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SAFETY IMPROVEMENTS FOR TWO-LANE RURAL ROADS
(KYSPR-00-211)

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16. Abstract

Two-lane rural roads in Kentucky have the highest fatal crash rate of any type of highway in Kentucky. This report is the first phase of a study with the objectives of: 1) identifying safety problems related to crashes on two-lane rural roads, 2) identifying high-crash locations, ad 3) recommending possible improvements. The procedure used in this phase of the study involved an analysis of crash data to identify characteristics of crashes on two-lane rural roads, use of the crash data to identify one-mile sections having critical crash rates, and a review of countermeasures to start development of recommendations to reduce crashes on this type of highway.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Two-lane rural roads have the highest fatal crash rate of any type of highway in Kentucky. This report is the first phase of a study with the objectives of: 1) identifying safety problems related to crashes on two-lane rural roads, 2) identifying high-crash locations, and 3) recommending possible improvements. The procedure used in this phase of the study involved an analysis of crash data to identify characteristics of crashes on two-lane rural roads, use of the crash data to identify one-mile sections having critical crash rates, and a review of countermeasures to start development of recommendations to reduce crashes on this type of highway.

The crash analysis revealed information about the characteristics of crashes on two-lane rural roads and identified high crash locations. The problems associated with fatal crashes on this type of road were identified.

There has been a problem with single vehicle crashes on this type of road which specifically involved the vehicle running off the road. For fatal crashes, there was also a high percentage of head on collisions. The characteristics of crashes on this type of road can be related to specific countermeasures.

A total of 585 one-mile sections were identified with a critical rate factor (CRF) of 1.00 or above. There were 66 sections with a CRF of 2.00 or more. These sections were sent to the Highway Districts for their review.

1.0 INTRODUCTION

Two-lane rural roads account for about 90 percent of the mileage on state maintained highways in Kentucky. However, since the typical average daily traffic (ADT) on these roads is only about 1,500, these roads only account for approximately 34 percent of the vehicle miles traveled. Crashes on two- lane rural roads account for 40 percent of all crashes on state maintained roads, 65 percent of fatal crashes, and 47 percent of injury crashes. The higher percentage of crashes compared to miles traveled results in relatively high crash rates, especially for fatal crashes. Two-lane rural roads have the highest fatal crash rate of any type of highway in Kentucky.

The objectives of this study were to: 1) identify safety problems related to crashes on two-lane rural roads, 2) identify high-crash locations, and 3) recommend possible improvements.

2.0 PROCEDURE

2.1 CRASH ANALYSIS

There were several types of analysis conducted using the computer file which contains all reported crashes in the state. Data for the three-year period of 1996 through 1998 were used. The following is a listing of the various traditional types of crash analysis which were performed.

1. A comparison was made between the characteristics of all crashes, as well as fatal crashes, occurring on two-lane rural roads with those on all types of roads.

2. Counties with the highest number of crashes (both total and fatal) on two-lane rural roads were identified. Counties with the highest crash rates were also identified.

3. One-mile sections of two-lane rural highways which had a critical rate factor (CRF) of 1.0 or more were identified. A file of all crashes which occurred on a two-lane rural road in the three years of 1996 through 1998 was obtained. The critical number of crashes for a one-mile section was determined to be ten. Sections having ten or more crashes were identified and then the crash rate for each section was compared to its critical rate to determine a critical rate factor. These sections were listed (giving the location and number of crashes and CRF) and those with the highest CRF were reviewed or inspected.

4. The numbers of total and fatal crashes occurring on specific routes in each county were summarized and sorted to determine the routes in specific counties with the highest number of crashes.

5. The locations of all fatal crashes were sorted by county, route, and milepoint to determine if there were any clusters of fatal crashes.

As part of another phase of the crash analysis portion of the study, a random sample of 150 fatal crashes on two-lane rural roads was obtained from the fatal crashes which occurred in 1996 through 1998. An inspection was made at each crash site. Copies of the accident report were obtained. The information from the inspection of these fatal crash sites was input into a file along with other information related to the crash. This data file was sent to Georgia Tech for use in a study of fatal crashes in the southeastern United States. The data from Kentucky will also be analyzed separately to determine trends in Kentucky which can be compared to the data from other states. This analysis will be summarized in the final report for this study.

2.2 DRIVER CHARACTERISTICS ANALYSIS

In addition to the traditional type of crash analysis, a procedure using the quasi-induced exposure method was utilized in another phase of the study to determine specific groups of at risk drivers. This method estimates crash rates for crash specific variables such as time of the day, driver and vehicle characteristics, and road features. These crash rates are used to identify the effect of road features, environmental driving conditions, and driver and vehicle characteristics on crashes. The database used contained crashes on rural roads in Kentucky between 1996 and 1998 with a total of 95,546 crashes.

The measure of the crash propensity used in the quasi-induced exposure method is the relative accident involvement ratio (RAIR). Based on the contributing human factors and possible citations after the crash, two types of drivers are identified in two-vehicle crashes, drivers at fault and drivers not at fault. The basic assumption is that in such a crash, one of the drivers is mostly responsible for its occurrence and that driver is called the at fault driver. Crashes where at-fault drivers cannot be clearly identified are excluded from the analysis (approximately 19% in this analysis). The RAIR is calculated by taking the ratio of the percentage of at-fault drivers in a specific subgroup to the percentage of not-at-fault drivers from the same subgroup. Crash ratios are calculated for single vehicle accidents and multi-vehicle accidents. For both cases, the percentage of not-at-fault drivers is used as the denominator, and the corresponding percentage of drivers at fault is used as the numerator. Specific subgroups of drivers are more likely to be involved in a crash if the ratio value is greater than 1.0, while a ratio less than 1.0 indicates that the drivers in the specific subgroup have a lower propensity to be involved in a crash.

Past research has indicated that age and gender are two estimators that could contribute to crash rates; therefore, countermeasures targeted specifically at risk groups of drivers based on age and gender could be developed. In the analysis used in this study, drivers were grouped in 13 age categories in 5-year increments with drivers below 20 years of age grouped in one category and drivers over 75 years old in another group.

Based on past research experience, several factors were deemed to be strong contributors to crash occurrence and crash propensity for the at-risk driver groups. These factors and their classification is as follows:

- speed limit: < 45 mph, 45 mph, ≥ 50 mph;
- road character: straight, curved;
- shoulder type; paved, stabilized, grass, curb;
- shoulder width: 0 to 2 feet, 3 to 5 feet, 6 to 7 feet, ≥ 8 feet;
- lane width: 7 to 8 feet, 9 to 10 feet, 11 to 12 feet;
- day of week: weekday, weekend;
- weather: clear, inclement, cloudy;
- time: day, night;
- directional analysis: sideswipe, rear end, head on, angle; and
- vehicle age: < 5 years, 5 to 10 years, > 10 years.

The data analysis was completed in three steps: 1) two-way variable analysis, 2) statistical significance analysis, and 3) result analysis. The two-way variable analysis involved computation of RAIR's by driver age and gender in conjunction with the roadway and environmental variables identified above. In the next step, logistic regressions were performed to obtain statistical significance of the results. Finally, possible reasons for the results observed were sought and discussed.

An analysis of crash rates based on driver characteristics was completed. Trends of several variables and their effect on the crash propensity of different age groups were identified. A statistical analysis was used to identify significant contributors to crashes of various age groups of drivers which could be used to target possible driver education actions.

2.3 COUNTERMEASURE ANALYSIS

A literature review was started to identify feasible countermeasures having the potential to reduce crashes on two-lane rural roads. A list of countermeasures will be developed along with associated crash reduction factors. The countermeasures will be grouped based on the specific aspects of roadway design and operational characteristics they could affect. A synopsis of the articles reviewed to date are included in the Appendix. The detailed analysis of countermeasures and recommendations will be included in the final report.

2.4 CHARACTERISTICS OF TWO-LANE RURAL ROADS

Information relating to the characteristics of two-lane rural roads was summarized using data from the Highway Information System. This included such information as lane width, horizontal curvature, average daily traffic, and percentage of trucks.

3.0 RESULTS

3.1 CRASH ANALYSIS

Various characteristics of crashes which occurred on all roads and on two-lane rural roads were summarized. Data for the comparison of all crashes are given in Table 1 with data for fatal crashes given in Table 2. The following three types of comparisons were made:

a) comparison of crashes on two-lane rural roads with all crashes,
b) comparison of fatal crashes on two-lane rural road with all fatal crashes, and
c) comparison of all crashes and fatal crashes on two-lane rural roads.

The following are summary comments relating to the comparison of all crashes on two-lane rural roads with all crashes on all roads as shown in Table 1.

VARIABLE	COMPARISON
Severity	Crashes on two-lane rural roads were more severe. The percentage of fatal crashes was twice that for all highways. The percentage of injury crashes was about 30 percent higher.
Aid System	A higher percentage occurred on highways in the "arterial" and "collector" rural categories.
Time of Day	There was a slightly higher percentage between 6 pm and 6 am on two-lane rural roads.
Day of Week	There was a slightly higher percentage on weekends on two-lane rural highways.
Month	The percentages were very close.
Number of Vehicles	There was a substantially higher percentage of single vehicle crashes on two-lane rural roads.
Driver Seatbelt Usage	The percentage was lower on two-lane rural roads. It should be noted that the reported usage using crash data is much higher than observed usage.
Directional Analysis	A much lower percentage occurred at intersections on two-lane rural roads. The largest difference was the higher percentage of "ran off roadway" crashes on two-lane rural highways. There were also higher percentages of head on, opposite direction sideswipe, overturned in road, and animal related crashes.

VARIABLE	COMPARISON
Land Use	There was a much lower percentage in business and residential areas on two-lane rural roads.
Road Surface Cond.	There was a slightly higher percentage on two-lane rural roads when the surface was not dry.
Weather	There was no substantial difference.
Road Character	There was a significantly higher percentage on two-lane rural roads occurring on curves (73 percent higher).
Light Condition	The percentage occurring during darkness with no roadway lighting was about twice as high on two-lane rural roads.
Speed Limit	The speed limits were higher on the rural roads.
Type Accident	There was a significantly higher percentage of accidents involving a fixed object on two-lane rural roads.
Contributing Factors	There was a substantially higher percentage of accidents involving unsafe speed and animal action on two-lane rural roads. Vehicular factors were also higher.
Vehicle Type	The percentages involving cars and trucks were very similar.

The following are summary comments relating to the comparison of fatal crashes on two-lane rural roads with fatal crashes on all roads as shown in Table 2.

VARIABLE	COMPARISON
Aid System	A higher percentage occurred on highways in the "arterial" and "collector" rural categories.
Time of Day	The percentages were very similar.
Day of Week	The percentages were very similar.
Month	The percentages were very similar.
Number of Vehicles	The percentages were very similar.

VARIABLE	COMPARISON
Driver Seatbelt Usage	The percentage was lower on two-lane rural roads.
Directional Analysis	A lower percentage occurred at intersections while the largest difference was the higher percentage of head on collisions on two-lane rural highways. There were also higher percentages of opposite direction sideswipe and "ran off roadway" crashes.
Land Use	There was a much lower percentage of crashes in business and residential areas.
Road Surface Cond.	There was a slightly higher percentage on two-lane rural roads when the surface was wet.
Weather	There was no substantial difference.
Road Character	There was a substantially higher percentage on two-lane rural roads occurring on curves (29 percent higher).
Light Condition	The percentage occurring during darkness with no roadway lighting was higher on two-lane rural roads.
Speed Limit	There were less rural roads with speed limits of 45 mph or lower.
Type Accident	There was a slightly higher percentage involving a fixed object on two-lane rural roads.
Contributing Factors	There was a slightly higher percentage involving unsafe speed, alcohol involvement, and slippery surface on two-lane rural roads.
Vehicle Type	There was a slightly lower percentage involving combination trucks on two-lane rural roads.

The following are summary comments relating to the comparison of all crashes on two-lane rural roads with fatal crashes on two-lane rural roads using data from Tables 1 and 2.

VARIABLE	COMPARISON
Aid System	There was a higher percentage of fatal crashes on rural arterials with a higher percentage of all crashes on rural collectors.
Time of Day	There was a higher percentage of fatal crashes from midnight to 6 am.

VARIABLE	COMPARISON
Day of Week	A higher percentage of fatal crashes occurred during the weekend.
Month	There was a slightly lower percentage of fatal crashes during the winter months of December through February.
Number of Vehicles	A higher percentage of fatal crashes involved a single vehicle.
Driver Seatbelt Usage	The usage in fatal crashes was only about one half the reported usage in all crashes.
Directional Analysis	A much lower percentage of fatal crashes occurred at intersections. The major difference was the much higher percentage of fatal crashes involving a head on collision.
Land Use	A lower percentage of fatal crashes occurred in a business area.
Road Surface Cond.	A higher percentage of fatal crashes occurred on dry pavement.
Weather	A lower percentage of fatal crashes occurred during rain or snow.
Road Character	There was a much higher percentage of fatal crashes occurring on curves (54 percent higher).
Light Condition	A substantially higher percentage of fatal crashes occurred during darkness with no roadway lighting (49 percent higher).
Speed Limit	A lower percentage of fatal crashes occurred on roads with a speed limit of 45 mph or less.
Type Accident	A higher percentage of fatal crashes involved a fixed object with a tree listed most often.
Contributing Factors	The major differences were the significantly higher percentage of fatal crashes involving an unsafe speed and alcohol.
Vehicle Type	A higher percentage of fatal crashes involved a truck.

Counties with the highest number of crashes on two-lane rural roads were identified. Following is a list of counties having 1,000 or more crashes on this type of road in the three-year period of 1996 through 1998.

