problems • No removable obstructions to improve sight distance problem
4. Widen Travel Lanes / Pavement Width	• Lane widths less that 11-feet where the lane narrow lane width appears to have contributed to the crash	• Lanes that are 11-feet wide or greater
5. Add Turn Lane (Left/Right)	• Locations where crashes are influenced by turning vehicles in the travel lane	• Low volume driveway or intersection locations • Locations where turning lanes were in place and clearly marked at the time of the crash

6. Improve Shoulder		
a. Add or Widen Graded or Stabilized Shoulder	• Locations where crashes are influenced by the lack of a traversable shoulder • Locations where drivers have insufficient shoulder to re-direct vehicle back onto roadway • Locations where unstabilized shoulder eroded adjacent to the road and this contributed to the crash	• Locations with wide graded or stabilized shoulders in place at the time of the crash
b. Pave Existing Graded Shoulder of Suitable Width	• Locations where crashes were influenced by the condition or traversability of the shoulder • Locations where unstabilized shoulder eroded adjacent to the road and this contributed to the crash	• Locations where existing graded shoulder is not a suitable width
c. Widen and Pave Existing Shoulder	• Locations where crashes were influenced by the condition or width of the shoulder	• Locations where existing shoulder is of suitable width and paved
7. Rumble Strips	• Locations with paved shoulders greater than 2' wide where crashes may have been avoided if rumble strips could alert the inattentive driver	• Locations where paved shoulders greater than 2' wide are not present • Locations where the crash occurred in a residential neighborhood • Locations where rumble strips were already present and in good condition
8. Improve Roadway Access Management	• Locations where crashes are directly influenced by poorly positioned driveways or intersections	• Locations with suitable access management • Locations without suitable access management and no feasible way to correct the problem

D. Roadside Improvements		
1. Install or Upgrade Guardrail	• Locations where an errant run-off-the-road vehicle will encounter an unsafe roadside environment within the clear zone • Locations where the side slope is not traversable, i.e. too steep, rocks, trees	• Locations where guardrails may create additional hazards, i.e. guardrail endpoints when accommodating numerous driveways, sight distance restrictions, intersections • Locations with guardrail in suitable condition that is adequately placed
2. Upgrade Guardrail End Treatment / Add Impact Attenuator	• Locations where errant vehicles either directly impacted the guardrail end treatment or were otherwise influenced by its placement and this contributed to the crash	• Locations where guardrail did not exist at the time of the crash
3. Clear Zone Improvements		
a. Widen Clear Zone	• Run-off-the-road crashes where vehicles have hit rigid and removable objects located in the reasonable clear zone	• Locations where objects in the clear zone are not removable • Locations with acceptable clear zone widths per standards in *Roadside Design Guide*
b. Flatten Side Slope	• Locations with side slope that is steeper than a horizontal:vertical ratio of 3:1 • Locations where an errant vehicle cannot regain control of the vehicle due to side slope design	• Locations where guardrails provide a superior solution • Locations where the side slope is already flatter than a 3:1 and traversable

c. Relocate Fixed Object	• Locations where fixed objects, such as utility poles, light standards, signs, mailboxes, and parked cars present a hazard to vehicles • Locations where objects can be relocated	• Locations where relocation of fixed object may create other hazards or re-locate the hazard
d. Remove Fixed Object	• Locations where fixed objects, such as utility poles, light standards, signs, mailboxes, and parked cars present a hazard to vehicles • Locations where objects can be removed	• Locations where removal of a fixed object may create other hazards, e.g. removing a light standard, warning sign, etc.
e. Convert Object to Breakaway	• Locations where fixed objects present a hazard to vehicles and are candidates for conversion to breakaway	• Locations where breakaway objects should not be realistically applied (for example, do not place breakaway poles at intersections corners)
f. Traversable Drainage Structure	• Locations with drainage culverts where pipe end treatments are not traversable	• Locations where guardrails provide a superior treatment due to side slope and drainage considerations and are a feasible countermeasure candidate • Locations with already suitably traversable drainage structures • Locations where non-traversable drainage structures are located outside the reasonable clear zone

E. Lighting		
1. Add Lighting (Segment)	• Locations with poor night visibility and road environment features that need supplemental illumination, such as access points, pedestrian crossings, or extreme roadway geometry and where driver was alert	• Locations with poor night visibility only but no substandard road environment features that contributed to the crash
2. Add Lighting (Intersection)	• Intersections with poor night visibility and no existing lighting and where driver was alert	• Intersections with adequate night visibility
3. Upgrade Lighting (Segment/Intersection)	• Locations with poor night visibility and insufficient existing lighting and where driver was alert	• Locations with adequate night visibility
F. Regulations		
1. Enforce Speed Limits	• Locations where the study crash was related to excessive speed above the posted speed limit	• Locations where excessive speed (above speed limit) does not appear to be a characteristic of the site

COUNTERMEASURE DEFINITIONS

AND CRASH APPLICATION

A. PAVEMENT MARKING

1. Add or Upgrade Edge line Pavement Marking

Overview

Edge lines are often added at the edge of outside travel lanes to help delineate the edge of road during poor visibility conditions (particularly nighttime and inclement weather conditions). Edge lines should be placed on freeways, expressway, and rural arterials with traveled way widths of 20-feet or moor and an ADT of 6,000 vpd or greater. Edge line markings shall not be continued through intersections, however edge line extensions may be placed through the intersections. Edge line markings should not be broken for driveways. Edge line marking may be used where edge delineation is desirable to minimize unnecessary driving on paved shoulders or on refuge areas that have lesser structural pavement strength than the adjacent roadway (MUTCD, 2000).

Crash Application

The addition of edgelines is an applicable countermeasure for crashes where vehicles ran-off-the-road during the course of the crash. For the countermeasure to be effective, the driver of the vehicle would need to be alert enough to be influenced by the pavement marking. If edgelines already exist, this countermeasure is only applicable if they are difficult to see (such as paint that is barely visible).

2. Add or Upgrade Centerline Pavement Marking

Overview

Centerline pavement markings are typical for most roads that are paved; however, if a road is excessively narrow and standard lane widths can not be achieved (road width less than 16 to 18-feet), the centerline marking may be omitted. This condition most often occurs on low-volume local roads. The centerline marking helps delineate the separation of opposing directions of travel and is particularly helpful during poor visibility conditions (particularly nighttime and inclement weather conditions) and at locations with horizontal curves.

Crash Application

The addition of centerline pavement marking is a suitable countermeasure for crashes where vehicles cross over the center of the road into the opposing direction of travel (often at horizontal curves). For the countermeasure to be effective, the driver of the vehicle would need to be alert enough to be influenced by the pavement marking. If centerlines already exist, this countermeasure is only applicable if they are difficult to see (like paint that is barely visible). If a centerline pavement marking is added to a narrow road (narrower than 16-feet), the centerline may inadvertently direct potential traffic onto the pavement edges creating a negative influence (MUTCD, 2000).

3. Add or Upgrade No-Passing-Zone Pavement Marking Lines

Overview

No-Passing-Zone designations are typical for inadequate sight distance locations. As a result, crest vertical curves and any horizontal curve other than extremely "flat" curves are candidates for no-passing-zones. In addition, no-passing zones should be maintained at intersection locations -- particularly isolated intersections where access into or out of the cross street is not expected. In the event traffic volume is heavy and warrants a level of service of C or greater, the addition of passing lanes is a common improvement strategy.

Crash Application

The addition of no-passing-zone lines is an applicable countermeasure for crashes where vehicles crossed over the center of the road in an effort to pass a vehicle at an inappropriate location (due to sight distance or access constraints). In the event a no-passing-zone was properly in place and the driver elected to ignore the marking, this countermeasure cannot be evaluated.

4. Add Raised Pavement Marking (RPMs) to Centerline

Overview

Raised pavement markers are often used on roads where typical pavement marking needs supplemental delineation; however, if snow frequently occurs in the analysis region a costly "snow plowable" RPM should be used.

Crash Application

The addition of RPMs is an applicable countermeasure for crashes where the pavement marking alone provides inadequate delineation or channelization (MTES, 1994). Placement of RPMs in the vicinity of pedestrian activity should not present tripping hazards. For the countermeasure to be effective, the driver of the vehicle would need to be alert enough to be influenced by the supplemental delineation. If RPMs already exist and are in good condition, this countermeasure cannot be evaluated.

B. TRAFFIC SIGNS

1. Warning Sign

Overview

Supplemental warning signs are often used to alert motorists to unexpected features that may pose a hazard and may not be readily apparent to road users. Common applications warn of railroad or pedestrian crossings, sharp horizontal curves, intersection information, etc. The use of warning signs should be kept to a minimum as the unnecessary use of warning signs tends to breed disrespect for all signs (MUTCD, 2000). In this countermeasure manual, chevron signs, advisory signs, and post delineators are included as separate countermeasures and should, therefore, not be included in evaluation of the warning sign countermeasure.

Crash Application

The addition of warning signs is an applicable countermeasure for crashes where the alert driver encountered an unexpected road feature. For example, the likelihood of a nighttime crash at a sharp horizontal curve may be reduced if an advanced “sharp curve ahead” warning sign is placed upstream of the curve. For the countermeasure to be effective, the driver of the vehicle would need to be alert enough to be influenced by the supplemental signage. If appropriate warning signs are already present and in good condition, this countermeasure cannot be evaluated.

2. Advisory Speed Sign

Overview

Advisory speed limits are often used to aid drivers in selecting slower safe speeds for hazardous locations such as curves, road work sites, intersections, and road sections with lower design speeds (FHWA, 1982). A sample advisory speed sign is depicted below.

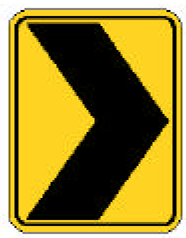
Crash Application

The use of advisory speed signs is an application for crashes where the alert driver appeared to exceed a safe operating speed at a "hazardous" location where reduced operating speed is warranted. Inherent with the concept of effective advisory speed signs is the assumption a driver adheres to, at a minimum, the regulatory speed limit and pays attention to supplemental signs. For the countermeasure to be effective, the driver of the vehicle would need to be alert enough to observe the advisory speed sign, if present, and consider adjusting his or her relative operating speed. If advisory speed signs already exist at the crash location, this countermeasure cannot be evaluated.

3. Chevron Alignment Sign

Overview

Chevron alignment signs are used to provide emphasis and guidance for a change in horizontal alignment. The chevron alignment sign can be used as an alternate or supplement to standard delineators on curves. The sign is installed on the outside of a turn or curve, in line with and approximately at a right angle to approaching traffic (in such a manner that the road user always has at least two chevron alignment signs in view at a time). A chevron alignment sign may alternatively be used on the far side of an intersection to inform drivers of a change of horizontal alignment through the intersection (MUTCD, 2000). A sample chevron alignment sign is depicted below.



Crash Application

The use of chevron alignment signs is an application for crashes where the alert driver failed to successfully negotiate a sharp horizontal curve (radius < 820') or failed to successfully traverse an intersection with a change in horizontal alignment. For the countermeasure to be effective, the driver of the vehicle would need to be alert enough to observe the chevron alignment signs and consider adjusting his or her driving behavior in response to the sign. If chevron alignment signs already exist at the crash location, this countermeasure cannot be evaluated.

4. Post Delineator

Overview

Post Delineators are used to provide emphasis and guidance at a location where the road alignment may be confusing or unexpected, such as at lane reduction transitions and horizontal curves. The post delineator is considered a guidance sign rather than warning sign. A typical delineator includes retroreflective devices mounted on posts above the roadway surface. They are placed along the side of the road to guide the driver through the road alignment feature. For horizontal curves, the post delineator is located in a series (based on degree of curvature) along the outside of the curve (MUTCD, 2000).

Crash Application

The use of post delineators is an application for crashes where the alert driver failed to successfully negotiate a horizontal curve (radius > 820' preferred application) or failed to successfully traverse an unexpected feature like lane reductions. For the countermeasure to be effective, the driver of the vehicle would need to be alert enough to observe the post delineators and consider adjusting his or her driving behavior in response to the delineators. If post delineators already exist at the crash location, this countermeasure cannot be evaluated.

C. ROADWAY IMPROVEMENTS

1. Modify Geometric Alignment

Overview

Often the horizontal or vertical road alignment can be substandard and directly contribute to safety problems. The most common problems are sharp horizontal curves where drivers must reduce speed to successfully negotiate the curves. Similarly, substandard crest curves often create sight distance hazards. Common geometric alignment improvements may include flattening the horizontal curve, "shaving" of the crest vertical curve, or performing a combination of horizontal and vertical improvements.

