Southeast Transportation Consortium

Final Report 624

Synthesis on the Contributing Factors and Effective Countermeasures for Low-Volume Roadway Fatality Rates in the Southeast

by

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Published by:

LOUISIANA TRANSPORTATION RESEARCH CENTER

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808 | (225) 767-9131 | www.ltrc.lsu.edu

TECHNICAL REPORT STANDARD PAGE

1. Title and Subtitle
Synthesis on the Contributing Factors and Effective Countermeasures for Low-Volume Roadway Fatality Rates in the Southeast

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Louisiana Department of Transportation and Development
P.O. Box 94245
Baton Rouge, LA 70804-9245

5. Report No.
FHWA/LA.17/624

6. Report Date
June 2020

7. Performing Organization Code
LTRC Project Number: 19-2PF
SIO Number: DOTLT1000288

8. Type of Report and Period Covered
Final
03/19-11/19

9. No. of Pages
106

10. Supplementary Notes
Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

11. Distribution Statement
Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.

12. Key Words
Low-volume roads; Highway safety; Countermeasures; Southeast

13. Abstract

In the Southeast US, the largest proportion of fatal crashes occur on low-volume roads (LVRs). Many state transportation agencies have recognized this problem and are implementing countermeasures to reduce fatality rates. This synthesis contributes to ongoing efforts to lower crash rates on LVRs by identifying and describing countermeasures for improving road safety. Countermeasures were selected based on a review of research literature, an examination of a number of manuals and handbooks that agency personnel can use to select appropriate treatments, and a survey of personnel who work at transportation agencies in member states of the Southeast Transportation Consortium (STC). This synthesis identifies best practices and countermeasures agency staff view as being the most effective. Summary sheets have been developed for treatments that hold the most promise; these summary sheets describe each countermeasure, comment on their effectiveness, review installation costs, and list crash types they are used to mitigate. Agency personnel may consult these sheets when deciding on what countermeasure(s) to implement.

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

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Acknowledgments

The authors would like to acknowledge the members of the Project Review Committee for their guidance and support throughout this project as well as the survey respondents (David Adams, Chris Armstrong, Nick Hendrix, Vicki Meredith, Joey Riddle, Nathan Ridgway, Tyson Rupnow, and Cynthia Smith) who provided invaluable feedback on the various countermeasures considered here. The project would not have been completed without the funding from the Southeast Transportation Consortium. The authors would also like to thank Paul Ross for developing graphics for each countermeasure. Finally, the guidance the team received from Elisabeta Mitran, Ph.D., throughout the project is greatly appreciated.

Implementation Statement

The research team will publicize the report findings through conference presentations, including at the Southeast Transportation Consortium annual meeting. The project principals are committed to preparing papers, making presentations, and advertising use of the synthesis and its associated summary sheets. These sheets can be used to train agency staff and provide a quick reference for practitioners. State and local agencies can use the summaries to quickly identify and implement appropriate countermeasures.

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Introduction

Of the more than four million miles of public roads in the United States, almost three million miles are rural roads [1]. In 2016, 50 percent of all fatal crashes occurred along rural roads, but only 30 percent of the total vehicle miles traveled were in rural areas [2]. Low-volume roads (LVRs) carry an annual average daily traffic (AADT) volume of fewer than 2,000 vehicles per day (vpd) and make up a large portion of the US roadway system [1]. These roads account for approximately 20 percent of the rural National Highway System and over 50 percent of the Federal-Aid System [1]. Despite these roads carrying low-traffic volumes, historical crash data indicate their crash rates are higher than other highways, accounting for half of all fatalities [2]. Typically, LVRs are classified as local roads, and most are located in rural areas. In 2016, the fatality rate on rural roads was 1.96 fatalities per 100 million vehicles miles of travel (MVMT); conversely, for all roads the fatality rate was 1.18 fatalities per 100 MVMT [2].

Researchers have consistently demonstrated that crash rates are higher on LVRs than other roads. Using a sample of nearly 5,000 miles of paved two-lane rural roads in seven states (Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia), Zegeer et al. [3] estimated a crash rate of 3.5 per MVMT on LVRs (which they defined as roads with ≤ 2,000 AADT) and a crash rate of 2.4 per MVMT on all high-volume roads. Fixed object crashes, rollover crashes, and other run-off-road (ROR) crashes occurred more frequently on LVRs. However, fewer multi-vehicle crashes, including rear-end, angle, and turning-related crashes, occurred on these roads.

In 2016, most of the Southeastern Transportation Consortium's (STC's) member states experienced higher fatality rates than the rest of the nation. For example, 834 fatality crashes occurred in Kentucky; 607 took place on rural roads (approximately 73 percent). In Mississippi, 98 percent of its 690 fatal crashes occurred on rural roads [2]. Because traffic data are lacking for local roads, it is exceptionally difficult to estimate crash rates and exposure, which are needed to prioritize roadways for safety interventions. Table 1 summarizes rural and urban traffic fatalities for states in the STC [2].

Table 1. Traffic fatalities for STC states (2016) and percent rural population (2010) [2, 4]

State	Location						Percent Rural Highway	Percent Rural Population
	Rural		Urban		Unknown			
	Number	Percent	Number	Percent	Number	Percent		
Alabama	647	62	326	31	65	6	73.2	41.0
Arkansas	362	66	183	34	0	0	83.3	43.8
Florida	1,388	44	1,757	55	29	1	29.7	8.8
Georgia	603	39	951	61	0	0	59.2	25.0
Kentucky	607	73	226	27	1	0	81.2	41.6
Louisiana	368	49	385	51	4	1	71.3	26.8
Mississippi	675	98	15	2	0	0	83.2	50.7
N. Carolina	902	62	543	37	5	0	61.5	33.9
S. Carolina	612	60	403	40	0	0	74.0	33.7
Tennessee	464	45	573	55	4	0	67.2	33.6
Virginia	477	63	281	37	2	0	64.8	24.6
W. Virginia	169	63	99	37	1	0	82.8	51.3
USA	18,590	50	17,656	47	1,215	3	70.7	19.2

Eight of the 12 STC states have higher fatal crash rates in rural areas than in urban settings. Factoring in a state's rurality (i.e., the percentage of the population that lives in rural areas), these figures may hint at an even larger problem as they indicate the percentage of rural highways is disproportionately large compared to rural populations. The significant LVR mileage in these states may contribute to high fatal crash rates. Similar issues were observed during a previous FHWA transportation pooled fund study that examined the fatal crashes in the Southeast Region IV [5].

Objective

The objectives of this synthesis are to:

1. Summarize factors that contribute to LVR crashes, drawing from prior domestic and international research;
2. Identify countermeasures that have been implemented to address LVR safety in the Southeast; and
3. Determine how effectively countermeasures address LVR safety.

This synthesis will supply transportation agency personnel with critical information to help them understand available countermeasures, including their effectiveness and range of applications. With this knowledge, they can identify the countermeasure that is most likely to produce the desired safety outcome.

Methodology

The research team prepared this synthesis using a two-phased approach. The first phase consisted of a literature review and designing a web-based survey to solicit information from STC member states on their current use of countermeasures for addressing LVR safety and the effectiveness of these practices. To compile the literature review, researchers searched for materials on the Transportation Research Information Database (TRID) and other databases. The survey was administered during the second phase. Researchers used survey data to synthesize the performance of each countermeasure and the circumstances in which each treatment can help improve LVR safety. This report documents the findings of both phases.

Scope

This synthesis only addresses practices used by the 12 STC member states. However, its findings are applicable to all states, since they were based on review of national practices. As noted, activities completed as part of this study included a literature review and web-based survey. Information gathered as part of these activities established the foundation for the analysis and conclusions presented in this document.

Literature Review

The following sections present information on various aspects of LVR safety and countermeasures agencies have used on these roads to lower crash risks along with manuals that describe countermeasure applications. A more targeted review of studies focused on the Southeast is also included.

Low-Volume Road Safety Issues

Previous research has focused on why LVRs suffer from higher crash rates. The road features that contribute to crashes include roadside features, cross-sectional elements, and alignment.

A study on LVRs in Kansas and Nebraska determined that culverts, bridges, driveways, trees, ditches, slopes, utility poles, and public broadcast service routing stations can all negatively impact driver safety [6]. However, it did not quantify the risks associated with these features because their focus was on identifying treatment options. A safety analysis of LVRs (400 vpd) in Iowa concluded that fixed object crashes involving culverts, ditches, embankments, trees, and poles were more common on LVRs than higher volume roads [7]. Crashes were more frequent at night, on rolling and hilly terrain, at bridges, railroad crossings, driveways, and at T- and Y- configuration intersections but less frequent at four-way intersections. Prato et al. [8] identified risk factors that influence crash severity on LVRs (AADT < 2,000 vpd) in Denmark. Increased crash severity was found on roads with speed limits over 50 mph, while a 14 percent decrease in fatalities was recorded on unpaved roads. Reduced sight distances increased fatal crashes by 20 percent; Cafiso et al. [9] concluded that segments with a sight distance less than 165 ft. were problematic.

Hossain [10] argued the higher risk levels and crash rates associated with LVRs may be a product of their substandard geometry. Combining an evaluation of geometric and roadside features with an analysis of crash histories along Oregon's LVRs, Hossain determined that the most restrictive features contributing to higher crash rates are length of horizontal and vertical curves under 100 ft., degree of curvature in excess of 30 degrees, vertical grade over 5 percent, lane width narrower than 11 ft., shoulder width of 0 ft., and driveway density of at least 5 driveways/mile. Another Oregon study on LVRs (AADT<1,000 vpd) determined that crashes are more likely to occur on narrower lanes, where shoulders are lacking, around sharp curves, in the presence of more driveways, and along road segments with steeper grades [11].

Several other researchers have looked at the influence of lane width on safety. Gross and Jovanis [12] examined the safety impacts of lane and shoulder widths on rural, two-lane highway segments in Pennsylvania, including low-volume segments (AADT < 500 vpd). Case study segments were paired with control segments to compare their safety. Lane widths between 10 to 11.5 ft. and greater than 13 ft. were less safe than other lane widths (i.e., 12 ft.). Of particular note is that lane widths less than 10 ft. were associated with lower crash risk. Shoulder widths of 0 to 3 ft. increased crash risk, although risk fell as shoulder width increased. Cafiso et al. [9] developed a safety index for rural roads in Italy using road safety inspection. Lane widths less than 9 ft. and greater than 14.7 ft. posed a safety concern. Shoulder widths less than 1 ft., unshielded trees, and ditches within 10 ft. of the roadway can all present issues to drivers. Wang et al. [13] evaluated rural two-lane roads in the state of Washington to identify causal factors in crashes, finding that wider shoulders and pavement sections reduced crash frequency. However, specific values associated with these risks were not cited. Gross et al. [14] studied whether increasing lane width or shoulder width results in greater safety benefits (given a constrained total width). Based on extensive crash data from Pennsylvania and Washington, they concluded that in some cases increasing lane width was a viable option, whereas in others it was not an appropriate solution.