COUNTY	NUMBER OF CRASHES
Pike	4,009
Floyd	1,948
Muhlenberg	1,945
Laurel	1,894
Madison	1,812
Daviess	1,695
Harlan	1,656
Pulaski	1,638
Bullitt	1,634
Warren	1,518
Perry	1,427
Marshall	1,395
Letcher	1,387
Scott	1,295
Hopkins	1,290
McCracken	1,272
Oldham	1,246
Grant	1,238
Carter	1,192
Graves	1,177
Henderson	1,171
Jessamine	1,162
Meade	1,107
Union	1,089
Ohio	1,076
Christian	1,074
Kenton	1,039
Rowan	1,008
Hardin	1,007

The summary shows that Pike County had about twice the number of crashes on two-lane rural roads compared to any other county. This would be related to the size of Pike County and the number of miles of this type of road. Most of the counties with the largest numbers of crashes are large in size and generally rural.

Following is a list of counties having the highest number of fatal crashes in the three-year period.

COUNTY	NUMBER OF FATAL CRASHES
Pike	40
Laurel	24
Madison	24
Pulaski	23
Bourbon	19
Marshall	19
Leslie	18
Lincoln	18
Carter	17
Casey	17
Grayson	17
Harlan	17
Muhlenberg	17
Perry	17
Shelby	17
Clay	16
Floyd	16
Graves	16
Letcher	16
Scott	16
Breathitt	15
Crittenden	15
Greenup	15
Whitley	15

As with total crashes, Pike County had substantially more fatal crashes than any other county. This would be related to the length of rural roads in this county and the terrain.

In addition to number of crashes, counties having the highest crash rates were determined. Following is list of counties with the highest rates along with the number of miles of two-lane rural roads in the county.

COUNTY	MILES	CRASHES/100MVM
Kenton	73	789
Campbell	72	552
Boone	123	414
Grant	163	414
Scott	173	393

COUNTY	MILES	CRASHES/100MVM
Jessamine	100	353
McCracken	188	351
Boyd	86	347
Trimble	106	339
Franklin	136	339
Bullitt	119	334
Mercer	136	326
Rowan	139	325
Anderson	109	324
Boyle	119	320
Pendleton	176	320
Jefferson	32	319
Henderson	231	317
Greenup	182	317
Carroll	121	313
Knox	191	311
Pike	415	308
Muhlenberg	282	306
Bath	146	305
Mason	162	300

The counties with the highest rates (Kenton and Campbell) had a lower number of rural roads with traffic volumes that were higher than typical.

One objective of the study was to identify high-crash sections on two-lane rural roadways. The length of road to be considered had to be determined. Given the generally low number of crashes, use of a 0.1 or 0.3 mile length was not considered adequate to obtain a trend in crashes. However, the length could not have been so long that the roadway characteristics would have changed dramatically. The decision was made to use a length of one mile in the analysis.

A summary of crashes and rates on two-lane rural roads was used to determine the average number and rates of crashes (Table 3). There were 96,136 crashes on 23,735 miles of roadway or about 4 crashes per mile. Calculations resulted in a critical number of 10 crashes in a one-mile section. Sections having 10 or more crashes in a one-mile section were identified. Then, using the average rate of 252 crashes per 100 million vehicle miles, the rate determined for each section, and the traffic volume, a critical rate and critical rate factor (CRF) were calculated.

Locations were ordered by their CRF. A total of 585 one-mile sections were identified with a CRF of one or more. There were 412 sections having a CRF between 1.00 and 1.49 with 107 between 1.50 and 1.99 and 66 over 2.00. Counties having the highest number of sections with a CRF of 1.00 or more were Pike with 37, Grant with 24, and Floyd and Jessamine with 22.

A list of the number of sections with CRF of 1.00 or more for each county is given in Table 4.

The number of one-mile sections with a CRF of 1.00 or more was summarized by Highway District. Following is a summary by highway district.

DISTRICT	NUMBER WITH GIVEN CRITICAL RATE FACTOR			
NUMBER	1.00-1.49	1.50-1.99	2.00 OR MORE	TOTAL
1	17	9	5	31
2	42	11	9	62
3	29	7	6	42
4	20	2	3	25
5	29	7	4	40
6	65	12	13	90
7	44	15	12	71
8	18	6	3	27
9	25	4	2	31
10	30	4	3	37
11	31	12	1	44
12	62	18	5	85

The highest numbers were in District 6 with Grant County, District 12 which contains Pike and Floyd Counties, and District 7 with Jessamine County.

The sections with the highest CRF values were provided to each Highway District for inspection to determine if a pattern of crashes could be identified which could result in a recommended countermeasure. It was noted that some of the sections were identified because of errors in the milepost system. These locations would be eliminated from the inspection process. A listing of the 66 sections with a CRF of 2.00 or above is given in Table 5.

The total and fatal numbers of crashes occurring on specific routes in each county were summarized and sorted to determine the routes with the highest number of crashes. These summaries are given in Tables 6 and 7 for total and fatal crashes, respectively. There were 33 routes in a single county having 300 or more crashes in the three-year period. The highest number was on US 31E in Jefferson County. There were four routes in Pike County listed in Table 6 (US 460, US 119, KY 194, and US 23). There were 25 routes in a county having five or more fatal crashes in the three-year period. The highest number was 10 on US 460 in Pike County with US 119 in Pike County also on this list. KY 9 in the adjacent counties of Lewis and Mason was on this list.

The location of all fatal crashes was sorted by county, route, and milepoint to determine if there were any clusters of fatal crashes. Counties and routes with two or more fatal crashes in a one-mile section in three years are listed in Table 8. There were five locations which had three fatal crashes within one mile.

3.2 DRIVER CHARACTERISTICS ANALYSIS

3.2.1 Age and Gender

The first step in this analysis was the examination of age and gender to determine whether there were any general trends for multi and single vehicle crashes. The data showed that younger (under 24 years) and older drivers (over 65 years) have a higher tendency to be involved in multi vehicle crashes when compared to middle-aged drivers (Figure 1). This trend is very similar to general trends of the effect of driver age on crashes and is not particularly alarming for two-lane rural roads. However, the aggregation of the data may mask some underlying trends and therefore further stratification of the data was deemed necessary.

The data for single-vehicle crashes showed that younger drivers have a higher probability to have crashes than older drivers (Figure 2). Moreover, there is a continuous reduction of crash propensity as drivers age which may be indicative of the increased ability of drivers to better handle automobiles and thus avoid single vehicle crashes. This trend is also similar to single vehicle crashes on other road types and thus is not particular to two-lane rural roads.

The relative involvement ratios by gender show a similar behavior in multi and single vehicle crashes (Figure 3). For both crash types, males have a higher propensity to be involved in crashes than females. This may be attributed to a more aggressive behavior by males. However, it should be pointed out that this behavior is not particular to these roads, since it has been observed on other roadway types.

3.2.2 Time of Day

For this analysis, crashes were classified as either occurring during day or night hours. The daytime includes crashes that occurred between 6:00 am to 6:59 pm and nighttime crashes are defined those occurring between 7:00 pm to 5:59 am. Multi and single vehicle crashes were considered separately.

The relative involvement ratios for multi-vehicle crashes indicate that there is an age effect with drivers over 65 exhibiting a higher tendency to be involved in this type of crash (Figure 4). This pattern was more apparent for nighttime crashes, which may be attributed to problems related to aging. However, drivers under 20 showed crash rates higher in daytime than other drivers, which may be attributed to youthful behavior. The data also indicate that drivers under 20 show a lower involvement in nighttime crashes on these roads, which may indicate less driving on two-lane roads at night. Relative involvement ratios were also examined for the effect of time of day on single vehicle crashes. The analysis showed a general trend of decreasing crash involvement as the driver ages, similar to that observed in Figure 2. The only notably different trend was an increase in nighttime crash involvement of drivers under 24 years of age, which may be attributed to the youthful behavior of these drivers. For both multi and single vehicle crashes, these trends are similar to those observed on other roads.

The gender analysis showed that the males are more likely to be involved in single vehicle crashes overall than females with this difference larger for night crashes (Figure 5).

3.2.3 Weather

The data were divided into three categories with respect to weather conditions: clear, inclement and cloudy. The analysis for multi-vehicle crashes showed that older drivers have a higher crash likelihood than younger drivers. The analysis of the relative involvement ratios for single vehicle crashes indicates a decreasing crash involvement with increasing driver age. This fact is similar to previously stated findings where driver experience becomes an important factor in avoiding single vehicle crashes. The analysis of gender showed that males have a tendency to be involved more in multi-vehicle crashes and single vehicle crashes on clear and cloudy days than under inclement conditions. This was somewhat expected based on the fact that drivers tend to alter their driving behavior under severe weather conditions, thus probably driving at lower speeds and more conservatively. Contrary to males, females have higher probability to be involved in multi-vehicle and single vehicle crashes during inclement weather conditions. However, there is no apparent explanation of this trend. For multi-vehicle crashes, as well as single vehicle crashes, no statistical significance was found for any weather condition.

3.2.4 Day of Week

Day of week crashes were categorized as weekend or weekday based on the day the crash occurred. The analysis of the multi-vehicle crashes indicates that there are differences based on the age of the driver with young and old drivers exhibiting higher ratios (Figure 6). However, no statistical differences were found for the day of the week, indicating that there is no difference between these two periods.

Relative involvement ratios for single vehicle crashes show that the highest incidence of crashes occurs for the population within the 20 to 24 years of age group. No statistical differences were found between crashes on weekdays and weekends which was also the case for the multi vehicle analysis.

The gender analysis showed that males have a small tendency to be involved more in multi-vehicle and single crashes during weekends than on weekdays. Contrary to males, females are more likely to be involved in multi-vehicle and single vehicle crashes on weekdays than on weekends, which may attributed to driving patterns differences between genders.

3.2.5 Lane Width

Lane width was analyzed to identify contributing factors to crashes based on geometric characteristics. The lane widths for two-lane rural roads were divided into three groups: 7 to 8 feet, 9 to 10 feet and 11 to 12 feet. The analysis for multi-vehicle and single vehicle crashes show the same general trends by age as previously noted, and the results for the comparison of the various lane widths within each age group were not found to be statistically significant. The gender analysis did not show any difference for males and females in crashes based on lane width for both multi- and single vehicle crashes.

3.2.6 Shoulder Width

Another roadway feature that was evaluated was shoulder width which was divided in four categories: 0 to 2 feet, 3 to 5 feet, 6 to 7 feet and 8 feet or more. The statistical analysis of the relative involvement ratios for multi- and single vehicle crashes by driver age showed no statistical significance for the effect of shoulder width. The age effects were stronger in this case, and they were statistically significant. There were no differences in crash involvement characteristics between males and females based on shoulder width for multi-vehicle as well as single vehicle crashes.

3.2.7 Shoulder Type

An additional geometric feature that was examined is the shoulder type. Four groups of shoulder types were used: paved, stabilized, grass and curb.

The age analysis showed that for both multi- and single vehicle crashes there is no statistical significance for the shoulder type within each age group. Similarly to previous results, the age factor is more important on these rates than the shoulder type.

The gender analysis showed that males are more likely to be involved in single vehicle crashes in roads with curbs (Figure 7). However, the other shoulder types do not have an impact on the relative involvement ratios, and all are equal within each gender.

3.2.8 Road Curvature

Road curvature was also considered as a parameter that could influence crash trends. Roadway segments were classified in two broad categories, straight or curved section, due to limited sample size for crashes on specific degrees of curvature.

The relative involvement ratios for multi-vehicle crashes show that older drivers have a higher propensity to be involved in crashes where the road section is straight (Figure 8). For younger drivers, ratios of involvement in crashes on curve sections decrease as the driver ages. This decrease could correspond to an increase in driving experience, allowing the driver to have more control of the vehicle on curves or providing the necessary knowledge base to understand the particulars of specific curves based on stimuli received while driving. For single vehicle crashes, even though the ratios for drivers under 24 indicate a higher propensity to be involved in crashes on curves than in straight sections, the results show no statistical significance with respect to road curvature.

The gender analysis of multi-vehicle crashes showed that males have a higher probability to be involved in crashes than females, but the road curvature does not affect the two genders differently. In single vehicle crashes, males are more likely to have crashes on straight sections of the road than in curves.

3.2.9 Speed Limit

To find the potential influence of speed limit in crashes within age groups, speed limits were classified in three categories: < 45 mph, 45 mph and ≥ 50 mph.

The multi-vehicle crash rates showed that drivers over 70 years of age have a higher likelihood to be involved in crashes on roads with any speed limits and in particular those under 45 mph. This could be due to the possible lower geometric characteristics of such roads (Figure 9). For single vehicle crashes, the relative involvement ratios do not show any significant difference along speed limits groups. Males have a higher probability to be involved in crashes than females in multi vehicle crashes. No trend was identified between speed limit categories in males as well as in females.

3.2.10 Vehicle Age

Vehicle age was another characteristic that was analyzed by classifying vehicles in three categories: < 5 years, 5-10 years and >10 years.

The expectancy for single and multi-vehicle crashes was that older cars might show a higher probability to be involved in crashes. However, the relative involvement ratios showed no statistical significance so this expectation could not be validated.

Based on gender, males have a higher probability to be involved in multi vehicle and single vehicle crashes than females for any age of the vehicle. Females who drive vehicles older than 10 years are less likely to be involved in multi-vehicle crashes as well as in single vehicle crashes.

3.3 COUNTERMEASURE ANALYSIS

The initial literature review was conducted to identify countermeasures to reduce crash occurrence on two-lane rural highways. A synopsis of related literature is given in the Appendix. The objective of the majority of the countermeasures found in the literature is to improve roadway features, i.e. improvements of vertical and horizontal alignments; enhancement of sight distance; removing and relocating fixed objects; installing traffic signs, flashing beacons, or pavement markings.

There have been three broad safety analysis or process areas applied to two-lane rural roads. These are: a) identifying high crash sites, b) conducting road safety audit reviews, and

c) utilizing expert systems. The first process is based on using large sets of crash data with this process corrective instead of preventive. This process is vulnerable to data errors, subject to regression to the mean biases, and likely to identify sites with no obvious cost effective benefit. The second method involves using independent professionals to review roads or road projects at any stage of development with the objective of identifying changes or improvements which can improve safety. The last process uses algorithms to identify types of collisions and associated remedies based on previous information and experience.

