SOUTHEAST REGIONAL FATAL STUDY --
A CAUSAL CHAIN ANALYSIS IN NORTH CAROLINA

FINAL REPORT

Prepared for the North Carolina Department of Transportation
By UNC Highway Safety Research Center

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16. Abstract

This project completed the North Carolina portion of the pooled fund Southeast Fatal Analysis Project. In addition to completing this portion of the causal chain analysis for NC Crashes, the project developed a ranked comprehensive list of candidate safety countermeasures likely to be effective for reducing both the number and severity of fatal crashes on two-lane rural roads in North Carolina. This list includes countermeasures ranked according to their expected influence on fatal crash frequency and severity for two-lane rural roads.

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For the North Carolina Department of Transportation

By the University of North Carolina Highway Safety Research Center

James Kevin Lacy

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TABLE OF CONTENTS

LIST OF TABLES

BACKGROUND

In 1995, North Carolina ranked 9th of the 50 states in terms of total highway-related deaths, with 1,418 people killed. The fatality rate of 1.9 people killed per 100 million vehicle miles of travel ranked North Carolina 20th nationally (1). Table 1 shows the fatalities for each state in the region and how the region compares with the nation as a whole. In response to these trends in traffic fatalities, the North Carolina DOT, other state DOT's in Region IV and the Federal Highway Administration have sought to better understand and prevent fatal crashes and their causal factors.

The eight southeastern states representing the Federal Highway Administration's former Region IV, namely Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee have consistently ranked among the highest nationally with respect to number of fatal crashes and fatal crash rates compared to other former FHWA regions over recent years. From a national perspective, it is disconcerting that an entire region appears over represented with respect to these gross statistics. The statistics shows that the region experienced approximately 25 percent of the total nation's fatalities and a fatality rate about 20 percent above the national mean rate. Recognizing this overrepresentation of the Southeast Region, a pooled fund study was initiated to attempt to isolate contributing factors and to identify potential solution strategies.

Table 1. Former FHWA Region IV 1995 Safety Record - Total Urban and Rural

State	Fatalities		Fatality Rate[1]	
	Number	**National Rank**	**Number**	**National Rank**
Alabama	1,113	12	2.2	11
Florida	2,805	3	2.2	12
Georgia	1,488	7	1.7	26
Kentucky	849	20	2.1	16
Mississippi	868	19	2.9	1
North Carolina	1,448	9	1.9	20
South Carolina	881	18	2.3	8
Tennessee	1,259	11	2.2	10
Mean Rank	**12.37**		**13.00**	
Total Region IV	**10,711**		**2.1**	
Total US	**41,798**		**1.7**	

[1] per 100 million vehicle-miles of travel

The goal of the regional pooled fund study entitled "Investigation and Identification of Principal Factors Contributing to Fatal Crashes in the Southeastern United States", is to better understand the causes of fatal crashes in eight southeastern states. The Georgia Institute of Technology is conducting and overseeing the regional project. In conjunction with this pooled fund study, the states are conducting a cooperative project to develop a comprehensive list of countermeasures likely to be effective in educing the severity and frequency of fatal crashes on two-lane rural highways.

The first phase of the pooled fund study examined the roadway, crash, vehicle, individual, and environmental factors that are associated with fatal and serious injury crashes in North Carolina between 1993 and 1997. The initial analysis identified road classifications, geographic characteristics, and time trends related to severe crashes using Highway Safety Information Systems (HSIS) segment and crash data. HSIS system highways in North Carolina include the state primary and major secondary routes. Non-HSIS roads include local streets and minor secondary streets. Both HSIS and non-HSIS data are used in the more detailed section of the study to analyze the severe crash factors on all HSIS highways, two-lane urban HSIS highways, two-lane rural HSIS highways, urban non-HSIS routes, and rural non-HSIS routes (2).

In the phase I report, a test of the standard error of a binomial proportion is used to find the statistical significance of the roadway, crash, vehicle, individual, and environmental factors related to severe crashes. The initial analysis shows that urban and rural two-lane roads are associated with the highest crash severity, mountain counties have the highest proportion of severe crashes, and crash severity remained stable for some of the most severe crash types. Factors associated with significantly high crash severity on all roadway types include curve, run-off-road, utility pole, tree, head-on, pedestrian, bicycle, darkness, and alcohol use. The final section of the report recommends countermeasures that can be used to reduce the incidence of fatal and serious injury crashes associated with these factors. The full text of this report is available at http://www.hsrc.unc.edu/pdf/2001/identofsevere.pdf.

As part of the Regional Pooled Fund Study, each state was to complete a causal chain analysis of the 150 randomly selected rural two-lane road fatal crashes. This study is the North Carolina portion of this part of the regional effort. This project included qualitative reconstruction of 150 randomly selected fatal crashes, determination of the most likely contributing factors, and development the sequence of events leading up to the fatal crash. Additionally, a list of predetermined countermeasures was evaluated to determine their potential effectiveness to prevent or reduce the severity of the crash. A crash database was constructed containing the subjective opinions of four engineers in North Carolina concerning the potential effectiveness of the countermeasures; crash level data; vehicle level data; driver level data; and roadway characteristic data.

Project Objective

The project objectives included:

- To complete the North Carolina portion of the causal chain analysis for the regional pooled fund study for a sample of fatal crashes.
- To develop a ranked comprehensive list of candidate countermeasures likely to be effective for reducing both the number and severity of fatal crashes on two-lane rural roads in North Carolina. This list will include countermeasures ranked according to their expected influence on fatal crash frequency and severity for two-lane rural roads. The list will be based upon the findings of causal analyses of actual fatal crashes.

North Carolina Portion of the Southeast Region Fatal Analysis Effort

The remaining North Carolina portion of the southeast region fatal analysis effort included providing the subjective crash data for the 150 fatal crashes that occurred in North Carolina and previously selected in the first phase of the regional study. This included completing a qualitative crash reconstruction and completing evaluations effectiveness forms for the 30 countermeasures provided by Georgia Institute of Technology and providing the data to Georgia Tech in an electronic database.

Qualitative Crash Reconstruction

This portion of the study utilized the data and photographs collected in the first phase of the study, along with the crash data and reporting officer's diagram and narrative to develop a qualitative crash reconstruction for each of the 150 crashes. All of the crashes identified in the first phase of the study occurred more than two years prior to the actual site visits. This time lapse makes it very difficult to determine some features and situations that may have affected the crash. For example, in some cases, the pavement markings appeared to have been repainted since the date of the crash.

The qualitative crash reconstruction primarily consisted of developing a sequence of events, geographically locating on a map, identifying potential contributing factors and presenting the information from the crash report and roadway inventory in an easy to understand format. All the information was placed in a separate file for each crash along with photographs showing the crash site from different perspectives. Appendix A provides and example of the contents of a file for one crash.

Countermeasures Evaluated

As part of the regional pooled fund study, Georgia Institute of Technology, in cooperation with the FHWA and Georgia Department of Transportation developed a list of countermeasures with the potential of reducing fatal crash occurrences and injury severity on two-lane rural roads. Table 2 shows the list of 30 countermeasures provided by the regional study. Appendix B contains the countermeasure handbook used by the engineers to evaluate the potential effectiveness of each countermeasure to reduce the severity or prevent the occurrence of the 150 randomly selected fatal crashes.

The NCDOT reviewed the list of 30 countermeasures and identified several other categories to consider adding to the regional list of countermeasures. The additional crash countermeasures that were reviewed for consideration were:

- Tree crashes
- Utility pole crashes
- Large trucks
- Older drivers
- Intersection related crashes (within 150 feet of an intersection)
- Pavement friction crashes (mainly run-off-road during wet road conditions)
- Road surface defects

- Bridge-rail and bridge-end crashes

The project team reviewed the 150 fatal crashes to determine if there were a sufficient number of crashes available to make an inference about these categories, i.e., are there enough crashes in the sample to justify the expense of expanding the Countermeasure Handbook. The Countermeasure Handbook contains an extensive amount of information about specific countermeasures; their application; and some information of their effectiveness based on past research and studies. After conducting the analyses of the 150 fatal crashes, recommendations were presented to the technical advisory committee and the conclusion was that there **were not a sufficient number of crashes in these other categories to warrant the additional expense** to add to the countermeasure evaluation manual for this project. Appendix C provides the documentation for this task and was an interim deliverable.