Crash Application

Modification of geometric alignment should be considered for a crash where it is apparent that the road contributed to the crash. For example, if a driver was not successful in negotiating a horizontal curve, this countermeasure should be evaluated to determine if any realistic improvements are feasible. If road alignment is adequate, this countermeasure is not applicable and should not be evaluated.

2. Modify Superelevation / Cross Slope

Overview

When a road has horizontal curvature and is not a low-speed road (such as a local road or minor collector), the pavement cross-section should be superelevated through the curve to assist vehicle motion (counteract forces that would direct the vehicle in a straight path). Similarly, in tangent sections the typical pavement cross section for a two-lane road is a "rooftop" scenario with 2-percent grade from the high point at the road centerline to the edge of the lane. Often these standards are not addressed and contribute to crashes (particularly during inclement weather conditions).

Crash Application

Modification of superelevation or cross slope should be considered for a crash where the pavement cross slope or superelevation is not compatible with the horizontal alignment and this incompatibility may have contributed to the crash.

3. Improve Sight Distance without Geometric Realignment

Overview

Often road features other than the physical road impact required sight distance. For example, a road with horizontal curvature may have a wooded region five feet from the edge of pavement. Other than the obvious roadside obstacle problem, the trees may prevent sight distance as a vehicle traverses around the curve. The driver looks along the "chord" of a horizontal curve rather than along the curve centerline, and the trees would directly impact this view. Similar problems can be addressed by improving the sight distance without costly reconstruction of the road.

Crash Application
Improvement of sight distance should be considered for crashes where it appears a driver did not have proper lines of sight. These can be both daytime and nighttime crashes; however, temporary obstacles such as a stalled car blocking sight distance do not apply to this countermeasure.

4. Widen Lanes or Pavement Width

Overview
A condition often affiliated with rural two-lane highways is substandard lane width. In the United States, the "desirable" lane width is assumed to be 12-feet; however, lane widths of 11-feet are generally considered acceptable.

Crash Application
Widening the lanes or total pavement width should be considered for crashes where it appears a driver was in some way influenced by the width. For example, if the vehicle's right tire exited the road this may be an indicator that the narrow lane contributed to the crash. It is important to note that the example of the tire exiting the right edge of the road could also be an indicator of driver inattentiveness.

5. Add Turn Lane

Overview
At high-speed rural locations, a vehicle waiting to complete a turning maneuver poses an unexpected obstacle to the fast moving vehicles. This problem occurs both at intersections as well as locations with driveway access to the subject road. One means of removing the turning vehicle from the traffic stream is to provide a dedicated turn lane so the stopped vehicle is no longer blocking the through traffic. Turn lanes are not generally recommended for isolated, low-volume driveway locations.

Crash Application
Adding a turn lane should be considered for crashes where it appears a driver encountered a turning vehicle in the through lane unexpectedly and this contributed to the crash. If a turn lane was already present, this countermeasure cannot be evaluated.

6. Improve Longitudinal Shoulder

a. Add or Widen Graded or Stabilized Shoulder

Overview
A graded or stabilized longitudinal shoulder adjacent to the travel lanes will help create a smooth transition between the travel lanes and the side slope adjacent to the road. Widening the shoulder may influence crashes (according to literature in

both a positive and negative way). Stabilizing the shoulder will help prevent drop-offs adjacent to the travel lanes.

Crash Application

Adding or widening the graded longitudinal shoulders should be considered for crashes where it appears the width or absence of the shoulder influenced a driver. For example, if the driver crossed the shoulder while exiting the road then this countermeasure may be applicable. Similarly, if an inattentive driver veered off the right edge of pavement and then could not successfully redirect the vehicle into the travel lane, shoulder improvements may be warranted such as stabilization.

b. Pave Existing Graded Shoulder of Suitable Width

Overview

A paved longitudinal shoulder adjacent to the travel lanes will help create a smooth transition between the travel lanes and the side slope adjacent to the road. Paving the shoulder may influence crashes (according to literature in both a positive and negative way). Paving the shoulder will also help prevent drop-offs adjacent to the travel lanes.

Crash Application

Paving the existing graded longitudinal shoulders should be considered for crashes where it appears the shoulder condition or traversability influenced a driver. For example, if the driver crossed the shoulder while exiting the road then this countermeasure may be applicable. Similarly, if an inattentive driver veered off the right edge of pavement and then could not successfully redirect the vehicle into the travel lane, shoulder improvements may be warranted.

c. Widen and Pave Existing Shoulder

Overview

A wide paved longitudinal shoulder adjacent to the travel lanes will help create a smooth transition between the travel lanes and the side slope adjacent to the road. Often on rural roads, a minimal paved shoulder (one to two feet wide) is provided to minimize pavement edge erosion and protect the pavement section of the road. Occasionally there is no shoulder provided (graded or paved) and as a result the road has an unsafe roadside environment. Paving the shoulder may influence crashes (according to literature in both a positive and negative way).

Crash Application

Widening and paving the longitudinal shoulders should be considered for crashes where it appears the shoulder condition or traversability influenced a driver. For example, if the driver crossed the shoulder while exiting the road then this countermeasure may be applicable. Similarly, if an inattentive driver veered off the right edge of pavement and then could not successfully redirect the vehicle into the travel lane, shoulder improvements may be warranted.

7. Add Rumble Strips

Overview

Rumble strips are pavement undulations that, when traversed by the tires of a vehicle, create an audible cue to alert the driver of the vehicle of a potential hazard. One common application of rumble strips is placement in a series at the approach to an intersection. The intersection application is used to warn drivers as they approach an isolated intersection (usually a stop sign location). A second, and more widely used, application of rumble strips is longitudinal placement along the edge of a road. Longitudinal rumble strips are used to warn drivers they are about to exit the traveled way. Another less common application of longitudinal rumble strips is centerline rumble strip placement to warn drivers they are about to cross into an opposing lane of travel. This rumble strip application is not common in Georgia. Rumble strips can be rolled into new pavement, or milled into the pavement. In addition, there are thermoplastic rumble strips that can be applied in unique locations like work zones. Morgan and McAuliffe (1997) recommend that continuous-shoulder rumble strips are preferable to cluster-type rumble strips. They also indicate that noise complaints from both drivers and nearby residents must be considered. Similarly, rumble strip placement should be compatible with bicycle activity if applicable at the location of interest.

Crash Application

Placement of rumble strips should be considered for crashes where it appears the driver was inattentive but the minor stimulus from the audible cue of the rumble strip would alert the driver to the prospective hazard. For example, if an inattentive driver crossed the paved shoulder while exiting the road, this countermeasure may be applicable if the paved shoulder had a width greater than two-feet. (In Georgia, a paved shoulder must be wider than two-feet before the standard rolled in rumble strips can be applied.) If the crash occurred in a residential neighborhood, rumble strips are not acceptable countermeasures due to their associated noise.

8. Improve Roadway Access Management

Overview

The frequent placement of driveways or street intersections without coordination with surrounding land development can create a hazard. For example, a driveway located near an intersection can create conflicts between vehicles turning into the driveway and vehicles traveling through the intersection with the expectation that they have right-of-way. One example may be a driver elects to turn left into a driveway located 50-feet beyond the far side on an intersection. The light turns green and the car following the vehicle expects it to continue beyond the intersection location and increase speed. As a result, the poor access management contributes to a potential rear-end collision.

Crash Application

Improvement of roadway access is a feasible crash countermeasure if an alternative access opportunity is present. For example, if two driveways are so closely placed to each other that vehicles exiting the driveways obscure the view of the driver in the other driveway, perhaps the two driveways could be combined to remove this sight distance problem. If the study crash does not relate to an access management issue, this countermeasure should not be evaluated.

D. ROADSIDE IMPROVEMENTS

1. Install or Upgrade Guardrail

Overview

The primary purpose of the installation or upgrade of guardrail systems is to prevent an errant run-off-the-road vehicle from encountering an unsafe roadside environment. As a result, guardrail is commonly placed adjacent to the road at locations where the side slope is not reasonably traversable, numerous roadside obstacles (such as a wood region) are adjacent to the road, or some unforgiving feature like a pond is located within the clear zone distance. The clear zone is basically the distance required for an errant vehicle to be expected to stop or re-direct its motion if the driver is alert.

Crash Application

Guardrail placement is not feasible at locations where the guardrail will create a direct hazard. For example, placement of guardrail assumes an errant vehicle may encounter the guardrail and the guardrail will protect the driver and vehicle occupants from some worse hazard. If a road segment has frequent driveways, then guardrail may not be suitable because it cannot be continuous and will create sight distance problems for vehicles leaving and entering the driveways. Similarly, the placement of guardrail at or near an intersection is generally discouraged because it adversely impacts driver's sight distance at the intersection. Guardrail as a countermeasure should be considered primarily for run-off-the-road crash conditions.

2. Upgrade Guardrail End Treatment / Add Impact Attenuator

Overview

The literature dealing with the effects of guardrail end treatments on crashes is limited. Basically, adequate guardrail end treatments will protect a motorist from skewering their vehicle on the end of the guardrail. Similarly, suitable guardrail will prevent vehicles that impact it from vaulting into the air (thereby creating a hazard). An impact attenuator is often placed at the end of a guardrail rather than the flared end treatment if space is restricted and proper tapering of the end treatment cannot be accomplished. In general, the literature indicates improved end treatment / attenuators may not prevent a crash (the vehicle will still impact the guardrail end), but will reduce the severity of the crash.

Crash Application

Upgrading the guardrail end treatment or adding an impact attenuator is not feasible at locations where guardrail was not already present at the time of the crash and the vehicle either impacted the end of the guardrail or somehow managed to drive behind the guardrail into a hazardous location. For example, if a vehicle impacted a substandard guardrail end treatment and as a result vaulted into the air before landing upside down, the end treatment is probably not appropriately placed and this countermeasure should be evaluated. If the crash did not involve the guardrail end treatment or some associated condition, this countermeasure should not be evaluated.

3. Clear Zone Improvements

a. Widen Clear Zone

Overview

The clear zone is the width of non-obstructed roadside environment necessary for an errant vehicle to stop or re-direct its motion if the driver is alert. Often rigid objects like utility poles are located in the clear zone width recommended in the Roadside Design Guide (AASHTO, 1996). Where feasible, widening the region next to the road where a vehicle can freely traverse is considered a good safety strategy; however, the excessive cost of right-of-way often prohibits appropriate clear zone width. The clear zone is determined based on the speed and traffic volume of the road (for a high-speed road with heavy traffic volume, it is assumed more likely a vehicle may run off the road and therefore more economically feasible to provide the wider clear zone region).

Crash Application

Clear zone improvement should be considered for any run-off-the road crashes. The concept of the clear zone is a reasonable width for the alert driver to be able to redirect or stop an errant run-off-the road vehicle. As a result, a crash where the errant vehicle continued to drive a considerable distance from the road until ultimately impacting a object would not be dramatically assisted by a reasonable clear zone. The AASHTO Roadside Design Guide (AASHTO, 1996) provides clear zone requirements. Often widening the clear zone may introduce additional issues for concern. For example, the relocation of a street light pole may improve clear zone but reduce road illumination at night.

b. Flatten Side Slope

Overview

Often the side slope adjacent to the road is steep and is not reasonable traversable. As a result, the driver of an errant vehicle may not be able to regain control of the vehicle and safely redirect the vehicle. Standard design approaches are to maintain a slope that is flatter than 3:1 with a 6:1 (horizontal:vertical ratio) considered desirable. For purposes of this evaluation assume flattening a side slope to approximately **4:1**.

Crash Application

Flattening the side slope should be considered for any run-off-the road crashes where a steep side slope influenced the behavior of the errant vehicle. If the terrain makes flattening the side slope infeasible (such as a large rock formation or a water feature), then the side slope should be protected with guardrail. One common problem is that the side slope transition into a roadside ditch does not provide a reasonable transition to the ditch back slope. When this occurs, a vehicle may be vaulted or flipped when it impacts the dramatic slope change at the base of the ditch.

c. Relocate Fixed Object

Overview

Often a rigid object is located proximate to the road. When an errant vehicle runs off the road, the object can represent a hazard to the vehicle. Common fixed objects include utility poles, trees, ornamental mail boxes (often made of brick), etc. In addition, parking permitted adjacent to the road may introduce parked vehicles as fixed objects.

Crash Application

Relocation of fixed objects should be considered for any run-off-the road crashes where a vehicle impacted or was otherwise influenced by a fixed object adjacent to the road. It is important to note, however, that if a vehicle impacts a multi-use object such as a utility pole that also serves as the support for a street light the relocation of the fixed object may remove a hazardous object but will be at the expense of reduced street lighting.

d. Remove Fixed Object

Overview

Often a rigid object is located proximate to the road. When an errant vehicle runs off the road, the object can represent a hazard to the vehicle. Common fixed objects include utility poles, trees, ornamental mail boxes (often made of brick), etc. In addition, parking permitted adjacent to the road may introduce parked vehicles as fixed objects. Complete removal of these fixed objects is generally an expensive but safe countermeasure.