3.4 CHARACTERISTICS OF TWO-LANE RURAL ROADS

Information obtained from the summary of data from the Highway Information System (HIS) is given in Table 9. In addition to the information provided in Table 9, the number of total miles of state-maintained highways and miles of two-lane rural highways were summarized by county. The counties with the highest number of total mileage were Jefferson, Christian, Pike, Graves, and Hardin. The counties with the highest number of two-lane rural highway mileage were Graves, Pike, Christian, Pulaski, and Breckinridge. When vehicle miles traveled was considered, Jefferson County had substantially more vehicle miles than any other county when total state-maintained miles was considered while Pike County had substantially more vehicle miles driven than any other county on two-lane rural roads.

The data in Table 9 show that about one-third of all two-lane rural roads have an average daily traffic (ADT) of under 500 with only 7 percent over 5,000. The most common lane width is 9 feet with about one-half having this lane width. Only about 7 percent have a lane width of 12 feet. Only 11 percent have a paved shoulder. The most common functional classification is minor collector with 40 percent in this category. Only 3.5 percent of these roads are on the National Highway System.

As would be expected on rural roads, about 72 percent had a speed limit of over 45 mph. There was about 23 percent with a speed limit of 35 mph which results from roads in small communities where the road is still classified as rural. About 90 percent of the roads had less than 10 percent trucks. Approximately 80 percent of the roads were in rolling terrain. About 11 percent of the pavements had a condition that had deteriorated to the extent that it would affect the speed of free-flow traffic. Only about four percent of the roads with a reported rating had a poor drainage condition adequacy rating.

About one-third of the roads had information relating to the horizontal and vertical curvature. Of those roads, only three percent of those roads had a curvature of 19.5 degrees or higher with 8.5 percent having a grade of 6.5 percent or more. The majority of the roads did not have 1,500 feet passing sight distance.

4.0 SUMMARY AND CONCLUSIONS

4.1 CRASH ANALYSIS

The crash analysis revealed information about the characteristics of crashes on two-lane rural roads and identified high crash locations. The problems associated with fatal crashes on this type of road were identified.

There was a problem with single vehicle crashes on this type of road involving vehicle running off the road. For fatal crashes, there was also a high percentage of head on collisions. The characteristics of crashes on this type of road can be related to specific countermeasures.

A total of 585 one-mile sections were identified with a critical rate factor (CRF) of 1.00 or above. There were 66 sections with a CRF of 2.00 or more. These sections were sent to the Highway Districts for their review.

The next phase of this study will include a detailed investigation of 150 fatal crashes on two-lane rural roads as well as an analysis of potential countermeasures. Recommendations will be made for countermeasures to reduce the number and severity of crashes on this type of roadway.

4.2 DRIVER CHARACTERISTICS ANALYSIS

This portion of the analysis focused on driver age and gender by developing crash ratios for multi- and single vehicle crashes on two-lane, rural roads. The quasi-induced exposure method was utilized. The analysis of driver age showed two different patterns with respect to type of crash. For multi-vehicle crashes, younger and older drivers seemed to have a higher probability to be involved in a crash while middle-aged drivers (between 25 and 64 years) had a lower propensity to be involved in crashes. This trend was observed for all variables of interest that were analyzed. This trend is very similar to the age distribution and trends of multi-vehicle crashes on other types of roads and thus, it is not particularly alarming for two-lane rural roads.

The trend of the driver age for single vehicle crashes was different than that of the multi-vehicle crashes and followed a generally decreasing trend as the driver ages. It is apparent that, as drivers age, they become more comfortable controlling their vehicles which makes them better prepared to avoid situations that may lead to single vehicle crashes. This trend was also apparent for all variables examined with some small differences regarding the ratios of young drivers (under 24 years). As for the multi-vehicle crashes, this is a trend that has been observed in other road types so it is not particular to rural roads.

The gender analysis indicated that males have a higher tendency to be involved in crashes than females. This was true for all variables examined and for both multi- and single vehicle crashes. Even though the methodology used accounts for exposure to crashes and no substantial reference was made in the literature that documents gender differences, it could be hypothesized that this tendency could be attributed either to different levels of aggression or driving patterns between genders.

The combination of age and each variable examined showed that within each age group the contribution of the various levels of the variable did not affect the crash rates of the group. Therefore, the age effect is much stronger than each particular variable examined and has a more significant contribution on the crash patterns of these drivers. Obviously, when the age effect was removed, most of these variables showed statistical significance with the exception of day of week, speed limit, and shoulder type. The same was true for the gender analysis, where the gender effect is stronger than the contributing variable.

Based on these findings, it is reasonable that countermeasures should be targeted toward the driver and the specific at risk groups identified. However, it should be recognized that driver education has a small impact on driver behavior and there are conflicting results regarding its success. Presentation of these trends to both young and older drivers to make them aware of their potential limitations while driving on these, or any other, roads is essential.

TABLE 1. COMPARISON OF ALL CRASHES TO CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998)

VARIABLE	CATEGORY	PERCENT OF TOTAL: ALL	PERCENT OF TOTAL: TWO-LANE RURAL
Severity	Fatal	0.58	1.24
	Injury	27.1	35.5
Aid System	Rural		
	Interstate	2.41	DNA
	Arterial	9.53	23.5
	Collector	17.1	54.2
	Local	11.3	8.21
	Urban		
	Interstate/Expressway	6.23	DNA
	Arterial	29.1	DNA
	Collector	3.57	DNA
	Local	22.1	DNA
Time of Day	Midnight - 5:59 am	7.35	8.79
	6:00 am - 11:59 am	25.5	26.3
	Noon - 5:59 pm	45.3	40.9
	6:00 pm - 11:59 pm	21.8	24.0
Day of Week	Monday - Friday	76.7	74.5
	Saturday - Sunday	23.3	25.5
Month	December - February	24.4	24.4
	March - May	24.8	24.4
	June - August	24.3	24.0
	September - November	26.5	27.2
Number of Vehicles	One	24.9	43.1
	Two	69.2	53.0
	More than two	5.83	3.85
Driver Seatbelt Usage Yes		90.4	81.5

TABLE 1. COMPARISON OF ALL CRASHES TO CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

VARIABLE	CATEGORY		PERCENT OF TOTAL ALL	PERCENT OF TOTAL TWO-LANE RURAL
Directional Analysis	Intersection			
		Angle	16.3	10.1
		Rear End	10.9	5.65
		Opposing Left Turn	0.95	0.84
		Fixed Object	1.29	1.15
		Same Direction Sideswipe	1.61	0.84
		Bicycle	0.25	0.04
		Pedestrian	0.27	0.27
		All Intersection	34.2	20.6
	Non-Intersection			
		Rear End	16.9	13.6
		Head on	0.80	1.28
		Same Direction Sideswipe	4.16	3.08
		Opposite Dir. Sideswipe	5.68	8.52
		Driveway Related	1.63	4.73
		Parked Vehicle	7.02	2.43
		Pedestrian	0.61	0.45
		Fixed Object	10.1	15.1
		Ran off Roadway	6.17	14.1
		Overturned in Road	0.96	1.92
		Bicycle	0.23	0.10
		Animal	3.58	8.19
		Bridge	0.09	0.10
		Interchange Ramp	0.02	0.01
		Train	0.07	0.05
Land Use		Rural	34.4	72.6
		Business/Industrial	37.4	18.2
		Residential	20.7	7.75
		School/Park	1.76	0.91
		Private Property	0.33	0.16
		Limited Access	5.44	0.43

TABLE 1. COMPARISON OF ALL CRASHES TO CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

		PERCENT OF TOTAL	
VARIABLE	CATEGORY	ALL	TWO-LANE RURAL
Road Surface Conditions	Dry	71.5	68.9
	Wet	23.8	25.5
	Snow/Ice	4.47	5.27
	Slush	0.18	0.19
	Muddy	0.09	0.11
Weather	Clear	58.1	58.2
	Raining	16.5	17.4
	Snowing	3.16	3.49
	Fog/Smog/Smoke	0.75	1.69
	Sleet/Hail	0.35	0.40
	Cloudy	21.2	19.0
Road Character	Straight/Level	60.4	46.7
	Straight/Grade	17.3	16.1
	Straight/Hillcrest	3.63	5.09
	Curve/Level	8.46	15.0
	Curve/Grade	8.54	14.3
	Curve/Hillcrest	1.59	2.87
Light Condition	Daylight	72.6	67.9
	Dawn	1.69	2.26
	Dusk	2.62	2.52
	Darkness-Lights on	10.7	3.50
	Darkness-Lights off	0.88	0.86
	Darkness-not lighted	11.5	22.9
Speed Limit	35 mph or less	49.5	20.1
	40 to 45 mph	17.2	11.9
	50 to 55 mph	29.5	68.0
	Over 55 mph	3.83	0.04

TABLE 1. COMPARISON OF ALL CRASHES TO CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

VARIABLE	CATEGORY	PERCENT OF TOTAL: ALL	PERCENT OF TOTAL: TWO-LANE RURAL
Type Accident - 1st Event	Collision with Non-Fixed Object		
	Other Vehicle	74.6	56.3
	Pedestrian	0.88	0.53
	Bicycle	0.48	0.14
	Animal	0.52	1.29
	Train	0.05	0.05
	Deer	3.02	6.80
	Collision with Fixed Object		
	Utility Pole	1.65	1.80
	Guardrail	1.32	1.67
	Crash Cushion	0.03	0.03
	Sign Post	0.62	0.84
	Tree	2.32	4.41
	Building/Wall	0.31	0.26
	Curbing	0.43	0.16
	Fence	1.58	2.99
	Bridge	0.36	0.46
	Culvert/Head wall	0.56	1.29
	Median/Barrier	0.45	0.05
	Snow Embankment	0.06	0.09
	Earth Embankment/ Rock Cut/Ditch	4.54	10.8
	Fire Hydrant	0.13	0.06
	Guard End Treatment	0.27	0.38
	Other Fixed Object	1.16	1.46
	Non-Collision		
	Overturned	1.02	2.02
	Fire/Explosion	0.19	0.25
	Submersion	0.02	0.03
	Ran off Roadway	1.81	3.72
	Other	0.84	1.15

TABLE 1. COMPARISON OF ALL CRASHES TO CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

VARIABLE	CATEGORY	PERCENT OF TOTAL: ALL	PERCENT OF TOTAL: TWO-LANE RURAL
Contributing Factors (Percent of all crashes listed as a factor)	Human		
	Unsafe Speed	7.67	12.2
	Failure to Yield	15.6	12.9
	Following too Close	6.24	3.61
	Improper Passing	1.16	1.54
	Disregard Traffic Control	3.20	1.25
	Improper Turn	2.38	1.30
	Alcohol Involvement	4.38	5.96
	Drug	0.39	0.60
	Sick	0.17	0.21
	Fell Asleep	1.19	1.76
	Lost Consciousness	0.29	0.41
	Driver Inattention	33.8	33.1
	Distraction	2.15	2.57
	Physical Disability	0.23	0.25
	Vehicular		
	Defective Brakes	1.39	1.49
	Lighting Defect	0.25	0.50
	Steering Defect	0.28	0.48
	Tire Problem	0.79	1.21
	Tow Hitch Defect	0.10	0.11
	Load Problem	0.31	0.53

TABLE 1. COMPARISON OF ALL CRASHES TO CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

VARIABLE	CATEGORY	PERCENT OF TOTAL: ALL	PERCENT OF TOTAL: TWO-LANE RURAL
Contributing Factors (continued)			
	Environmental		
	Animal Action	3.97	9.18
	Glare	0.82	1.02
	View Obstruction	9.22	3.80
	Debris in Roadway	0.66	0.85
	Improper/non-working Traffic Control	0.11	0.08
	Defective Shoulder	0.20	0.40
	Hole/Bump	0.14	0.15
	Road Construction	0.38	0.30
	Improperly Parked Vehicle	0.29	0.20
	Fixed Object	0.20	0.20
	Slippery Surface	11.8	15.5
	Water Pooling	1.06	1.54
Vehicle Type	Passenger Car	94.3	93.7
	Single Unit Truck	1.29	1.44
	Combination Truck	2.64	2.97
	Bus	0.20	0.04
	School Bus	0.35	0.40
	Motorcycle	0.34	0.48
	Emergency Vehicle	0.27	0.24

DNA - Does not apply

TABLE 2. COMPARISON OF ALL FATAL CRASHES TO FATAL CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998)

VARIABLE	CATEGORY		PERCENT OF TOTAL: ALL	PERCENT OF TOTAL: TWO-LANE RURAL
Aid System	Rural			
		Interstate	5.27	DNA
		Arterial	46.2	67.1
		Collector	13.8	25.1
		Local	12.4	5.13
	Urban			
		Interstate/Expressway	13.2	DNA
		Arterial	6.97	DNA
		Collector	0.26	DNA
		Local	2.00	DNA
Time of Day	Midnight - 5:59 am		17.6	15.4
	6:00 am - 11:59 am		22.5	22.4
	Noon - 5:59 pm		34.7	36.0
	6:00 pm - 11:59 pm		25.2	26.2
Day of Week	Monday - Friday		69.7	69.7
	Saturday - Sunday		30.3	30.3
Month	December - February		21.8	21.4
	March - May		24.2	24.1
	June - August		25.9	26.0
	September - November		28.1	28.4
Number of Vehicles	One		53.7	54.3
	Two		39.0	39.6
	More than two		7.31	6.06
Driver Seatbelt Usage Yes			46.4	42.0