Table 2. Countermeasure List Used in the Regional Study

Code	Counter Measure	Category
A 1	Add/Upgrade Edgeline	Pavement Marking
A 2	Add/Upgrade Centerline	Pavement Marking
A 3	Add/Upgrade No-Passing-Zone Lines	Pavement Marking
A 4	Add Raised Pavement Markings (RPM's) to Centerline	Pavement Marking
B 1	Warning Sign	Traffic Signs
B 2	Advisory Speed Sign	Traffic Signs
B 3	Chevron Alignment Sign	Traffic Signs
B 4	Post Delineator	Traffic Signs
C 1	Geometric Realignment (Horizontal, Vertical,	Roadway Improvements
C 2	Modify Superelevation / Cross Slope	Roadway Improvements
C 3	Improve Sight Distance without Geometric	Roadway Improvements
C 4	Widen Travel Lanes / Pavement Width	Roadway Improvements
C 5	Add Turn Lane (Left/Right)	Roadway Improvements
C 6a	Improve Shoulder - Add or Widen Graded or Stabilized	Roadway Improvements
C 6b	Improve Longitudinal Shoulder - Pave Existing Graded	Roadway Improvements
C 6c	Improve Longitudinal Shoulder - Widen and Pave	Roadway Improvements
C 7	Add Rumble Strips	Roadway Improvements
C 8	Improve Roadway Access Management	Roadway Improvements
D 1	Install or Upgrade Guardrail	Roadside Improvements
D 2	Upgrade Guardrail End Treatment / Add Impact	Roadside Improvements
D 3a	Clear Zone Improvements - Widen Clear Zone	Roadside Improvements
D 3b	Clear Zone Improvements - Flatten Side Slope	Roadside Improvements
D 3c	Clear Zone Improvements - Relocate Fixed Object	Roadside Improvements
D 3d	Clear Zone Improvements - Remove Fixed Object	Roadside Improvements
D 3e	Clear Zone Improvements - Convert Object to	Roadside Improvements
D 3f	Clear Zone Improvements - Traversable Drainage	Roadside Improvements
E 1	Add Lighting (Segment)	Lighting
E 2	Add Lighting (Intersection)	Lighting
E 3	Upgrade Lighting (Segment/Intersection)	Lighting
F 1	Enforce Speed Limits	Regulations

Method for Completing Countermeasure Evaluation

To facilitate the organization, logistics and analysis of the countermeasure evaluation results, a Microsoft Access database was developed with data entry screens. The reviewing engineers entered their responses for each countermeasure for all 150 fatal crashes directly into the database. Appendix B provides examples of the countermeasure evaluation form used in North Carolina rather than the paper form.

Subjective Crash Database

The subjective database contains information about the crash site, vehicles, drivers, and responses provided by four engineers that evaluated the countermeasures for all 150 crashes. The data resides in a Microsoft Access Database and was the primary deliverable for this project. The database was sent to Dr. Simon Washington on December 4, 2001. A complete copy of the database is provided with this final report on a compact disk and requires Microsoft Access to open.

Develop Subjective Estimates Crash modification Factors (q_{subj})

The subjective estimates include crashes where all four engineers provided a response other than "N/A", not applicable and some countermeasures did not have any crashes that received responses from all evaluating engineers. Table 3 shows the number of crashes, the subjective mean and standard deviation and the subjective crash modification factor for each countermeasure.

The most likely value for the crash modification factor, θ_{subj}, is based upon the values of α, β and the subjective mean. The shape parameters, α and β, can be determined by the fact that $\alpha+\beta = n$ and $\alpha=m_{\beta}*n$, where n is the sample size and m_{β} is estimated by (3). Table 3 shows the necessary information to calculate the likely values of the crash modification factors for each of the countermeasures where all four engineers provided responses.

The highlighted rows indicate the top five countermeasures based upon the randomly selected 150 crashes, the 30 countermeasures evaluated and the subjective opinions of the four evaluating engineers. Notice that four of the top five countermeasures involve roadside improvements. In addition, notice that the estimates for θ_{subj} are quite different from the estimates of the means alone, the fourth column in Table 4.

Table 3. Subjective estimates of the crash modification factors

Code	Counter Measure	Fatal Crashes	Mean m_{subj}	Std. Dev. s_{subj}	a	b	q_{subj}	Rank
A 1	Add/Upgrade Edgeline	10	0.93	0.13	9.34	0.65	1.00	13
A 2	Add/Upgrade Centerline	7	0.94	0.20	6.58	0.41	1.00	13
A 3	Add/Upgrade No-Passing-Zone Lines	0						
A 4	Add Raised Pavement Markings (RPM's) to CL	16	0.93	0.16	15.0	0.99	1.00	13
B 1	Warning Sign	14	0.84	0.17	11.8	2.14	0.91	7
B 2	Advisory Speed Sign	10	0.87	0.16	8.76	1.23	0.97	11
B 3	Chevron Alignment Sign	8	0.85	0.16	6.84	1.15	0.98	12
B 4	Post Delineator	1	0.91	0.16	0.91	0.08	1.00	13
C 1	Geometric Realignment	12	0.86	0.16	10.4	1.56	0.94	9
C 2	Modify Superelevation / Cross Slope	0						
C 3	Improve Sight Distance w/o Geometric Realign	1	0.67	0	0.67	0.33	1.00	13
C 4	Widen Travel Lanes / Pavement Width	49	0.92	0.14	45.2	3.79	0.94	9
C 5	Add Turn Lane (Left/Right)	0						
C 6a	Improve Shoulder - Add or Widen Graded or Stabilized Shoulder	4	0.81	0.16	3.25	0.74	1.00	13
C 6b	Improve Longitudinal Shoulder - Pave Existing Graded Shoulder of Suitable Width	6	0.87	0.16	5.25	0.74	1.00	13
C 6c	Improve Longitudinal Shoulder - Widen and Pave Existing Shoulder	6	0.86	0.16	5.17	0.82	1.00	13
C 7	Add Rumble Strips	1	0.83	0.19	0.83	0.16	1.00	13
C 8	Improve Roadway Access Management	0						
D 1	Install or Upgrade Guardrail	12	0.56	0.24	6.75	5.24	0.58	2
D 2	Upgrade Gdrl End Trtmnt / Add Impct Attn.	0						
D 3a	Clear Zone Improvements - Widen Clear Zone	13	0.80	0.18	10.4	2.56	0.86	6
D 3b	Clear Zone Improvements - Flatten Side Slope	12	0.76	0.19	9.18	2.81	0.82	4
D 3c	Clear Zone Improvements - Relocate Fixed Obj.	0						
D 3d	Clear Zone Improvements - Remove Fixed Obj.	8	0.74	0.18	5.93	2.06	0.82	4
D 3e	Clear Zone Imp - Convert Object to Breakaway	0						
D 3f	Clear Zone Improvements - Traversable Drainage Structure	5	0.5	0.17	2.5	2.5	0.50	1
E 1	Add Lighting (Segment)	8	0.81	0.16	6.51	1.48	0.92	8
E 2	Add Lighting (Intersection)	1	0.83	0.19	0.83	0.16	1.00	13
E 3	Upgrade Lighting (Segment/Intersection)	0						
F 1	Enforce Speed Limits	39	0.71	0.30	27.8	11.2	0.73	3

Combine Subjective Estimates with Current Estimates of Crash Modification Factors (CMF) to Obtain Posterior Likelihoods of Theta

The current estimates of the crash modification factors are outlined in the *Countermeasure Handbook* provided in Appendix B. The combination of the two estimates requires a factor of reliability for the current estimate. The reliability factors assigned in this study where subjective and received low estimates if they were based upon opinions from state surveys and higher reliability factors if the estimates are based upon actual completed studies. Other elements such as the date of the study, the number of sites used in the study and the study methodology may have had some bearing on the subjective reliability factor.

The method used to combine the two estimates is based upon combining the shape parameters α and β. If α and β represent the shape parameters for the subjective estimates found in the previous section and α' and β' represent the shape parameters for the estimates from the current estimates from the *Countermeasure Handbook*, then the combined shape parameters are α'' and β'' where $\alpha'' = \alpha' + \alpha$ and $\beta'' = \beta' + \beta$. However, the reliability factor will have an effect on the estimates as mentioned. The higher the reliability factor, then more weight is given to the estimates from the literature. The final shape parameters used the reliability factor (r_f) in the following form.

$$\alpha'' = r_f \cdot \alpha' + (1- r_f) \cdot \alpha$$

$$\beta'' = r_f \cdot \beta' + (1- r_f) \cdot \beta$$

Table 4 provide the final estimates of the crash modification factors for the countermeasures evaluated based upon combining the subjective estimates and estimates from past research and surveys.

Notice the effect that combining the estimates had on the top five countermeasures. Because there were not any estimates available to include with the subjective estimate, the top countermeasure, D 3f, did not change. However, the second ranked countermeasure, D 1, crash modification factor changed from 0.58 to 0.7 after combining the subjective and previous estimates. Countermeasures C 1 and C 2 moved up into the top five, while D 3b and D 3d dropped out of the top five. The enforcement countermeasure, F 1, shifted from third to fourth in the combined estimates.