Crash Application

Removal of fixed objects should be considered for any run-off-the road crashes where a vehicle impacted or was otherwise influenced by a fixed object adjacent to the road. It is important to note, however, that if a vehicle impacts a multi-use object such as a utility pole that also serves as the support for a street light the relocation of the fixed object may remove a hazardous object but will be at the expense of removing street lighting.

e. Convert Object to Breakaway

Overview

The literature dealing with converting a roadside object to a breakaway type is limited. But the few studies that have dealt with this countermeasure have provided positive feedback on its effects on the severity of crashes with no real influence on frequency of crashes. It is important to note that some objects pose greater hazards if they are converted to breakaway. One example of a breakaway hazard is a utility pole at an intersection. In order to construct the pole reasonably, it must have support from all directions and adding a breakaway component would diminish this needed support. Often the utility companies supplement these intersection poles with supplemental guy wires that attach to rods drilled into the ground in an effort to improve stability.

Crash Application

Converting a fixed object to breakaway should be considered for any run-off-the road crashes where a vehicle impacted or was otherwise influenced by a fixed object adjacent to the road. If the pole is situated at a location where wires connect to it and cross the street, the unsupported wires may themselves become a hazard.

f. Construct Traversable Drainage Structure

Overview

A common problem with drainage culverts is that the end treatments are not traversable. As a result, when an errant vehicle exits the road and drives across an acceptable side slope, the presence of a drainage structure that is not traversable may create a hazard. There are several culvert end treatments or grate inlets specifically designed to assure a vehicle can safety drive over the drainage structure without vaulting or overturning.

Crash Application

Improvement of a traversable drainage structure should be considered for crashes where the driver ran off the road and impacted or was influenced by a non-traversable drainage structure (pipe or box culvert for example). Often a culvert is located beneath a driveway or cross street. In this circumstance, an alternative treatment like protecting the drainage structure end treatment with guardrail is not feasible.

E. LIGHTING

1. Add Street Lights to Road Segment

Overview

Often poor night visibility can be directly attributed to safety problems. Street lights are commonly added to illuminate road features such as access points or extreme roadway geometry. In urban environments, street lights are also located adjacent to the road to enhance pedestrian safety and better illuminate the entire roadway environment.

Crash Application

The addition of street lights is an applicable countermeasure for crashes where vehicles crashed during nighttime conditions. For the countermeasure to be considered effective the driver of the vehicle should be alert and the crash should be due to possible visibility issues. It is important to note that when street lights are added adjacent to the road, a roadside obstacle is added to the road environment. Therefore, you may improve one problem (poor visibility) by creating another problem (roadside obstacle). One recommended strategy is to try to use joint-use poles for utilities and street lights. This will reduce the number of obstacles placed next to the road. Another benefit of a street light is that the driver's eye is not adjusted to the darker street environment. This means that drivers are less prone to being temporarily "blinded" by approaching vehicle headlights.

2. Add Lighting to Intersection

Overview

Often poor night visibility can be directly attributed to safety problems. Street lights are commonly added to illuminate road features such as intersections and adjacent access points. In urban environments, street lights are also located adjacent to the road to enhance pedestrian safety and better illuminate the entire roadway environment.

Crash Application

The addition of street lights is an applicable countermeasure for crashes where vehicles crashed during nighttime conditions. For the countermeasure to be considered effective the driver of the vehicle should be alert and the crash should be due to possible visibility issues. It is important to note that when street lights are added adjacent to the road, a roadside obstacle is added to the road environment. Therefore, you may improve one problem (poor visibility) by creating another problem (roadside obstacle). One recommended strategy is to try to use joint-use poles for utilities and street lights. This will reduce the number of obstacles placed next to the road. Another benefit of a street light is that the driver's eye is not adjusted to the darker street environment. This means that drivers are less prone to being temporarily "blinded" by approaching vehicle headlights.

3. Upgrade Street Lighting for Segment or Intersection

Overview

Often poor night visibility can be directly attributed to safety problems. Street lights are upgraded to enhance illumination that is not adequately addressed with the existing lighting system. Often street light plans are initially designed by an electrical engineer on a "flat piece of paper" with little understanding about the influence of horizontal and vertical influences. As a result, it is not uncommon for "dark spots" to exist that require additional illumination by supplementing current lights.

Crash Application

The upgrade of a street lighting system is only an applicable countermeasure for crashes that occurred during nighttime conditions at locations with existing street lights. For the countermeasure to be considered effective the driver of the vehicle should be alert and the crash should be due to possible visibility issues.

F. REGULATIONS

1. Enforce Speed Limits

Overview

Often motorists elect to ignore posted speed limits and may do so knowing that the corridor on which they travel is rarely subjected to police speed enforcement. Crash research regarding enforced speed limits primarily focuses on work zone regions. In all cases, highly visible speed enforcement is effective (but also quite costly) in reducing corridor operating speeds.

Crash Application

The use of enhanced speed limit enforcement is an application for crashes where the alert driver appeared to exceed the posted speed limit and where reduced operating speed is warranted to assure safety. Inherent with the concept of police speed enforcement is the assumption a driver is aware of the legal implications and takes prudent measures when driving. Historically, for example, driving under the influence of alcohol often coincides with speeding. This pairing of hazards is probably due to the driver's impaired senses. Also, a driver under the influence of alcohol knows he or she is breaking the law by driving, so the assumption that increased speed limit enforcement will influence this driver type is probably not accurate. If the subject crash was not due to excessive speed conditions (above the posted speed limit), this countermeasure should not be evaluated.

III. APPENDIX A. COUNTERMEASURE LITERATURE REVIEW

A. PAVEMENT MARKING

1. Add or Upgrade Edgeline Pavement Marking

The literature regarding edgelines tends to favor placement of them to enhance safety; however, most of the studies provided estimated crash reductions based primarily on expert opinion (subjective evaluation).

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of edgelines to the edge of the pavement travel way (Agent et. al., 1996).

Table A-1. Kentucky Edgeline Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Edgeline Markings (All Crashes)	19	20
Edgeline Markings (Run-Off-Road Crashes Only)	2	25
Literature Review Estimates:		
Edgeline Markings (All Crashes)	11	15
Edgeline Markings (Run-Off-Road Crashes Only)	3	36
Researcher's Resulting Estimates:		
Edgeline Markings (All Crashes)	---	15
Edgeline Markings (Run-Off-Road Crashes Only)	---	30

A FHWA study (Bali et. al., 1978) concluded that results of analyses of crash rates at sites with edgelines versus those without edgelines are mixed (no statistically significant conclusion could be drawn from this comparison). In contrast, a study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 15-percent reduction should occur in total crashes due to the addition of edgelines.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent reduction for several countermeasures. This study was based on improvements at hazardous conditions. The authors emphasize the percent crash reductions estimated are not directly applicable to moderately or mildly hazardous locations. Locations where edgelines were added (centerline-only previous to improvement) resulted in the estimated values shown in the following table.

Table A-2. FHWA Edgeline Crash Reduction Estimates

Countermeasure	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Add Edgeline in Tangent Section	7	0	5	10
Add Edgeline in Horizontal Curve	10	5	10	10
Add Edgeline in Vertical Curve	5	5	5	5
Add Edgeline at Intersection	5	5	5	5

2. Add or Upgrade Centerline Pavement Marking

The literature regarding centerlines favors placement of them to enhance safety; however, most of the studies provided estimated crash reductions based primarily on expert opinion (subjective evaluation).

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of centerline markings (Agent et. al., 1996).

Table A-3. Kentucky Centerline Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates: Centerline Markings (All Crashes)	19	36
Literature Review Estimates: Centerline Markings (All Crashes)	13	24
Researcher's Resulting Estimates: Centerline Markings (All Crashes)	---	35

A FHWA Study (Bali et. al., 1978) concluded that highways with centerlines have lower crash rates than highways with no treatment at all. These findings were consistent for tangent sites, winding road locations, and for isolated horizontal curves. Similarly, a study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 30-percent reduction should occur in total crashes due to the addition of centerlines.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where centerlines were added resulted in the following estimated values.

Table A-4. FHWA Centerline Crash Reduction Estimates

Countermeasure	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Add Centerline in Tangent Section	7	0	5	10
Add Centerline in Horizontal Curve	10	10	10	10
Add Centerline in Vertical Curve	5	5	5	5
Add Centerline at Intersection	5	5	5	5
Add Centerline at Bridge Location	5	5	5	5

3. Add or Upgrade No-Passing-Zone Pavement Marking Lines

The literature regarding no-passing zones favors placement of them to enhance safety. Many of the studies, however, include strong subjective assessment rather than quantified improvement analysis.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of no passing zones (Agent et. al., 1996).

Table A-5. Kentucky No-Passing-Zone Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
No Passing Zones (All Crashes)	12	42
No Passing Zones (Passing Crashes Only)	---	---
Literature Review Estimates:		
No Passing Zones (All Crashes)	7	48
No Passing Zones (Passing Crashes Only)	2	85
Researcher's Resulting Estimates:		
No Passing Zones (All Crashes)	---	---
No Passing Zones (Passing Crashes Only)	---	40

Council and Harwood (1999) summarized a group of "Accident Modification Factors" for a variety of conditions. The influence of passing lane factors was based on an assumed base condition that no passing lanes are present. Analysis was for the total (two-way) crashes for the length of a passing lane. The authors concluded crashes would reduce by 25-percent for one added passing lane and by 35-percent for short four-lanes sections. Similarly, a study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 40-percent reduction should occur in total accidents due to the addition of no passing zone lines. An Indiana study (Ermer et. al.,

1992) estimated crash reduction factors based on a before-after study and combined with historic analyses in the state of Indiana. The upgrade of a facility's no-passing zones rated an estimated 30-percent reduction in total crashes.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where a passing lane was installed resulted in the estimated values shown in the following table. This is a further enhancement above restricting no-passing zones.

Table A-6. FHWA Passing Lane Crash Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Install Passing Lane	10	20	15	10

4. Add Raised Pavement Marking (RPMs)

The literature regarding RPMs favors placement of these markers to enhance safety; however, widescale use of RPMs is extremely expensive and may be cost prohibitive.

Stimpson et. al. (1977) determined the use of RPMs on both the centerline and edgeline represented a 68-percent reduction in potential hazard but would cost 900 times the standard pavement markings.

Zador et. al. (1987) tested several delineation treatments including RPMs and concluded all tested treatments affected driver behavior at night. They observed speed increases of about 1 ft/sec at night with RPMs, but indicated the resulting speeds almost always remain below the daytime speeds.

Krammes et. al. (1990) determined that highways with RPMs have lower crash rates than similar roads with painted centerlines. Similarly, a before-after study summarized in Wright et. al. (1983) evaluated RPMs placed along the centerline (four abreast at 20-foot centers) and across the 4-ft-wide shoulders at a 45-degree angle. The RPMs contributed to a 42-percent decrease in projected crashes.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of RPMs (Agent et. al., 1996).

Table A-7. Kentucky Raised Pavement Marker Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Raised Pavement Markers (All)	15	13
Raised Pavement Markers (Wet/Night)	7	21
Raised Pavement Markers (Night)	8	17
Literature Review Estimates:		
Raised Pavement Markers (All)	7	6
Raised Pavement Markers (Wet/Night)	3	29
Raised Pavement Markers (Night)	4	18
Researcher's Resulting Estimates:		
Raised Pavement Markers (All)	---	10
Raised Pavement Markers (Wet/Night)	---	25
Raised Pavement Markers (Night)	---	20

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where RPMs were added to complement pavement markings resulted in the percent crash reduction depicted in the following table.

Table A-8. FHWA Raised Pavement Marking Crash Reduction Estimates

Countermeasure	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Add RPMs in Tangent Section	5	0	5	5
Add RPMs in Horizontal Curve	10	10	10	10
Add RPMs at Intersection	5	5	5	5

A study performed by Creasy and Agent (1985), based on a combination of 42 literature reviews, 22 state surveys, and a before and after analysis, provided a subjective estimate that a 5-percent reduction should occur in total crashes due to the addition of raised pavement markers. For nighttime accidents on wet pavements, the reduction is as high as 20-percent with a 10-percent estimated reduction for dry pavement nighttime crashes.

Wattleworth et. al. (1988) developed accident reduction factors related to the crash experience in Florida. The researchers performed before-after analysis of crash data from three years before and three years after a safety countermeasure was implemented. They estimated a 5-percent reduction in the number of total crashes due to installation of reflectorized raised pavement markers at the roadway centerline.