TABLE 2. COMPARISON OF ALL FATAL CRASHES TO FATAL CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

		PERCENT OF TOTAL	
VARIABLE	CATEGORY	ALL	TWO-LANE RURAL
Directional Analysis	Intersection		
	Angle	9.40	6.73
	Rear End	0.70	0.76
	Opposing Left Turn	1.13	0.76
	Fixed Object	0.26	0.17
	Same Direction Sideswipe	0.22	0.08
	Bicycle	0.44	0.08
	Pedestrian	0.74	0.34
	All Intersection	13.9	9.92
	Non-Intersection		
	Rear End	3.05	1.43
	Head on	10.8	15.1
	Same Direction Sideswipe	1.65	1.26
	Opposite Dir. Sideswipe	8.27	10.4
	Driveway Related	1.96	1.85
	Parked Vehicle	1.26	0.84
	Pedestrian	7.23	4.21
	Fixed Object	26.2	27.4
	Ran off Roadway	13.1	16.6
	Overturned in Road	4.40	3.95
	Bicycle	0.70	0.67
	Animal	0.35	0.42
	Train	0.44	0.34
Land Use	Rural	68.0	90.1
	Business/Industrial	12.4	4.30
	Residential	10.6	5.06
	School/Park	0.57	0.33
	Private Property	0..35	0.00
	Limited Access	8.15	0.17

TABLE 2. COMPARISON OF ALL FATAL CRASHES TO FATAL CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

		PERCENT OF TOTAL	
VARIABLE	CATEGORY	ALL	TWO-LANE RURAL
Road Surface Conditions	Dry	77.0	74.5
	Wet	20.3	22.4
	Snow/Ice	2.57	2.78
	Slush	0.13	0.25
Weather	Clear	60.5	59.1
	Raining	12.7	13.4
	Snowing	2.31	2.45
	Fog/Smog/Smoke	2.40	2.95
	Sleet/Hail	0.22	0.34
	Cloudy	21.9	21.8
Road Character	Straight/Level	39.3	29.5
	Straight/Grade	17.8	16.1
	Straight/Hillcrest	4.46	4.73
	Curve/Level	17.0	23.5
	Curve/Grade	18.6	22.4
	Curve/Hillcrest	2.80	3.71
Light Condition	Daylight	57.4	59.1
	Dawn	2.58	2.28
	Dusk	2.54	2.71
	Darkness-Lights on	5.73	1.02
	Darkness-Lights off	0.87	0.68
	Darkness-not lighted	30.9	34.3
Speed Limit	35 mph or less	14.7	4.72
	40 to 45 mph	8.54	4.21
	50 to 55 mph	68.4	91.1
	Over 55 mph	8.41	0.00

TABLE 2. COMPARISON OF ALL FATAL CRASHES TO FATAL CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

VARIABLE	CATEGORY	PERCENT OF TOTAL: ALL	PERCENT OF TOTAL: TWO-LANE RURAL
Type Accident - 1st Event	Collision with Non-Fixed Object		
	Other Vehicle	44.6	44.7
	Pedestrian	7.97	4.54
	Bicycle	1.13	0.76
	Animal	0.22	0.34
	Train	0.44	0.34
	Deer	0.17	0.17
	Collision with Fixed Object		
	Utility Pole	2.31	1.68
	Guardrail	2.57	1.77
	Crash Cushion	0.04	0.00
	Sign Post	1.13	0.93
	Tree	11.2	13.5
	Building/Wall	0.09	0.08
	Curbing	0.35	0.50
	Fence	2.26	2.44
	Bridge	1.35	1.18
	Culvert/Head wall	2.18	3.53
	Median/Barrier	0.22	0.00
	Earth Embankment/ Rock Cut/Ditch	9.84	12.4
	Fire Hydrant	0.04	0.08
	Guard End Treatment	0.91	0.42
	Other Fixed Object	0.96	0.59
	Non-Collision		
	Overturned	4.53	4.12
	Fire/Explosion	0.04	0.00
	Submersion	0.22	0.17
	Ran off Roadway	3.31	4.21
	Other	0.96	0.59

TABLE 2. COMPARISON OF ALL FATAL CRASHES TO FATAL CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

		PERCENT OF TOTAL	
VARIABLE	CATEGORY	ALL	TWO-LANE RURAL
Contributing Factors (Percent of all crashes listed as a factor)	Human		
	Unsafe Speed	27.2	30.4
	Failure to Yield	16.6	17.4
	Following too Close	0.44	0.50
	Improper Passing	1.13	1.60
	Disregard Traffic Control	4.35	3.28
	Improper Turn	0.48	0.17
	Alcohol Involvement	20.0	22.4
	Drug	1.83	2.10
	Sick	0.74	0.59
	Fell Asleep	3.87	3.11
	Lost Consciousness	1.04	1.09
	Driver Inattention	19.8	21.0
	Distraction	1.70	1.85
	Physical Disability	0.39	0.42
	Vehicular		
	Defective Brakes	1.00	0.76
	Lighting Defect	0.52	0.34
	Steering Defect	0.26	0.42
	Tire Problem	2.09	2.44
	Load Problem	0.35	0.42

TABLE 2. COMPARISON OF ALL FATAL CRASHES TO FATAL CRASHES ON TWO-LANE RURAL HIGHWAYS (1996-1998) (continued)

VARIABLE	CATEGORY	PERCENT OF TOTAL: ALL	PERCENT OF TOTAL: TWO-LANE RURAL
Contributing Factors (continued)			
	Environmental		
	Animal Action	0.61	0.93
	Glare	0.91	0.76
	View Obstruction	3.74	4.12
	Debris in Roadway	0.70	0.42
	Improper/non-working Traffic Control	0.13	0.08
	Defective Shoulder	0.48	0.50
	Hole/Bump	0.22	0.17
	Road Construction	0.17	0.00
	Improperly Parked Vehicle	0.17	0.00
	Fixed Object	0.26	0.42
	Slippery Surface	9.80	11.6
	Water Pooling	1.35	1.60
Vehicle Type	Passenger Car	86.7	88.2
	Single Unit Truck	2.46	2.60
	Combination Truck	6.41	4.88
	Bus	0.14	0.06
	School Bus	0.42	0.28
	Motorcycle	2.34	2.33
	Emergency Vehicle	0.17	0.17

DNA - Does not apply.

TABLE 3. SUMMARY OF CRASHES AND RATES ON TWO-LANE RURAL ROADS

YEAR	NUMBER OF CRASHES ALL	FATAL	INJURY	VEHICLE MILES TRAVELED (100 MILLION)	RATE (PER 100MVM) ALL	FATAL
1996	29,887	360	10,672	126.43	236	2.85
1997	32,544	394	11,439	121.91	267	3.23
1998	33,705	415	11,831	132.68	254	3.12
1996-1998	96,136	1,169	33,942	381.02	252	3.07

TABLE 4. NUMBER OF ONE-MILE SECTIONS WITH CRF OF 1.00 OR MORE

COUNTY	CRITICAL RATE FACTOR (CRF)			TOTAL SECTIONS
	1.00-1.49	1.50-1.99	2.00 OR ABOVE	
Adair	2	0	0	2
Allen	1	1	0	2
Anderson	3	3	0	6
Ballard	0	4	0	4
Barren	1	2	1	4
Bath	2	0	0	2
Bell	0	1	0	1
Boone	14	0	3	17
Bourbon	1	0	0	1
Boyd	1	0	1	2
Boyle	5	0	3	8
Bracken	4	0	1	5
Breathitt	3	0	0	3
Breckinridge	0	0	0	0
Bullitt	8	0	0	8
Butler	2	0	0	2
Caldwell	2	0	0	2
Calloway	1	1	1	3
Campbell	5	1	4	10
Carlisle	0	0	0	0
Carroll	4	0	1	5
Carter	5	1	0	6
Casey	0	0	0	0
Christian	3	4	3	10
Clark	1	0	0	1
Clay	5	0	0	5
Clinton	0	0	0	0
Crittenden	2	1	1	4
Cumberland	0	0	0	0
Daviess	6	3	0	9
Edmonson	1	2	0	3
Elliott	0	0	0	0
Estill	6	2	2	10
Fayette	0	0	0	0
Fleming	0	0	0	0
Floyd	14	6	2	22
Franklin	4	1	3	8

TABLE 4. NUMBER OF ONE-MILE SECTIONS WITH CRF OF 1.00 OR MORE (continued)

COUNTY	CRITICAL RATE FACTOR (CRF) 1.00-1.49	1.50-1.99	2.00 OR ABOVE	TOTAL SECTIONS
Fulton	0	0	0	0
Gallatin	0	0	0	0
Garrard	8	1	0	9
Grant	21	2	1	24
Graves	1	0	1	2
Grayson	1	0	0	1
Green	2	0	0	2
Greenup	7	1	0	8
Hancock	0	0	0	0
Hardin	8	2	2	12
Harlan	7	1	1	9
Harrison	1	4	1	6
Hart	0	0	0	0
Henderson	4	2	3	9
Henry	3	2	0	5
Hickman	0	0	0	0
Hopkins	3	0	2	5
Jackson	0	0	0	0
Jefferson	0	0	0	0
Jessamine	10	8	4	22
Johnson	3	1	1	5
Kenton	11	3	1	15
Knott	5	2	0	7
Knox	8	5	0	13
Larue	2	0	0	2
Laurel	6	3	0	9
Lawrence	0	0	0	0
Lee	0	0	0	0
Leslie	0	0	0	0
Letcher	9	2	0	11
Lewis	1	0	0	1
Lincoln	3	0	0	3
Livingston	3	0	0	3
Logan	3	0	3	6
Lyon	2	0	0	2
McCracken	0	0	0	0

TABLE 4. NUMBER OF ONE-MILE SECTIONS WITH CRF OF 1.00 OR MORE (continued)

COUNTY	CRITICAL RATE FACTOR (CRF) 1.00-1.49	1.50-1.99	2.00 OR ABOVE	TOTAL SECTIONS
McCreary	0	0	0	0
McLean	0	0	0	0
Madison	7	1	1	9
Magoffin	4	0	0	4
Marion	2	0	0	2
Marshall	4	2	2	8
Martin	2	1	0	3
Mason	0	0	0	0
Meade	2	0	0	2
Menifee	0	0	0	0
Mercer	3	0	2	5
Metcalfe	0	0	0	0
Monroe	1	0	0	1
Montgomery	0	0	0	0
Morgan	7	0	0	7
Muhlenberg	8	2	0	10
Nelson	2	0	0	2
Nicholas	0	0	0	0
Ohio	0	0	0	0
Oldham	9	3	1	13
Owen	1	1	0	2
Owsley	0	0	0	0
Pendleton	4	1	1	6
Perry	6	2	0	8
Pike	29	6	2	37
Powell	2	0	1	3
Pulaski	9	4	2	15
Robertson	0	0	0	0
Rockcastle	3	0	0	3
Rowan	9	2	1	12
Russell	1	1	0	2
Scott	3	1	2	6
Shelby	0	1	0	1
Simpson	2	1	0	3
Spencer	2	0	0	2
Taylor	0	0	0	0

TABLE 4. NUMBER OF ONE-MILE SECTIONS WITH CRF OF 1.00 OR MORE (continued)

COUNTY	CRITICAL RATE FACTOR (CRF) 1.00-1.49	1.50-1.99	2.00 OR ABOVE	TOTAL SECTIONS
Todd	3	0	0	3
Trigg	4	1	0	5
Trimble	3	0	0	3
Union	11	0	1	12
Warren	15	1	2	18
Washington	1	0	1	2
Wayne	0	1	1	2
Webster	5	0	0	5
Whitley	5	2	0	7
Wolfe	2	0	0	2
Woodford	3	1	0	4
All	412	107	66	585

TABLE 5. ONE-MILE SECTIONS WITH A CRF OF 2.00 OR ABOVE

COUNTY	ROUTE	MILEPOINT RANGE	NUMBER CRASHES	ADT	RATE (/100MVM)	CRF
Logan	US/KY 79	11.5-12.4	78	860	8,283	11.58
Hopkins	KY 70	0.0-0.7	43	604	6,501	7.94
Logan	US/KY 79	10.4-11.4	51	860	5,416	7.57
Campbell	KY 10	4.3-5.3	32	412	7,093	7.40
Christian	KY 695	7.9-8.8	27	507	4,863	5.54
Marshall	US 641	7.8-8.8	129	4,988	2,362	5.52
Pulaski	KY 80	0.0-1.0	58	2,057	2,575	4.79
Barren	US 31	1.0-2.0	88	3,813	2,108	4.63
Powell	KY 213	5.6-7.5	32	902	3,240	4.61
Hardin	US 31W	0.1-1.1	37	1,164	2,903	4.51
Boyle	US 150	0.0-0.9	56	2,143	2,386	4.49
Graves	US 45	0.0-1.0	37	1,220	2,770	4.38
Hardin	US 31W	1.2-2.0	34	1,109	2,800	4.28
Bracken	KY 10	9.5-10.5	28	821	3,115	4.28
Franklin	KY 1665	0.0-1.0	39	1,368	2,602	4.27
Henderson	KY 266	4.2-5.1	17	417	3,723	3.90
Warren	KY 1435	0.1-0.9	19	517	3,356	3.85
Warren	KY 1435	1.1-1.8	18	517	3,180	3.65
Christian	KY 695	8.9-9.6	17	507	3,062	3.49
Mercer	US 68	17.5-18.5	47	2,905	1,478	3.03
Pike	KY 611	2.9-3.8	20	885	2,064	2.91
Pike	KY 195	4.3-5.3	23	1,158	1,814	2.82
Franklin	KY 2820	1.2-2.0	16	677	2,158	2.76
Rowan	KY 1167	0.7-1.7	17	751	2,067	2.75
Boyd	US 60	0.0-1.0	90	7,800	1,054	2.70
Kenton	KY 17	0.0-1.0	25	1,410	1,619	2.68
Pendleton	KY 22	10.9-11.8	38	2,579	1,346	2.67
Campbell	KY 8	17.5-18.2	17	800	1,941	2.64
Harlan	KY 522	15.2-16.1	14	590	2,167	2.62
Hopkins	KY 1069	0.9-1.9	21	1,128	1,700	2.62
Estill	KY 52	6.6-7.6	112	10,947	934	2.55
Floyd	KY 1428	15.7-16.7	92	8.786	956	2.51
Boyle	US 68	2.0-2.9	11	431	2,331	2.48
Henderson	KY 1299	7.5-8.5	10	367	2,488	2.47
Union	US 60	16.2-17.2	132	14,032	859	2.44
Oldham	KY 22	3.8-4.7	53	4,623	1,047	2.40
Boone	KY 18	0.6-1.6	13	614	1,934	2.38