There were a few other countermeasures without estimates from previous work. There were also countermeasures where a subjective estimate was not produced. Using this process provides a systematic method to develop crash modification factors when research and evaluations do not provide such information. It also provides a method to supplement the information if the estimates from literature searches appear suspect. However, it is advisable to develop a method to assign the reliability factor based upon the merits of the work.

Table 4. Estimates of crash modification factors for evaluated countermeasures based upon combining subjective and past estimates.

Code	Counter Measure	No. of Estimates	m_{cur}	a'	b'	q_{cur}	r_f	a''	b''	q_{final}	Rank
A 1	Add/Upgrade Edgeline	30	0.85	25.50	4.50	0.88	0.10	3.14	1.35	1.00	17
A 2	Add/Upgrade Centerline	13	0.76	9.88	3.12	0.81	0.10	1.36	1.21	1.00	18
A 3	Add/Upgrade No-Passing-Zone Lines										
A 4	Add Raised Pavement Markings (RPM's) to CL	6	0.94	5.64	0.36	1.00	0.10	1.46	0.94	1.00	18
B 1	Warning Sign	11	0.70	7.70	3.30	0.75	0.10	2.70	1.15	0.89	8
B 2	Advisory Speed Sign	2	0.70	1.40	0.60	1.00	0.10	1.25	0.93	0.98	15
B 3	Chevron Alignment Sign	3	0.70	2.10	0.90	1.00	0.10	1.25	0.97	0.98	16
B 4	Post Delineator	13	0.80	10.36	2.64	0.85	0.10	1.11	1.16	1.00	18
C 1	Geometric Realignment	51	0.67	34.02	16.98	0.67	0.50	17.79	8.96	0.72	3
C 2	Modify Superelevation / Cross Slope										
C 3	Improve Sight Distance w/o Geometric Realign	16	0.69	11.04	4.96	0.72	0.50	5.69	2.98	0.75	5
C 4	Widen Travel Lanes / Pavement Width	15	0.78	11.70	3.30	0.82	0.50	7.75	2.12	0.92	11
C 5	Add Turn Lane (Left/Right)										
C 6a	Improve Shoulder - Add or Widen Graded or Stabilized Shoulder	16	0.80	12.80	3.20	0.84	0.30	4.36	1.66	0.92	10
C 6b	Improve Longitudinal Shoulder - Pave Existing Graded Shoulder of Suitable Width	1	0.80	12.80	3.20	1.00	0.30	4.36	1.66	0.93	12
C 6c	Improve Longitudinal Shoulder - Widen and Pave Exting shldrs	20	0.92	18.40	1.60	0.97	0.85	15.76	1.51	0.97	14
C 7	Add Rumble Strips	6	0.79	4.74	1.26	0.94	0.50	2.45	1.13	1.00	18
C 8	Improve Roadway Access Management	1	0.40	0.40	0.60	1.00	0.50		0.30	1.00	18
D 1	Install or Upgrade Guardrail	17	0.85	14.45	2.55	0.90	0.30	8.00	1.17	0.70	2
D 2	Upgrade Gdrl End Trtmnt / Add Impct Attn.	10	0.67	6.72	3.28	0.72	0.30		0.98	1.00	18
D 3a	Clear Zone Improvements - Widen Clear Zone			0.00	0.00			2.56	0.86	0.86	7
D 3b	Clear Zone Improvements - Flatten Side Slope	20	0.86	17.20	2.80	0.90	0.85	15.04	2.50	0.89	8
D 3c	Clear Zone Improvements - Relocate Fixed Obj.	2	0.58	1.16	0.84	1.00	0.50		0.42	1.00	18
D 3d	Clear Zone Improvements - Remove Fixed Obj.	10	0.78	7.80	2.20	0.85	0.50	4.93	1.51	0.84	6
D 3e	Clear Zone Imp - Convert Object to Breakaway										
D 3f	Clear Zone Improvements - Traversable Drainage Structure			0.00	0.00			2.50	0.50	0.50	1
E 1	Add Lighting (Segment)	5	0.90	4.50	0.50	1.00	0.30	2.39	0.79	0.96	13
E 2	Add Lighting (Intersection)	2	0.75	1.50	0.50	1.00	0.30	0.56	0.85	1.00	18
E 3	Upgrade Lighting (Segment/Intersection)	6	0.88	5.25	0.75	1.00	0.30		0.23	1.00	18
F 1	Enforce Speed Limits			0.00	0.00			11.20	0.73	0.73	4

Recommendations for Applying Results

The application of the findings of this study may be tempered because the crashes were a subset of all reported crashes. These crashes included 150 randomly selected rural-two-lane fatal crashes reported in North Carolina in 1997.

The recommended next step would be to find areas where the countermeasures may be applied. One such method would be to develop warranting criteria in the HSIP to identify locations where these countermeasures may be applied. However, it is recommended to expand the data to multiple years and to all reported crashes. Table 5 shows the countermeasures reviewed which are sorted by the crash modification factor, where the crash modification factor exceeded five percent.

Table 5. This list includes countermeasures ranked according to their expected influence on fatal crash frequency and severity for two-lane rural roads.

Code	Counter Measure	q_{final}	Crash Reduction Factor	Rank
D 3f	Clear Zone Improvements - Traversable Drainage Structure	0.5	50%	1
D 1	Install or Upgrade Guardrail	0.7	30%	2
C 1	Geometric Realignment	0.72	28%	3
F 1	Enforce Speed Limits	0.73	27%	4
C 3	Improve Sight Distance w/o Geometric Realign	0.75	25%	5
D 3d	Clear Zone Improvements - Remove Fixed Object.	0.84	16%	6
D 3a	Clear Zone Improvements - Widen Clear Zone	0.86	14%	7
B 1	Warning Sign	0.89	11%	8
D 3b	Clear Zone Improvements - Flatten Side Slope	0.89	11%	8
C 6a	Improve Shoulder - Add or Widen Graded or Stabilized Shoulder	0.92	8%	10
C 4	Widen Travel Lanes / Pavement Width	0.92	8%	11
C 6b	Improve Longitudinal Shoulder - Pave Existing Graded Shoulder of Suitable Width	0.93	7%	12

Another opportunity to apply the results of this project is in the driveway permit process and requirements. Since the traversable drainage structure countermeasure, D 3f, had the highest crash modification factor, it would be reasonable to require new driveways to be constructed so that they are traversable. This should include all new driveways, including residential driveways. This recommendation combined with a HSIP warrant to identify and treat potentially hazardous locations could reduce the risk of fatal crashes on rural two-lane roads.

Currently, NCDOT does not have a complete list of crash reduction factors for all countermeasures implemented. This process can be modified and used to develop a more complete list of crash modification factors. Since the process has already been developed through this project, the only components need to apply this methodology to other situations is the crash selection process. Once the crash selection process is developed, then the engineers would complete the same process and analyses that were used in this project. The resulting product would be a more complete list of crash reduction factors that NCDOT could use to help prioritize safety projects.

The last recommendation includes developing HSIP warranting criteria and working with the Governor's Highway Safety Program (GHSP) and law enforcement agencies to target speed enforcement. Such targeted programs could help identify locations and times where there are higher incidents of speed related crashes.

Summary of Recommendations

- Develop target crash type and Highway Safety Improvement Program warranting criteria to identify locations where countermeasures can be applied.
- Identify applications in policy and procedures, such as the driveway manual.
- Modify the procedures used in this study to complete a crash reduction factors list to help prioritize projects.
- Develop target crash type and HSIP listing and working through the Governor's Highway Safety Program and law enforcement agencies to focus speed enforcement.

Conclusion

This study reviewed only a select number of countermeasures and it would be preferable to evaluate more countermeasures than the 30 identified. However, the cost of developing the additional countermeasures prevented adding additional countermeasures in this study. If a similar program became standard practice during the review of all fatal crashes, then over time, a robust source of information concerning fatal crashes in North Carolina could be developed.

References

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(2) Herman Huang, Robert Schneider, Charles Zegeer, A.J. Khattak, V.J. Amerlynck, and J.K. Lacy. *Identification of Severe Crash Factors and Countermeasures in North Carolina – Final Report.* University of North Carolina for North Carolina Department of Transportation. Raleigh, North Carolina. August 2001

(3) Simon Washington, Karen Dixon, Jennifer Ogle, Peter Parsonson, and John Leonard. *Investigating of Countermeasures for Reducing Fatal Crashes in Georgia: A Causal Chain Analysis*. Georgia Institute of Technology. Atlanta, Georgia. May 1999

Appendix A. Example of Crash File

DMV-349 (Rev. 4/96) FATAL-1

THIS REPORT IS FOR THE USE OF THE DIVISION OF MOTOR VEHICLES. THE DATA IS COLLECTED FOR STATISTICAL ANALYSIS AND SUBSEQUENT HIGHWAY SAFETY PROGRAMMING. DETERMINATIONS OF "FAULT" ARE THE RESPONSIBILITY OF INSURERS OR OF THE STATE'S COURTS.