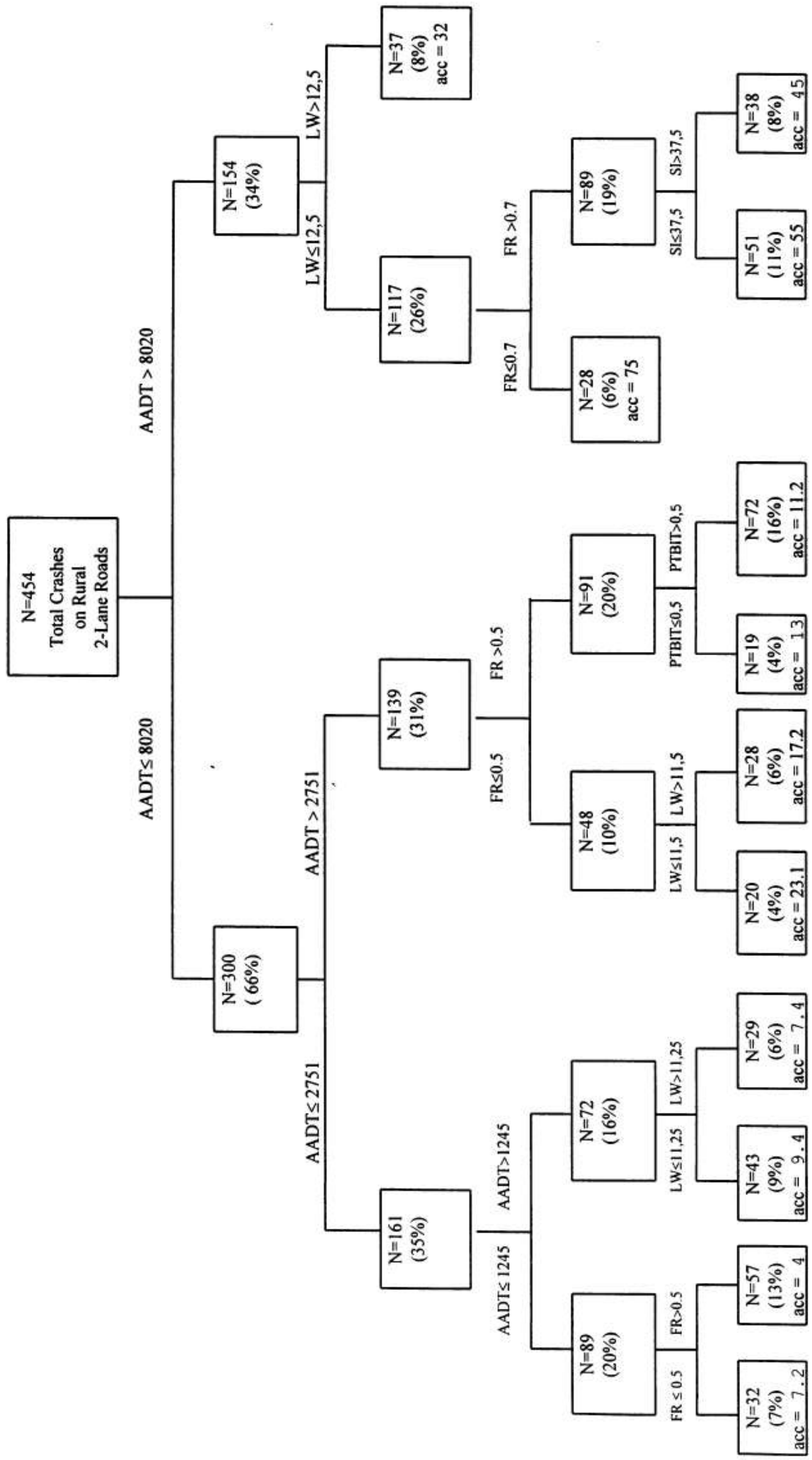
Stamatiadis et al. [15] examined the likelihood of drivers in three age cohorts (< 35, 35-64, ≥65) being involved in crashes on LVRs (AADT < 5,000 vpd) in Kentucky and North Carolina. Younger (< 35) and middle-age (35-64) drivers were more likely to be involved in crashes when lane widths were 8-9 ft., but only younger drivers were at a higher risk if lane widths were between 9-10 ft. Shoulder widths of 0-1 ft. presented greater risk to younger drivers, while widths of 1-5 ft. posed more of a risk to younger and middle-age drivers. Roads with an AADT less than 2,000 vpd posed a more pronounced risk to younger and middle-age drivers. For two-vehicle crashes, both younger and older driver groups were at a higher risk compared to middle-age drivers.

A study that examined the cost-effectiveness of countermeasures on rural two-lane roads in Italy, quantified how various features impact safety risks [16]. They found that roadway geometry issues increased crash risk by 700 percent. Deficiencies in other areas also increased safety risks: driveway presence (135 percent), delineation (30 percent), markings (20 percent), pavement (10 percent), roadside features (200 percent), sight distance (50 percent), and signage (20 percent).

Attempting to identify cost-effective countermeasures for LVRs in Oregon, Al-Kaisy et al. [17] catalogued numerous treatments that can ameliorate safety concerns, including those which improve clear zones and roadside features, lane and shoulder widths, sight distance, signs and markings, pavement surface conditions, driveway density, horizontal and vertical curves, and pavement edge drop off.

Karlaftis and Golias [18] developed a hierarchical tree-based regression to assess the effect of various geometric characteristics on crash rates (Figure 1). Geometric characteristics that influence crash rates for rural, two-lane roads include AADT, lane width, pavement serviceability index, friction, pavement type, and access control. They cited AADT as the most important variable, followed by lane width.

Figure 1. Regression tree for accidents and geometric characteristics on rural two-lane roads [18]



Countermeasure Identification

Many countermeasures have been studied and subsequently recommended to improve LVR safety. Previous researchers have compared the value of potential safety measures through historical crash analysis and quantifying costs. Benefit-costs analysis is a valuable tool for comparing the effectiveness of different countermeasures.

For roadway departure crashes, Peng et al. [19] concluded that shoulder width, lateral clearance, and side slope conditions are all significant influences. Zegeer [20], based on a finding that ROR and opposite direction crashes were the only types associated with narrow lanes and shoulders on rural, two-lane roads, recommended that agencies identify road segments with five or more ROR and opposite direction crashes and evaluate them to determine if a cost-effective widening option is available.

The Lee and Mannering [21] study of the factors that influence the frequency and severity of ROR crashes advanced guidance for identifying cost-effective design-oriented countermeasures to reduce the probability of ROR crashes. Suggested countermeasures included avoiding cut side slopes, decreasing the distance from outside shoulder edge to guardrail, reducing the number of isolated trees along roadway sections, and increasing the distance from outside shoulder edge to light poles. Complex interactions tend to arise between roadside features, such as guardrails, various fixed objects, sign supports, tree groups, and utility poles, and may need to be addressed.

Shoulder width and type have also been central in addressing LVR safety. Schrock et al. [22] evaluated the safety benefits of increasing shoulder widths (from 2-8 ft.) and adding passing lanes to LVRs in Kansas. They developed crash modification factors (CMFs) to identify and quantify the benefits of safety improvements. Benefit-cost ratios were derived from the CMFs as well. Shoulder widening yielded a CMF of 0.95 and benefit-cost ratio of 0.08. Adding passing lanes produced a CMF of 0.65 and benefit-cost ratio of 0.24. With benefit-cost ratios less than 1.0, neither treatment was viewed as an optimal investment. The authors also found that calculating a local CMF, rather than using national CMFs, is useful for estimating and comparing safety benefits and alternatives.

Hallmark et al. [23] identified paved shoulders as a potential countermeasure for reducing the number of total crashes, ROR crashes, and single-vehicle ROR crashes on LVRs. Results indicated a 4.1 percent drop in the expected number of crashes for each additional ft. of shoulder added. An 8.8 percent reduction in the expected number of total crashes in the first year following the paving of shoulders was also found. For ROR crashes, a reduction of 1.3 percent was expected the first year following intervention whereas the expected decline in crashes after 10 years was 12.9 percent. For single-vehicle ROR crashes, a reduction of 1.5 percent was expected the first year following intervention whereas the expected decrease in crashes after 10 years was 14.1 percent. All of which point toward safety benefits amplifying over time.

Many drop-off related crashes could be prevented or mitigated with the installation of a safety edge. FHWA defines the safety edge as a treatment in which the edge of the pavement is sloped at an angle, typically between 30 and 35 degrees [24]. This treatment aims to allow for safe correction of vehicles that have left the traveled way and could encounter a pavement-shoulder drop-off. The safety edge is typically implemented on the entire length of a project where frequent edge drop-offs occur, particularly on rural roads with unpaved shoulders [24]. Graham et al. [25] conducted a study to determine the safety effectiveness of the safety edge treatment and they found a small positive crash reduction effect with the best effectiveness measure for rural two-lane highways having a CRF of 5.7. However, this was not statistically significant. A more recent study estimated a CMF of 0.79 for ROR crashes and concluded that the safety edge application is a highly cost-effective countermeasure [26].

Lechtenberg et al. [27] reported that while trees have caused many fatal and serious crashes on LVRs, the AASHTO Roadside Design Guide offers limited guidance on safety treatments for trees. Researchers performed an incremental benefit-cost analysis for three safety treatments: do nothing, tree removal, and installation of a crashworthy guardrail system. Field data were limited to two segments of unpaved, LVRs (one 8-mile and one 13-mile segment) with fewer than 500 vpd. Tree removal had the highest benefit-cost ratio, always in excess of 1.0. Because the analysis was based on benefit-cost ratios alone, engineers could use the study's findings to further investigate specific locations, parameters, and performance metrics.

Abel and Garber [28] identified factors that contribute to crashes along two-lane highways and countermeasures for reducing crash frequencies. The authors analyzed various highway classifications (urban primary, urban secondary, rural primary, rural secondary) and collision types (rear-end, angle, head-on, sideswipe, ROR, deer, and other). Explanatory variables used in their prediction models included lane width, time of crash, ADT, surface condition, grade, curvature, cross grade density, driver age, and driver action. Countermeasures were recommended for different collision types, highway classifications, and influencing factors (see Appendix A) including geometric alterations (e.g., turn lane additions, roadway widening, adding to or improving shoulders) and enhancing signage and markings (e.g., adding warning or advisory signs and chevrons). Conducting before-and-after studies once countermeasures are implemented to determine their economic benefit and crash reduction factor (CRF) can assist agencies with identifying safety interventions that may warrant expanded use.

Beale et al. [29] examined whether enhanced signage (i.e., installing additional safety signs and replacing existing safety signs) reduced crash frequencies on LVRs in 24 Ohio townships. Existing signs can be improved by making them larger and more reflective. This countermeasure is considered one of the least expensive treatments. Total crashes reduced by 10 percent and serious crashes by 35 percent following countermeasure adoption, while the benefit-cost ratio was greater than 1.

Ford and Calvert [30] evaluated the effectiveness of improving signs and markings on arterials and collectors in Mendocino County, California, by comparing crash rates for sections of roads that underwent a review similar to a Road Safety Audit (RSA) and not reviewed by the Mendocino County Department of Transportation. Crashes on reviewed roads fell 42.1 percent while crashes on roads not reviewed increased 26.5 percent.

The use of rumble strips has been also evaluated in efforts to address LVR safety. Persaud et al. [31] studied the effectiveness of installing centerline rumble strips along rural, undivided, two-lane roads. Rumble strips alert distracted or fatigued drivers that their vehicle is about to cross the centerline. Changes in safety for a given crash type were estimated after centerline rumble strips were installed. The authors found that using rumble strips reduced frontal and opposing-direction sideswipe crashes by 25 percent and lowered all crashes along rural, two-lane roads by 12 percent. Lyon et al. [32] evaluated the effectiveness of combining shoulder rumble strips and centerline rumble strips into a single treatment as part of a strategic highway safety effort. Geometric, traffic, and crash data for rural, two-lane roads were obtained for Kentucky, Missouri, and Pennsylvania. They found a decline in all crash types (injury, ROR, head-on, and sideswipe-opposite-direction crashes) across all states. No significant trends between CMF and values for posted speed, lane width, or shoulder width were identified. Benefit-cost ratios ranged from 20 to 55 (based on cost and service life assumptions), which suggest that even the most expensive treatments can be highly cost-effective.