TABLE 5. ONE-MILE SECTIONS WITH A CRF OF 2.00 OR ABOVE (continued)

COUNTY	ROUTE	MILEPOINT RANGE	NUMBER CRASHES	ADT	RATE (/100MVM)	CRF
Henderson	KY 136	22.1-22.9	15	783	1,750	2.36
Washington	US 150	8.5-9.5	11	10,710	861	2.34
Boyle	US 150	1.0-1.8	29	2,143	1,235	2.33
Campbell	KY 10	5.4-6.4	10	412	2,217	2.31
Boone	KY 536	3.9-4.8	13	652	1,821	2.29
Christian	KY 695	6.8-7.8	11	507	1,981	2.26
Floyd	KY 122	17.9-18.9	42	3,723	1,030	2.25
Logan	US/KY 79	12.5-13.0	15	860	1,593	2.23
Madison	KY 977	0.0-0.9	15	871	1,573	2.21
Harrison	KY 32	8.4-9.1	15	881	1,555	2.19
Scott	US 62	3.1-4.0	62	6,398	885	2.18
Campbell	KY 8	21.3-22.2	14	800	1,598	2.18
Johnson	KY 40	7.1-8.1	34	2,958	1,050	2.16
Jessamine	KY 1980	3.2-4.2	29	2,381	1,112	2.16
Jessamine	KY 29	0.0-0.7	10	464	1,968	2.16
Marshall	KY 408	6.9-7.9	16	1,015	1,440	2.14
Crittenden	US 60	9.0-10.0	87	9,958	780	2.14
Scott	US 25	11.0-12.0	20	1,440	1,268	2.12
Boone	KY 14	1.1-1.9	19	1,340	1,295	2.11
Wayne	KY 92	1.0-2.0	10	485	1,883	2.10
Jessamine	KY 169	16.2-16.8	24	1,901	1,153	2.10
Calloway	KY 94	7.7-8.6	37	3,465	975	2.09
Carroll	KY 55	4.8-5.8	13	768	1,546	2.07
Pulaski	KY 80	1.1-2.0	25	2,057	1,110	2.07
Mercer	US 68	18.6-19.5	32	2,900	1,008	2.06
Grant	US 25	14.4-15.4	10	12,377	738	2.05
Estill	KY 89	9.8-10.6	17	1,207	1,286	2.02
Franklin	US 421	5.5-6.5	27	2,374	1,039	2.01
Jessamine	KY 169	1.5-2.5	14	916	1,396	2.00

TABLE 6. COUNTIES AND ROUTES WITH THE HIGHEST NUMBER OF CRASHES

COUNTY	ROUTE	NUMBER OF CRASHES
Jefferson	US 31E	976
Grant	US 25	631
Pike	US 460	528
Barren	US 31E	503
Union	US 60	497
Breathitt	KY 15	493
Clay	US 421	490
Floyd	KY 1428	463
Perry	KY 15	455
Carter	US 60	454
Muhlenberg	US 431	442
McCracken	US 60	421
Laurel	US 25	421
Ohio	US 231	402
Henderson	US 60	397
Scott	US 25	390
Harlan	US 421	385
Pulaski	US 27	377
Estill	KY 52	372
Pike	US 119	366
Floyd	KY 122	361
Madison	US 25	359
Kenton	KY 17	355
Muhlenberg	US 62	353
Daviess	US 431	336
Pendleton	US 27	333
Rockcastle	US 25	328
Pike	KY 194	326
Pike	US 23	317
Campbell	US 27	316
Adair	KY 55	311
Harlan	KY 38	309
Rowan	KY 32	303

TABLE 7. COUNTIES AND ROUTES WITH THE HIGHEST NUMBER OF FATAL CRASHES

COUNTY	ROUTE	NUMBER OF CRASHES
Pike	US 460	10
Clay	US 421	7
Lewis	KY 9	7
Pulaski	US 27	7
Magoffin	Mt. Parkway	6
Leslie	US 421	6
McCreary	US 421	6
Shelby	US 60	6
Mason	KY 9	6
Breathitt	KY 15	6
Bell	US 119	6
Casey	KY 70	6
Bourbon	US 460	6
Lincoln	US 27	5
Garrard	US 27	5
Grayson	US 62	5
Muhlenberg	KY 70	5
Knott	KY 160	5
Morgan	KY 172	5
Pike	US 119	5
Cumberland	KY 90	5
Scott	US 25	5
Greenup	KY 7	5
Carter	US 60	5
Letcher	US 119	5

TABLE 8. COUNTIES AND ROUTES WITH TWO OR MORE FATAL CRASHES IN ONE-MILE SECTION (1996-1998)

COUNTY	ROUTE	CRASH LOCATIONS (MILEPOINT)		
Adair	KY 55	12.157	12.819	
Allen	US 31E	7.415	8.0	
	KY 100	10.128	10.228	
Barren	KY 90	4.1	4.464	
Bath	KY 11	1.1	1.5	
Bell	US 119	5.8	6.1	6.9
Boone	KY 14	0.786	1.086	
	US 42	7.988	8.088	
Bourbon	US 460	2.996	3.664	
Butler	KY 70	15.15	15.55	
	US 231	7.5	8.228	
Calloway	KY 121	13.161	13.392	
	KY 121	16.145	16.924	
Carter	US 60	19.11	19.872	
Casey	US 127	5.7	5.9	
Clay	US 421	14.907	15.282	15.3
Cumberland	KY 61	11.038	11.469	
	KY 90	14.7	15.4	
Daviess	KY 144	0.257	1.055	
Edmonson	KY 259	10.559	10.8	11.596
Estill	KY 89	12.226	12.977	
Floyd	KY 1428	10.609	10.809	
Garrard	US 27	12.328	12.4	
Grayson	KY 224	4.0	4.8	
Hardin	US 62	4.476	4.476	
Harlan	KY 72	8.0	8.0	
	KY 72	9.883	10.9	
Jessamine	US 68	9.4	9.476	
	KY 1980	3.305	3.981	
Larue	KY 210	7.8	8.1	
Laurel	US 25	0.774	0.94	1.0
	KY 80	19.7	20.6	
Letcher	KY 15	9.216	9.716	
Lewis	KY 8	29.775	29.835	
	KY 9	16.667	16.867	
Lincoln	US 27	3.0	3.4	

TABLE 8. COUNTIES AND ROUTES WITH TWO OR MORE FATAL CRASHES IN ONE-MILE SECTION (1996-1998) (continued)

COUNTY	ROUTE	CRASH LOCATIONS (MILEPOINT)		
Logan	KY 100	8.989	9.866	
McLean	KY 56	8.873	9.3	
Madison	US 421	2.034	2.706	
Magoffin	9009	72.34	72.54	
Marshall	US 68	2.0	2.5	
	KY 95	0.753	0.753	
Mason	KY 9	0.598	0.598	
Meade	KY 333	0.31	1.0	
Metcalfe	KY 90	4.721	4.721	
Montgomery	US 460	16.589	17.3	
Morgan	KY 172	3.2	4.0	
	US 460	20.269	20.529	
Nelson	US 62	4.6	5.6	
Ohio	US 62	11.4	11.9	
Oldham	KY 393	4.0	4.241	
Perry	KY 7	7.512	8.5	
	KY 550	0.533	1.1	
Pike	US 119	15.172	15.901	
	US 460	10.484	10.884	
	US 460	14.359	14.374	
Pulaski	US 27	29.5	30.3	
	KY 80	14.6	15.2	
Rockcastle	KY 461	8.181	8.2	8.709
Scott	US 460	3.608	4.308	
	US 460	11.905	11.905	
Shelby	KY 55	10.668	11.095	
	US 60	14.031	14.1	
Todd	US 68	12.315	12.8	
Union	KY 141	9.8	10.8	

TABLE 9. CHARACTERISTICS OF TWO-LANE RURAL ROADS

VARIABLE	CATEGORY	PERCENT OF TOTAL
Average Daily Traffic	Under 500	35.1
	500-999	22.7
	1,000-1,499	11.6
	1,500-1,999	6.6
	2,000-2,999	9.2
	3,000-3,999	5.4
	4,000-4,999	2.4
	5,000 or Above	7.0
Lane Width	Under 8 Feet	4.7
	8 Feet	18.0
	9 Feet	47.3
	10 Feet	17.9
	11 Feet	5.2
	12 Feet or More	6.9
Shoulder Type	Paved	11.3
	Stabilized (Granular Material)	41.6
Functional System	Principal Arterial	4.8
	Minor Arterial	6.6
	Major Collector	29.4
	Minor Collector	40.2
	Local	19.0
National Highway System	On System	3.5
Speed Limit	35 mph or Below	23.1
	40 - 45 mph	5.2
	Over 45 mph	71.7
Percent Trucks	5 Percent or Less	27.4
	5.1 - 9.9 Percent	62.2
	10.0 - 19.9 Percent	9.2
	20 Percent or More	1.2

TABLE 9. CHARACTERISTICS OF TWO-LANE RURAL ROADS (continued)

VARIABLE	CATEGORY	PERCENT OF TOTAL
Type of Terrain	Flat	6.0
	Rolling	79.2
	Mountainous	14.8
Pavement Condition	New	3.1
	Few Signs of Deterioration	56.7
	Ride Quality Affected	29.1
	Affect Speed of Free-Flow Traffic	7.0
	Extremely Deteriorated	4.2
Drainage Adequacy (Reported for 45 Percent of Roads)	Good	37.0
	Fair	58.8
	Poor	4.2
Horizontal Curvature (Reported for 31 Percent of Roads)	Less than 2.5 Degrees	65.8
	2.5 - 5.4 Degrees	14.1
	5.5 - 10.9 Degrees	12.2
	11.0 - 19.4 Degrees	4.9
	19.5 Degrees or Higher	3.0
Grades (Reported for 33 Percent of Roads)	Less than 2.4 Percent	60.1
	2.5 - 4.4 Percent	21.3
	4.5 - 6.4 Percent	10.1
	6.5 Percent or Higher	8.5
Percent with 1,500 Feet Passing Sight Distance (Reported for 88 Percent of Roads)	0 Percent	79.5
	10 - 20 Percent	8.5
	30 - 40 Percent	4.5
	50 - 60 Percent	2.8
	70 Percent or Above	4.7

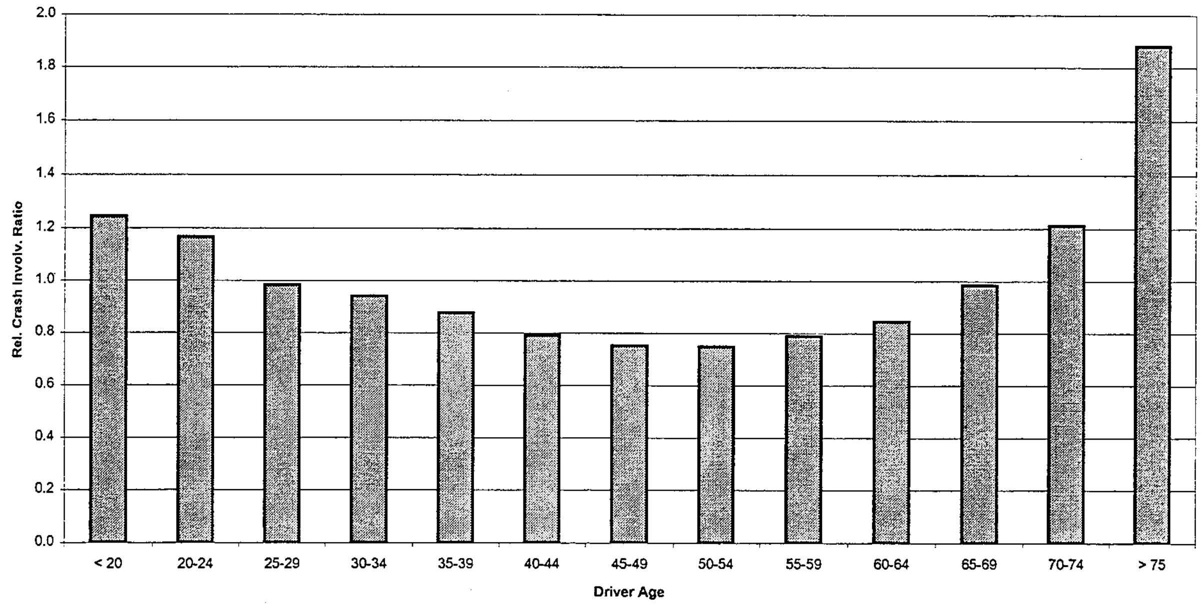

Figure 1. Relative Involvement Crash Ratio in Multi-Vehicle Crashes by Driver Age

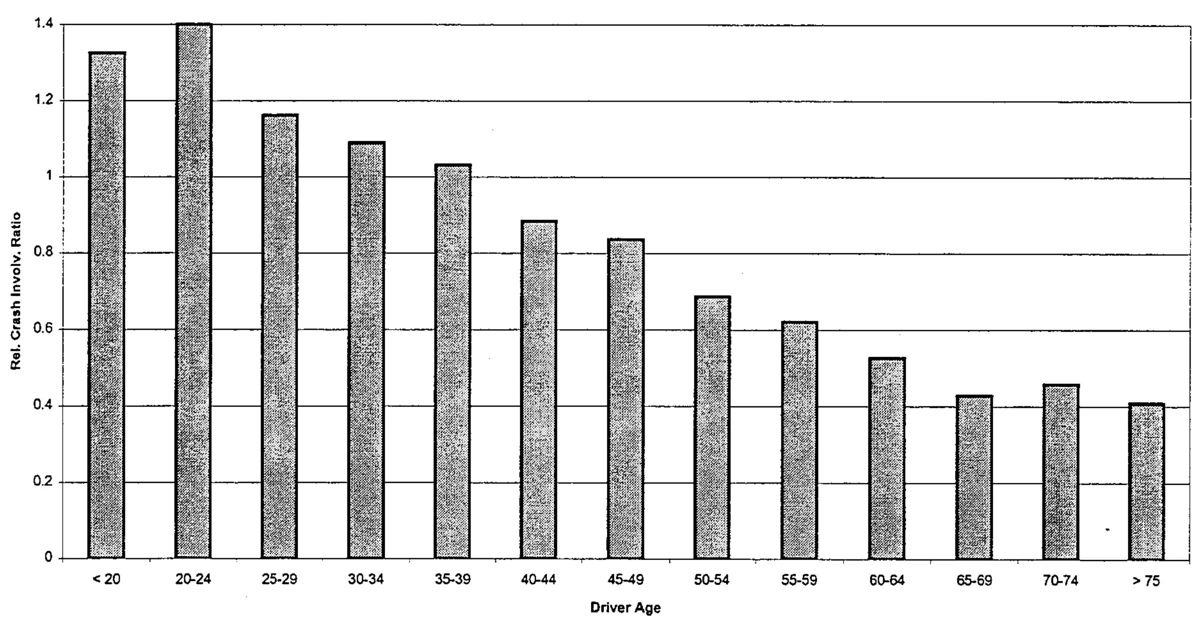

Figure 2. Relative Involvement Crash Ratio in Single-Vehicle Crashes by Driver Age