B. TRAFFIC SIGNS

1. Warning Sign

The literature regarding warning signs emphasizes sign placement to enhance safety; however, excessive placement of warning signs may diminish their impact on safety.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous conditions. The authors emphasized the percent crash reductions estimated are not directly applicable to moderately or mildly hazardous locations. Locations where a warning sign was added resulted in the estimated values shown in the following table.

Table A-9. FHWA Warning Sign Crash Reduction Estimates

Countermeasure: Add warning Sign	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Intersection	5	5	5	5
Curve	10	15	10	10
Curve with advanced speed	20	30	25	20
Narrow bridge	5	5	5	5
Route Guidance	5	5	5	5
Slippery when wet	1	1	1	1
Speed Zone	5	15	10	5

A study performed by Creasy and Agent (1985), based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided a subjective estimate that a 40-percent reduction should occur in total crashes due to the addition of warning signs at intersections, 20-percent reduction at mid-block sections, and 30-percent reduction on curves, all in rural areas.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of different types of warning signs (Agent et. al., 1996).

Table A-10. Kentucky Warning Sign Crash Reductions Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
General	12	23
Curve Warning (All Crashes)	16	32
Curve Warning (Run-off-Road)	2	28
Intersection Related	14	36
Bridge Related	2	34
Railroad Crossing	5	29
Pavement Condition	2	18
Pedestrian	1	15
School Zone	3	14
Animal	2	8
Literature Review Estimates:		
General	11	30
Curve Warning (All Crashes)	11	37
Intersection Related	5	32
Pavement Condition	1	80
Animal	1	5
Researcher's Resulting Estimates:		
General	---	25
Curve Warning (Run-off-Road)	---	30
Intersection Related	---	30
Railroad Crossing	---	30
Pavement Condition	---	20
School Zone	---	15

2. Advisory Speed Signs

Rutley (1972) conducted a literature survey and concluded that advisory signs used in the USA have been useful in eliminating surprise on some sharp curves and have reduced congestion and crashes. The research team evaluated advisory speeds at curves for three counties in England. They determined that there appeared to be a reduction in the number of crashes at curves in all three counties when compared to the number of other crashes for similar roads in the counties. The observed crash reduction, however, was statistically significant in only one of the counties evaluated.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of advisory speed limit signs (Agent et. al., 1996).

Table A-11. Kentucky Warning Sign Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates: Advisory Speed	2	26
Literature Review Estimates: Advisory Speed	2	30

Chowdhury et. al. (1998) evaluated driver compliance to advisory speed signs at horizontal curves. They found that on average nine out of ten drivers exceeded the posted advisory speed. Compliance also varied based on the specific advisory speed. The following table depicts observed compliance.

Table A-12. Driver Compliance with Advisory Speed

Posted Advisory Speed (mph)	Percentage Compliance	
	Average	Range
15 to 20	0%	0% to 0%
25 to 30	8%	0% to 38%
35 to 40	5%	0% to 32%
45 to 50	35%	0% to 56%

3. Chevron Alignment Sign

Wattleworth et. al. (1988) developed accident reduction factors related to the accident experience in Florida. The researchers performed before-after analysis of crash data from three years before and three years after implementation of a safety countermeasure. A 35-percent reduction in the number of total crashes is estimated due to installation of chevron signs.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of chevron alignment signs at horizontal curves (Agent et. al., 1996).

Table A-13. Kentucky Chevron Warning Sign Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates: Chevron	2	55
Literature Review Estimates: Chevron	3	30

Wright et. al. (1983) performed a state survey for low-cost countermeasures suitable for reducing the frequency of run-off-the-road crashes. All 38 surveyed states used chevron signs as a means of alerting drivers to the presence and sharpness of upcoming curves. Jennings and Demetsky (1985) evaluated vehicle tracking through curves and recommended chevron use at curves sharper than approximately 7-degrees (radius less than 820-feet).

4. Post Delineator

A study performed by Bali et. al. (1978) used linear regression analysis to estimate the relationship between roadway environment, geometric data, traffic volumes, delineation and accident rates for tangent, winding and horizontal curve sections. Model development utilized crash data for 514 sites from 10 states and covered 13,000 accidents. The researchers determined that, for tangent and or winding sites, highways with post delineators have lower crash rates than those without post delineators (in the presence or absence of edgelines). Similarly, for isolated horizontal curves there is some indication (based on average corridor crash rate estimates) that sites with post delineators also have lower crash rates than sites without post delineators.

Wattleworth et. al. (1988) developed accident reduction factors related to the crash experience in Florida. The researchers performed before-after analysis of crash data from three years before and three years after implementation of a safety countermeasure. A 30-percent reduction in the number of total crashes and 25-percent in fatal accidents was estimated due to installation of post delineators on curves.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia, and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of post delineators (Agent et. al., 1996).

Table A-14. Kentucky Post Delineator Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Post Delineators / Curve (All Crashes)	14	23
Post Delineators / Curve (Night Crashes)	2	30
Delineators / Tangent (All Crashes)	17	28
Delineators / Tangent (Night Crashes)	2	30
Flexible Delineators (All Crashes)	1	40
Literature Review Estimates:		
Post Delineators / Curve (All Crashes)	8	23
Post Delineators / Curve (Night Crashes)	1	30
Delineators / Tangent (All Crashes)	5	16
Delineators / Tangent (Night Crashes)	1	30
Researcher's Resulting Estimates:		
Post Delineators (Night Crashes)	---	30

Jennings and Demetsky (1985) evaluated vehicle tracking through curves and recommended post delineators for delineation at curves less than 7-degrees (radius greater than 820-feet). Zador et. al. (1987) observed a short-term increase in speed (about 2 ft/sec to 2.5 ft/sec at night) in locations where post-mounted delineators were added. The long-term speed conditions remained consistent with those observed for short-term speed evaluations.

C. ROADWAY IMPROVEMENTS

1. Modify Geometric Alignment

The literature regarding the modification of geometric alignment is based upon both subjective assessment and analytical evaluation.

A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 30-percent reduction should occur in total crashes due to a change (improvement) in the horizontal alignment. Similarly, a 45-percent reduction should occur in total crashes for a change (improvement) in vertical alignment, with a 50-percent reduction attributed to a change in both horizontal and vertical alignment.

Fink and Krammes (1995) verified the general conclusion that the relationship between crash rate and degree of horizontal curvature is easy to quantify where the sharper radius directly contributes to more crashes than a larger radius. More specifically, the research team determined that horizontal curves that do not require speed reductions (generally, curves with degrees of curvature < 4-degrees [approx. radius of 1432']) have similar mean crash rates than horizontal curves that do require speed reduction (Krammes et. al., 1995).

A study performed for the State of Washington evaluated numerous environmental and physical road features in an effort to identify their relationship to crashes (Milton and Mannering, 1996). The researchers determined that curves of more than 2-degrees (R > 2865') tend to decrease crash probability. In addition long curves tend to increase the crash probability for collectors and minor arterials.

Mohamedshah et. al. (1993) determined for truck crashes on two-lane rural roads, the significant degree of curvature is 6-degrees or greater. They were not able to determine any significant relationship between the road gradient and truck crashes.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for several methods of geometric realignment (Agent et. al., 1996).

Table A-15. Kentucky Geometric Improvement Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Add Any Type of Median (All Crashes)	10	35
Add Mountable Median (All Crashes)	4	20
Add Non-mountable Median (All Crashes)	11	27
Horizontal Realignment (All Crashes)	20	44
Horizontal Realignment (Run-Off-Road Crashes)	2	50
Curve Reconstruction (All Crashes)	6	50
Vertical Realignment (All Crashes)	13	41
Vertical Realignment (Run-Off-Road Crashes)	2	50
Horizontal & Vertical Realignment (All Crashes)	6	52
Literature Review Estimates:		
Add Any Type of Median (All Crashes)	7	14
Add Mountable Median (All Crashes)	4	28
Add Non-mountable Median (All Crashes)	8	10
Horizontal Realignment (All Crashes)	5	40
Curve Reconstruction (All Crashes)	11	54
Vertical Realignment (All Crashes)	4	39
Horizontal & Vertical Realignment (All Crashes)	12	38
Researcher's Resulting Estimates:		
Horizontal Realignment / Curve Reconstruction	---	40
Vertical Realignment	---	40
Modify Horizontal & Vertical Realignment	---	50

One study relating truck crashes to road geometry (Miaou, et. at., 1993) determined heavy vehicle crash rate on horizontal curves is a factor of curve length and degree of curvature. The following table summarizes general expected reductions in truck crash involvement on a rural two-lane undivided arterial road following an improvement.

Table A-16. Miaou Geometric Improvement Crash Reduction Estimates

Length of Original Curve (mi.)	Horizontal Curvature (HC) in degrees / 100-ft arc: for $2^o \leq HC \leq 30^o$ (percent reduction)				
	Reduce 1^o	Reduce 2^o	Reduce 5^o	Reduce 10^o	Reduce 15^o
0.10	9.4 ($\pm$1.1)	18.0 ($\pm$2.0)	39.1 ($\pm$3.8)	62.9 ($\pm$4.6)	77.4 ($\pm$4.3)
0.25	10.0 ($\pm$1.8)	19.0 ($\pm$3.3)	41.0 ($\pm$6.1)	65.2 ($\pm$7.4)	79.5 ($\pm$6.8)
0.50	11.0 ($\pm$4.7)	20.7 ($\pm$8.4)	44.1 ($\pm$15.4)	68.7 ($\pm$20.2)	82.5 ($\pm$22.0)
0.75	11.9 ($\pm$7.6)	22.4 ($\pm$13.6)	47.0 ($\pm$26.2)	71.9 ($\pm$42.6)	85.1 (---)
$>$1.00	12.8 ($\pm$10.6)	24.0 ($\pm$19.0)	49.7 ($\pm$39.6)	74.7 (---)	87.3 (---)

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations with horizontal and vertical realignment resulted in the estimated values depicted in the following table.

Table A-17. FHWA Geometric Improvement Crash Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Horizontal realignment	40	40	30	25
Vertical realignment	40	40	40	50

One accident reduction factor study (SDDOT, 1998) evaluated sixty-two hazardous sites and attempted to quantify accident reduction factors (ARFs) for the sites. These ARFs were calculated by dividing the total number of crashes following an improvement project by the total number from previous years. A value greater than one, therefore, represents an increase in the number of crashes. Realignment of horizontal configurations resulted in an ARF of zero (or a 100% crash reduction). Realignment of horizontal and vertical resulted in an ARF of 1.12 (or an increase in crashes).

A 1991 study (Zegeer et. al., 1991) determined that curve flattening (increasing the length of the radius for the horizontal curve) reduces crash frequency by as much as 80-percent, depending on the central angle and amount of flattening.

2. Modify Superelevation / Cross Slope

The literature regarding the modification of superelevation or cross slope is based upon both subjective assessment and analytical evaluation.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for modifying the roadway superelevation (Agent et. al., 1996).

Table A-18. Kentucky Superelevation Improvement Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates: Modify Superelevation (All Crashes)	13	46
Literature Review Estimates: Modify Superelevation (All Crashes)	5	34
Researcher's Resulting Estimates: Modify Superelevation (All Crashes)	---	40

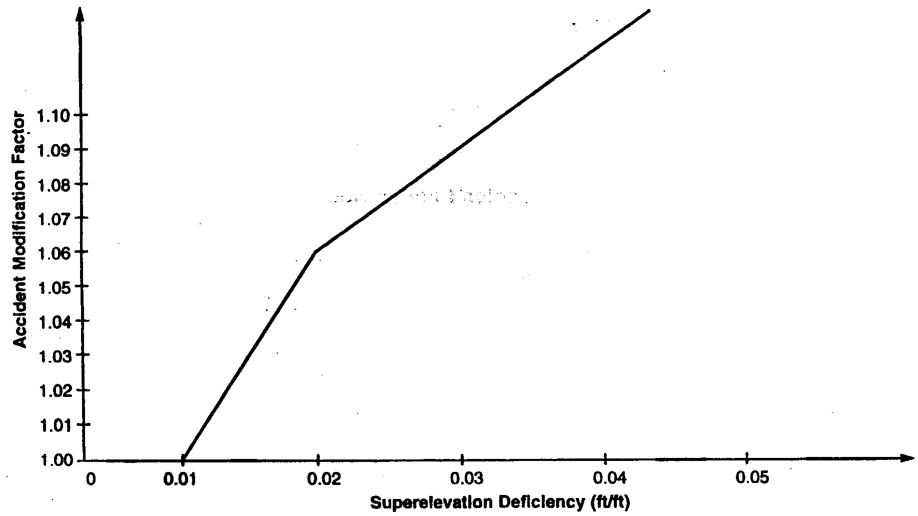
A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 40-percent reduction should occur in total crashes due to the correction or improvement of roadway superelevation.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations with changes to superelevation correction or cross slope improvement resulted in the estimated values shown below.