The literature discussed thus far has relied on the assessment of crash data as the main method of analysis. Traditional methods for estimating crash frequency along roads are based on crashes per vehicle miles traveled. However, one limitation of this method is that it excludes the consideration of other variables [15], which can be limiting when proposing ways to improve highway safety. Efforts have been undertaken to look at different approaches for identifying key issues to compare and recommend specific countermeasures for improving the safety on LVRs.

As part of a Texas-based study Fitzpatrick et al. [33] evaluated crash data and conducted a survey to gather information on low-cost safety improvements for LVRs. More than 60 percent of the road network in Texas consists of rural roads; 30 percent of the network is low-volume, rural roads (AADT < 2,000 vpd). Crash data from 1999 indicated percentage of fatal injury crashes along these roads was more than double that of other roads; for crashes with incapacitating injuries it was nearly double. To obtain recommendations for low-cost safety improvements, surveys were sent out to district engineers in Texas, California, Florida, and Washington, and one design engineer in each remaining state. Proposed safety treatments focused on addressing clear zones, wildlife crossings, additional lanes, pavement surface treatments, pavement markings, sign improvements, signal improvements, and other improvements. A detailed list of the treatments suggested for reducing roadway departures, nighttime crashes, driveway and access point crashes, and crash severity is presented in Appendix B.

Gross et al. [34] examined safety concerns associated with LVRs and how they can be analyzed using RSAs to identify crash clusters and trends. RSAs are a useful tool for improving road safety and can also be used to identify and address safety issues along roadway segment. The authors applied this approach to low-volume paved roads with an AADT of fewer than 1,000 vpd, noting that 40 percent of crashes occur on local roads. Design standards for local roads are often lower than for higher-volume roads. Elements which may have different design standards include cross slope for drainage, curve superelevation, and safety hardware for roadside protection. Designing or evaluating an LVR is also challenging because they must accommodate a broad range of users, from passenger vehicles to people on horseback. Posted (or in some cases, unposted) speed limits may not accord with the roadway geometry or vehicles on the road. Special considerations on LVRs include environmental concerns, enforcement concerns, and seasonal variations. RSAs can be useful for addressing some of these issues since they consider safety issues of all road users under all conditions. Furthermore, the report describes common safety issues on rural, LVRs while offering promising low-cost measures (Table 2). One difference between an RSA and a traditional traffic engineering study is that the audit does not rely solely on crash data to identify problems. Field visits conducted as part of RSAs to observe possible behaviors and interactions may take longer on LVRs because of the low traffic volumes.

Table 2. Common safety issues on rural, low-volume paved roads [34]

Topic Area	General Issues	Specific Issues
Cross section	Limited separation among vehicles	Narrow lanes Lack of turn lanes
	Limited or difficult recovery area for errant vehicles	Narrow or no paved shoulders Vertical pavement edge drops > 2 in.
Horizontal curves	Geometric deficiencies	Limited sight distance Inadequate superelevation Reduced skid resistance
	Insufficient or inconsistent delineation	Inconsistent and old signage Faded pavement markings No edge lines
Roadside hazards	Fixed objects in close proximity to roadway	Trees, utility poles, embankments, drainage features (inlets, headwalls, and culverts), mailboxes
	Design of roadside hazards	Unprotected embankments Non-breakaway devices
Intersections	Lack of driver expectancy	Sight distance to the intersection Inconsistent and old signage
	Obstructions in sight triangle	Sight distance at intersection
	Driver behavior	Poor gap acceptance at stop-controlled intersections
Pedestrians and bicyclists	Lack of designated facilities for pedestrians and bicyclists	No sidewalks or shared-use paths and limited paved shoulders
	Driver behavior	Lack of driver awareness of pedestrians and bicyclists Lack of familiarity with road network (tourists)
	Pedestrian and bicyclist behavior	Lack of familiarity with road network and safety issues (tourists)
Animals	Open range livestock	Animals crossing road and grazing along roadside
	Wildlife	Uncontrolled wildlife crossings

Al-Kaisy et al. [17] summarized countermeasures that can be used to address a variety of issues (Table 3). Economically feasible treatments they highlighted include installing shoulder and centerline rumble strips, object markers, centerline markings, safety edges, edge line and centerline markings, and horizontal alignment signs; widening centerline and edge line markings as well as unpaved shoulders; stabilizing shoulders; removing or relocating objects near the road; flattening slide slopes; and adding curve warning signs. Widening paved shoulders and lanes, installing dynamic speed limit signs, and applying high friction surfaces were not regarded as economically feasible.

Table 3. Issues and countermeasures [17]

Issue	Countermeasure
Alignment	Curve delineation
	Curve warning pavement markings
	Curve warning signs
Roadside Cross Section	Lane widening
	Pavement friction
	Shoulder improvements
Roadside Features	Clear zone improvements
	Flattening side slopes
	Prevent pavement edge drops
Other Measures	Centerline and edge line marking improvements
	Centerline and edge line rumble strips/stripes
	Lighting improvements
	Other warning signs
	Transverse lane markings and warnings
	Transverse rumble strips

Hossain's [10] efforts to identify hazardous locations on LVRs accounted for geometric and roadside features and examined the feasibility of countermeasures based on the types of risk mitigated, including those related to roadway alignment, cross section, and other roadside features. Appendix C summarizes the low-cost countermeasures examined.

Powers [35] identified challenges related to maintaining unpaved roads in rural Arizona, including increased volumes and loading, growing recreational traffic, the need for safety improvements, surface corrugation and wash boarding, limited maintenance budgets, historical limitations, deterioration of features, inadequate drainage, higher service expectations from drivers, dust, raveling, slipperiness, potholes, soft spots, and erosion rills. The study concluded that applying polymer and millings were the most effective countermeasures.

Systemic countermeasure applications have been utilized to address safety issues in order to provide for a wider application and increased safety benefits. Systemic applications have the advantage that they can reduce costs due to their large number of application sites and have the ability to utilize simultaneously several low-cost countermeasures to address safety [36]. A summary of such applications for improving safety at stop-controlled intersections documented the benefits of the application of multiple low-cost countermeasures across the US. The countermeasures used include pavement markings, signs, and visibility and sight distance improvements. More specifically, the countermeasures utilized for through approaches include doubled up, oversized advance warning signs with street name plaques, retroreflective sheeting on sign posts, and enhanced pavement markings that delineate through lane edge lines. The countermeasures for the stop-controlled approaches include doubled up, oversized advance “Stop Ahead” warning signs and “Stop” signs, retroreflective sheeting on sign posts, stop bars being placed at optimal locations, removal of any vegetation, parking, or physical obstructions that limits sight distance, and double arrow warning signs at the stem of the T-intersections. The results indicate significant crash reductions (e.g., South Carolina had 45 percent fewer fatal and injury crashes per year after the installation, Louisiana had a 64 percent reduction at four-legged intersections for fatal and injury crashes, and Ohio had 23 percent reduction of fatalities).

Stamatiadis et al. [15] proposed safety countermeasures based on an analysis of LVRs in Kentucky and North Carolina. The authors examined driver-related issues to determine if specific characteristics of the driver population relate to crash frequency. Decreasing crash rates among younger drivers, they argued, could be done through improved driver education as this builds better driving habits and stronger competencies. Single-vehicle crashes may be reduced through geometric improvements (e.g., widening shoulders and straightening sharp curves). Newer vehicles, the authors suggested, are more likely to be involved in single-vehicle crashes because they confer a false sense of security to drivers. Crashes involving older vehicles may be reduced by implementing vehicle inspection programs to detect safety-related deficiencies.

Gibbons et al. [37] examined ROR crashes and the effectiveness of active and passive curve warning and delineation systems on rural, two-lane roads for reducing vehicle speeds and assisting lane-keeping. A human-factor study and observational study found there was no significant difference between the passive and active curve warning and delineation system with respect to driver speed and lane keeping. Elvik [38] studied the performance of median barriers, guardrails, and crash cushions Median barriers increased crash rates while reducing crash severity, whereas guardrails and crash cushions lowered both crash rates and crash severity.

Countermeasure Manuals

With nearly three million miles of rural roads in the US, state transportation agencies (STAs) may find it challenging to locate high-risk segments of LVRs that warrant the use of cost-effective safety treatments. Numerous methods and manuals have been produced that agency personnel can use to identify treatment options to help them achieve a desired safety outcome. This section highlights some of these materials.

Avelar et al. [39] sought to identify LVR segments (AADT ≤ 1,000 vpd) in rural areas that merit an engineering study to improve safety. Safety performance functions for tangent, curve, and combination sections were generated separately. Tangent sections were further split into 0.25-mile sections and 1.0-mile sections with speed limits less than or equal to 55 mph. Curve sections were 0.25-mile length with sharp to mild curvature. Combination sections included curves and tangents, were 1.0-mile long, and affected by various influences: speed limit, percentage of curvature, and sharp horizontal curves. The authors generated safety performance functions (SPFs) and used regression analysis to estimate the number of injury or fatality crashes per five years. Statistical analysis resulted in tables and charts that can be used to identify the best engineering practice for LVRs. Graphs provided a stepwise function based on AADT and crash severity, indicating regions where safety assessments or special safety enhancements should be recommended. Example cases were given with explanations for using the tables and charts to analyze road conditions.

Many of Canada’s provincial highways were constructed 30 to 40 years ago and are unable accommodate increased trucking demands. Furthermore, design standards are outdated and unable to make appropriate operations, safety, and cost trade-offs on LVRs (≤ 500 AADT). Retzlaff et al. [40] developed guidelines in response intended to give designers the flexibility to address safety, operational, and preservation problems. They adopted Levels of Improvements (LOI) to prioritize roads and maintain safe and efficient operations at the lowest capital costs using a field review and rating system. Based on field reviews, geometric elements are rated from 1 to 6 (Table 4). A weighting system is applied to each geometric element (Table 5). After summing points and performing a sensitivity analysis, each road segment is assigned to one of the following LOIs – Minor Upgrading (50-66 points), Major Upgrading (25-50 points), or Reconstruction (>25 points). If a combination of geometric elements are rated poor, improvements focused on a combination of geometric elements can be made (Table 5). Designers can use the rating system to narrow down geometric elements that need improvements.