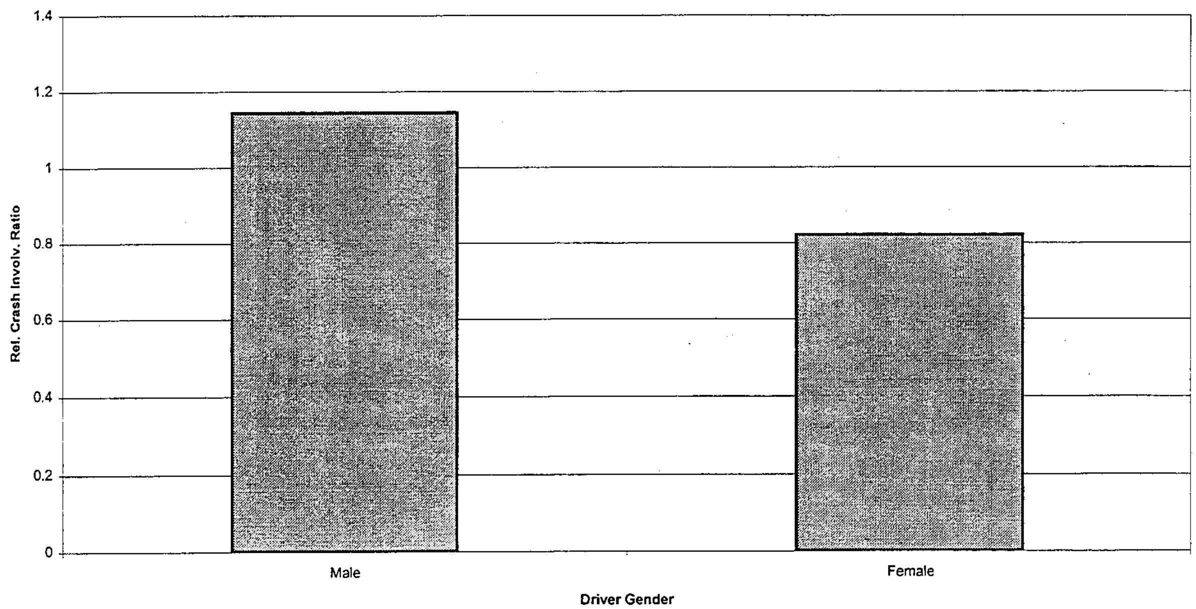

Figure 3. Relative Involvement Crash Ratio in Single-Vehicle Crashes by Driver Gender

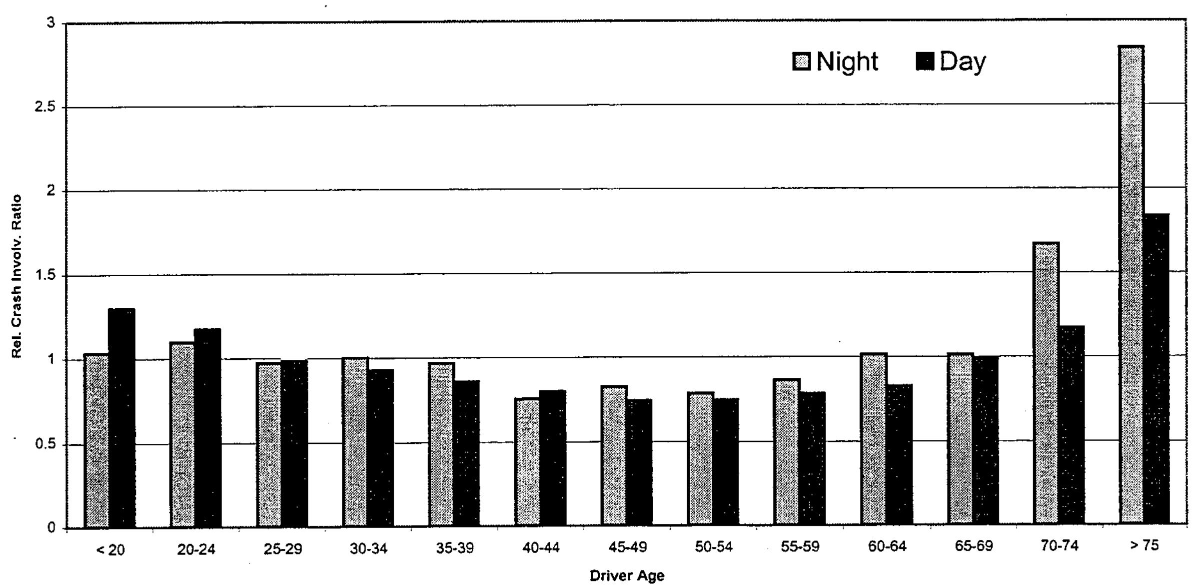

Figure 4. Relative Involvement Crash Ratio in Multi-Vehicle Crashes by Time and Driver Age

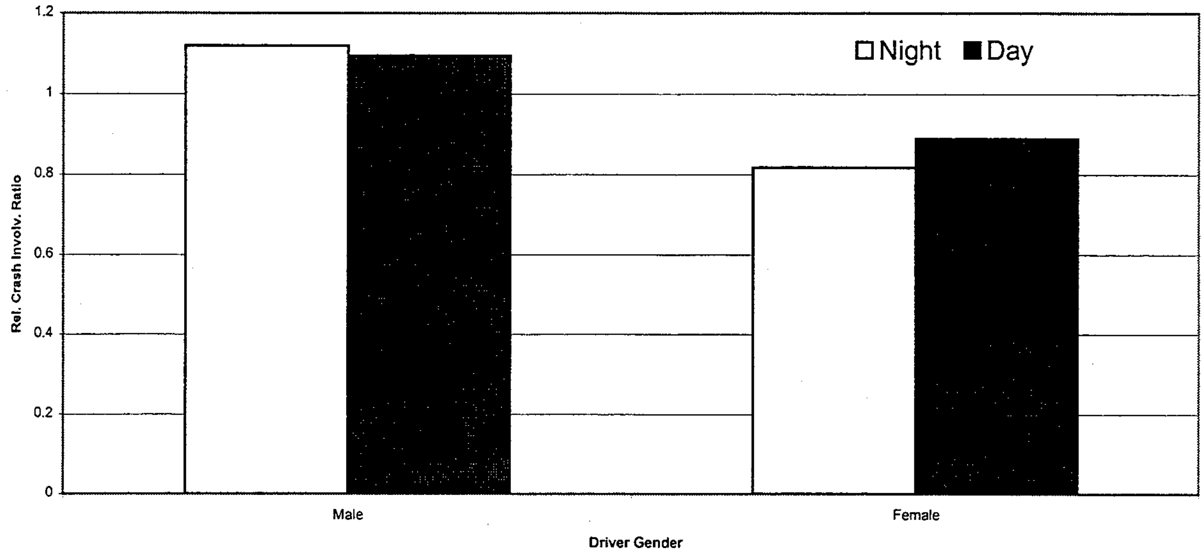

Figure 5. Relative Involvement Crash Ratio in Single-Vehicle Crashes by Time and Driver Gender

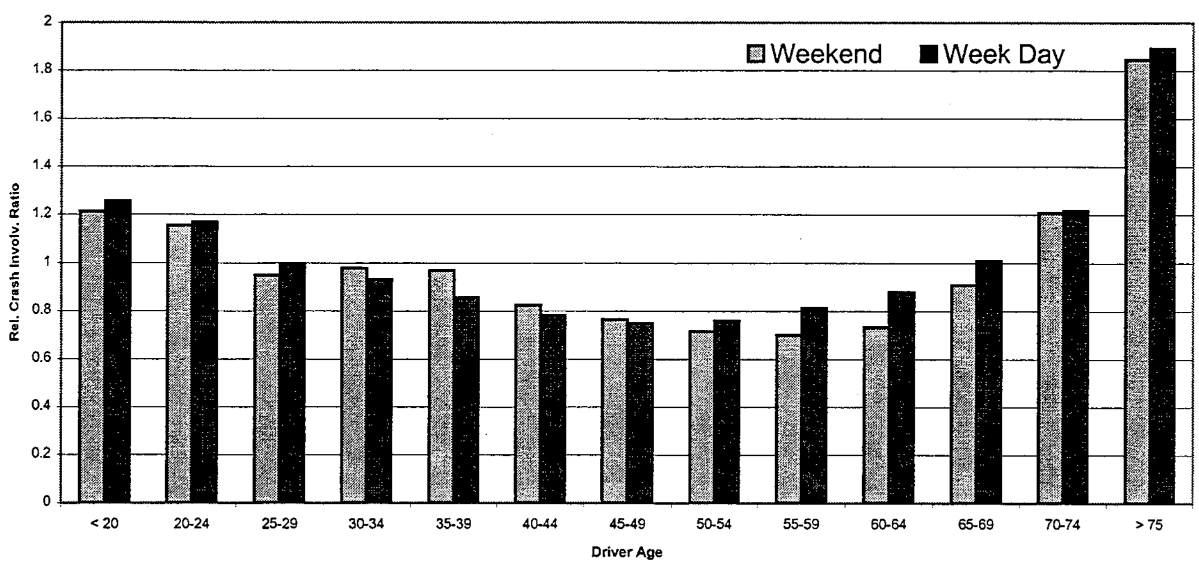

Figure 6. Relative Involvement Crash Ratio in Multi-Vehicle Crashes by Day of Week and Driver Age

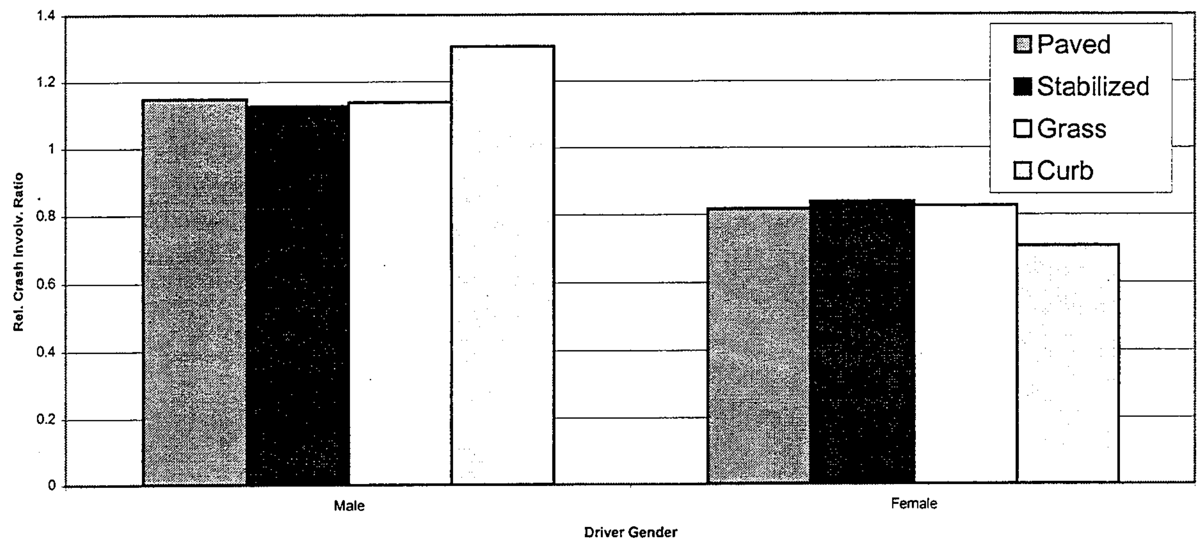

Figure 7. Relative Involvement Crash Ratio in Single-Vehicle Crashes by Shoulder Type and Driver Gender

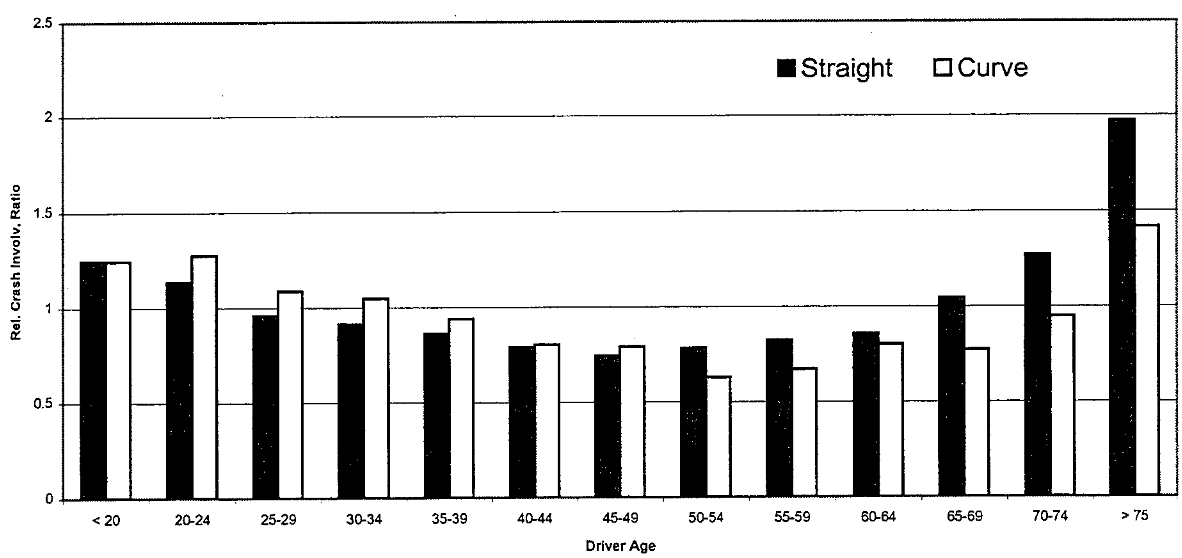

Figure 8. Relative Involvement Crash Ratio in Multi-Vehicle Crashes by Road Character and Driver Age

