

# Appendix A

Source: R. E. Abel and N. Garber, "Evaluation of Crash Rates and Causal Factors for High-Risk Locations on Rural and Urban Two-Lane Highways in Virginia," University of Virginia, 2008.

**Table A-1. Recommended countermeasures by collision type, highway classification, and causal factor**

Collision Type	Highway Classification(s)	Influencing Factor (effect on crashes) <sup>1</sup>	Countermeasure
Rear-end	Rural Primary, Urban Secondary	Presence of Turn Lanes (-)	Add turn lanes at intersections
	Rural Primary, Urban Primary	Stoplight Density (+)	Advance warning signs
Angle	Rural Secondary, Urban Secondary	Increased Shoulder Width (-)	Add or improve shoulders
	Urban Primary, Urban Secondary	Stop Sign Density (-)	Add stop signs where appropriate
Head-on	Rural Secondary, Urban Primary	Steep Grade (+)	Add advisory signs or realignment
	Rural Primary, Rural Secondary, Urban Primary	Passing Allowed (+)	Add advisory signs or adjustment of passing segments
	Rural Primary, Rural Secondary, Urban Secondary	Increased Lane Width (-)	Roadway widening
Sideswipe	Rural Primary, Rural Secondary, Urban Primary	Passing Allowed (+)	Add advisory signs or adjustment of passing segments
	Rural Primary, Rural Secondary, Urban Primary	Sharp curvature (+)	Add advisory signs and chevrons or realignment
	Rural Secondary	Steep Grade (+)	Add advisory signs or realignment
	Rural Primary	High operating Speed (+)	Reduce speed limit
	Rural Primary, Rural Secondary	Chevrons (-)	Add additional chevrons

<b>Collision Type</b>	<b>Highway Classification(s)</b>	<b>Influencing Factor (effect on crashes) <sup>1</sup></b>	<b>Countermeasure</b>
<b>Run-off-road</b>	Rural Primary, Urban Primary, Urban Secondary	Increased Lane Width (-)	Roadway widening
	Rural Primary, Rural Secondary	Sharp curvature (+)	Add advisory signs and chevrons or realignment
	Rural Secondary, Urban Primary, Urban Secondary	Increased Shoulder Width (-)	Add or improve shoulders
	Rural Primary, Rural Secondary	Passing Allowed (+)	Add advisory signs or adjustment of passing segments
<b>Deer</b>	Urban Primary	Sharp Curvature (+)	Add advisory signs and chevrons or realignment
	Rural Primary, Rural Secondary, Urban Primary	High Operating Speed (+)	Reduce speed limit
<b>Other</b>	Rural Primary, Rural Secondary	Sharp Curvature (+)	Add advisory signs and chevrons or realignment
	Rural Primary, Urban Secondary	Increased Lane Width (-)	Roadway widening

<sup>1</sup> A negative sign indicates the variable reduces crashes and should therefore be implemented; a positive sign indicates the variable increase crashes and should be improved in order to reduce crashes.

## Appendix B

Source: K. Fitzpatrick, A. Parham, M. Brewer, and S. Miaou, "Characteristics of and Potential Treatments for Crashes on Low-Volume, Rural Two-Lane Highways in Texas," 2001.

**Table B-1. Potential safety treatments for various issues**

Category	Potential Safety Treatment
<b>Clear Zone</b>	Flatten side slopes
	Increase clear zone
	Make culverts traversable by adding bars to prevent tires from entering culvert
	Mow
	Remove headwalls or adding fill to bring ground level with headwall
	Remove trees
	Upgrade safety appurtenances
	<i>Other</i>
<b>Wildlife Control</b>	Methods to control wildlife management
	Reflectors to alert wildlife of approaching vehicles
	Sign (with or without flashers) to alert drivers of wildlife
	<i>Other</i>
<b>Additional Lane</b>	Climbing lane
	Passing lane
	Right-turn lane
	Left-turn lane
	Two-way left-turn lane
	<i>Other</i>
<b>Pavement surface Treatments</b>	Centerline rumble strips
	Edge line rumble strips
	Rumble strips on approaches to intersections or horizontal curves
	Shoulder texturing
	Skid resistance improvements
	Thicker thermoplastic pavement markings
	<i>Other</i>