2 No. of Units Involved

☐ Supplemental Report

97001812

JAN 22 1997

N.C. COLLISION REPORT

Date	Day of Week	County	Time	Local Use / Patrol Area
Jan 4 1997 (MONTH DAY YEAR)	SATURDAY	ANSON	21:05 (24 Hour Clock)	116 (Sec No.) 05 (Area)

LOCATION

Collision occurred ☐ In ☒ Near POLKTON (Municipality) or 2 . 9 4 Miles ☐ N ☐ S ☐ E ☒ W outside municipality

on RP-1413 (Highway Number, or Highway, Street. (If ramp or service road, indicate on)) (R.R.Crossing # ____) 0 . 5 8 Miles (Of-At-Intersection) ☒ N ☐ S ☐ E ☐ W

of/from RP-1414 (Use Highway Number, Street Name or Adjacent County or State Line) ☒ N ☐ S ☐ E ☐ W toward NC-218 (Use Highway Number, Street Name or Adjacent County or State Line)

☒ VEHICLE 1 ☐ HIT & RUN	☒ VEHICLE 2 ☐ PEDESTRIAN ☐ HIT & RUN ☐ OTHER
Driver 1 [redacted] (First / Middle / Last)	Driver 2 [redacted] (First / Middle / Last)
Address [redacted]	Address [redacted]
City [redacted] State [redacted] Zip [redacted]	City [redacted] State [redacted] Zip [redacted]
Same Address on Driver's License? ☐ Yes ☐ No	Same Address on Driver's License? ☒ Yes ☐ No
Driver's Phone No. W ____ H [redacted]	Driver's Phone No. W ____ H [redacted]
D.L.# NONE State ____ DOB [redacted] (month/day/year)	D.L.# [redacted] State NC DOB [redacted] (month/day/year)
Vision 1. Obstruction 1 2. Physical Condition 6 3. Intoxication 4 Restrictions 0	Vision 1. Obstruction 1 2. Physical Condition 5 3. Intoxication 2 Restrictions 0
Owner SAME AS DRIVER	Owner SAME AS DRIVER
Address	Address
City ____ State ____ Zip ____	City ____ State ____ Zip ____
VIN MO15011-57	VIN SMH2007603
Plate # NONE State ____ Year ____	Plate # JTL-7240 State NC Year 1997
Veh. Year UNK Veh. Make WEST POINT Veh. Type Code BI	Veh. Year 1980 Veh. Make HONDA Veh. Type Code P
Commercial Vehicle ☐ Yes ☒ No — Trailer Type Code	Commercial Vehicle ☐ Yes ☒ No — Trailer Type Code
Air Bag Deployed ☐ Yes ☒ No — 1st Trailer No. of Axles	Air Bag Deployed ☐ Yes ☒ No — 1st Trailer No. of Axles
Passenger ☐ Yes ☒ No — Width ____ inches	Passenger ☐ Yes ☒ No — Width ____ inches
Vehicle Drivable ☐ Yes ☒ No — Length ____ feet	Vehicle Drivable ☐ Yes ☒ No — Length ____ feet
Post Crash Fire ☐ Yes ☒ No — 2nd Trailer No. of Axles	Post Crash Fire ☐ Yes ☒ No — 2nd Trailer No. of Axles
Rollover ☐ Yes ☒ No — Width ____ inches	Rollover ☐ Yes ☒ No — Width ____ inches
Hazardous Cargo ☐ Yes ☒ No — Length ____ feet	Hazardous Cargo ☐ Yes ☒ No — Length ____ feet
Spilled ☐ Yes ☒ No — TAD BD-5	Spilled ☐ Yes ☒ No — TAD LFR-3
Crossed Median ☐ Yes ☒ No — Est. Damage $ 50.00	Crossed Median ☐ Yes ☒ No — Est. Damage $ 1,200.00
Insurance Company NONE	Insurance Company NONE
Policy #	Policy #

Other Property Damaged LAWN — Estimated Damage $100.00 — Owner Name RICHARD NEAL CARPENTER — Address ROUTE 2 BOX 344 POLKTON, NC 28135

OCCUPANT SECTION INSTRUCTIONS: Give Injury Class, Belt/Helmet/Usage, Race/Sex and Age of all occupants in the space corresponding to the seat occupied (see codes at top). Names and addresses are necessary for all occupants.

Seat	4. Inj. Class	5. Belt /Hel.	Race /Sex	Age	Injured Names and Addresses	Seat	4. Inj. Class	5. Belt /Hel.	Race /Sex	Age	Injured Names and Addresses
Left Front	K	1	W/M	52	DRIVER 1	Left Front	B	3	W/M	35	DRIVER 2, PEDESTRIAN, OTHER
Center Front						Center Front					
Right Front						Right Front					
Left Rear						Left Rear					
Center Rear						Center Rear					
Right Rear						Right Rear					

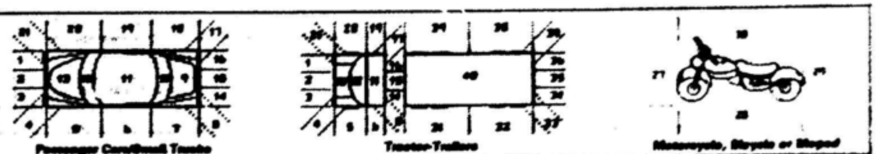
Total Number Occupants 1 — Total Number Injured 1 — Total Number Occupants 1 — Total Number Injured 1

Ambulance Requested ☒ Yes ☐ No — If yes, Ambulance Arrived At U N K (24 Hour Clock)

Injured Taken To ANSON COUNTY HOSPITAL, WADESBORO, NC (Treatment Facility and City or Town) — Serviced by ANSON RESCUE SQUAD (NAME OF EMS)

MARKS > < ADDED BY:

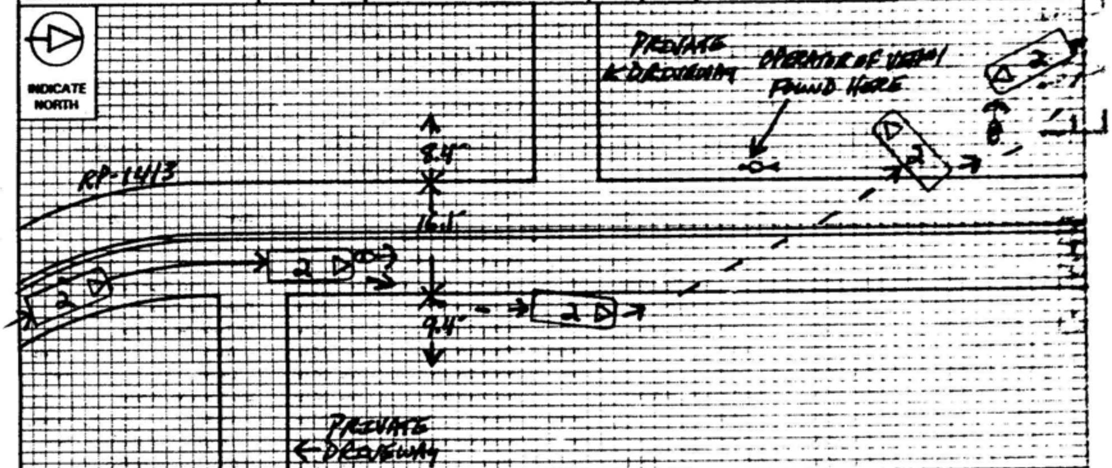
POINTS OF INITIAL CONTACT (Write in Codes)	
VEH. 1	VEH. 2
29 (001 c4c VAL	
	5
	12



UNDERNEATH: 0. No Contact 25. Rollover 22. Front 23. Center 24. Rear 26. Unknown

ACCIDENT SEQUENCE	Veh. 1	Veh. 2 or Ped.		Veh. 1	Veh. 2 or Ped.
6. Vehicle Maneuver / Ped. Action	4	4			
7. First Harmful Event	9		Speed Limit (for each vehicle)	55	55
7. Most Harmful Event	9	9	Estimated Original Traveling Speed	10	55
8. Object Struck	1	3	Estimated Speed at Impact	10	45
9. Distance to Object Struck	8	1	Tire Impressions Before Impact (ft.)	0	0
10. Vehicle Defects	8	8	Distance Traveled After Impact (ft.)	248.3	258.9

ROADWAY INFORMATION (See Front)			
11. Locality	3	19. Road Defects	7
12. Development Type	2	20. Road Condition	1
13. Road Feature	14	21. Light Condition	5
14. Road Character	6	22. Weather	1
15. Road Class	4	23. Traffic Control	11
16. Number of Lanes	2	Operating Yes No	
17. Road Configuration	2	Visible Yes No	
18. Road Surface	3		