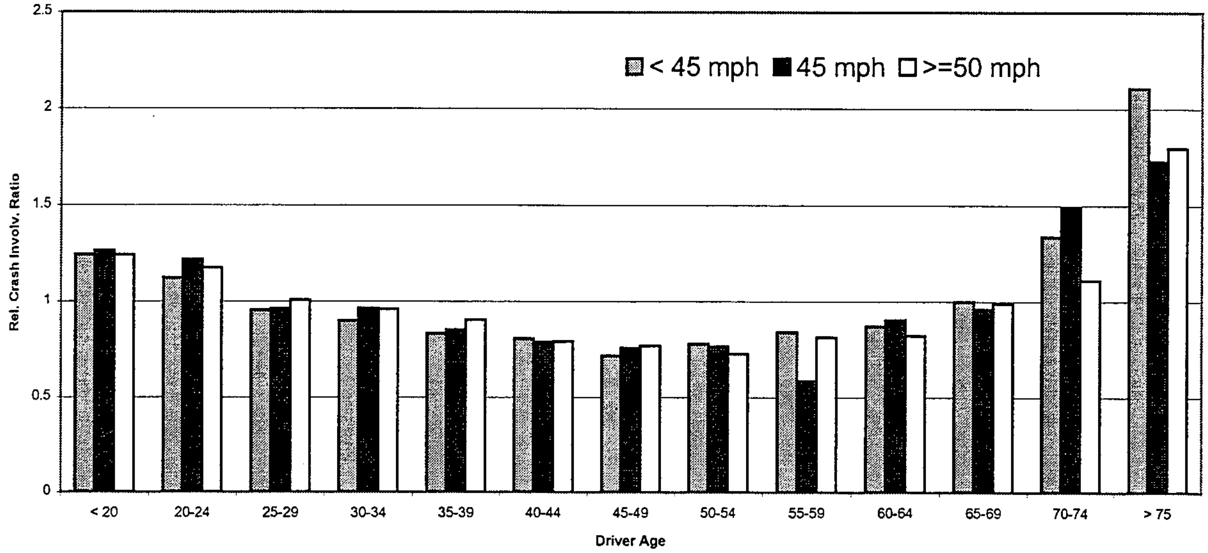

Figure 9. Relative Involvement Crash Ratio in Multi-Vehicle Crashes by Speed Limit and Driver Age

APPENDIX

SYNOPSIS OF COUNTERMEASURE ARTICLES

Alexander, H.; "An Investigation of Passing Accidents on Two-Lane, Two-Way Roads," Public Roads, Vol. 56, No 2, 1992.

After analyzing passing crashes, it was concluded that these type of crashes did not represent a significant problem. The occurrence of this type of crash was random. Based on the study, the conclusion was that the minimum sight distances required by the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) did not represent a hazard to drivers. Therefore, it was not necessary to change sight distance recommendations. Comparing crashes in passing and non-passing zones, it was found that the passing crashes are somewhat more severe than non-passing crashes. Most of the crashes only involved property damage. More crashes occurred under favorable driving conditions, such as dry roadway surfaces, straight sections and level roads with shoulders, and during clear weather. No geometric, environmental, or traffic factors could be identified as principal causes of crashes in passing and non-passing zones. Drivers under 40 years of age were found more involved in passing zone crashes. Lack of enough passing zones causes frustration in drivers causing them to make passing maneuvers in non-passing zones. In addition to pavement markings, it was recommended to install other traffic control devices such as the no-passing pennant sign to further differentiate a passing zone from a no-passing zone or a change between the two. Signing was strongly recommended where existing pavement markings are obstructed. When high traffic volumes and high-posted speeds are present, passing lanes should be provided.

Boyle, J.; "Clear the Way to Roadside Safety," Traffic Safety, September/October 1998.

This paper discussed the importance of removing obstacles on the roadside. Almost all roadside-hazard crashes involved only one vehicle; half occurred between the hours of 9 p.m. and 6 a.m. Forty-five percent of the drivers killed were men younger than 35 years. The fatally injured had a blood alcohol concentration at or above 0.10 percent in about half of the cases. Trees were the most common object hit by drivers and caused the majority of roadside deaths. Embankments, utility poles, and guardrails followed as the next most prevalent causes. Environmentalists are against removing trees from the roadside, and it is necessary to consider whether human life is worth the environmental cost. Technology can be used to solve problems with roadside fixed objects. Utility and light poles can be designed to break away upon impact which can reduce the potential of serious injury.

Council, F.; "Safety Benefits of Spiral Transitions on Horizontal Curves on Two-Lane Rural Roads," Transportation Research Record 1635, 1998.

Previous studies identified horizontal curves as one of the strongest factors affecting the safety on rural roads relating to increasing crash rates. Increases in the degree of curve and central angle and decreases in lane and shoulder widths and roadside clear zone generate increases in crash rates. Curves have crash rates that range from 1.4 to 5 times higher than other similar tangents. These situations point to the importance of the design effect as a contributor in crash rates. A

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curve transition can provide and direct the driver into a safe path while the motorist is changing his/her position from a fixed position on the tangent to a second fixed position on the curve. The curve transition must provide a transition to the superelevation. This involves change from the normal crown of the tangent to the full superelevation required in the circular curve to minimize excess side friction forces. Designers have three alternatives of design; no transition section which requires the driver to make his/her own transition path; a mixed curve transition, where a short section of less sharp curve is placed between the tangent and the principal curve; and a spiral transition which begins as a tangent and ends with the same degree of curvature as the curve. The study analyzed curves without transition sections and curves with spiral transition sections. The study used crash and road inventory data from over 15,000 transition sections in the state of Washington. The research searched for differences in crash probability using contingency tables and linear logistic regressions of one or more crashes and divided the crash occurrence by types of terrain (level, rolling and mountainous). Crash probability decreased in level terrain where spirals are used in curves with degree of curvature greater than approximately three degrees. When the average daily traffic is greater than 3,700 vehicles per day in rolling terrain, a decrease in crash rates was predicted with the use of a spiral. The model for mountainous terrain did not fit the data well, indicating the presence of undetermined variables.

Harwood, D.; "Effective Use of Passing lanes on Two-Lane Highways," Transportation Research Record 1195, 1988.

Passing lanes are used to improve passing opportunities on two-lane highways. Use of passing lanes eliminates many problems resulting from lack of passing opportunities due to limited sight distance and heavy oncoming traffic volumes. Passing lanes improve traffic operations on two-lane highways at a lower cost than required for constructing a four-lane highway. Passing lanes reduce delays at specific bottleneck locations and improve overall traffic operations by breaking up traffic platoons and reducing delays caused by inadequate passing opportunities over substantial lengths of highway. Passing lanes are constructed at isolated locations to improve travel time at specific bottlenecks, and their configuration fits the location conditions. When the goal is to improve overall traffic operations, passing lanes are provided over a length of road generally at regular intervals. Signing has to be provided to drivers in three locations at passing lanes sites: in advance of passing lane, at the lane addition, and in advance of the lane drop. The traffic operational effectiveness can be predicted as a function of flow rate, passing-lane length and the percentage of traffic traveling platoons. It was recommended to follow the already developed passing lanes geometric design, signing and marking practices.

Lum, H.; "Edgeline Widths and Traffic Accidents," Public Roads, Vol. 54, No 1, 1990.

Investigations have been performed to determine if there was a relationship between edgeline widths and crash occurrence on rural roads within the United States. The normal edgeline width is between 4 and 6 inches; however, some states are using the wider 8 inches. Ohio conducted a study in 1956-57 using 116 miles of two-lane rural highways for control and treatment sites.

The study concluded that, in the after period, sites with 4 inch edgelines had significantly less accidents compared with those sites with no edgelines. A similar study in Kansas showed a significant reduction in the number of accidents at access points such as driveways and intersections. New Mexico and Virginia performed studies to evaluate the effectiveness of the wide (8 inch) edgelines in preventing run-off the road crashes. Although the study showed that the wider edgelines have no significant effect on traffic safety, researchers were undecided as to whether to accept their findings due to the small number of miles sampled. In the early 1980's two studies were conducted to evaluate the effect in driver performance in response to different edgeline width. Both studies concluded that wider edgelines generate better driver performance. The objective of the study was to determine whether the more expensive wide edgelines are cost beneficial in terms of reducing edgeline-related crashes. An edgeline-related crash was defined as a run-off the road crash in which the driver was not forced off the road. As a complementary part of this study, a limited evaluation was performed to establish the efficiency of the 4-inch and 8-inch edgelines on drivers' performance in an unrestrained situation. The study concluded that 8-inch edgelines are not cost effective for installation on two-lane road in those areas where: 1) there is heavy snowfall and the use of deicing materials and abrasives tends to deteriorate the edgelines; 2) pavement widths are less than or equal to 22 feet; 3) roads have pavement shoulders over 6 feet wide. However, the study suggested that 8-inch edgelines could be potentially cost effective in reducing run-off the road crashes on two-lane rural roads with pavement widths of at least 24 feet, unpaved shoulders, and an average ADT of 2,000 to 5,000. The study also showed that 8-inch edgelines might be appropriate as a safety improvement when applied at spot locations such as isolated horizontal curves and approaches to narrow bridges.

Kaub, A.; "Passing Operations On a Recreational Two-Lane Two-Way Highway," VTI Report 372 A.

Because passing crashes in America are responsible for 6,000 fatalities and 100,000 serious injuries each year, it is important to analyze the magnitude of the problem. The provision of passing opportunities in two-lane two-way highways is a very important issue of traffic safety. In order to establish the effects of delay on the driver's performance and safety of the passing maneuver over variable traffic volume levels, the author presented the results of field measurements. The study identified a delay level of driver's tolerance. This delay was calculated as five percent of the total travel time of the studied segment. The delay level indicates where the passing driver becomes affected by the inability to tolerate further delay, and thus also begins to accept excessive risk in the passing maneuver by changing safety for delay savings. In addition, drivers notably overestimate their driving ability and the ability of their vehicle to complete passing maneuver safely.

Hashem R,; "Evaluation of Safety Impact of Highway Projects," Transportation Research Record 1401, 1993.

Using data from the state of Indiana, an empirical Bayesian approach was performed to evaluate the safety impact of reducing crash frequency and severity from a specific type of highway project. The study was focused on wedge and resurfacing projects. The evaluation was based on the expected number of crashes which were developed according with the Bayesian approach. Based on the results, it was concluded that wedge and level resurfacing improvements did not have a significant effect in the number of crashes at the 95 percent probability level on undivided rural roads having average daily volume less than 4,000 vehicles per day. Additionally, resurfacing projects did not have any significant impact at the five percent probability level on the level of traffic crashes on the same type of roads.

Raymond, A.; "Geometric Inconsistencies and Accident Experience on Two-Lane Rural High Ways," Transportation Research Record 1356, 1992.

This paper discussed the relationship between geometric inconsistencies and crash experience on two-lane rural highways. Inconsistent geometric features can generate operational and safety problems. Problems are caused by disparities between the expected and the actual driver workload and attention level requirements of the features. The U.S. policy is based on the design-speed concept which does not provide procedures for preventing geometric inconsistencies. Several European countries and Australia complement their geometric design procedures with consideration of operating-speed profiles looking for consistency along an alignment. Based on the benefits, it was concluded that it would be desirable that U.S. policy adopts similar procedures. Changes in operating speed and in driver workload are used to quantify geometric inconsistencies. Operating speed that is limited in application to horizontal curves and vertical grades can be directly measured in the field, but driver workload cannot. Workload is more adequate to qualify inconsistencies because operating speed is only one of the observable outputs of the driving task. Workload value qualifies the criticality of individual features and the interacting effects of combinations of features along the alignment. The study showed that Messer's procedure to measure workload might be a good indicator of crash experience on two-lane rural highways. Workload value can be a valuable tool to explain, predict, and qualify crash likelihood of rural highways. The paper suggests reviewing the European and Australian design procedures and their safety effectiveness. If further studies will show strong correlations between crash experience and the severity of geometric inconsistency, procedures should be adopted to evaluate geometric design consistency of existing and new rural highways.

Zegeer, C.; "Safety Effects of Geometric Improvements on Horizontal Curves," Transportation Research 1356, 1992.

The main objective of this research was to develop predictive models concerning crashes on curves related to geometric features and cross-section variables. The study dealt with three basic aspects: curve features that affect crash occurrence on two-lane rural roads, determining geometric improvements on curves that affect crash experience, and developing crash reduction factors. The project used information from 10,900 curves in the State of Washington. The study found, using statistical modeling analysis, higher curve crashes for sharper curves, limited curve width, lack of spiral transitions, and increased superelevation deficiency. Also, longer curves were associated with high crash occurrence. Using the predictive models, the following effects of curve improvements were obtained:

- curve flattening reduces crash frequency by as much as 80 percent, depending on the central angle and amount of flattening;
- widening lines on horizontal curves is expected to reduce crashes by up to 21 percent for 4-feet of lane widening;
- widening paved shoulders can reduce crashes by as much as 33 percent for 10-feet of widening (each direction);
- adding unpaved shoulders is expected to reduce crashes up to 29 percent for 10 foot widening;
- adding a spiral to a new or existing curve will reduce total curve crashes by approximately 5 percent; and
- improving superelevation can significantly reduce curve crashes where there is superelevation deficiency.