Table A-19. FHWA Superelevation or Cross Slope Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Raise superelevation	5	5	10	20
Correct superelevation runoff	5	5	5	5
Correct cross slope break at shoulders	5	5	5	5
Flatten cross slope on pavement	5	5	5	5
Flatten cross slope on shoulder	5	2	2	2

Harwood et. al. (2000) summarized a group of "Accident Modification Factors" (AMF) for a variety of conditions. They captured their perception of the influence of superelevation deficiency using as depicted in the following graphic. If the AMF is greater than 1.0, the configuration has a greater likelihood of crashes.



3. Improve Sight Distance without Geometric Realignment

The literature regarding improved sight distance is based upon both subjective assessment and analytical evaluation. It is important to note that some of the studies did not specifically identify how sight distance was improved, so it is difficult to know if physical road improvements were included.

A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 30-percent reduction should occur in total crashes due to an improvement in sight distance. This improvement condition was separated from geometric improvement analysis in the study.

An Indiana study (Ermer et. al., 1992) estimated crash reduction factors based on a before-after study and combined with historic analyses in the state of Indiana. The improvement of sight distance rated an estimated 30-percent reduction in total crashes. It is important to note, geometric elements were not specifically separated in this study so the possible sight distance improvements may include some geometric features.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for improved sight distance (Agent et. al., 1996). In this study, the actual method of improvement was not identified; however, the same study included a separate evaluation of geometric realignment.

Table A-20. Kentucky Sight Distance Improvement Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Sight Distance Improvement (All Crashes)	13	26
Sight Distance Improvement for Intersection Only (All Crashes)	1	30
General Sight Distance Improvement other than Intersection (All Crashes)	4	32
Literature Review Estimates:		
Sight Distance Improvement (All Crashes)	1	30
Sight Distance Improvement for Intersection Only (All Crashes)	4	23
General Sight Distance Improvement other than Intersection (All Crashes)	11	34
Researcher's Resulting Estimates:		
Sight Distance Improvement (All Crashes)	---	30

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where sight distance improvements were implemented (specific type of improvements unknown) resulted in the following estimated values.

Table A-21. FHWA Sight Distance Improvement Crash Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Sight distance on horizontal curve	5	5	5	5
Sight distance at Intersection	50	60	50	40
Sight distance at railroad grade crossing	25	25	25	25

4. Widen Lanes or Pavement Width

Numerous researchers evaluated the effect of lane width on the number of crashes. In general, improving lane width up to widths ranging from 11 to 12 ft consistently reduced crash rates.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the widening of travel lanes (Agent et. al., 1996).

Table A-22. Kentucky Lane Width Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Widen Pavement (All Crashes)	19	26
Widen Pavement (Run-off-Road Crashes only)	2	30
Literature Review Estimates:		
Widen Pavement (All Crashes)	15	22
Researcher's Resulting Estimates:		
Widen Pavement (All Crashes)	---	25

A study performed by Creasy and Agent (1985), based on a combination of 42 literature reviews, 22 state surveys and a before-after analysis, provided the subjective estimate that a 20-percent reduction should occur in total crashes due to lane widening.

Benekohal and Hashmi (1990) considered data from 1981 to 1987 for two-lane rural highways in the state of Illinois. These researchers evaluated the relationship between roadway characteristics, environmental conditions and crash frequency. The researchers concluded "any roadway improvement consisting of lane and shoulder widening… generally results in the reduction of accident frequency of related accidents." The analysis model indicated that crash frequency decreases by about 3-percent as lane width increases.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. The researchers based this study on improvements at hazardous locations. The authors emphasized the percent crash reductions estimated are not directly applicable to moderately or mildly hazardous locations. Locations where pavement was widened resulted in the estimated values shown in the following table.

Table A-23. FHWA Lane Widening Crash Reduction Estimates

Countermeasure	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Pavement Widening on Sections	0	-10	-5	5
Pavement Widening on Horizontal and Vertical Curves	5	-5	0	10

Griffin and Mak (1988) suggested that by increasing surface width, the single-vehicle crash rate for average annual daily traffic (AADT) greater than 400 would decrease. They used data on two-lane, rural, farm-to-market roads in the state of Texas. The study included crash data and roadway inventory data from 1985. The analyses indicated that surface widening would not reduce multi-vehicle crash rates. The researchers determined the influence of surface widening for a given AADT category to be a function of (1) existing road width and (2) the width to which the road is widened. The percent reduction in single-vehicle crashes when the resurfacing conforms to various road widths is shown in the column titles in the following table. For example, resurfacing from 18 ft to 20 ft on a roadway with AADT in the range 401-700 results in a 7.05-percent reduction in crashes.

Table A-24. Texas Pavement Widening Single-Vehicle Crash Reduction Estimates

AADT	Existing Pavement Width (feet)	Final Pavement Surface Width (feet)			
		20	22	24	26
401-700	18	7.05	13.42	19.24	24.59
	20	---	6.86	13.12	18.87
	22	---	---	6.72	12.90
	24	---	---	---	6.63
701-1000	18	11.82	22.52	32.28	41.26
	20	---	12.13	23.20	33.39
	22	---	---	12.60	24.19
	24	---	---	---	13.26
1001-1500	18	13.92	26.50	37.99	48.57
	20	---	14.62	27.97	40.25
	22	---	---	15.64	30.02
	24	---	---	---	17.05

Hadi et. al. (1995a) estimated a relationship between a variety of cross section design variables for all types of crashes. The analysis used four years (1988-1991) of crash data from Florida. The authors determined that for two-lane rural highways, widening lane widths up to 13-feet could be expected to decrease crash rates.

In 1957, Schoppert used linear regression analysis to estimate the relationship between traffic crashes and roadway elements for rural two-lane highways with gravel shoulders in Oregon. He used data for years 1952, 53 and 54. In general he determined fewer crashes can be expected on roadways with wider lanes (Schoppert, 1957). Similarly, Vogt and Bared (1998) independently arrived at a conclusion similar to that of the 1957 study.

Zegeer and Deacon (1987) identified the three most important factors that affect crash experience. Lane width was included as one of these three factors. The simple percentage decrease in the number of run-off-road and opposite direction crashes from a before condition to an after situation are summarized in the following table:

Table A-25. Percent Crash Reduction Due to Lane Widening (Based on KY Data)

Lane Width "Before" (feet)	Lane Width "After" (feet)	Percent Crash Reduction
8	10	23
	11-12	36
9	10	10
	11-12	29
10	11-12	23

Another Florida study (Hadi et. al., 1995b) determined that roadway widening on curves as a safety countermeasure is cost-effective. An extensive review of literature identified previously derived relationships between geometric design elements and crash rates. Conclusions drawn from this review include:

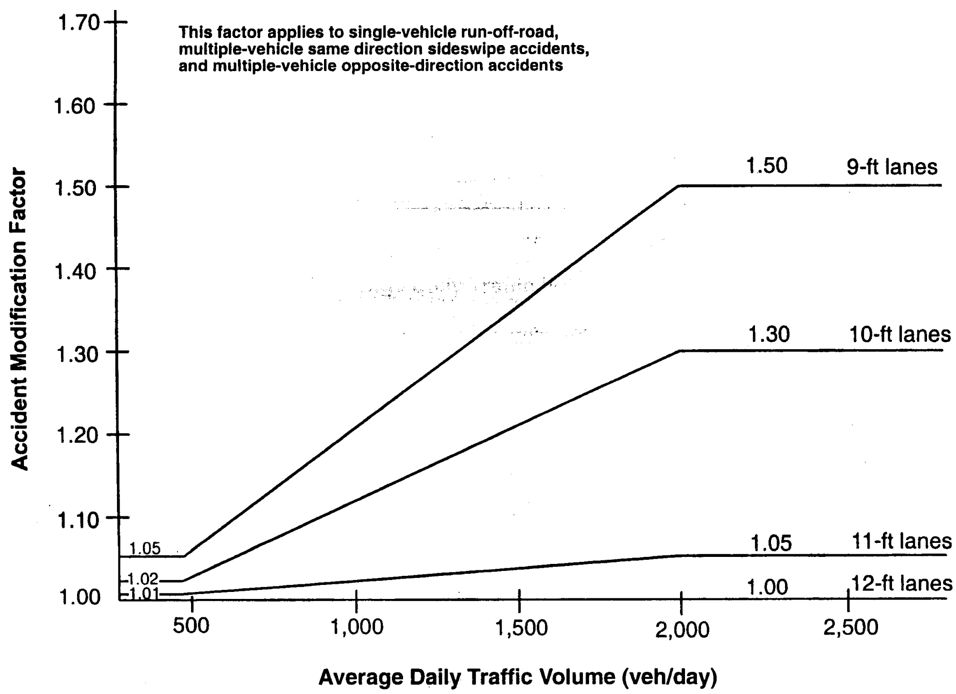
- Crash rates decreased as lane width increased up to 11-feet, then remained relatively constant.
- A before-after study showed a significant decrease in crash rates when widening lanes from 9-12 feet, especially at high-crash sections.
- Pavements 22-24 feet wide had fewer crashes than narrower and wider pavements for two-lane roads.
- A before-after study recorded that widening lanes at 17 sites from 9 and 10 feet to 11 and 12 feet resulted in a 22-percent reduction in crash rates.
- The researchers determined that the only crashes that could be expected to decrease with lane widening were run-off-road and opposite-direction crashes. They also found that only property damage and injury crashes decreased as lane width increased. They did not observe a change in fatality rate.
- As the lane widening increased, the percentage reduction in related crashes also increased. The first foot of lane widening between 8 and 12 feet caused a 12-percent reduction in related crashes, 2 feet caused a 23-percent reduction, 3 feet caused a 32-percent reduction and 4 feet caused a 40-percent reduction. This applies to only rural two-lane highways with lane widths of 8-12 feet, shoulder width of zero to 12 feet, and traffic volumes of 100 to 10,000 vpd.

In addition to their literature review summary above, Hadi et. al. (1995b) developed models to identify the relationship between various factors and crash experience. They determined that as lane width increased from 9 feet to 13 feet, the total, injury and fatal crash rates were decreased by 4.26, 4.17, and 9.23-percent respectively.

Zegeer et. al. (1991) determined that widening lanes and shoulders on curves can reduce the frequency of curve crashes by as much as 33-percent. The researchers indicated that, irrespective of the degree of curve, central angle, length of curve, or the ADT, the predicted number of curve crashes always decreased as lane width increased on a horizontal curve. This increase in lane width is limited to the curve regions and not the entire length of the roadway. Estimated crash reductions were in a range from

4-percent for 2 feet of total roadway widening to 36-percent for 20 feet of total roadway widening.

Harwood et. al. (2000) summarized a group of AMFs for a variety of conditions. The influence of lane width was based on an assumed base lane width of 12-feet. The researchers based their analysis on single-vehicle run-off-road crashes, multi-vehicle same direction sideswipe crashes, and multi-vehicle opposite direction crashes. As AADT values increase the likelihood of a crash associated with a lane width also increases. The following graphic demonstrates the accident reduction factors for lane width. If the AMF is greater than 1.0, the configuration has a greater likelihood of crashes.



5. Add Turn Lane

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of turn lanes (Agent et. al, 1996).

Table A-26. Kentucky Added Turn Lane Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Left-turn (At Signal) (All Crashes)	17	30
Left-turn (At Signal) (LT Rear End)	2	75
Left-turn (No Signal) (All Crashes)	16	28
Left-turn (No Signal) (LT Rear End)	2	87
Right-turn (All Crashes)	5	27
Two-way Left-turn Lane (All Crashes)	21	34
Literature Review Estimates:		
Left-turn (At Signal) (All Crashes)	3	27
Left-turn (No Signal) (All Crashes)	3	30
Two-way Left-turn Lane (All Crashes)	10	31
Researcher's Resulting Estimates:		
Left-turn (All Crashes)	---	25
Left-turn (LT Related Crashes)	---	50
Right-turn (All Crashes)	---	25
Right-turn (RT Related Crashes)	---	50
Two-way Left-turn Lane (All Crashes)	---	30

A study conducted by Creasy and Agent (1985) evaluated a combination of previous research available in literature, 22 state surveys, and a before-after analysis. This study provided a subjective estimate of the influence of the addition of a left-turn lane and concluded there would be:

- A 25-percent reduction in total crashes when there is no traffic signal present,
- A 30-percent reduction when there is a traffic signal, and
- A 30-percent reduction when a two-way left-turn lane is added.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reductions estimated are not directly applicable to moderately or mildly hazardous locations. Locations where a turn lane was added resulted in the estimated values shown in the following table.