Table 4. Summary of the rating system [36]

Geometric Element		Rating			Weight
		Poor (1-2)	Fair (3-4)	Good (5-6)	
Lane Width		< 3.3 m	3.3 - 3.5 m	≥ 3.5 m	1.5
Shoulder Width		< 0.3 m	0.3 - 0.5 m	≥ 0.5 m	1.5
Road top Width		< 7.2 m	7.2 - 8.0 m	≥ 8.0 m	
Horizontal Alignment (curve c)		< Minimum	Min. - 1000 m	> 1000 m	1.5
Clear Zone/ROW		< 30 m	30 - 44 m	≥ 44 m	1.5
Ditch Depth		< 0.8 m	0.8 - 1.0 m	1.0 - 1.2 m	1.2
Ditch Width		< 3.0 m	3.0 - 5.0 m	≥ 5.0 m	1.2
Side-slope		< 3:1	3:1 - 4:1	≥ 4:1	1.3
Backslope		< 2:1	2:1 - 4:1	≥ 4:1	0.7
Vertical Alignment					0.6
GRAVEL: Design Speed 90 km/h	Sag	< 25	25 - 35	≥ 35	
	Crest	< 30	30 - 60	≥ 60	
SURFACED: Design Speed 100 km/h or 110 km/h	Sag	< 35	35 - 55	≥ 55	
	Crest	< 60	60 - 110	≥ 110	

Table 5. Summary of LOI for geometric element combinations [40]

Geometric Element Combination	Recommended LOI
Lane Width and Shoulder Width	Minor Upgrading
Ditch Width, Backslope, Sideslope, and Ditch Depth	Major Upgrading
Lane Width, Shoulder Width, and Sideslope	Minor or Major Upgrading
Shoulder Drop and Narrow Lane Width	Minor Upgrading
Horizontal Alignment (Curve Data)	Reconstruction
Horizontal Alignment Superimposed with Vertical Alignment	Reconstruction

FHWA has identified challenges many agencies face when improving the safety of high-risk rural roads: insufficient funding, lack of technical experience, and lack of data. To help agencies make judicious decisions about countermeasures, FHWA has published the *Manual for Selecting Safety Improvements on High Risk Rural Roads*. The manual evaluates 10 safety treatment categories: horizontal curves, signalized/unsignalized intersections, non-motorist user, pavement and shoulder resurfacing, pavement marking, roadside, signage, vertical curves, and other treatments [24]. In addition to evaluating countermeasures, the manual provides information on the circumstances under which each should be used. For each countermeasure, the manual summarizes in a table initial implementation costs, performance rating, CMF, and benefit-cost ratio. A flowchart is included for identifying two-lane, high-risk rural roads that are candidates for safety improvements. Some countermeasure narratives describe their application on LVRs. Summary tables are presented in Appendix D.

FHWA has also published a manual on low-cost countermeasures that local transportation agencies can use to address roadway departure crashes along horizontal curves on lower volume two-lane roads [41] For each category of countermeasure (e.g., pavement markings, signs, pavement surface applications, roadside improvements, addressing intersections in curves) several low-cost treatments are described with discussions looking at design, application, effectiveness, and cost considerations. A small number of countermeasures with higher implementation costs are presented as well. For an agency to address safety, the manual suggests it focus on (1) locations with high numbers of severe crashes and (2) systemically addressing high-risk locations or segments.

Low-Volume Roads and Road Safety Audits has a comprehensive list of countermeasures and applications drawn from the findings of hundreds of RSAs [34]. It can be used in a manner similar to other manuals (e.g., [41]). For each of the six topic areas listed in Table 2, the manual describes how they pertain to LVRs, general issues faced, and promising low-cost treatments. Appendix E lists these countermeasures.

The American Traffic Safety Services Association (ATSSA) and the National Association of County Engineers (NACE) has published a manual containing detailed reviews of the following low-cost safety treatments which can be used on local roads [42]:

- Sign and pavement marking improvements
- Post-mounted delineators and chevrons in curves
- In-street pedestrian crossing signs (to increase driver yielding compliance)
- Rear-facing flashing beacons on school speed limit signs
- Speed displays (to reduce traffic speeds and increase speed limit compliance)
- Edge lines on two-lane roadways
- Wider longitudinal pavement markings
- Raised pavement markers on two-lane roadways
- Shoulder and edge line rumble strips (to reduce ROR crashes)
- Centerline rumble strips (to reduce head-on and sideswipe crashes)

- Pavement markings over rumble strips (rumble stripes)
- On-pavement horizontal signing
- Converging chevron pavement marking pattern
- Longitudinal channelizers at highway-railroad grade crossings
- Roadside cable barrier (to reduce the severity of ROR crashes)
- Cable median barrier (to reduce crossover crashes)

Other manuals recommend several of these countermeasures for addressing LVR safety, including improved signs and markings, wider edge lines, rumble strips for shoulders and centerlines, and cable barriers.

Sperry et al. [43] published a handbook of safety measures for low-volume local roads groups countermeasures into the following categories: signing and delineation, traffic calming, pavement marking and rumble strips/stripes, roadside and clear zone, guardrail and barriers, lighting, pavements and shoulders, intersections, railroad crossings, bridges and culverts, and miscellaneous. For each strategy, the handbook reviews project contact information and project details, including the program start year, number of miles it was applied to, comments, potential benefits, cost, and CRF (if applicable). Strategies for each category can be found in Appendix F.

Many rural roads in the US carry fewer than 400 vpd. Counties and townships with LVRs encounter numerous challenges in their attempt to provide a safe roadway system [44]. The *National Handbook of Traffic Control Practice for Low-Volume Rural Roads and Small Cities Volume 1: Low-Volume Roads*, which supplements the *Manual on Uniform Traffic Control Devices* (MUTCD), was published to help local governments provide safe local roads at a minimum cost.

Neuman et al. [45] proposed countermeasures to reduce the number of fatal ROR crashes, including the installation of shoulder and centerline rumble strips, enhanced pavement markings and delineation, addressing roadside obstacles, improving roadway skid resistance, addressing shoulder deficiencies, improving roadway geometry, and improving design of roadside hardware. Table 6 reports on the timeframe required to implement each countermeasure as well as the cost to install and operate them. The list is not, however, an exhaustive catalogue of strategies for addressing ROR crashes.

Table 6. Classification of strategies according to expected timeframe and relative cost [45]

Timeframe for Implementation	Strategy	Relative Cost to Implement and Operate			
		Low	Moderate	Moderate to High	High
Short (<1 year)	A1-Install rumble strips	X			
	A3-Install mid-lane rumble strips	X			
	A4-Provide enhanced delineation of sharp curves	X			
	A6-Provide enhanced pavement markings	X			
	B3-Remove/relocate objects in hazardous locations[1]	X			
Medium (1-2 years)	A7-Provide skid-resistant pavements		X		
	A8-Eliminate shoulder drop-off[2]	X			
	B1-Provide shoulder treatments[3] or four-lane sections at key locations		X		
	B2-Design safer slopes and ditches			X	
	C1-Improve roadside hardware			X	
	C2-Improve barrier and attenuation systems			X	
Long (>2 years)	A5-Improve horizontal curve geometry[4]			X	

Notes: A: Roadside encroachment; B: Minimization of crash likelihood; and C: Crash severity reduction

[1] Removal/relocation of some objects (e.g., bridge abutments and drainage structures) can be costly, depending upon the object. It is assumed here, however, that most objects will be small appurtenances.

[2] The action could be done in a short timeframe. However, it is assumed to be done at little extra cost as part of a regular repaving program.

[3] The classification of shoulder treatments and safer slopes and ditches as moderate-cost or moderate-to-high cost treatments assumes that no additional right-of-way is needed. If right-of-way is needed, the cost could be high and the time required would be long.

[4] Although the AASHTO Strategic Highway Safety Plan is focused upon relatively low-cost, short-term strategies, there are some higher-cost strategies such as curve flattening that have potential for such significant effectiveness that they have been included. Curve flattening would primarily be applicable in rehabilitation, resurfacing, and restoration (3R) and reconstruction projects that have been programmed outside the context of the AASHTO plan initiative.

The *Highway Safety Manual* (HSM) is another useful resource for improving LVR safety [46]. CMFs have been developed for several countermeasures discussed in this section and can be used to evaluate alternative strategies (e.g., shoulder widening, expanding clear zones, removing fixed objects, realignment, and others). Keep in mind that the

HSM provides CMFs for AADT ranges specific to LVRs and the appropriate factor should be chosen accordingly.

Safety in Southeastern States

This section reviews studies focused on safety issues in the US Southeast. Most of the studies the research team identified do not have an exclusive focus on LVRs, but instead look at a variety of roadway environments, thus painting a broad picture of safety issues that are consequential throughout the region.

In 1998, a pooled-fund study was initiated to examine and then quantify the factors which contribute to the Southeast's high fatal crash rates [5]. Eight states participated in the study: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee. It focused on six areas: two-lane rural roads, safety restraint use, driver education and licensing, commercial vehicle operations, fixed-object crashes, and speeding. States used their crash records to identify unique issues within their jurisdiction and develop a list of potential countermeasures. Seven of the eight states identified two-lane rural roads as a primary source of elevated fatal crashes in the Southeast. Several countermeasures were proposed, including shoulder widening, enhancing delineation, and protecting the clear zone.

As part of this study, Agent et al. [47] studied the characteristics of 150 fatal crashes that occurred on two-lane rural roads in Kentucky. A literature review and field data were used to identify and summarize countermeasures that could reduce the severity and number of crashes on these roads. A mandatory seat belt law was the most promising for lowering crash numbers. Roadway countermeasures with the greatest potential included adding shoulders or centerline rumble strips and installing chevron signs.

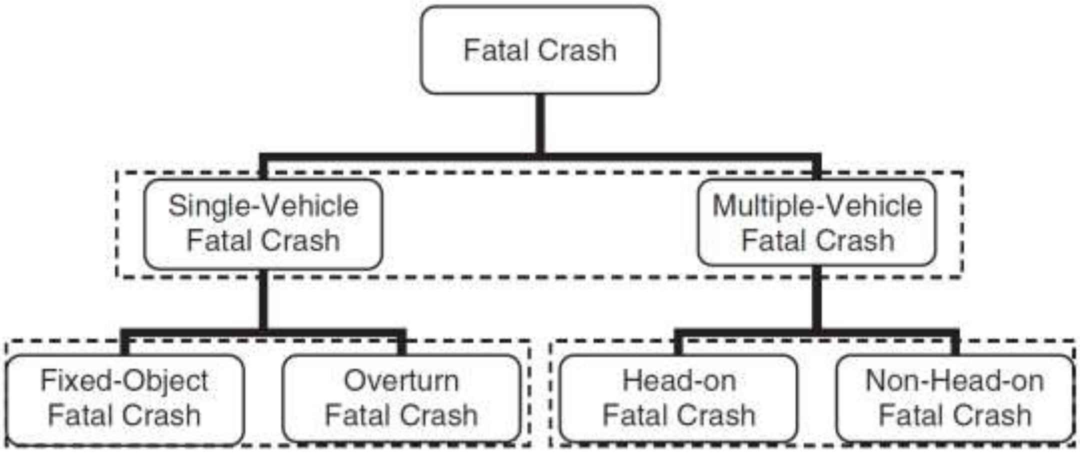
Lacy [48] developed and ranked countermeasures geared toward reducing the number and severity of fatal crashes on North Carolina's two-lane rural roads. After reconstructing 150 fatal crashes, 30 countermeasures were evaluated; a crash database and CMFs were used to appraise countermeasure effectiveness. Table 7 ranks countermeasures according to their potential to influence fatal crash rates.

Table 7. Countermeasures ranking order for two-lane rural roads [48]

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

In an extension of the pooled-fund study, a cross-sectional analysis of 150 rural highway single-vehicle fatal crashes that occurred in Alabama, Georgia, Mississippi and South Carolina was undertaken [49]. Relying on site visits and video recordings, the researchers developed a classification tree for fatal crashes (Figure 2). Factors they found that could influence single-vehicle fatal crashes included location, lane width, shoulder width and type, horizontal curve direction, presence of crest vertical curves, horizontal and vertical geometric interactions, roadside hazard rating, traffic volume, driveway type, lighting conditions, and time of day. The countermeasures for addressing single-vehicle fatal crashes include improving geometric alignment, widening lanes or pavement, adding or widening a graded or stabilized shoulder, and widening or improving clear zones.