Lamm, R.; "Safety Module For Highway Geometric Design," Transportation Research Record 1512, 1995.

This study addressed the need of a tool that evaluates the factors involved in crash occurrence in two-lane highways. Safety module is a system that analyzes the relationships between highway geometric design, driver behavior, the crash situation and driving dynamics on road networks or roadway sections, or both. To understand the results from the module, it is important to link them with existing processing systems for highway engineering or with Geographic Information Systems (GIS), or both. Three safety criteria were proposed to evaluate curved roadway sections, including transition sections, with the goal of reducing crash frequency and severity. These criteria are: (a) achieving consistency between successive design elements; (b) harmonizing design speed and operating speed, specially on wet pavements; and (c) providing adequate dynamic safety of driving. The degree of curve was found in research studies conducted in the USA to be the most successful parameter in explaining much of the variability in operating speeds and crash rates. Similar results were found in the Federal Republic of Germany. In both, researchers found that operating speeds decreased with an increasing degree of curve and crash rates increase with an increasing degree of curve. In order to classify networks, highway sections, or both, changes in operating speeds were developed. In order to fit the second criteria of harmonizing design speed and operating speed, the 85th percentile speed of every independent tangent or curve must be coordinated with the existing or selected design speed according to the recommended design ranges. The third criteria, providing adequate dynamic safety of driving, examines whether or not the assumed side friction factors for curve design in the highway geometric design guidelines of a given country are sufficient for actual driving behavior in curves or curved sections. Further crash research is necessary to establish reliable boundaries for this criterion, as well as to assign possible individual weights to the three safety criteria for combining them in a safety module.

Zegeer, C.; "Accident Relationships of Roadway Width on Low-Volume Roads," Transportation Research Record 1445, 1994.

The main objective of this study was to qualify the crash effect of lane width, shoulder width and shoulder type on rural roads carrying equal or less than 2,000 vehicles per day. A detailed statistical analysis was performed on a database of approximately 4,100 miles of low-volume, two-lane roads in seven states. Using covariance analysis, adjusted crash rates were calculated for various lane and shoulder widths. Three additional independent databases (Illinois, Minnesota and North Carolina) totaling more than 54,000 miles were analyzed in order to validate and investigate the mentioned relationships. The crash effects of other variables were also determined in the analysis. Wider roadway width, improved roadside condition, flatter terrain and fewer driveways per mile are the features that significantly reduce crash rates on paved, low-volume roads. When comparing crash rates for paved and unpaved shoulders, no differences were found. Occurrence of single-vehicle and opposite direction crashes are more highly correlated with lane and shoulder width than other type of crashes. Significant crash reduction was associated with the presence of shoulders on roads with lane widths of 10 feet or greater. On roads with lane widths of 10 feet, shoulders of 5 feet or greater are needed to reduce crash rates. On roads with lane widths of 11 feet and 12 feet, shoulder widths of at least 3 feet result in significant crash reduction in comparison with the number of crashes on roads with narrower shoulders. For roads with lane width of 9 feet, there is no noticeable reduction in the number of crashes from widening those lanes from 9 feet to 10 feet unless shoulders of 5 feet or more are also added. The study stated that existing roads with 9 foot lanes with narrow or wide shoulders are preferable to roads with 10 foot lanes with narrow shoulders, possibly due to lower speeds on roads with 9 foot lanes and lower number of crashes. Crash occurrence did not show a significant difference for unpaved versus paved roadway surfaces at traffic volumes of 250 vpd or less. Unpaved roadways shows higher crash occurrence than paved roadways for traffic volumes greater than 250 vpd.

Vogt, A.; "Accident Models for Two-Lane Rural Segments and Intersections," Transportation Research Record 1635, 1998.

This study developed crash models for segments and three-legged and four legged intersections with stop control on the minor legs. The research used crash and roadway data from the states of

Minnesota and Washington on rural two-lane highways. The innovative part of this study was the use of advanced statistical techniques. The main objective was to develop improved crash prediction models that take into account the effect of multiple design elements such as horizontal curve, vertical curve, and cross section. Also, the research used traffic volume, shoulder widths, roadside hazard rating, channelization and number of driveways. The common features for these roads are roads without medians, which are a class of roads for which crash rates are relatively high. The models are of negative binomial and extended binomial form and yield R^2 values from 0.42 to 0.73 and overdispersion parameters from 0.20 to 0.51. The study provided goodness of fit measures and cross-validation between states. Also, a segment model combining both states and using state as a variable, and intersection models derived from Minnesota data, is featured. The study found that segment crashes depend significantly on most of the roadway variables collected, while intersection crashes depend primary on traffic. The final recommendation of this study was to develop adjustment factors and times for different regions as well as further development of extended negative binomial models.

Persaud, B.; "Microscopic Accident Potential Models for Two-Lane Rural Roads," Transportation Research Record 1485, 1995.

The main objective of this paper was the use of hourly traffic volumes in regression models for estimating accident potential on two-lane rural roads. Estimation of crash potentials of road sections usually requires the use of a relationship between crashes and a measure of traffic volume, traditionally the average daily traffic (ADT). ADT-based models are inappropriate to estimate safety during certain portions of the day (specific hours, peak hours, and nighttime) when the relationship between crashes and ADT is not linear. Estimating safety during these periods of time is very important to evaluate strategies that concern traffic volumes or safety during certain parts of the day and to identify potentially unsafe traffic operating conditions. This paper points out that, for these kind of estimates, it is preferable to use microscopic models with hourly volumes as the measure of traffic intensity. Models were calibrated for the different combinations of time periods (24 hours, daylight hours and nighttime hours) and geometric characteristics (roadway and shoulder width). The study used data from Ontario, Canada and a regression package that allowed the assumption of a negative binomial error structure. For single-vehicle crashes and multi-vehicle crashes the effect of day/night conditions was different. The potential of being involved in a crash at night was higher for single-vehicles, while high crash potential for multi-vehicle crashes was found during daylight hours. The study also illustrated the refinement of regression predictions by the empirical Bayesian estimation procedure. The Empirical Bayesian procedure provides better estimates of crash potential than the conventional method only on the basis of the short-term crash count for a section.

McCormack, E.; "ITS and Rural Road Safety: An Evaluation in Washington State," ITS Quarterly, Spring-Summer 1999 Issue.

Information from the state of Washington was studied to determine which factors contributed to crashes. The results were used to evaluate how ITS applications might reduce different types of rural crashes. Driver behavior was identified as the most common contributor to rural crashes. Some ITS applications can be used to mitigate the effect of driver behavior. A good example is the use of radar linked to speed warnings signs that warn drivers at specific locations. Other ITS applications that can be used in reducing crashes linked with driver behavior, are those that inform drivers about unsafe situations such as bad weather, slippery pavement, etc. Unfortunately, human factors issues such as impaired drivers or poor driver judgment cannot be solved with the available ITS technology. Because in Washington 30 percent of the crashes was linked with the roadway or roadside environment, it is important to warn drivers before the identified hazardous location. Weather was defined as the most common factor in crashes linked with the road environment. Using ITS weather programs providing area-wide information about travel and roadway conditions, hazardous locations, and problems such as ice or high winds, rural safety will be impacted positively. ITS can deal with hazards at intersections, work zones and railroad crossings. If advance information about road conditions is provided to drivers, the number of crashes related with roadside environment will be reduced. Vehicle factors as a crash contributor was identified in a small percentage of crashes. ITS can help make automobiles and trucks more compliant with safety laws. Safety benefits were found using emergency notification systems, such as extended use of roadside call boxes or cellular phone-based systems within the vehicle. This system is part of the post-crash information system. Communication technologies play an important role in ITS solutions because they provide information to drivers. One limitation to ITS application in rural roads is the limited access to those places to communication systems, with a particular limitation on those that allow two-way communication. Improvements in the actual communication systems or new developments in this area will benefit ITS application in rural areas.

Hasson, P.; "Rural Road Safety: A Global Challenge," Public Roads, September/October 1999.

This paper summarized the findings of the last meeting of the Research in Road Transport and Intermodal Linkages (RTR). RTR is a research program created in 1968 by the Economic Cooperation and Development (OECD) that includes 14 countries. This program provides regular interaction exchange among national road researches, and this paper summaries the last renewal in December 1997. The researchers divided the countermeasures into conventional and ITS. The study also divided the countermeasures by type of crash: Run-off-the-road (ROR), Head on (HO) and Intersection (I). The study identified the following conventional low cost countermeasures (type of crash is indicated in the parenthesis): upgrading edge and center lines (ROR, HO); adding raised reflective pavement markers (ROR); upgrading advance warning (ROR, I); rumble devices (ROR); improved sight triangles at intersections (I); roadside markings (ROR); and roadside safety knowledge transfer and training (ROR). The following conventional medium cost countermeasures were identified: removal/protection of roadside hazards (ROR, HO), flattening side slopes (ROR, HO); improving pavement skid resistance (ROR, HO, I); increasing superelevation (ROR, HO); paving shoulder (ROR, HO); eliminating pavement edge drops (ROR); channelization (I); road lighting (I); safety impact assessment and safety audit (ROR, HO, I); conflict-free overtaking (ROR, HO); increase lane and shoulder widths (ROR, HO, I); and forgiving roadside shoulder widths (ROR). Conventional high cost countermeasures included: separating opposing traffic (HO); narrow physical separation by barrier (HO); flattening horizontal curves (ROR, HO); and roundabouts (I). ITS low cost countermeasures: speed control advisory (ROR), speed control: adaptive cruise control (ROR, I); intersection approach warning (I); guidelight warning (ROR, HO); weather information systems (ROR, I); crash avoidance (all); lateral guidance warning (ROR); crash mitigation systems: smart belts/bags (all); and vehicle data recorders (all). The study identified as a ITS medium cost countermeasure speed control roadside control (I) and as a medium-high cost lateral guidance control (ROR).

Schwarts, D.; "Analysis of Policies for Safety Improvements on Low-Volume Rural Roadways," Midwest Transportation Center, October 1994.

The main objective of this study was to examine safety improvements programs of Iowa, Kansas, Missouri and Nebraska relative to their consideration of low-volume rural roadways and to recommend policy modifications to improve their consideration of low-volume rural roadways. The low exposure rates of rural roads make risks more difficult to identify than on higher-volume roads. It is important to identify the risks so countermeasures can be adopted. Hazardous location identification: the methods that seem more adequate to identify truly hazardous locations combine other measures with crash-based measures. The study recommends use of empirical-Bayes methods to identify location of true crash potential such as the one developed by Hauer. If a crash history method is used the study will be subject to large number of errors. It is important to use at least five years of crash data in order to obtain significant results. The most effective method for low-volume locations is a system-wide survey using hazard index, because it eliminates dependency on crash history. Countermeasures evaluation: A comprehensive database including crash locations, crash severity, roadside hazards and countermeasures performance should be used to evaluate and select countermeasures. A good aid for the selection process is a database that includes hierarchy improvements from low-cost countermeasures to large-scale projects. In the selection process the major efforts have to be directed to low-cost countermeasures; these low-cost countermeasures would be more easily justified. System-Wide Safety Improvements: The safety needs for low-volume rural roadways can be addressed using system-wide safety programs. The 3R design standards would foster much-needed consistency. Past system-wide safety improvements were found cost-effective in the four states. Another form to implement safety improvements on low-volume rural roadways would be to incorporate them into resurfacing, restoration and rehabilitation (3R) projects. To facilitate the safety review for 3R projects, 3R design guidelines should be developed which are distinct from state's construction standards. If this procedure is followed, the demonstration of the deficiencies of a road section will be easier.

Zegeer, C.; "Safety Effectiveness of Highway Design Features," Federal Highway Administration, Publication No FHWA-RD-91-046, December 1992.

This study discussed the relationship between cross-section elements and crash experience. In general, wider lanes and/or shoulders will result in fewer crashes. A great number of studies have analyzed the effect of lane width, shoulder width and shoulder type on crash experience. Because the mentioned road features only affect a limited number of type crashes, there is a need to express crash effects as a function of those crash types. The study presents results on crash reduction of related crash types for lane widening with crash reduction percentages from 12 to 40 percent for widening from one foot (i.e. from 10-feet to 11-feet) to four feet, respectively. Reduction in related crashes due to widening paved shoulders varies from 16 to 49 percent for shoulder widening from two to eight feet, respectively. In the same way, the reduction in related crashes due to widening unpaved shoulders was calculated as from 13 to 43 percent for shoulder widening from two to eight feet, respectively. When two or more roadways improvements are proposed simultaneously, the crash effects are not additive. A table was developed which presented crash reduction factors for projects involving various combinations of lane widening, shoulder widening, and shoulder surfacing.

Zegeer, C.; "Safety Improvements on Horizontal Curves for Two-Lanes Rural Roads – Information Guide," Federal Highway Administration, Publication No FHWA-RD-90-074, October 1991

Guidance is provided for the design of horizontal curves on new highway sections and for reconstruction and upgrading of existing curves on two-lane rural roads. The guide also presents a procedure to evaluate the costs and benefits of various curve-related improvements by type of road. The procedure requires data from the physical site features and countermeasure alternatives. The study assists highway designers when designing new highway sections or reconstructing existing highway alignments taking into account curve geometrics, safety and operations. To determine benefits from curve improvements, the guide estimates crash benefits. These benefits are those expected due to one or more proposed curve improvements on a specific section of two-lane rural road. The procedure measures the benefits for the following countermeasures: curve flattening, adding spiral transition, improving deficient superelevation, lane widening, shoulder widening on the curve, shoulder surfacing on the curve, sideslope flattening, and removing roadside obstacles to increase the clear recovery distance. After determining an appropriate solution for a specific section of the roadway, construction costs are estimated. The final step presented the method to perform an economic analysis to determine project cost effectiveness.