Table A-27. FHWA Turn Lane Construction Crash Reduction Estimates

Countermeasure	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Add turn lanes at signalized intersection	25	15	20	25
Add turn lanes at intersections without signals	60	45	55	65

Hadi et. al., (1995b) reviewed a before-after study of 53 left-turn channelization projects at urban and rural intersections in California that was performed by Hammer in 1969. This study determined that the addition of left-turn lanes resulted in the following conclusions:

- At unsignalized intersections, rear-end, left-turn, and total crashes were reduced by 85, 37, and 48-percent respectively. Right-angle crashes, however, increased by 153-percent.
- At signalized intersections, left-turn and total crashes were reduced by 54 and 17-percent respectively. No significant changes in right-angle and rear-end crashes were reported.

Ermer et. al. (1992) developed crash reduction factors related to various highway improvement projects in Indiana. These factors were developed from before-and-after analysis of crash data from 1983 through 1987. For construction of a new turn lane, the researchers suggested a percentage reduction of 20-percent in the number of crashes.

Council and Harwood (1999) postulated the use of published research and expert panels to develop Accident Modification Factors (AMFs)for incorporation into the Federal Highway Administration's Interactive Highway Safety Design Module (IHSDM). AMFs are characterized as percentage changes in crash frequencies as a function of a change in an individual roadway parameter. The following table depicts these AMFs for installation of left-turn lanes and right-turn lanes, respectively, on the major-road approaches to intersection on two-lane rural highways.

Table A-28. IHSDM Accident Modification Factors for Turn Lanes

Intersection Type	Intersection Traffic Control	Number of Major Road Approaches on which Left-Turn Lanes are Installed	
		One Approach	Both Approaches
3-Leg Intersection	Stop Sign	0.78	---
	Traffic Signal	0.85	---
4-Leg Intersection	Stop Sign	0.76	0.58
	Traffic Signal	0.82	0.67
		Number of Major Road Approaches on which Right-Turn Lanes are Installed	
3-Leg Intersection	Stop Sign	0.95	---
	Traffic Signal	0.975	---
4-Leg Intersection	Stop Sign	0.95	0.90
	Traffic Signal	0.975	0.95

6. Improve Longitudinal Shoulder

Several feasible improvements fall within the general description of "Improve Longitudinal Shoulder." These are individually identified and reviewed in the following paragraphs.

a. Add or Widen Graded or Stabilized Shoulder

The literature regarding adding or widening graded or stabilized roadway shoulders is considerable and is based upon both subjective assessment and analytical evaluation.

Barbaresso and Bair (1983) performed statistical analysis on several crashes associated with a variety of shoulder widths on two-lane roads. Their goal was to determine whether there is a significant difference in crash frequency between two-lane roadways with shoulder widths that meet minimum standards and those that do not. The results of their study did not support the idea that roadways with wider shoulders experience fewer crashes than roadways with narrow shoulders. Interestingly, they did find that fixed object crash frequency is significantly lower for roadways with shoulders less than 7 feet wide than it is for roadways with wider shoulders. The authors hypothesize that wider shoulders may give drivers a false sense of security and the drivers may, therefore, drive at speeds faster than appropriate for roadway conditions. This hypothesis was not, however, tested in their study.

A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 20-percent reduction should occur in total crashes due to the addition of a shoulder as well as the widening of a shoulder. An Indiana study (Ermer et. al., 1992) estimated crash reduction factors based on a before-after study and combined with historic analyses in the state of Indiana. The construction and/or reconstruction of shoulders rated an estimated 9-percent reduction in total crashes.

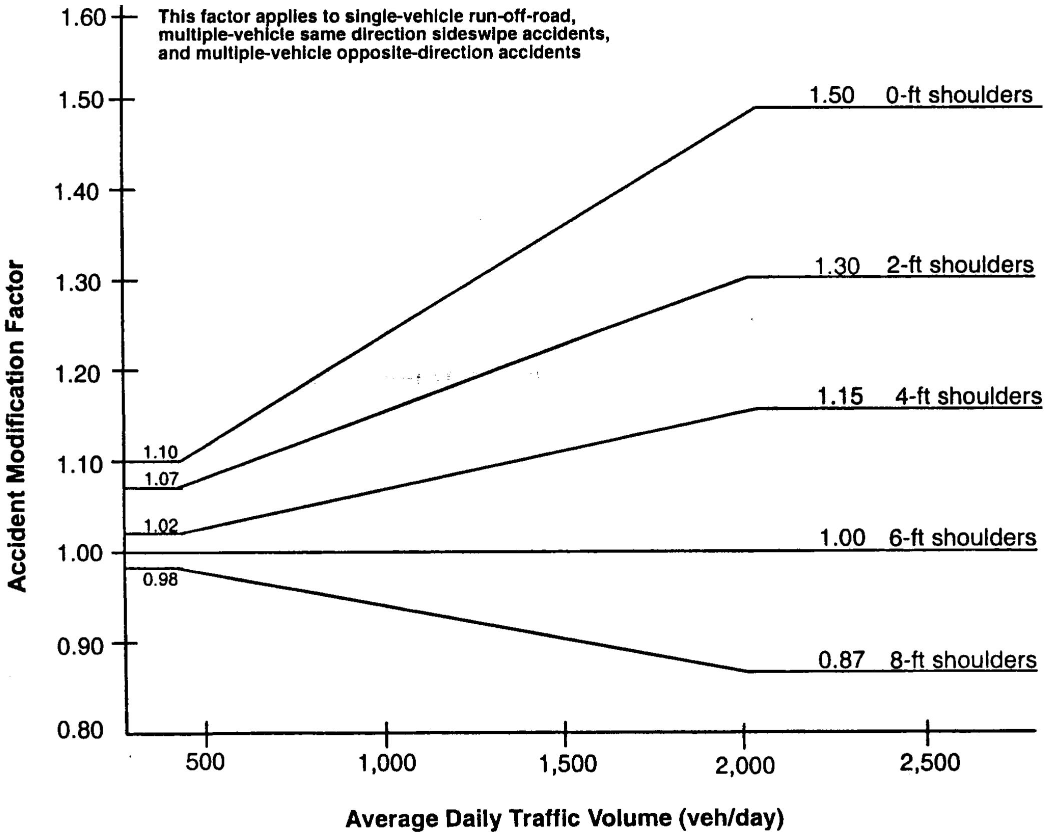
A Florida study (Hadi et. al., 1995a) determined that a greater total shoulder width (paved plus unpaved) was associated with lower crash rates on two-lane rural highways.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for widening or stabilizing roadway shoulders (Agent et. al., 1996).

Table A-29. Kentucky Shoulder Widening/Stabilizing Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Widen Shoulder General Improvement (All Crashes)	18	19
Widen Shoulder General Improvement (Run-Off-Road Crashes Only)	2	15
Widen Shoulder 2-4 Feet (All Crashes)	2	24
Widen Shoulder Over 4 Feet (All Crashes)	2	42
Shoulder Stabilization / Dropoff (All Crashes)	5	23
Literature Review Estimates:		
Widen Shoulder General Improvement (All Crashes)	16	20
Widen Shoulder General Improvement (Run-Off-Road Crashes Only)	1	13
Widen Shoulder 2-4 Feet (All Crashes)	1	15
Widen Shoulder Over 4 Feet (All Crashes)	2	25
Shoulder Stabilization / Dropoff (All Crashes)	3	39
Researcher's Resulting Estimates:		
Widen Shoulder General Improvement (All Crashes)	---	20
Widen Shoulder 2-4 Feet (All Crashes)	---	20
Widen Shoulder Over 4 Feet (All Crashes)	---	35
Shoulder Stabilization / Dropoff (All Crashes)	---	25

Harwood et. al. (2000) summarized a group of "Accident Modification Factors" (AMF) for a variety of conditions. The influence of shoulder width was based on an assumed base shoulder width of 6-feet. The researchers based their analysis on single-vehicle run-off-road crashes and multi-vehicle opposite direction crashes. As AADT values exceed 2000 vpd, shoulders narrower than 6-feet dramatically influenced subject crashes (up to 50-percent more crashes for roads with no shoulders). For AADT values less than 2000 vpd, the factors converged and were quite similar for low volume conditions. The following graphic demonstrates the accident reduction factors for shoulder width. If the AMF is greater than 1.0, the configuration has a greater likelihood of crashes.



One study relating truck crashes to road geometry (Miaou et. al., 1993) determined heavy vehicle crash rate is a factor of width of stabilized outside shoulder. The following table summarizes general expected reductions in truck crash involvement on a rural two-lane undivided arterial road following an improvement.

Table A-30. Miaou Stabilized Shoulder Improvement Crash Reduction Estimates

Stabilized Outside Shoulder Width per Direction (OSH): for OSH ≤ 12 ft (percent)				
Increase 1 ft	Increase 2 ft	Increase 3 ft	Increase 4 ft	Increase 5 ft
3.3 (±1.9)	6.6 (±3.7)	9.7 (±5.4)	12.7 (±6.9)	15.6 (±8.4)

A study performed for the State of Washington evaluated numerous environmental and physical road features in an effort to identify their relationship to crashes (Milton & Mannering, 1996). They determined that for very low volume roads, such as collectors and minor arterials, shoulder widths have little effect on the number of crashes because the exposure to these sections is low. As the shoulder width increases, however, the crash probability for minor arterials tends to increase. This may be because drivers are lulled into a false sense of security by the increased shoulder width and tend to increase speeds as a result. Substandard right shoulders also tend to increase the frequency of crashes for principal arterials and collectors. This is assumed to be because drivers have less room to take corrective actions after making an errant maneuver.

The Minnesota Department of Transportation performed a two-lane rural crash analysis with associated cost benefit evaluations for improvements (MinDOT, 1980). For evaluation of all crashes, they determined that even the narrowest permitted shoulder standard would have to have a very high average daily traffic volume before widening could be justified on the basis of normally anticipated savings in crash costs. If the shoulders could be widened 3-feet for minimal cost, the benefits from reduced crashes would justify the construction cost. When evaluating run-off-road crashes, they found crashes decreased as shoulder width increased (a similar observation for total crashes). The researchers were not able to determine a relationship between shoulder type and crash rate.

In 1995, a University of Florida study (Hadi et. al., 1995b) concluded that for rural two-lane highways increasing the total shoulder width (paved and unpaved) from 3-feet to 9-feet was found to decrease the total crash rate by 8.62-percent and the injury crash rate by 11.85-percent.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reduction estimated is not directly applicable to moderately or mildly hazardous locations. Locations with shoulder improvements (stabilizing shoulders) resulted in the estimated values shown below.

Table A-31. FHWA Shoulder Stabilization Crash Reduction Estimates

Countermeasure	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Stabilize Shoulders (Tangent)	5	0	5	10
Stabilize Shoulders (Horizontal Curve)	15	10	10	10
Stabilize Shoulders (Intersection)	10	5	5	5

One accident reduction factor study (SDDOT, 1998) evaluated sixty-two hazardous sites and attempted to quantify accident reduction factors (ARFs) for the sites. These ARFs were calculated by dividing the total number of crashes following an improvement project by the total number from previous years. A value greater than one, therefore, represents an increase in the number of crashes. Shoulder widening resulted in an ARF of 0.80 (a reduction in crashes). It is important to note that of the sixty-two improvement sites, only one site involved shoulder widening so this ARF is from a single data point.

Zegeer et. al. (1987) found for shoulder widths between 0 and 12 feet, the percent reduction in related crashes as a result of adding unpaved shoulders would result in 13, 25, and 35-percent reduction in related crashes for 2, 4, and 6-feet of widening, respectively.

A 1991 study (Zegeer et. al., 1991) determined the percent reduction in crashes due to unpaved shoulder widening as represented in the following table.

Table A-32. Zegeer Unpaved Shoulder Widening Crash Reduction Estimates

Total Amount of Shoulder Widening (ft.)		Percent Crash Reduction for Unpaved Shoulder Widening
Total	Per Side	
2	1	3
4	2	7
6	3	10
8	4	13
10	5	16
12	6	18
14	7	21
16	8	24
18	9	26
20	10	29

b. Pave Existing Graded Shoulder of Suitable Width

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the paving of shoulders (Agent et. al., 1996).

Table A-32. Kentucky Paved Shoulder Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Pave Shoulder (All Crashes)	3	18
Pave Shoulder (Run-off-Road Crashes only)	2	15
Literature Review Estimates:		
Pave Shoulder (All Crashes)	1	20
Researcher's Resulting Estimates:		
Pave Shoulder (All Crashes)	---	15

Hadi et. al. (1995b) determined that based on a Florida study data of 1988-1991 no significant relationship could be found between shoulder type and crashes. The analysis model evaluated the total shoulder width and did not separate the width of paved and unpaved shoulders.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reduction estimated is not directly applicable to moderately or mildly hazardous locations. Locations where the shoulders were paved resulted in the following estimated values.