Figure 2. Fatal Crash Classification [49]



One question the abovementioned studies omit is whether regional analysis or comparisons offer meaningful insights and, if so, how their findings should be interpreted. Washington et al. [50] addressed this issue by comparing crashes in Southeast and non-Southeast states. They observed that making such comparisons may be disadvantageous because it is hard to determine why regional differences exist. They attributed differences to variability in external factors, such as roadway types (high-speed facilities versus complex designs versus roadside hazards), seat belt use, speed limits, travel amounts, and emergency response times. But studying regional differences can also help identify statistically significant inter-regional differences. Researchers also need to be mindful of the potential of interactions of the several variables, such as safety belt use, roadway functional class, vehicle miles of travel, and driver age when making safety evaluations. Identifying interactions will prevent double counting the same effects.

The effectiveness of multiple countermeasures applied simultaneously has not been studied extensively. A South Carolina study evaluated the safety effectiveness of multiple low-cost treatments at stop-controlled intersections to reduce the frequency and severity of crashes [51]. The treatments include signing and pavement markings that alert and warn drivers of an approaching intersection. The signing treatments were doubling of signs to warn drivers, adding retroreflective strips on the sign posts, adding and repainting stop lines, and adding additional markings at turn lanes. The results suggest that the benefit-cost ratio is 12.4 to 1 when considering a 3-year service life, conservative cost estimates, and the benefits for total crashes.

Stamatiadis and Puccini [52] examined whether socioeconomic attributes help to explain why the Southeast experiences higher fatality rates than other regions. Table 8 summarizes the socioeconomic data used in the study. Seventy-five percent of drivers involved in fatal crashes resided in areas where the annual household income is less than $30,000. For single-vehicle crashes, a significantly higher crash rate was observed for individuals with incomes below $20,000, but this was not a variable was not significant for evaluating multi-vehicle crashes. Drivers from areas with lower educational attainment were more likely to be involved in single-vehicle crashes but not multi-vehicle crashes. Single-vehicle crashes were more likely in rural or semi-rural areas with multi-vehicle crashes more common in urban or semi-urban areas. It is possible unemployment negatively influences the fatality rates of single-vehicle crashes.

Table 8. Socioeconomic conditions for the Southeast and the United States [52]

State	Rural Population (%)	Educational Score[1]	Unemployment (%)	Median Household Income ($)
Alabama	39.67	1.25	6.87	23,597
Florida	15.21	1.41	5.78	27,483
Georgia	36.77	1.35	5.74	29,021
Kentucky	48.17	1.17	7.37	22,534
Mississippi	52.93	1.21	8.43	20,136
N. Carolina	49.68	1.33	4.79	26,647
S. Carolina	45.34	1.28	5.58	26,256
Tennessee	39.13	1.25	6.41	24,807
Southeast	35.50	1.32	6.03	26,045
USA	24.79	1.45	6.31	30,270

[1] Educational score is a weighted score based on the percent of people with various degrees of education

Kirk et al. [53] compared the influence of socioeconomic factors and safety regulations on fatal crash patterns in Kentucky and the remainder of the US. At the national level, median income, percentage of the population below the poverty line, population density, and proportion of the population with high school degrees or equivalent had a statistically significant influence on fatal crash rates. Kentucky crash data, however, indicated none of these factors were statistically significant.

Using Kentucky crash data, Agent et al. [54] identified safety problems related to crashes on two-lane rural roads, pinpointed high-risk locations, and recommended potential improvements. Recommended countermeasures included improving vertical and horizontal alignments; enhancing sight distance; removing and relocating fixed objects; and installing traffic signs, flashing beacons, or pavement markings.

Adanu et al. [55] examined the influence of gender on fatal crash rates in Alabama for the period 2009–2016. They found that young male drivers were involved in about 72 percent of fatal crashes, most crashes occurred at rural areas, and a large percentage of young males does not use seatbelts (Table 9). The findings suggest that rural communities and communities with lower income may benefit from targeted education and outreach training.

Table 9. Categorization of Classes of Crashes by Gender [55]

Latent Class	Male	Female
1	17%—weekend crashes on dark two-lane roads close to the driver's home.	14%—weekend crashes not in rural areas, not close-to-home.
2	4%—all single vehicle crashes involving a distracted driver. Some 70% were unbelted (34% ejected). Two-thirds during dark conditions.	5%—weekday single-vehicle crashes involving drivers without a valid license.
3	12%—all involved speeding on rural roads close-to-home, with more than 60% unbelted drivers. More than half during the weekend and some 42% occurred during the summer.	12%—single-vehicle crashes on rural roads close-to-home, attributable to speeding. More than half during the weekend and involved unbelted drivers. About 41% occurred during the summer.
4	6%—all attributable to aggressive driving. More than half occurring in the summer, close-to-home, and involving only one vehicle.	8%—appear to be red-light or stop sign running crashes with roughly half attributable to aggressive driving during the weekend.
5	9%—all DUI related, involving a single vehicle primarily occurring on rural roads close-to-home under dark conditions during the weekend. Almost 90% unbelted.	7%—single-vehicle crashes on weekend nights during the school year on two-lane roads. One third due to distracted driving and a third due to DUI. More than 60% unbelted.
6	12%—red-light or stop sign running crashes close-to-home attributable to aggressive driving.	9%—red-light or stop sign running crashes on two-lane roads close-to-home, attributable to aggressive driving.
7	13%—single-vehicle weekend crashes on two-lane roads close-to-home in which more than 80% were unbelted.	21%—single-vehicle crashes with 60% unbelted and 46% ejected
8	15%—weekday crashes on rural roads close-to-home, occurring during the school year.	11%—weekday crashes during the school year on two-lane rural roads close-to-home
9	12%—weeknight crashes on rural roads close-to-home during the school year.	13%—single-vehicle crashes on two-lane rural roads close-to-home during summer weekend nights. Over 50% were unbelted.

Summary

Researchers have sought to determine what features of LVRs contribute to their high crash rates. Roadside features, cross-sectional elements, and geometric design elements significantly influence road safety. With respect to roadside features, culverts, bridges, driveways, trees, ditches, slopes, utility poles, and public broadcast service routing stations can all pose a threat to drivers [6]. Cross-sectional elements that impact road safety include lane width, shoulder type and width, and pavement edge drop off. Salient geometric design elements include horizontal and vertical curves, driveway density, sight distance, and vertical grade.

Identifying high-risk road segments and implementing cost-effective safety treatments on LVRs is an enormous challenge for STAs. Researchers have proposed countermeasures to bolster LVR safety. These include widening shoulders and lanes, adding centerline and/or edge line rumble strips, widening centerline and edge line markings, installing additional horizontal alignment signage, remedying shoulder and side slope deficiencies, relocating objects situated near roads, correcting geometric deficiencies, and installing more visible pavement markings and signage. A number of manuals are available that instruct users on countermeasure selection (e.g., [24] [42]).

Several studies have looked at why the US Southeast has higher crash and fatality rates than other regions. Most of these studies have zeroed in on socioeconomic attributes to explain the Southeast’s higher crash rates. While the countermeasures recommended by researchers to address this problem are similar to those suggested for implementation elsewhere, they have stressed the importance of reaching target populations, especially via educational initiatives, and in one study through the adoption of a mandatory safety belt law.

Survey Results

The research team surveyed STA personnel across the Southeast to collect information on practices and countermeasures used to improve LVR safety. The goal of the survey was to identify the most frequently used treatments, have agency staff rate their effectiveness, and develop a list of countermeasures STAs can use to improve LVR safety.

Before administering the survey, the research team obtained email contacts for possible respondents from the Project Review Committee. Potential respondents were contacted and asked if they would be willing to participate in the survey. Survey participants were sent an e-mail invitation letter that described the scope of the survey; it also linked to the survey. The survey was administered via Qualtrics. Posted in April 2019, participants received four weeks to enter their responses. A week before the deadline, the research team sent out email reminders to participants who had not responded. Once the deadline had passed, a second email was sent to participants who had not finished the survey, extending the deadline to increase the number of respondents. Appendix G contains the survey. It asked respondents to provide information on the following topics:

1. An overview of their background and how their agency addresses LVR safety,
2. Countermeasures their agency has implemented,
3. A rating of each countermeasure’s effectiveness, and
4. Potential cases studies.

Subsequent sections in in this chapter address each these areas.

A total of 12 respondents from the following nine STAs participated: Georgia, Kentucky (3 respondents), Louisiana, Mississippi, South Carolina, Tennessee, Virginia, North Carolina, and Arkansas (2 respondents). For most of the states, one response was obtained with the exception of a few with more than one response as noted here. While the research team did not obtain responses from all states, those which participated constituted a representative sample of Southeast agencies.

Respondents’ Background and Agency Process

Nine respondents were from STAs, two were employed with county departments, and one did not specify their agency type. Four respondents said their primary area of practice is safety analysis; this was followed by maintenance (2), planning (2) and one (1) each for program development, design construction, all of the above, and not stated.

Six respondents indicated their agency has policies to address LVR safety (e.g., moving driveway entrances, rumble strips/stripes, safety edge, speed research, funding, HISP spot/corridor and systemic treatments, signing and marking, and safety assessments). Four agencies do not have any policies. Practices used to evaluate LVR safety include: road safety audits (2), cost-benefit analysis (4), HSM crash prediction models (2), all of the above (2), and none (1).

Respondents were also asked to define the maximum traffic volumes paved and unpaved roadways can carry and still be classified as an LVR. Values for paved LVRs ranged from 1,000 to 3,000 vpd; some respondents said they were not aware of a threshold value. For unpaved LVRs, respondents provided two answers: 500 or not aware of/unknown.

Countermeasures Use and Effectiveness Scores

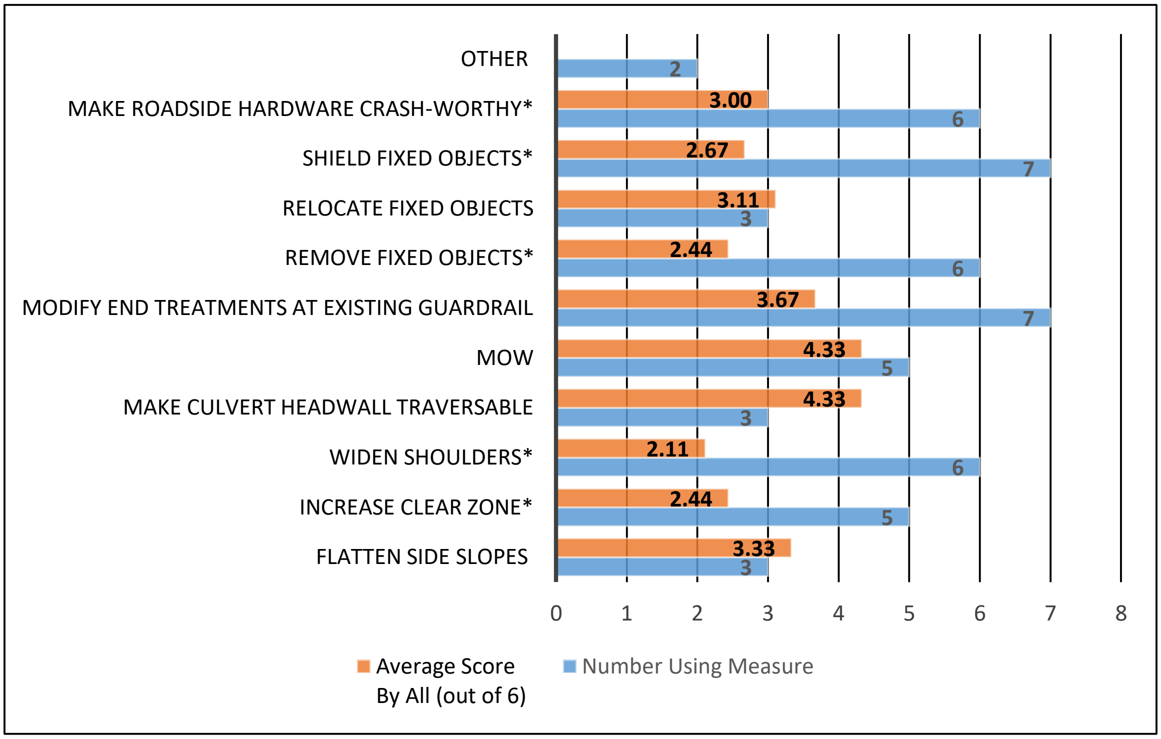
Respondents rated countermeasures on a scale from 1 (very effective) to 6 (not effective at all). Composite scores were used to rank the countermeasures to determine their relative importance. Answers from this section helped the research team identify countermeasures most often deployed in the Southeast and to prepare summary sheets for those treatments. To qualify for development of a summary sheet, treatments had to be used by at least five state agencies and garner a rating 3.0 or less. Countermeasures meeting these criteria are noted in the following figures with a star (*) beside their description. The following sections summarize the findings about each family of countermeasures as defined in the survey.