Vehicle 1 was Traveling [X] N [ ] S [ ] E [ ] W on RP-1413

Vehicle 2 was Traveling [X] N [ ] S [ ] E [ ] W on RP-1413

DESCRIBE WHAT HAPPENED: VEHICLE 1 AND VEHICLE 2 WERE TRAVELING NORTH ON RP-1413. VEHICLE 1, A BICYCLE, WAS BEING OPERATED IN THE CENTER OF THE NORTHBOUND LANE OF RP-1413. VEHICLE 2 CAME OVER A HILLCREST AND AROUND A CURVE AND WAS UNABLE TO AVOID VEHICLE 1, STRIKING IT IN THE REAR. AFTER IMPACT BOTH VEHICLES CAME TO REST IN A YARD ON THE WEST SIDE OF RP-1413. THE OPERATOR OF VEHICLE 1 WAS DECEASED WHEN INVESTIGATOR ARRIVED. THE OPERATOR OF VEHICLE 2 HAD A STRONG ODOR OF ALCOHOL ON HIS BREATH. STATED HE DID NOT SEE VEHICLE 1 UNTIL HE CRESTED THE HILL AND WAS UNABLE STOP HIS VEHICLE OR TAKE EVASIVE ACTION.

CIRCUMSTANCES CONTRIBUTING TO THE COLLISION (Check as many as apply)

Driver 1	Driver 2		Driver 1	Driver 2		Driver 1	Driver 2	
[X]	[ ]	1. None	[ ]	[ ]	10. Pass stopped school bus	[ ]	[ ]	19. Safe movement violation
[ ]	[X]	2. Alcohol Use	[ ]	[ ]	11. Passing on hill	[ ]	[ ]	20. Following too closely
[ ]	[ ]	3. Drug use	[ ]	[ ]	12. Passing on curve	[ ]	[ ]	21. Improper backing
[ ]	[ ]	4. Yield	[ ]	[ ]	13. Other improper passing	[ ]	[ ]	22. Improper parking
[ ]	[ ]	5. Stop sign	[ ]	[ ]	14. Improper lane change	[ ]	[ ]	23. Unable to determine
[ ]	[ ]	6. Traffic signal	[ ]	[ ]	15. Use of improper lane	[ ]	[ ]	24. Left of center
[ ]	[ ]	7. Exceeding speed limit	[ ]	[ ]	16. Improper turn	[ ]	[ ]	25. Right turn on red
[ ]	[ ]	8. Exceeding safe speed	[ ]	[ ]	17. Improper or no signal	[ ]	[ ]	26. Other
[ ]	[ ]	9. Failure to reduce speed	[ ]	[ ]	18. Improper vehicle equipment			

Veh. 1 removed to DESTINATION by POV Authority POV

Veh. 2 removed to MEACHUM WRECKER SERVICE by ROTATION Authority WRECKER

	Driver 1	Driver 2
24. Direction	N 1	N 1
25. Violation	1	2
26. Misc. Action		
27. Charges	N	Y
28. Investigating Agency		

WITNESSES: Name NONE Address Phone No.
Name Address Phone No.

ARRESTS: Name CHARLES WILLIAM KIKER Charge(s) DWI, DWLR, OTHER CHARGES PENDING
Name Charge(s)

Sign Here	Tpr. B.K. Ratliff	2754	SHP H/3	Jan 4 97
	Officer's Rank and Name	Number	Department	Date of Report

97001812

Crash Level

Date/Time Saturday 1/4/97 9:05:00 PM

Location Anson County On SR 1413 .58 miles N of SR 1414 towards NC 218

Crash Type:	Weather:	Road Condition:	Road Surface Type:	Light:
PEDALCYCLIST	CLEAR	DRY	SMOOTH ASPHALT	DARK - ROADWAY NOT LIGHTED

Comments

Roadway:

Unlit rural 2-lane roadway, Mild horizontal and veritcle curve near crash site

Traffic Control Devices:

Center and edgeline pavement markings present, no passing zone.

Roadside:

Operations:

Posted speed limit is 55 mph
ADT less than 500 vpd
No Access Control

Environmental Conditions:

Light Condition -- Dark no street lights
Road Condition -- Dry
Weather -- Clear

Unit1:

It is unknow whether the bike had visible reflectors on the rear or whether the bike was using a front light.

Unit2:

Driver charged with DWI and driving while license revoked.

Sequence of Events

Vehicle 1 (bike) traveling north in center of northbound lane. Vehicle 2 traveling north in norhtbound lane. Vehicle 2 rear-ended the Vehicle 1. Veh 2 runs-off-road to the right then crosses road coming to a rest on the S-W bound shoulder. Driver of vehicle 1 was thrown from the bike, veh 1 continued north and came to rest on the S-W bound soulder. Veh 2 did not leave skid marks, there was no indication that vehicle 2 altered speed before striking veh 1.

97001812

Unit/Operator 1

Veh. Type PEDALCYCLE	**Vehicle Maneuver:** GOING STRAIGHT AHEAD		**Contrib. Circumstance 1:** NO CONTRIBUTING CIRCUMSTANCES INDIC	
Model Year	**Non-Motorist Action:** OTHER		**Contrib. Circumstance 2:**	
Vehicle Make				
Registration State	**Speed Limit:**	**Est. Speed:**	**Contrib. Circumstance 3:**	
Length of Tire Impression	**Distance Traveled**		**Obj Dist and Dir from Road:** STRAIGHT AHEAD 11-30 FT	
Person Type: PEDALCYCLIST	**AGE:** 52	**Race/sex:** WHITE MALE	**Restraint/Helmet Use** NONE USED	**Injury:** KILLED

Unit/Operator 2

Veh. Type PASSENGER CAR	**Vehicle Maneuver:** GOING STRAIGHT AHEAD		**Contrib. Circumstance 1:** ALCOHOL USE	
Model Year 1980	**Non-Motorist Action:** OTHER		**Contrib. Circumstance 2:**	
Vehicle Make HONDA				
Registration State NORTH CAROLINA	**Speed Limit:** 55	**Est. Speed:** 55	**Contrib. Circumstance 3:**	
Length of Tire Impression	**Distance Traveled** 258		**Obj Dist and Dir from Road:** STRAIGHT AHEAD 11-30 FT	
Person Type: DRIVER	**AGE:** 35	**Race/sex:** WHITE MALE	**Restraint/Helmet Use** SHOULDER AND LAP BELT	**Injury:** B TYPE INJURY

97001812

Horizontal Alighment

General Alignment:	Direction of Curve:	Estimated Curve Radius:	Location of crash relative to curve:
Curved	Right	Mild/Gentle Curve	Inside of Curve

Vertical Alighment

Direction of Slope:	Estimate of the % of Slope:	Crest Vertical Curve:	Sag Vertical Curve:	Terrain:
Down	Mild Slope (2-6% +/-)	No	No	Rolling

Cross-Section

Cross Section Type: Superelevated

Other Cross-Section Discription:

Lane Width:	Shoulder Type:	Paved Shoulder Width:	Graded Shlder Width:	Turning lanes:	Passing lanes:	Emergency lanes:
8	6	NA	NA	0	0	0

Surface Type: Blacktop

Other Surface Type:

Operations

Posted Speed Limit: 55

Speed Limit Type: Regulatory

Pavement Markings 03 08

Raised Pavement Reflectors ☐

Delineator Presence: None

Type of Delineator: NA

Roadside Parking: No Roadside Parking

Highway Traffic Signal NA

Other Traffic Signal:

Regulatory Signs: NA

Other Regulatory Signs:

Warning Signs: NA

School Zone Signs: NA

Other School Zone Signs:

Number of Driveways or Intersections within 250 feet of the crash site.