Table A-33. FHWA Shoulder Improvement Crash Reduction Estimates

Countermeasure	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Pave Shoulders (Tangent)	5	5	10	10
Pave Shoulders (Horizontal Curve)	15	15	15	15
Pave Shoulders (Intersection)	10	10	10	10

Zegeer et. al. (1987) found for shoulder widths between 0 and 12 feet, the percent reduction in related crashes as a result of adding paved shoulders is 16-percent for 2-feet of widening, 29-percent for 4-feet of widening, and 40-percent for 6-feet of widening.

c. *Widen and Pave Existing Paved Shoulder*

In 1995, a University of Florida study (Hadi et. al., 1995b) concluded that for rural two-lane highways increasing the total shoulder width (paved and unpaved) from 3-feet to 9-feet was found to decrease the total crash rate by 8.62-percent and the injury crash rate by 11.85-percent.

A 1991 study (Zegeer et. al., 1991) determined the percent reduction in crashes due to paved shoulder widening as represented in the following table.

Table A-34. Zegeer Shoulder Improvement Crash Reduction Estimates

Total Amount of Shoulder Widening (ft.)		Percent Crash Reduction for Paved Shoulder Widening
Total	Per Side	
2	1	4
4	2	8
6	3	12
8	4	15
10	5	19
12	6	21
14	7	25
16	8	28
18	9	31
20	10	33

7. Add Rumble Strips

The literature regarding the influence of the addition of rumble strips to the roadway environment is limited.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for addition of rumble strips (Agent et. al, 1996).

Table A-35. Kentucky Rumble Strip Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates: Rumble Strips	10	29
Literature Review Estimates: Rumble Strips	6	21
Researcher's Resulting Estimates: Rumble Strips	---	25

A study performed by Creasy and Agent (1985), based on a combination of 42 literature reviews, 22 state surveys and a before-after analysis, provided a subjective estimate that a 25-percent reduction should occur in total crashes due to the addition of rumble strips.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent crash reduction for several countermeasures. This study was based on improvements at hazardous locations. The authors emphasize the percent crash reductions estimated are not directly applicable to moderately or mildly hazardous locations. Locations where rumble strips were added resulted in the estimated values depicted in the following table.

Table A-36. FHWA Rumble Strips Crash Reduction Estimates

Countermeasure – Add rumble strips	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Horizontal curve	30	60	40	25
Intersection	20	50	30	15
Bridge	30	60	40	25
Railroad grade crossing	10	10	10	10

8. Improve Roadway Access Management

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of a frontage road (Agent et. al., 1996).

Table A-37. Kentucky Driveway Density Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Frontage Road	7	39
Literature Review Estimates:		
Frontage Road	1	40
Researcher's Resulting Estimates:		
Frontage Road	---	40

Hadi et. al. (1995a) developed models based on Florida crash data from 1988 to 1991. They concluded the presence of an additional intersection in a rural two-lane road section increased the mid-block crash rate and the injury crash rate by 6.07 and 6.19-percent respectively.

Schoppert (1957) used regression analysis to estimate the relationship between traffic crashes and roadway elements for rural two-lane highways with gravel shoulders in Oregon. He based his study on crash data from 1952, 53 and 54. He concluded that access to highways through driveways or intersections was directly related to crashes at all AADT levels. Residential driveways also showed a positive relationship to crashes in all AADT ranges, but the higher the density of residential driveways, the higher the number of crashes.

Vogt and Bared (1998) developed crash prediction models for two-lane rural roads. The study included crash data from Minnesota and Washington for 1985-89 and 1993-95 respectively. The final model indicated that reducing driveway density results in a reduced number of crashes.

Dart and Mann (1970) developed a model to represent the relationship between crash rates and the number of traffic conflict points. The study was based on crash and roadway information from 1962 to 1966 in the state of Louisiana. Traffic conflict points are defined as the total number of traffic access points on both sides per mile of highway section. These access points include only minor road intersections (intersections with major roads were considered as break points between study sections) and principal access driveways to abutting property along highway section. The researchers concluded that traffic conflict points per mile is one of the two most important factors affecting crash rates. This conclusion was based on interactions with traffic volume.

Ivan and O'Mara (1997) developed a model to represent the relationship between traffic conditions, geometric variables, and highway crash rates. The model utilized a Connecticut database that contained crash and roadway information for the period

1991 through 1993. The researchers found that for all evaluated factors, the one that had the greatest influence on crash rates was the number of intersections per mile.

D. ROADSIDE IMPROVEMENTS

1. Install or Upgrade Guardrail

The literature regarding the addition of guardrail favors its placement to enhance safety. Many of the studies include subjective assessment, but a few evaluated before and after conditions to determine countermeasure effectiveness.

A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 55-percent reduction should occur in the number of fatal crashes due to the addition of guardrail. Similarly, a 35-percent reduction should occur in the number of injury crashes due to the guardrail addition. An Indiana study (Ermer et. al., 1992) estimated crash reduction factors based on a before-after study and combined with historic analyses in the state of Indiana. The installation of guardrail rated an estimated 4-percent reduction in total crashes, while the replacement of guardrail rated a 7-percent reduction value.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent reduction for several countermeasures. This study was based on improvements at hazardous conditions. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where guardrail was installed resulted in the estimated values shown below.

Table A-38. FHWA Guardrail Installation Crash Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
General Guardrail Installation	5	50	15	-5

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the installation of guardrail (Agent et. al., 1996).

Table A-39. Kentucky Guardrail Installation Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Install Guardrail (All Crashes)	17	22
Install Guardrail (Fatal Crashes Only)	6	64
Install Guardrail (Injury Crashes Only)	6	31
Upgrade Guardrail (All Crashes)	11	8
Upgrade Guardrail (Fatal Crashes Only)	4	51
Upgrade Guardrail (Injury Crashes Only)	5	37
Literature Review Estimates:		
Install Guardrail (All Crashes)	7	20
Install Guardrail (Fatal Crashes Only)	3	68
Install Guardrail (Injury Crashes Only)	3	32
Upgrade Guardrail (All Crashes)	10	10
Researcher's Resulting Estimates:		
Install Guardrail (All Crashes)	---	5
Install Guardrail (Fatal Crashes Only)	---	65
Install Guardrail (Injury Crashes Only)	---	40
Upgrade Guardrail (All Crashes)	---	5
Upgrade Guardrail (Fatal Crashes Only)	---	50
Upgrade Guardrail (Injury Crashes Only)	---	35

2. Upgrade Guardrail End Treatment / Add Impact Attenuator

The literature dealing with the effects of end treatment on crashes is limited. Generally, the improvement of guardrail end treatments results in a reduction in the severity of crashes.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for upgrading the end treatment. (Agent et. al., 1996).

Table A-40. Kentucky Guardrail End Treatment Crash Reductions Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Upgrade End Treatment	1	10
Install Impact Attenuator (All Crashes)	16	29
Install Impact Attenuator (Fatal Crashes)	4	75
Install Impact Attenuator (Injury Crashes)	4	50
Literature Review Estimates:		
Upgrade End Treatment	6	35
Install Impact Attenuator (All Crashes)	10	31
Install Impact Attenuator (Fatal Crashes)	3	65
Install Impact Attenuator (Injury Crashes)	3	36
Researcher's Resulting Estimates:		
Install Impact Attenuator (All Crashes)	---	5
Install Impact Attenuator (Fatal Crashes)	---	75
Install Impact Attenuator (Injury Crashes)	---	50

Wattleworth et. al. (1988) developed accident reduction factors related to crash experience in Florida. The researchers performed before-after analysis of crash data from three years before and three years after implementation of the guardrail end treatment safety countermeasure. A 10-percent reduction in the number of total crashes and 55-percent in the number of fatal crashes was estimated due to end treatment of guardrail.

3. Clear Zone Improvements

Several feasible improvements fall within the general description of "Clear Zone Improvements." These are individually identified and reviewed in the following paragraphs.

a. Widen Clear Zone

The literature regarding the improvement of the clear zone is minimal. The primary source of information should be the Roadside Design Guide (AASHTO, 1996).

Illinois researchers (Boyce et. al., 1989) attempted to find a relationship and cost justification between acceptable clear zone and average daily traffic (ADT). They found little evidence to indicate a specific clear zone width would be cost-effective for a roadway in a certain ADT class. They did, however, note that crash frequency generally declines with increasing clear zone width and increases with increasing ADT.

b. Flatten Side Slope

The literature regarding the flattening of side slopes is based upon both subjective assessment and analytical evaluation.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction when the side slope is "flattened" (Agent et. al., 1996).

Table A-41. Kentucky Flatten Side Slope Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Flatten Side Slopes (All Crashes)	11	30
Flatten Side Slopes (Run-Off-Road Crashes Only)	2	46
Literature Review Estimates:		
Flatten Side Slopes (All Crashes)	10	19
Researcher's Resulting Estimates:		
Flatten Side Slopes (All Crashes)	---	30

Illinois researchers (Boyce et. al., 1989) evaluated the effect of roadside characteristics on crashes and determined that roads with steep lateral slopes ($>$ 3:1) and narrow clear zones (□15 feet) experienced over twice as many crashes per mile as roads with flat lateral slopes (□5:1) and wide clear zones ($>$28 feet). Unfortunately, a companion cost benefit analysis that evaluated flattening side slopes and removing affected fixed obstacles indicated the improvement cost exceeded the savings from the predicted reduction in run-off-road crashes.

A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 15-percent reduction should occur in total crashes due to the flattening of the side slope.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent reduction for several countermeasures. This study was based on improvements at hazardous conditions. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where side slope improvements were implemented resulted in the following estimated values.

Table A-42. FHWA Flattening Side Slope Crash Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Flatten side or back slope	30	75	50	20
Round ditches	5	10	10	5
Remove pavement edge dropoffs (tangent section)	25	15	15	15
Remove pavement edge dropoffs (horizontal curve)	20	20	20	20

Zegeer et. al. (1987) found the rate of single-vehicle crashes decreases steadily for side-slopes of 3:1 to 7:1 or flatter. However, they observed only a slight reduction in single-vehicle crashes for a 3:1 side slope compared to a side slope of 2:1 or steeper.

In a follow-up paper, Zegeer et. al. (1988) developed the following table for expected percent reduction in single-vehicle crashes due to side slope flattening.

Table A-43. Zegeer Flattening Side Slope Expected Crash Reduction Estimates

Side Slope Ratio in Before Condition	Side Slope Ratio in After Condition				
	3:1	4:1	5:1	6:1	7:1 or Flatter
2:1	2	10	15	21	27
3:1	0	8	14	19	26
4:1	---	0	6	12	19
5:1	---	---	0	6	14
6:1	---	---	---	0	8

c. Relocate Fixed Object

The literature regarding the relocation of fixed objects is based upon both subjective assessment and analytical evaluation.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the relocation of fixed objects (Agent et. al., 1996).

Table A-44. Kentucky Fixed Object Relocation Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Relocate Fixed Objects (All Crashes)	10	41
Relocate Fixed Objects (Fatal Crashes Only)	4	40
Relocate Fixed Objects (Injury Crashes Only)	4	15
Relocate Fixed Objects (Run-Off-Road Crashes Only)	2	55
Literature Review Estimates:		
Relocate Fixed Objects (All Crashes)	2	42
Relocate Fixed Objects (Fatal Crashes Only)	2	40
Relocate Fixed Objects (Injury Crashes Only)	2	15
Researcher's Resulting Estimates:		
Relocate Fixed Objects (All Crashes)	---	25
Relocate Fixed Objects (Fatal Crashes Only)	---	40
Relocate Fixed Objects (Injury Crashes Only)	---	25

Benekohal and Hashmi (1990) evaluated crashes for a number of roadways where improvements (of a large variety) occurred. One general project conclusion was that the fixed objects most frequently involved in run-off-the-road crashes were guardrails, highway signs, fences, trees, and utility poles (82-percent to 84-percent of all objects struck). They encouraged utility pole relocation as a reasonable safety countermeasure. Zegeer and Cynecki (1984) evaluated utility pole countermeasure effectiveness conditions. They found that increasing lateral pole offset causes a reduction in utility pole crashes but may contribute to an increase in other run-off-road crashes (possibly because if the pole is relocated another object like a tree may be impacted). They found increasing lateral placement reduces run-off-road utility pole crash severity.

A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 40-percent reduction should occur in fatal crashes due to the relocation of fixed objects. Similarly, a 15-percent reduction should occur in injury only crashes after relocation of fixed objects.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent reduction for several countermeasures. This study was based on improvements at hazardous conditions. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where fixed objects were either removed or relocated resulted in the estimated values shown below.