Two bars are shown in each figure depicting the rating for the countermeasure based on the scores received (numbers with decimals) and the number of states that had indicated that they have used the countermeasure (integer values). It should be noted, that the scores were calculated based on the number of respondents who evaluated and not on the number of states that indicated that they have used them before.

Clear Zone Improvements

According to respondents, the most effective clear zone improvement is shoulder widening (2.11), followed by removing fixed objects (2.44), increasing clear zone (2.44), shielding fixed objects (2.67) and improving the crashworthiness of hardware (3.00) (Figure 3). All treatments are in use at five or more agencies. Two additional countermeasures listed under the *Other* category were piping ditches to expand the clear zone and removing hazardous mailbox structures.

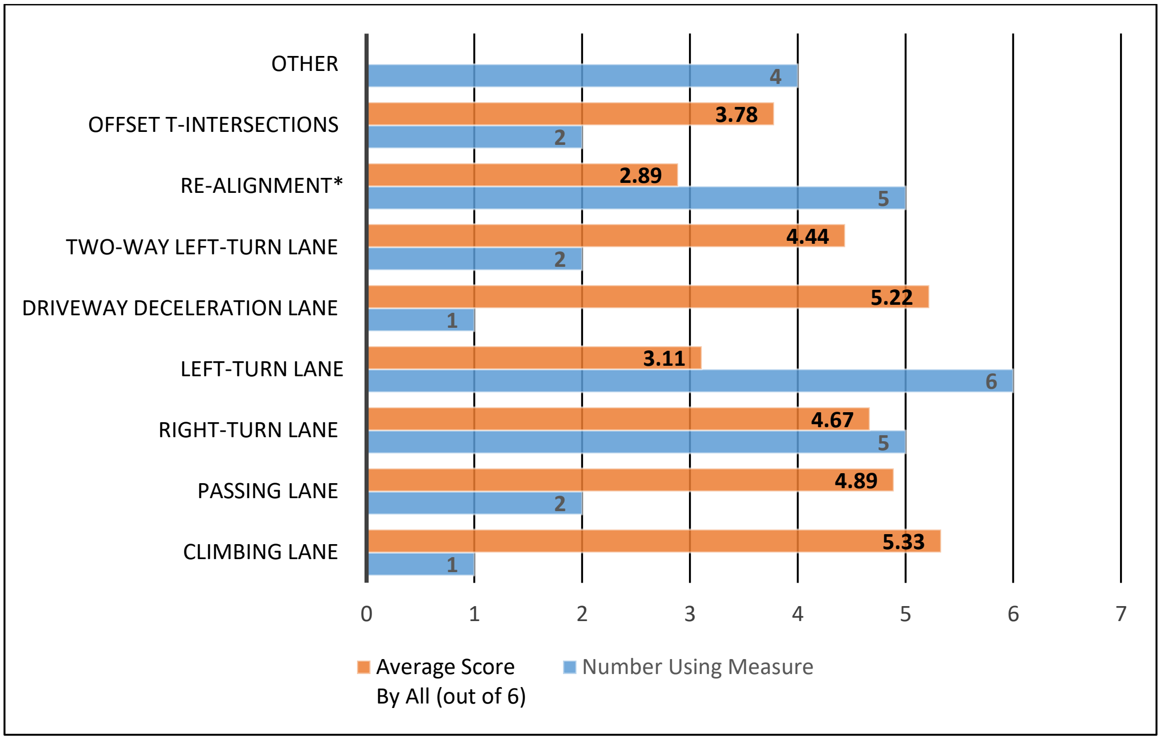
Figure 3. Summary of responses for clear zone countermeasures



Geometry Improvements

Under geometry improvements, repondents said that realignment is the most effective countermeasure (2.89), followed by adding a left-turn lane (3.11) (Figure 4). At least five agencies use these treatments. The addition of left-turn lane had a scoreof 3.11 and six agencies are using the treatment. Nonetheless, this countermeasure is included in the summary sheets due to its potential effectiveness. Countermeasures identified in the *Other* category included curve realignment, superlevation improvements, intersection realignment, vertical and horizontal realignment, and 3R alignment enhancement. Each of these could potentially be grouped into the *Realignment* category. Extending left-turn lanes was metnioned as well; it could be grouped with the addition of a left-turn lane.

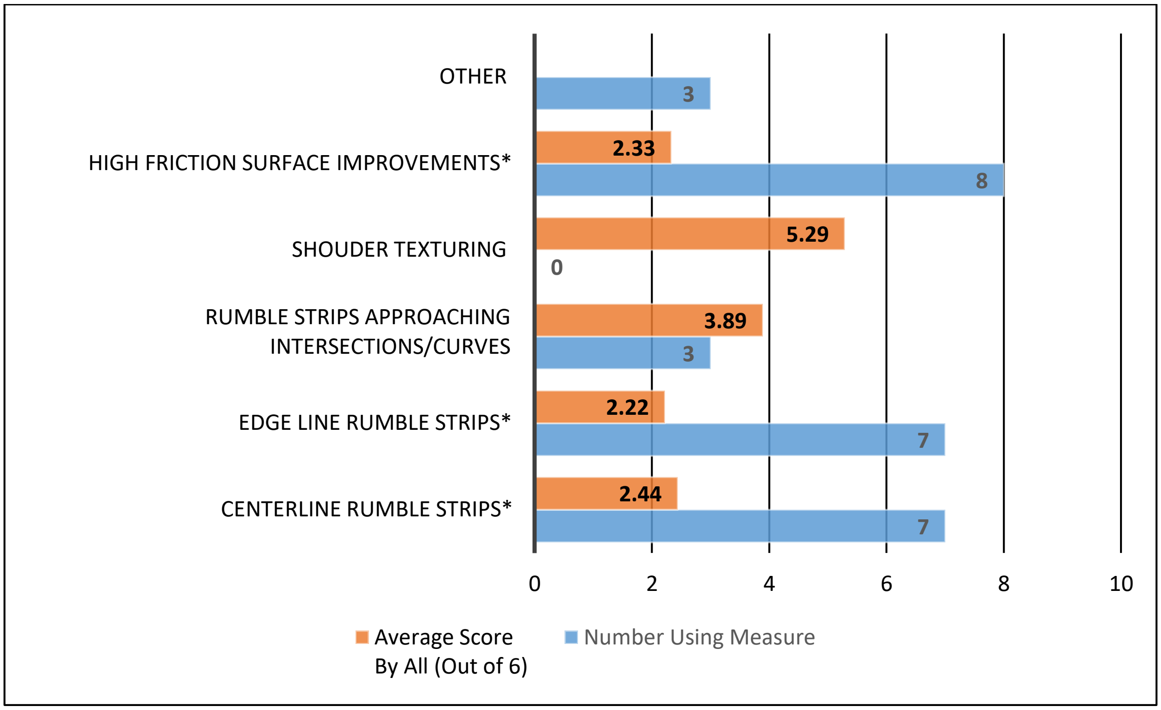
Figure 4. Summary of responses for geometry improvements countermeasures



Pavement Surface Treatments

Edge line rumble strips was the highest ranked pavement surface treatment (2.22), followed by high friction surface treatments (2.33) and centerline rumble strips (2.44) (Figure 5). Seven respondents commented that their agencies use all three of these countermeasures. While placing rumble strips on intersection approaches or curves garnered a high score (3.89), only three agencies have adopted this practice. Nonetheless, this countermeasure is included in the summary sheets due to its potential effectiveness. Two countermeasures listed under the *Other* category were removing reverse superelevation and using a safety edge.

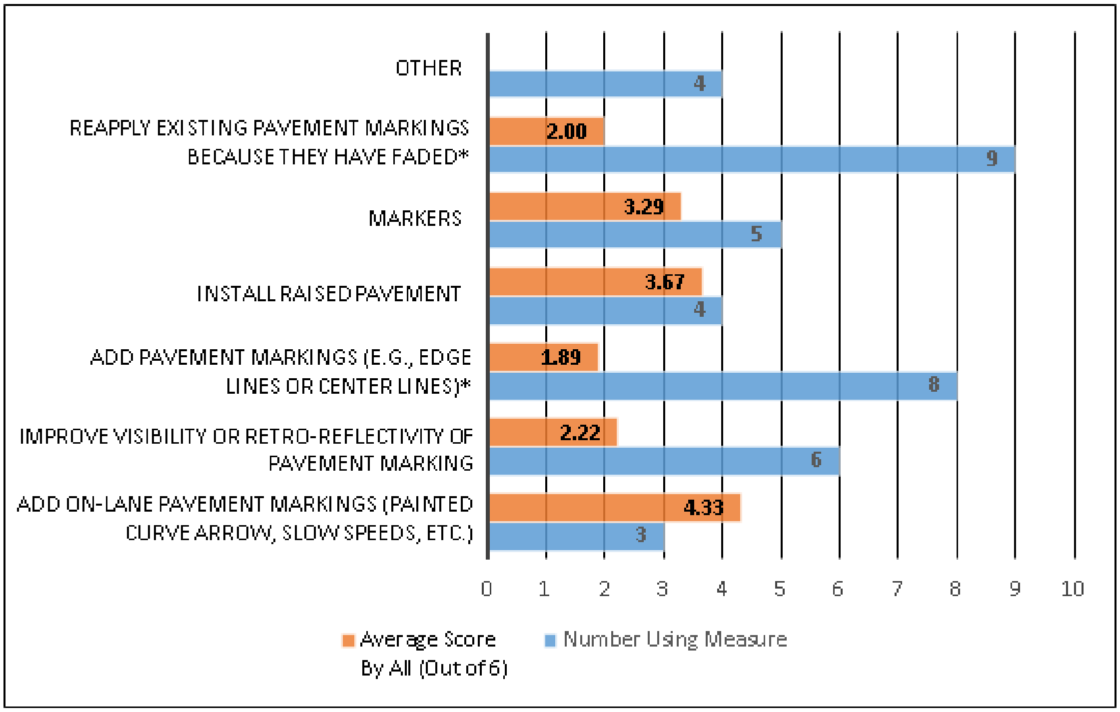
Figure 5. Summary of responses for pavement surface treatments countermeasures



Pavement Markings

Respondents viewed the addition of pavement markings (striping) (1.89), restriping faded existing markings (2.00), and improving visibility/retro-reflectivity (2.22) as the most effective pavement marking countermeasures (Figure 6). All of these treatments are in use at six or more agencies. Interestingly, and despite its universal adoption, restriping faded markings was rated second. This information could help improve an agency's striping program as it implies that placing pavement markings on roadways without them may be viewed as more effective than restriping of existing markings. The addition of pavement markers received a score of 3.29 and five agencies use it as a countermeasure. Nonetheless, this countermeasure is included in the summary sheets due to its potential effectiveness. Countermeasures noted in the *Other* category included the use of wider stripes and long-life pavement markings.