Driveways: 5

Intersections 0

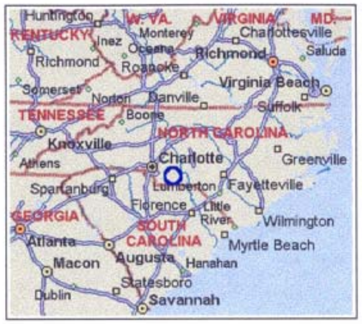
Bikeway No Bikeway

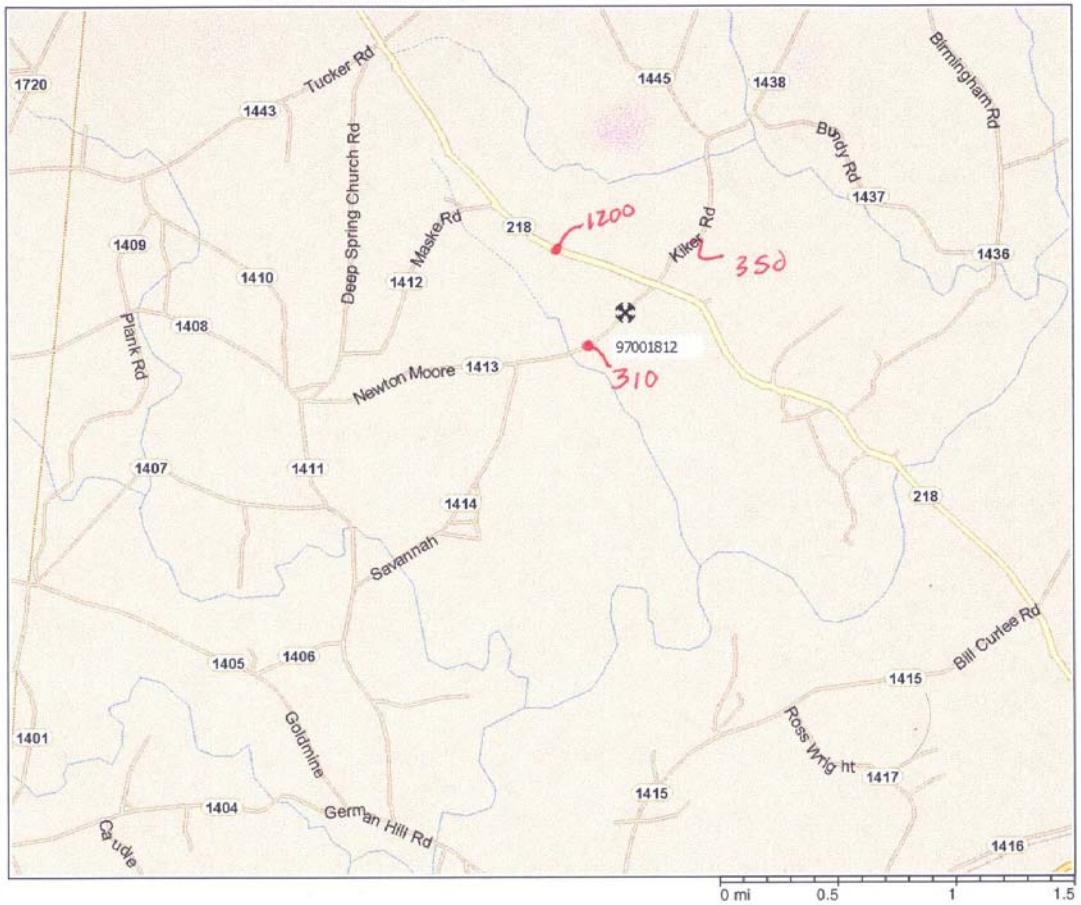
Roadside Illumination: No Illumination Fixtures

Roadside

Bridge/Railroad Involvement:	Guardrail/Bridge Railing:	Other Guardrail/Railing:
NA	None	

SE Fatal Crashes





1999
ADT

(1) RP 1413 0.58 mile north from RP 1414 looking east

(2) Looking east several 100’ east of picture number 1

(3) Looking east from driveway in picture 2

(4) Looking West approximately 300 feet east of driveway

(5) Looking west approximately100 feet east of driveway and on the eastbound shoulder

Appendix B. Listing of Countermeasures Evaluated and Countermeasure Handbook

Last Name of Reviev

Lacy

Date and Tim

/18/01 3:07:39

Crash Id:

97153844

Countermeasures

A 1:	1	C 3:	1	D 3a:	1
A 2:	1	C 4:	1	D 3b:	1
A 3:	1	C 5:	0.67	D 3c:	1
A 4:	1	C 6a:	1	D 3d:	
B 1:	0.67	C 6b:	1	D 3e:	
B 2:	0.67	C 6c:	1	D 3f:	
B 3:	1	C 7:	1	E 1:	1
B 4:	1	C 8:	1	E 2:	1
C 1:	0.67	D 1:	1	E 3:	
C 2:	1	D 2:		F 1:	0.67

Rating and Descriptions

Rating	Rating Description
N	Not Applicable at this Location
P	Application WOULD PREVENT the crash
R	Application would NOT PREVENT the crash, but WOULD REDUCE the severity
M	Application would NOT PREVENT the crash, but MAY REDUCE its severity
O	Application would have NO EFFECT on the outcome of this crash
W	Application would worsen the severity of this crash

Code	Countermeasure
A 1	Add/Upgrade Edgeline
A 2	Add/Upgrade Centerline
A 3	Add/Upgrade No-Passing-Zone Lines
A 4	Add Raised Pavement Markings (RPM's) to Centerline
B 1	Warning Sign
B 2	Advisory Speed Sign
B 3	Chevron Alignment Sign
B 4	Post Delineator
C 1	Geometric Realignment (Horizontal, Vertical, Intersection)
C 2	Modify Superelevation / Cross Slope
C 3	Improve Sight Distance without Geometric Realignment
C 4	Widen Travel Lanes / Pavement Width
C 5	Add Turn Lane (Left/Right)
C 6a	Improve Shoulder - Add or Widen Graded or Stabilized Shoulder
C 6b	Improve Longitudinal Shoulder - Pave Existing Graded Shoulder of Suitable Width
C 6c	Improve Longitudinal Shoulder - Widen and Pave Existing Shoulder
C 7	Add Rumble Strips
C 8	Improve Roadway Access Management
D 1	Install or Upgrade Guardrail
D 2	Upgrade Guardrail End Treatment / Add Impact Attenuator
D 3a	Clear Zone Improvements - Widen Clear Zone
D 3b	Clear Zone Improvements - Flatten Side Slope
D 3c	Clear Zone Improvements - Relocate Fixed Object
D 3d	Clear Zone Improvements - Remove Fixed Object
D 3e	Clear Zone Improvements - Convert Object to Breakaway
D 3f	Clear Zone Improvements - Traversable Drainage Structure
E 1	Add Lighting (Segment)
E 2	Add Lighting (Intersection)
E 3	Upgrade Lighting (Segment/Intersection)
F 1	Enforce Speed Limits

Countermeasure Handbook

Prepared for the Georgia 1997 Fatal Crash Study

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

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TABLE OF CONTENTS

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.

<u>*Crash Application*</u>
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

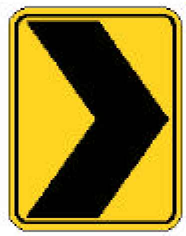
<u>*Overview*</u>
Advisory speed limits are often used to aid drivers in selecting slower safe speeds for hazardous locations such as curves, road work sites, intersections, and road sections with lower design speeds (FHWA, 1982). A sample advisory speed sign is depicted below.

<u>*Crash Application*</u>
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.

<u>*Crash Application*</u>

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

<u>*Overview*</u>

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.

<u>*Crash Application*</u>

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

<u>*Overview*</u>

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.

<u>*Crash Application*</u>

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

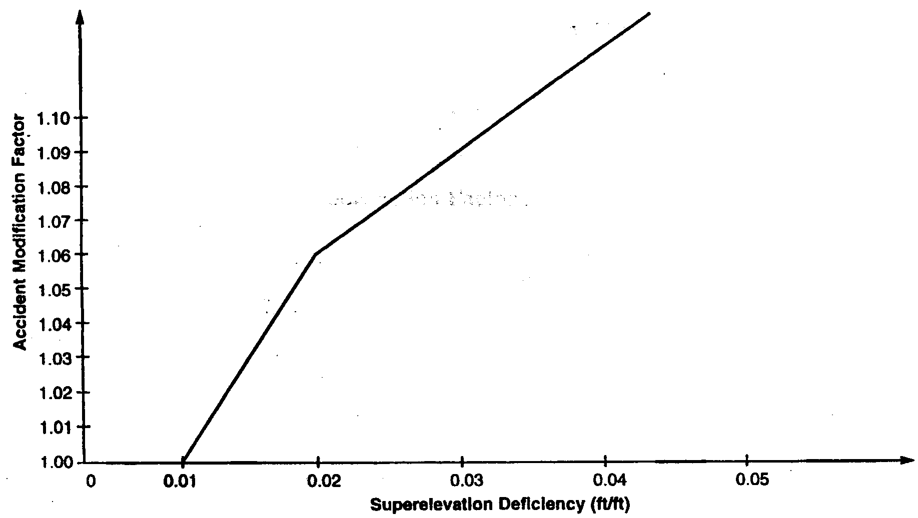
A study (Creasy and Agent, 1985) based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis, provided the subjective estimate that a 40-percent reduction should occur in total crashes due to the correction or improvement of roadway superelevation.