Table A-45. FHWA Fixed Object Relocation Crash Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Remove / Relocate Fixed Objects	60	65	60	55

d. Remove Fixed Object

The literature regarding the removal of fixed objects is based upon both subjective assessment and analytical evaluation.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the removal of fixed objects (Agent et. al., 1996).

Table A-46. Kentucky Fixed Object Removal Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
Remove Fixed Objects (All Crashes)	15	32
Remove Fixed Objects (Fatal Crashes Only)	8	50
Remove Fixed Objects (Injury Crashes Only)	8	17
Remove Fixed Objects (Run-Off-Road Crashes Only)	2	55
Literature Review Estimates:		
Remove Fixed Objects (All Crashes)	10	22
Remove Fixed Objects (Fatal Crashes Only)	3	53
Remove Fixed Objects (Injury Crashes Only)	3	17
Researcher's Resulting Estimates:		
Remove Fixed Objects (All Crashes)	---	30
Remove Fixed Objects (Fatal Crashes Only)	---	50
Remove Fixed Objects (Injury Crashes Only)	---	30

Benekohal and Hashmi (1990) evaluated crashes for a number of roadways where improvements (of a large variety) occurred. One general research conclusion indicated that the fixed objects most frequently involved in run-off-the-road crashes were guardrails, highway signs, fences, trees, and utility poles (82-percent to 84-percent of all objects struck). They encouraged tree removal as a reasonable safety countermeasure. Zegeer and Cynecki (1984) evaluated utility pole countermeasure effectiveness conditions. They found that completely removing utility poles by placing utility lines underground effectively eliminates utility pole crashes, but may cause an increase in other run-off-road crashes (the vehicle hits another object). This countermeasure also reduces the average percent of injury and fatal crashes.

A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 50-percent reduction should occur in fatal crashes due to the removal of fixed objects. Similarly, a 15-percent reduction should occur in injury only crashes after removal of fixed objects.

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent reduction for several countermeasures. This study was based on improvements at hazardous conditions. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where fixed objects were either removed or relocated resulted in the following estimated values.

Table A-47. FHWA Fixed Object Removal Crash Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Remove / Relocate Fixed Objects	60	65	60	55

One accident reduction factor study (SDDOT, 1998) evaluated sixty-two hazardous sites and attempted to quantify accident reduction factors (ARFs) for the sites. These ARFs were calculated by dividing the total number of crashes following an improvement project by the total number from previous years. A value greater than one, therefore, represents an increase in the number of crashes. Removal of a fixed object resulted in an ARF of zero (or a 100-percent crash reduction). It is important to note that of the sixty-two improvement sites, only one site involved removal of fixed objects so this ARF is from a single data point.

A 1970’s study in Georgia (Wright & Mak, 1972) determined that the presence of fixed objects along the roadside has little effect on off-road accident experience. Off-road accident rates are not closely related to the presence of continuous roadside objects. Basically, this means that a person in no more likely to run off the road and crash at locations with roadside objects as at locations without objects.

e. Convert Object to Breakaway

The literature dealing with converting a roadside object to a breakaway type is very sparse. But the few studies that have dealt with this countermeasure have provided positive feedback on its effects on the severity of crashes.

Based on the combined estimates resulting from a survey of 43 states and the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for converting an object to a breakaway type. (Agent et. al., 1996).

Table A-48. Kentucky Breakaway Fixed Object Crash Reduction Estimates

Category -- Convert to Breakaway	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
All Crashes	15	28
Fatal Crashes	4	60
Injury Crashes	4	30
Run-off-the-Road Crashes	2	45
Literature Review Estimates:		
All Crashes	11	52
Fatal Crashes	1	60
Injury Crashes	1	30
Researcher's Resulting Estimates:		
All Crashes	---	5
Fatal Crashes	---	60
Injury Crashes	---	30

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent reduction for several countermeasures. This study was based on improvements at hazardous conditions. The authors emphasize the percent crash reductions estimated are not directly applicable to moderately or mildly hazardous locations. Locations where breakaway poles were installed resulted in the following estimated values.

Table A-49. FHWA Breakaway Utility Pole Crash Reduction Estimates

Countermeasure	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Install breakaway poles	0	60	20	-15

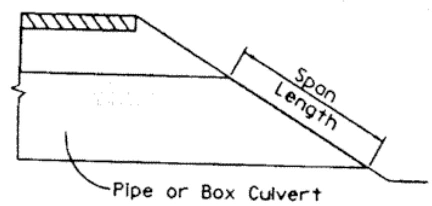
Creasy and Agent (1985) performed a study based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis. They provided a subjective estimate that a 60-percent reduction in fatal crashes and 30-percent reduction in injury crashes should occur due to the conversion of roadside signs to breakaway signs. Installation of breakaway utility poles results in reductions of 40- and 30-percent in fatal and injury related crashes. It is important to note, breakaway utility poles must be supported by adjacent rigid utility poles, so application of this strategy is not feasible systemically but rather individually.

Wattleworth et. al. (1988) developed accident reduction factors related to crash experience in Florida. The researchers performed before-after analysis of crash data from three years before and three years after implementation of the breakaway safety countermeasure. A 35-percent reduction in the number of total crashes was estimated due to conversion of an obstacle to breakaway.

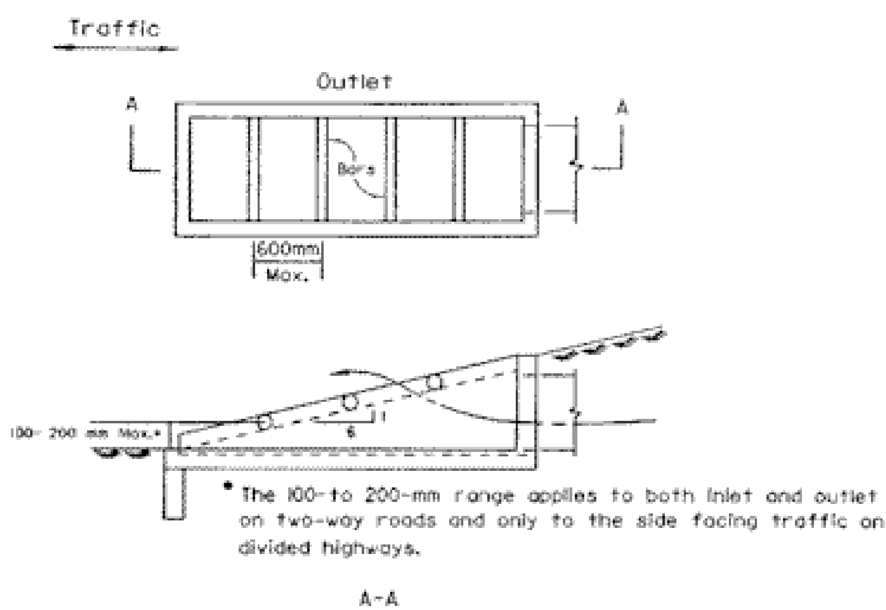
f. Construct Traversable Drainage Structure

The literature regarding construction of a traversable drainage structure is limited. The primary reference for guidance in this type of countermeasure is the Roadside Design Guide (AASHTO, 1996); however, this is a manual that is a guideline and does not include assessment of different treatments.

The "blending" of the slope of the drainage structure to the slope of the embankment assists in providing a traversable design. The picture shown below is from the Roadside Design Guide (AASHTO, 1996) and represents this traversable concept.



For large drainage structures, the drainage design often should include bars spaced across the opening. One of the purposes of these bars is to provide traversability for vehicle tires as they drive across the large opening to the drainage structure.



E. LIGHTING

1. Add Street Lights to Road Segment

The literature regarding the addition of street lights favors placement of them to enhance safety. Many of the studies include subjective assessment, but there is also a strong literature base that includes quantified assessment in favor of street light placement.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers developed the following estimation of percent crash reduction for the addition of street lights (Agent et. al., 1996).

Table A-50. Kentucky Addition of Street Light Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
General Use (All Crashes)	6	25
New Roadway (All Crashes)	10	28
New Roadway (Night Crashes Only)	12	45
Literature Review Estimates:		
General Use (All Crashes)	5	10
New Roadway (All Crashes)	7	19
New Roadway (Night Crashes Only)	5	38
Researcher's Resulting Estimates:		
General Use (All Crashes)	---	25
General Use (Night Crashes Only)	---	50
Roadway Segment (All Crashes)	---	25
Roadway Segment (Night Crashes Only)	---	45

A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 25-percent reduction should occur in total crashes due to the addition of street lights. For nighttime crashes only, a reduction of 50-percent should be expected. An Indiana study (Ermer et. al., 1992) estimated crash reduction factors based on a before-after study and combined with historic analyses in the state of Indiana. The installation of street lights rated an estimated 37-percent reduction in total crashes. One accident reduction factor study (SDDOT, 1998) evaluated sixty-two hazardous sites and attempted to quantify accident reduction factors (ARFs) for the sites. These ARFs were calculated by dividing the total number of crashes following an improvement project by the total number from previous years. A value greater than one, therefore, represents an increase in the number of crashes. Addition of roadway lighting resulted in an ARF of 0.83 (or a decrease in crashes).

A comprehensive study for the FHWA (Smith et. al., 1983) estimated percent reduction for several countermeasures. This study was based on improvements at hazardous conditions. The authors emphasize the percent crash reduction estimated are not directly applicable to moderately or mildly hazardous locations. Locations where lighting was added adjacent to the road resulted in the estimated values shown below.

Table A-51. FHWA Street Lighting Crash Reduction Estimates

Alignment Changes	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property Damage Only
Add Lighting in Horizontal Curve, at an Intersection, or at a Bridge	10	15	15	10
Add Lighting at Tangent Section	---	10	5	5

2. Add Lighting to Intersection

Wortman et. al. (1972) developed a methodology that measures the effects of illumination of rural at-grade intersections. The researchers determined that though the severity of crashes is not directly related to illumination, illumination does reduce the frequency of nighttime crashes.

Preston and Schoenecker (1999) performed an extensive literature survey and estimated installation of intersection lighting resulted in a 25- to 50-percent reduction in the night time crash to total crash ratio. They further conducted a system-wide comparative crash analysis of 3,400 rural intersections along the Minnesota highway system and a before-after analysis of 12 intersections. The system-wide comparative analysis showed that the nighttime crash rate for intersections with and without street lighting was 0.47 and 0.63 respectively. This represents a 25-percent lower nighttime crash rate at rural intersections with street lighting. From the before-after study, the researchers determined where street lighting was installed they experienced an overall decrease in the nighttime crashes of approximately 40-percent.

Walker and Roberts (1976) performed a before-after study for three years immediately before and after lighting at 47 at-grade rural intersections. The results showed a 49-percent overall reduction in nighttime crashes.

3. Upgrade Street Lighting for Segment or Intersection

The literature regarding the improvement or upgrade of street lights is sparse, but it favors this countermeasure strategy to enhance safety.

Based on the combined estimates resulting from a survey of 43 states plus the District of Columbia and a comprehensive literature review, Kentucky researchers presented the following estimation of percent crash reduction for the upgrade of street lights (Agent et. al., 1996).

Table A-52. Kentucky Upgrade of Street Lights Crash Reduction Estimates

Category	Number of Estimates	Average Percent Crash Reduction
State Survey Estimates:		
General Use (All Crashes)	6	25
Upgrade Roadway (Night Crashes Only)	2	42
Literature Review Estimates:		
General Use (All Crashes)	5	10
Researcher's Resulting Estimates:		
General Use (All Crashes)	---	25
General Use (Night Crashes Only)	---	50
Roadway Segment (All Crashes)	---	25
Roadway Segment (Night Crashes Only)	---	45

An Indiana study (Ermer et. al., 1992) estimated crash reduction factors based on a before-after study and combined with historic analyses in the state of Indiana. The modernization of existing lighting rated an estimated 25-percent reduction in total crashes.

F. REGULATIONS

1. Enforce Speed Limits

The literature dealing with the effect of police enforcement of speed limits on the number of crashes is limited.

Dart (1977) used time series plots of speed, volume and crash data for North Carolina, Mississippi and Louisiana for the period of 1973 and 1974 to evaluate the probable role of police enforcement of speed limits on the number of crashes. The energy crisis in the fall of 1973 had brought about a reduction in the average speed to about 55 mph, which was assumed to be a fuel efficient speed. Though the speeds returned back to pre-crisis levels within 2 years, they were more uniform. The researcher identified strong indications that the increased enforcement levels of 1974 to 1976 are responsible for maintaining the uniform and safer speed levels. For example, Louisiana data for 1974 and 1975 (compared with data from 1971 and 1972) showed not only significantly fewer fatalities on rural highways, but also large reductions in the percentage of all rural crashes and of rural fatal crashes for which excessive speed was cited as a contributing factor.

IV. APPENDIX B. REFERENCES

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