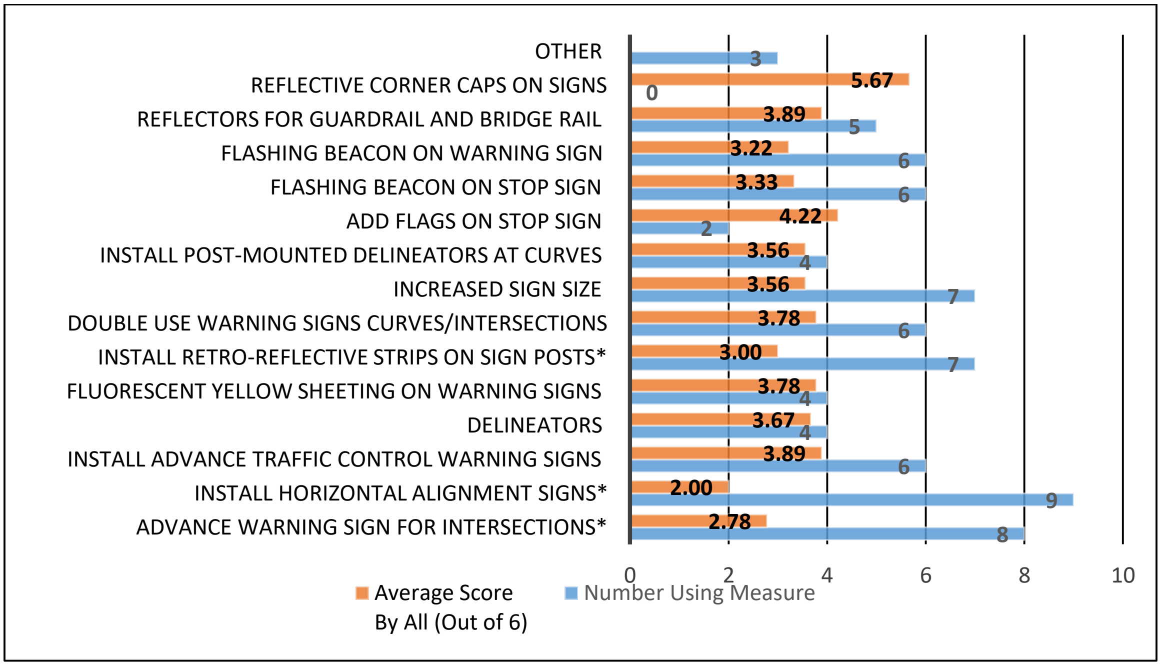
Figure 6. Summary of responses for pavement markings countermeasures



Sign Improvements

For sign improvements, the best-rated countermeasure was installing horizontal alignment signs (2.00), followed by installing advanced warning signs for intersections (2.78) and installing retroreflective strips of sign posts (3.00) (Figure 7). All of these countermeasures are being used at seven or more agencies. And while a number of other treatments have been adopted by at least six agencies (e.g., flashing beacon warning signs, increased sign size), all received ratings of 3.22 or worse. A number of these countermeasures relate to improving sign visibility and may be less effective on LVRs than in other road environments. Countermeasures referenced in the *Other* category included intersection conflict warning systems (ICWS), converting two-way stops to all-way stop intersections, and using chevrons or delineators in curves.

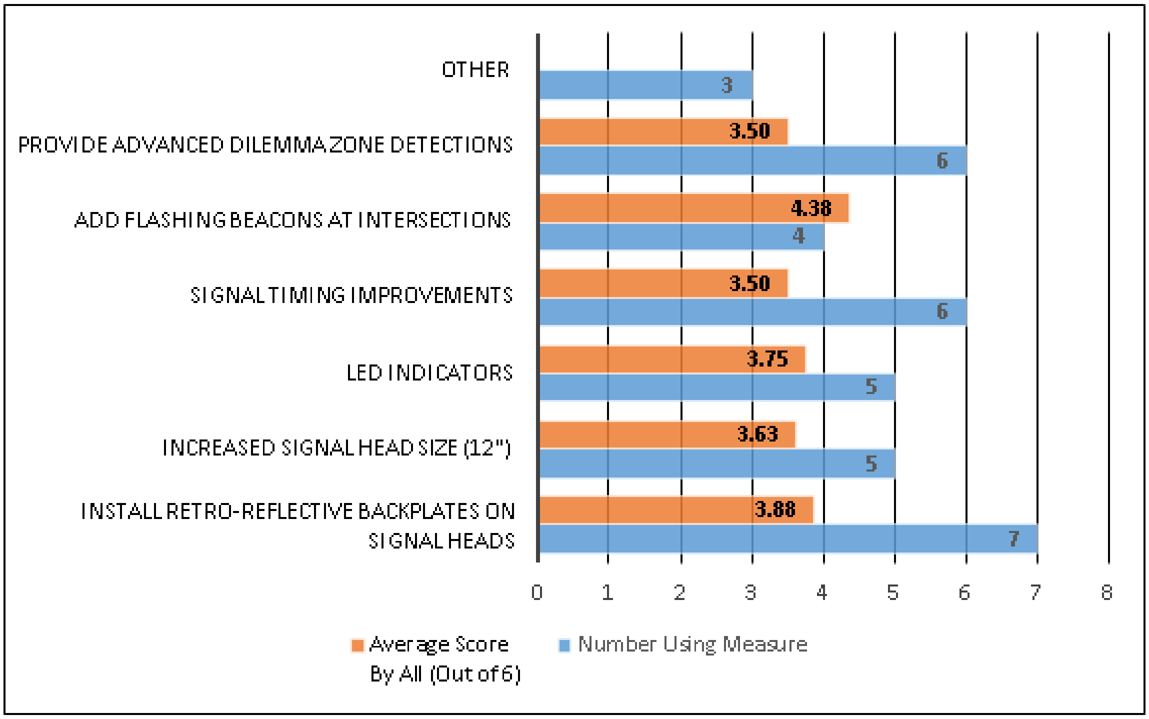
Figure 7. Summary of responses for sign improvements countermeasures



Signal Improvements

No countermeasures in the signal improvements category earned a score lower than 3.0 (Figure 8), situating this as the least effective family of countermeasures. Signal timing improvements and advanced dilemma zone detections both received ratings of 3.50, and each are in use at six agencies. Installing retroreflective backplates was rated 3.88 and is in use at seven agencies. It is possible that many respondents focused on potential costs when rating these treatments (and by extension benefit-cost ratios) rather than on just their effectiveness. Given the placement of these countermeasures on LVRs, the overall benefits may be limited.

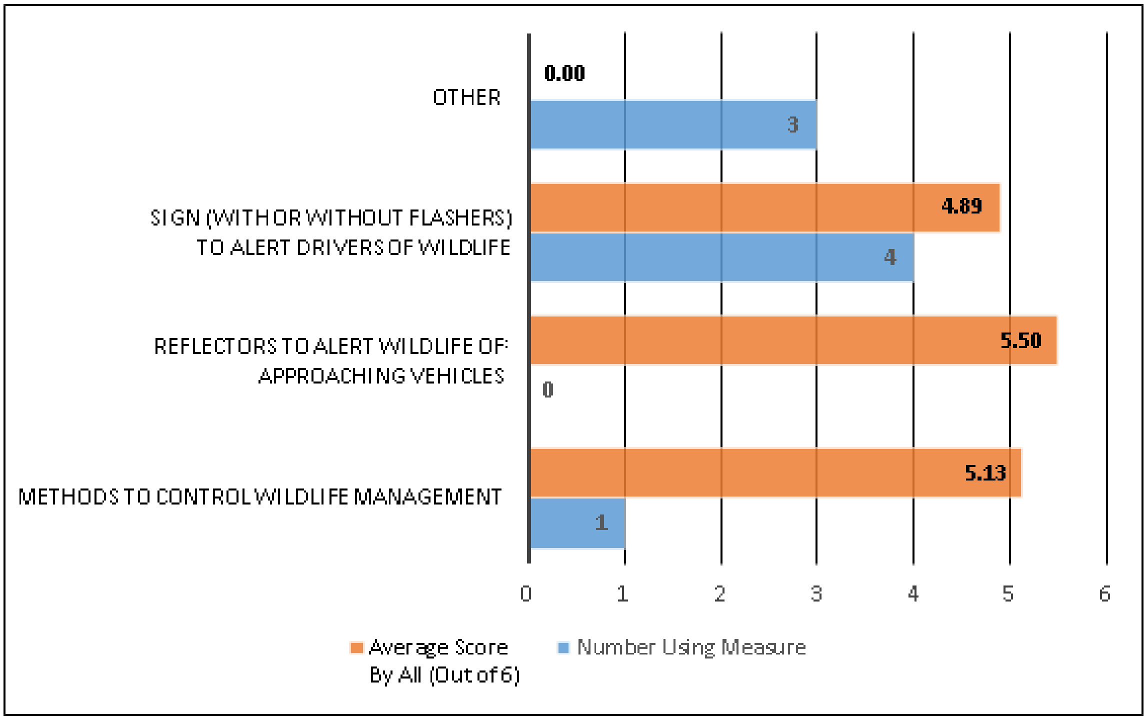
Figure 8. Summary of responses for signal improvements countermeasures



Wildlife Control

For wildlife control, respondents rated installing signs to alert drivers of wildlife most highly (4.89) and four agencies are employing them (Figure 9). No other countermeasures were rated highly or are in widespread use.

Figure 9. Summary of responses for wildlife control countermeasures



Other Countermeasures

The survey asked respondents to describe countermeasures being used at their agencies to improve LVR safety that were not listed in any of the survey's categories. Treatments mentioned included using ICWS, restricted crossing U-turns (RCUT), and median U-turn crossover. Agencies have also installed static and actuated flashers at intersections but with mixed results. The North Carolina DOT's systemwide conversion to all-way stop control for all LVR intersections is highly effective, having reduced total injury crashes (includes fatal and non-fatal injuries) by 71 percent.

Examples of Effectiveness

Respondents were asked to describe instances of a countermeasure being used and its effectiveness. The following examples were identified:

1. Systemic application of high friction surface treatments reduced wet-weather crashes by 90 percent and dry weather-related crashes by 77 to 80 percent.