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 11-12	23 36
9	10 11-12	10 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:

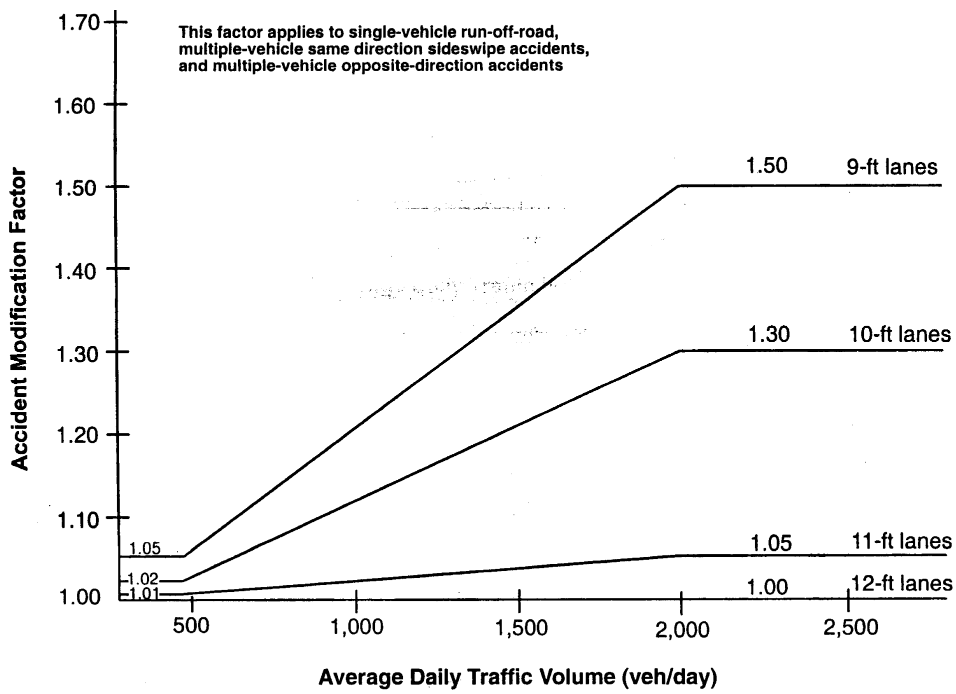
- Crash rates decreased as lane width increased up to 11-feet, then remained relatively constant.
- A before-after study showed a significant decrease in crash rates when widening lanes from 9-12 feet, especially at high-crash sections.
- Pavements 22-24 feet wide had fewer crashes than narrower and 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.

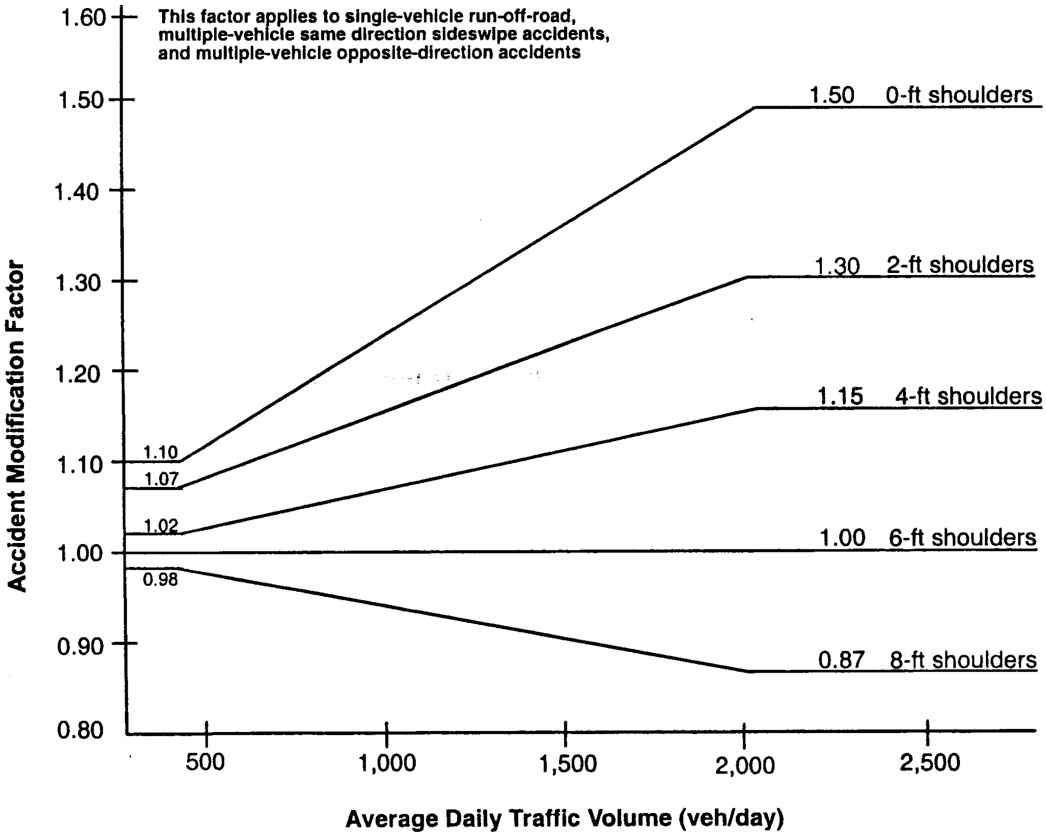
A Florida study (Hadi et. al., 1995a) determined that a greater total shoulder width (paved plus unpaved) was associated with lower crash rates on two-lane rural highways.

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

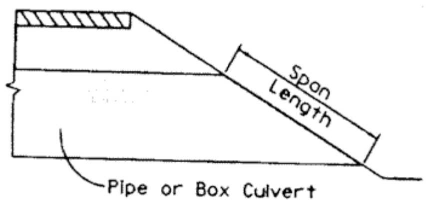
Creasy and Agent (1985) performed a study based on a combination of 42 literature reviews, 22 state surveys, and a before-after analysis. They provided a subjective estimate that a 60-percent reduction in fatal crashes and 30-percent reduction in injury crashes should occur due to the conversion of roadside 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.

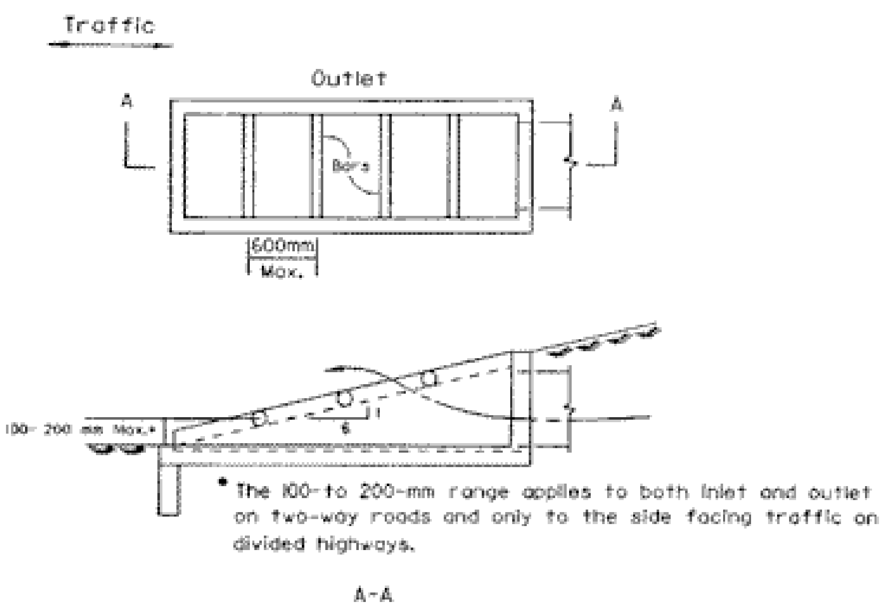
f. Construct Traversable Drainage Structure

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.

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Appendix C. Review of North Carolina Crash Data for Supplementing Countermeasures Evaluated

SOUTHEAST FATAL CRASHES DISTRIBUTION RESULTS

In our meeting in April, we discussed comparing the distribution of the existing 150 fatal crashes from 1997 to those of the fatal crashes reported between 1998 and 2000. While the 150 crashes contain only rural two-lane road fatal crashes, the 1998-2000 contains all reported fatal crashes during the three-year period. The main purposes were to determine if the 1997 crash types provided a large enough sample to make some inferences about particular crash types, to determine the need to develop additional countermeasures for this study, and to help select the 30 additional crashes for review in this project. The crash types of specific interest are:

- Tree crashes
- Utility pole crashes
- Large trucks
- Older drivers
- Intersection related crashes (within 150 feet of an intersection)
- Pavement friction crashes (mainly run-off-road during wet road conditions)
- Road surface defects
- Bridge-rail and bridge-end crashes

Fixed Objects

The fixed object category contains the tree, utility pole and bridge crashes. Table 1 shows the distribution of the fatal crashes by object struck for the two samples. The table only shows the specific crash types discussed in the April meeting and the ones with relatively high percentages in both groups. Tree crashes were the only fixed object discussed in the April meeting that had a sample size greater than 10. The table also shows that the 1997 sample does not reflect the 1998-2000 distribution for these crash types. Both sample show a higher representation for fatal crashes involving ditch banks and pedestrians.