2. Converting rural intersections to all-way stops statewide lowered total injury crashes by 71 percent (includes fatal and non-fatal injuries).
3. Improving superelevation and installing guardrails along a curve with an unprotected culvert in a rural area reduced total crashes by 80 percent.
4. Adopting a wider paved shoulder, clear zone improvements, guardrails, wider roadside, and wider and brighter signs and markings to reduce road departure crashes on rural routes.
5. Using edge line rumble strips where an RSA was completed and where applicable. A 4-in. rumble strip standard was developed to be bike friendly and can be used on roads with little to no paved shoulder; it has helped reduce roadway departure crashes.
6. Installing reflective strips on stop and stop ahead signs. Attempted as part of safety projects, reduced crashes at stop-controlled intersections, which removed the state from FHWA's stop-controlled intersection focus list.
7. One project implemented several countermeasures, including pavement widening, earth shouldering, converting non-traversable headwalls, and improving superelevation. Despite being completed roughly two years ago, preliminary safety evaluations show a 30 percent reduction in crashes (from 10 to 7 per year) and no injury crashes to date (from 3.6 per year before).
8. Using reflective roadway striping (spray thermo plastic or preformed) to address lane crossover and lane departure crashes increased the visibility of striping in rural areas with no roadway lighting.
9. Improving horizontal alignment reduced total crashes 92 percent.
10. One state earned a national safety award for a centerline rumble strip project focused on segments with ADT < 2,000 vpd.

Summary

Fifteen countermeasures that are considered effective (i.e., effectiveness score of 3.0 or less) are currently used by a majority of responding agencies (i.e., at least five states). Pavement markings (e.g., adding new markings, repainting faded markings, and improving the retro-reflectivity of existing markings); pavement surface treatments (e.g., edge line and centerline rumble strips and high friction surface treatments); widening shoulders and installing horizontal warning signs are regarded as the most effective countermeasures. One explanation for these rankings is that respondents factored in benefit-cost analyses when scoring treatments. More costly treatments, such as improving horizontal alignments, removing fixed objects, and increasing clear zones, were also noted as effective but received higher scores. Adopting more expensive countermeasures can bring significant safety improvements, as noted in some of the examples, although in some cases their costs may be prohibitive due to the level of investment required.

Countermeasure Summaries

Table 10 ranks by anticipated cost the countermeasures survey respondents cited most often. For each one, the research team prepared a summary sheet that describes the treatment, discusses its effectiveness, identifies crash types addressed by its use, and presents a generic cost estimate (Appendix H). In addition to the countermeasures identified with low scores and high usage, the addition of left-turn lane at intersections, addition of pavement markers, and installation of rumble strips at intersection or curve approaches were also included in the summaries because of their potential for safety gains and they had a reasonable number of states using them. Moreover, the installation of rumble strips is considered an effective and innovative countermeasure.

Table 10. Countermeasure attributes summary

Countermeasure	Affected Crashes	Cost	Maintenance		Effectiveness	
			Cost	Frequency	CMF	B/C
Install safety edge	Run-off-road Drop off	Low	-	20 years	0.85-0.92	40.9
Add centerline rumble strips	Run-off-road Head-on Sideswipe Adverse weather condition crashes	Low	-	10 years	0.75 to 0.85	26.1
Add edge line rumble strips	Run-off-road Adverse weather crashes	Low	-	10 years	0.78 to 0.90	71.8
Install advanced intersection warning signs	Right angle Rear end Head-on	Low	-	15 years	0.73; 0.425 (rear end)	-
Install horizontal alignment signs	Run-off-road	Low	$1,280	5 years	0.70	43.5
Install retro-reflective strips on sign posts	Run-off-road Right angle Rear end Head-on	Low	-	-	-	-

Countermeasure	Affected Crashes	Cost	Maintenance		Effectiveness	
			Cost	Frequency	CMF	B/C
Install rumble strips for intersection/curve approaches	Run-off-road (for curves) Right angle Rear end Head-on	Low	-	-	0.76 to 0.91	-
Add pavement markers	Run-off-road wet or night conditions	Low-Medium	-	3 years	CMF ≤ 0.76	-
Add pavement markings	Run-off-road Head-on Sideswipe Night crashes	Medium	-	5 years	0.56 -062 (edge line); 0.67 (centerline)	20.2 (centerline and edge line)
Add high-friction pavement surface	Run-off-road wet conditions	High	-	10 years	0.25 to 0.60	4.1
Remove/shield fixed objects	Run-off-road fixed object	High	$7,000	5 years	CMF ≤ 0.71	4.6
Widen shoulders	Run-off-road Sideswipe Head-on	High-Very High	-	-	0.90 - 0.97	-
Add left-turn lane	Head-on Rear end	Very High	$20,000	10 years	-	6.0 (Four-leg); 3.7 (three-leg)
Increase clear zone	Run-off-road fixed object	Very High	-	-	0.78 (3.3 ft. to 16.7 ft.)	-
Re-align roadway segments	Head-on Sideswipe Rear end Run-off-road	Very High	-	-	Reduce crashes by 28 percent	-

Low-cost countermeasures are reasonably effective, with CMFs ranging from 0.70 to 0.92. This equates to a reduction in crashes of 8 to 30 percent. These treatments also have high benefit-cost ratios (ranging from (26.1 to 71.8). Survey respondents scored most of these countermeasures as highly effective. For example, horizontal alignment signs, edge and centerline rumble strips, warning signs for intersections, and retroreflective strips earned lower scores (2.00, 2.22, 2.44, 2.78, and 3.00, respectively). These countermeasures can be used to address ROR crashes as well as intersection-related crashes (e.g., right angle, head-on, and rear end). It should be noted that the installation of safety edge was added based on its cost-effectiveness and suggestion of the panel.

Medium-cost treatments such as adding pavement markers or pavement markings, can help reduce ROR and head-on crashes. CMFs for these countermeasures range from 0.56 to 0.76. Survey respondents also rated the addition of pavement markings as the most effective countermeasure garnering the lowest score (1.89).

Countermeasures with a high cost include high friction pavement surfaces and removing fixed objects. Both treatments seek to reduce ROR crashes and have low CMFs (0.25–0.71), which indicate higher anticipated crash reductions than other countermeasures discussed. Survey respondents scored both at about the same level of effectiveness (high friction pavement surfaces 2.33 and removing fixed objects 2.44).

The final group of countermeasures are typically very expensive to adopt and require major reconstruction or potentially acquiring additional right of way. Treatments in this category include widening shoulders, increasing clear zones, adding a left turn, and road realignment. CMFs for these countermeasures range from 0.72 to 0.97. Survey respondents tended to view them as less effective, with all treatments accorded scores greater than 2.0. As the expense of these treatments may deter agencies from using them, their effectiveness has not been evaluated to the same extent as lower-cost countermeasures. It is possible these treatments are more effective at reducing crash severity, although further research is needed.

Overall, the subjective ratings provided by survey respondents align well with previous research findings. Readers, however, should bear in mind that the effectiveness of several countermeasures on LVRs has not been explicitly studied. Although it is reasonable to assume treatments will perform similarly across different road types, their performance on LVRs may be impacted by lower traffic volumes. When evaluating the prospects of various treatments, it is imperative to study the environments in which they have previously been applied. Additional research is needed to document and analyze the track record of specific countermeasures for improving LVR safety in the Southeast.

Conclusions

Researchers have devoted significant energy to understanding why crash rates on LVRs are higher than other highways. Because STAs are responsible for managing an enormous number of rural roadway miles, it is challenging for personnel to identify high-risk areas in which to implement cost-efficient safety treatments on LVRs.

To identify countermeasures for improving LVR safety, the research team conducted literature review and surveyed STA personnel employed by organizations in the Southeast. Especially promising countermeasures include adding edge line and centerline markings, adding horizontal alignment signs, improving faded pavement markings, installing shoulder and centerline rumble strips, increasing shoulder width, removing or relocating objects near the road, and correcting geometric deficiencies. The literature review did not point toward a single set of countermeasures for addressing overall safety. Most researchers and practitioners argue that it is critical for agency staff to develop a thorough understanding of the issues they want to resolve – including crash severity – before determining which countermeasure(s) is optimal. Agency staff have the option to consult several manuals to help them select an appropriate treatment based on their budget and the desired safety improvement.

The research team developed summary sheets for each countermeasure STAs across the Southeast currently in use to bolster LVR safety. Each sheet describes a treatment, how it can be implemented, its effectiveness, crash types addressed, and installation costs. While most of the countermeasures identified by the research team are inexpensive and can be used as either a spot treatment or more systemically, a few require major capital investments. The effectiveness of very expensive countermeasures has not been studied in-depth because they have not been implemented widely.

One issue that has not been completely addressed in this document is the application of multiple countermeasures. This is a complex issue that merits further investigation and it has been partially addressed [36, 51]; it is also a topic that will be addressed in future revisions of the HSM. The influence of countermeasures on crash severity is another understudied topic of interest. Acquiring more data to look at these issues will help researchers make more accurate determinations of countermeasure effectiveness.

This synthesis and the accompanying summary sheets describe countermeasures that have been used most frequently in the Southeast, and which STA personnel consider as the best performing. This document can be circulated widely to agencies at the state and local levels as it gives them a starting point to identify countermeasures to achieve their targeted safety outcomes. Readers should consult the references listed at the end of this document for more in-depth coverage of each countermeasure. Before selecting a countermeasure, an agency should thoroughly document the issues it intends to address (inclusive of crash severity). Only with this knowledge can staff make an informed decision about which treatment is most likely to produce the desired result.

The research team's findings demonstrate additional research is needed to address LVR safety in the Southeast. Potential research topics include:

- Evaluating the performance of countermeasures on LVRs in the Southeast. Research could address countermeasure effectiveness and identify additional parameters these treatments address. This work is particularly urgent for treatments in the high and very high cost categories.
- Evaluating the performance of multiple countermeasures used in combination. This topic has national implications and has use for understanding how countermeasure performance on LVRs differs from other rural roads.
- Evaluating how the performance of countermeasures adopted systemically differs from spot applications. Little research has been conducted in this area. Any knowledge gained could prove beneficial for addressing the safety of LVRs and all rural roads. Several STAs apply various countermeasures to address safety concerns systemwide, and the impacts of such decisions require assessment. This topic may become more salient as AASHTO continues its transition to performance based practical design.
- Update the pooled-fund study on fatalities in the Southeast. Crash data indicate the Southeast continues to be the region with the highest fatality rates in the US. Most of the 12 states in the STC have fatal crash rates above the national average. This could be also critical for identifying more state-specific efforts to lower fatal crash rates and develop a unified approach for addressing safety in the Southeast.

Acronyms, Abbreviations, and Symbols

Term	Description
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ATSSA	American Traffic Safety Services Association (ATSSA)
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
DOT	Department of Transportation
DOTD	Department of Transportation and Development
FARS	Fatal Accident Reporting System
FHWA	Federal Highway Administration
ft.	Feet
HSM	Highway Safety Manual
ICWS	Intersection conflict warning system
in.	Inches
LOI	Level of Improvement
LTRC	Louisiana Transportation Research Center
LVR	Low-Volume Road
MUTCD	Manual on Uniform Traffic Control Devices
MVMT	Million Vehicles Miles of Travel
NACE	National Association of County Engineers
PDO	Property damage Only
RAIR	Relative Accident Involvement Ratio
RCUT	Restricted crossing U-turn
ROR	Run-Off-Road
RSA	Road Safety Audit
SPF	Safety Performance Function
STA	State Transportation Agencies
STC	Southeast Transportation Consortium
TRID	Transportation Research Information Database

Term	Description
US	United States
vpd	Vehicles per day

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Appendix

The appendix in full can be found separately online at www.ltrc.lsu.edu/pubs_final_reports.html under FR 624 (19-2PF) as well as a link to the accompanying publication "Countermeasures to Improve Low-volume Road Safety in the Southeast."

This public document is published at a total cost of $250
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