Table 1: Fixed Objects Stuck

Object Struck	1997 Stratified Sample		1998-2000 Reported Fatal Crashes	
TREE	19	20.2%	619	14.0%
UTILITY POLE	3	3.2%	148	3.4%
LUM POLE-NON-BRK	1	1.1%	8	0.2%
LUM POLE-BRKWY	0	0.0%	1	0.0%
BRIDGE RAIL END	6	6.4%	36	0.8%
BRIDGE RAIL FACE	0	0.0%	13	0.3%
DITCH BANK	21	22.3%	308	7.0%
PEDESTRIAN	14	14.9%	1497	34.0%

Recommendations

If fixed objects crashes are a priority in this project, then note the following recommendations.

- There are several countermeasures concerning keeping vehicles on the roadway and shielding hazardous roadside conditions already included in the list from Georgia Tech. Therefore, it is not recommended to develop additional countermeasures for analyses in this project.
- Combine similar roadside hazards such as trees and poles into one group and collecting additional crashes to build to at least 30 cases.
- Treat ditch banks as a separate item for investigation and build the sample size to at least 30 cases.
- Treat bridge rail issue be treated separately and to collect additional crashes to increase the number of cases if this crash type becomes a priority for this study.

These recommendations require collecting data for 40 additional crashes from the 1998-2000 sample to meet a 30 case sample size for each of the three fixed object categories.

Large Trucks

Table 2 shows the frequency and distribution of the large trucks included in both samples. Review of the crash reports indicates that many of the "TT" and "TTST" vehicles recorded in the old crash reporting system converted to "TRUCK/TRAILER" in the new crash reporting system. There are not enough crashes in the 1997 sample that involve large truck to make inferences about the fatal truck-involved crashes. In addition, several other projects are in progress either through the US DOT, GHSP and/or the DMV focus on large trucks.

TABLE 2: Vehicle Type Distribution

Vehicle Type	1997		1998-2000	
	Vehicles Involved	Percentage	Vehicles Involved	Percentage
SINGLE UNIT TRUCK (3 OR MORE AXLES)	1	0.4%	87	4.2%
TRUCK/TRAILER	16	6.5%	315	0.2%
TRUCK/TRACTOR	0	0.0%	17	1.5%
TRACTOR/SEMI-TRAILER	0	0.0%	108	0.0%
TRACTOR/DOULBES	0	0.0%	3	0.1%

Recommendations

Due to the limited sample size and the other projects already in progress, the following recommendation are provided.

- Do not develop additional countermeasures focusing on large truck crashes for this project.
- Do not use large truck-involved crashes as a criterion to select the additional crashes for review in this project.

Older Drivers

The percentages of older drivers in both samples are similar with 14.1 percent for the 1997 sample and 15.6 percent for the 1998-2000 sample. The 1997 sample contain 36 operators or pedestrians over the 60 years old, with another 10 between 55 and 60 years old. All the countermeasures except for one are engineering countermeasures not specifically designed for any age group of drivers. If the older driver issue is a priority for this project, then NCDOT and HSRC will need to develop documents for the study that emphasizes treatments for older drivers. Some of the existing countermeasures may be modified to specifically address older drivers such as wider pavement marking in the pavement-marking category (although not definitive if they truly help older driver).

Recommendations

The physical condition of the older driver is critical to determine if any “older” driver countermeasures would have been effective in a particular. However, this information will not be readily available to the engineers completing the countermeasure evaluation process. This requires the engineer to make subjective decisions about the condition of the driver during the crash. Examples of these subjective decisions are: “Would the driver have the cognitive ability to recognize the treatment” or “Did the light conditions further erode the drivers depth perception to the point that large signs would not have provided sufficient time for the driver to react.” Since there will not be specific information concerning the actual drivers physical condition other than what is collected on the crash report, the following recommendations are submitted.

- For this project, do not develop additional countermeasures that focus on the older driver issue.
- Do not use the criterion of “older driver” to select the additional crashes for review.
- Develop research questions concerning how an agency can collect data concerning the physical condition of a driver involved in a crash.

Intersection Related

One would expect that urban crashes would contain a higher percentage of crashes occurring at or near an intersection. Therefore, it is expected that the 1997 sample will not reflect the same distribution as the 1998-2000 sample because of the stratification of the earlier sample. For the purpose of this review, the standard Y-line of 150 feet was used to designate if a crash is considered as an intersection crash. Tables 3 and 4 show the distribution of the distance from the reference intersection as recorded by the reporting officer.

Very few of the countermeasures from the Georgia Tech list specifically address intersection crashes. In addition, there is a wide variety of treatments or combinations of treatments available to engineers for crash prone intersections. Developing even a partial listing is a sizable task upon itself.

The following recommendation are made for intersection related crashes.

- Do not use intersection crashes as a selection criterion for selecting the additional crashes for review in this project.

TABLES 3 & 4: Distribution of Distance from Reference Intersections

1997

Distance from Reference Intersection	Crashes	Percentage
150 feet or less	43	28.7%
151 feet to 0.25 mile	41	27.3%
0.26 to 0.5 mile	24	16.0%
0.51 to 0.75 mile	19	12.7%
0.76 to 1.0 mile	11	7.3%
1.01 to 1.5 miles	8	5.3%
1.51 to 2.0 miles	3	2.0%
Greater than 2.01 miles	1	0.7%
	150	

1998-2000

Distance from Reference Intersection	Crashes	Percentage
150 feet or less	1,603	37.5%
151 feet to 0.25 mile	1,326	31.0%
0.26 to 0.5 mile	657	15.4%
0.51 to 0.75 mile	292	6.8%
0.76 to 1.0 mile	174	4.1%
1.01 to 1.5 miles	125	2.9%
1.51 to 2.0 miles	43	1.0%
Greater than 2.01 miles	56	1.3%
	4,276	

- Do not develop intersection countermeasures for this project
- Develop a SPR needs statement for developing a similar document for intersection improvements
- Develop a SPR needs statement for developing a systematic method for developing subjective crash reduction factors for standardization in the department.

Pavement Friction

There is not a measure of the pavement friction at the specific crash sites available during the time of the crash. Therefore, it is necessary to develop a surrogate indicator to identify crashes where poor pavement friction may have contributed to the crash. As in previous studies completed by the Traffic Safety Systems Management Unit (TSSMU), run-off-road during wet road conditions was used as the surrogate for this review. In the 1997 sample, 10 crashes (42 percent of the wet road condition crashes) meet these conditions. In the 1998-2000 sample, 294 crashes (38 percent of the wet road condition crashes) meet these conditions. With only the crash report and limited roadway inventory data, it will be very difficult to determine if the pavement friction, or the lack of it, is a contributing factor. There have been plans to develop a link between the TSSMU and the Pavement Management Unit concerning this issue. It is recommended to further develop this option rather than attempting to address this issue with such a limited number of crashes. I also recommend that either of these units develop a research statement of need for next fiscal years SPR project funding to further develop a process to improve the review of crashes where poor pavement friction may have contributed to the crash.

Road Defects

The 1997 sample did not have any crashes where the officer indicated that road defects contributed to the crash. In the 1998-2000 sample, there were only seven crashes where ruts, holes and bumps were identified as contributing to the crash. This may not be a representative picture of the total crash frequency where road defects were contributing factors.

Recommendations

The frequency of fatal crashes where defective road surfaces contributed to the crash make it prohibited to include in this project. However, it is also not know how many crashes are a result of a driver attempting to avoid a road defect. Considering these issues, the following recommendations are submitted.

- Develop a SPR project needs statement on the effects of lower maintenance standards on the frequency and severity of motor vehicle crashes. This information may provide additional insights to the overall cost of not fully funding the maintenance of the state and local roads.
- Do not include road defects as selection criterion for this project

Conclusion

Based upon this review, several recommendations are provided. It is ultimately up to the NCDOT to decide whether the additional expense to develop additional countermeasures for the limited number of crashes meets their goals for the 30 additional crashes. The Highway Safety Research Center will assist NCDOT in developing additional countermeasures if desired; however, this review leads to the conclusion that fixed objects crashes continue to contribute to a considerable proportion of the fatal crashes in North Carolina. Many of the countermeasure on the Georgia Tech list either directly of indirectly address these issues. The overall recommendation is to use the additional crashes to further investigate the fixed object crash issue.