Category	Potential Safety Treatment
<b>Pavement Markings</b>	Add on-lane pavement markings (painted curve arrow, slow speeds, etc.)
	Add oversized glass beads
	Add pavement markings (e.g., edge lines)
	Add raised pavement marker on centerline or edge line
	Add retroreflective pavement markers
	Reapply existing pavement markings because they have faded
	Remove existing buttons to convert to guidance markings
	<i>Other</i>
<b>Sign Improvements</b>	Advance signing for intersections
	Advance signing for horizontal curves
	Advance signing for stop signs
	Delineators
	Diamond grade sheeting at restricted width bridge
	Diamond grade chevron signs at curves
	Flags on stop sign
	Flashing beacon on stop sign
	Flashing beacon on warning sign
	High intensity strobe (HIS) in advance of curves
	In-rail reflectors for guardrail and bridge rail
	Reflective corner caps on signs (contrasting colors)
	<i>Other</i>
<b>Signal Improvements</b>	Backboards for traffic signals
	High intensity strobe (HIS) in signal
	<i>Other</i>
<b>Other Improvements</b>	Illumination
	Improve/standardize approaches to narrow bridges
	Increase pavement edge maintenance
	Speed detection/notification devices
	<i>Other</i>

## Appendix C

Source: F. Hossain, "Risk Factors Associated with High Potential for Crashes on Low-Volume Roads," Montana State University-Bozeman, 2016.

**Table C-1. Countermeasures related to highway alignment**

Safety Countermeasures	B/C (ODOT values)	B/C (HSM values)
Horizontal Alignment Sign	<b>2.96</b>	<b>1.78</b>
Horizontal Alignment Sign with Static Advisory Speed	<b>2.96</b>	<b>1.78</b>
Flashing Beacon for Curve Warning	<b>1.47</b>	0.75
Chevrons	0.87	0.39
Post Mounted Delineators for Curves	<b>1.26</b>	0.98
Raised Pavement Markers for Curves	<b>1.11</b>	0.56
Dynamic Speed Feedback Display on Approach to Curves	0.06	0.01
High Friction Surface Treatment for Curves	0.31	0.24

Note: Bold values indicate positive B/C ratios

**Table C-2. Countermeasures related to roadway cross-section**

Safety Countermeasures	B/C (ODOT values)	B/C (HSM values)
Widen 1 ft. Lanes	0.08	0.13
Widen 1ft. Paved Shoulder	0.03	0.06
Widen Un-paved shoulder – unspecified amount	<b>1.46</b>	<b>1.32</b>
Add Paved Shoulder	0.90	0.82
Stabilize Shoulder	<b>2.02</b>	<b>1.83</b>
High Friction Surface Treatment	0.20	0.19

Note: Bold values indicate positive B/C ratios

**Table C-3. Countermeasures related to roadside features**

Safety Countermeasures	B/C (ODOT values)	B/C (HSM values)
Flatten Side Slopes	<b>1.53</b>	<b>1.39</b>
Install Safety Edge	<b>7.74</b>	<b>7.01</b>
Improve Roadside Hazard Rating	0.77	0.69
Install Object Markers for Objects Near the Roadway	<b>10.67</b>	<b>8.82</b>
Relocate Objects Near the Roadway	<b>1.49</b>	<b>1.27</b>
Remove Objects Near the Roadway	<b>1.84</b>	<b>1.56</b>
Install Guardrail	<b>1.44</b>	<b>1.34</b>

Note: Bold values indicate positive B/C ratios

**Table C-4. Other safety countermeasures**

Safety Countermeasures	B/C (ODOT values)	B/C (HSM values)
Install Shoulder Rumble Strips	<b>25.32</b>	<b>22.92</b>
Install Centerline Rumble Strips	<b>21.49</b>	<b>19.46</b>
Install Edge line Markings	<b>9.26</b>	<b>7.78</b>
Install Centerline Markings	<b>28.45</b>	<b>25.49</b>
Install Edge line and Centerline Markings	<b>6.38</b>	<b>5.65</b>
Widen Edge line Markings	<b>7.60</b>	<b>6.75</b>
Widen Centerline Markings	<b>25.70</b>	<b>23.00</b>
Install Seasonal Wildlife Warning Sign	<b>3.56</b>	<b>1.80</b>
Vegetation Removal	<b>1.50</b>	0.00
Install Fence	0.11	0.04
Install Fence, Gap & crosswalk	0.03	0.00

Note: Bold values indicate positive B/C ratios

# Appendix D

Source: J. E. Atkinson et al., "Manual for Selecting Safety Improvements on High Risk Rural Roads," 2014.

**Table D-1. Horizontal curves**

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO <sup>19</sup>			
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install Curve Warning Signs	11	\$	\$	5	P	0.70	33.8	270.1	43.5	428.4
Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting	12	\$	-	5	P	0.66	63.1	490.4	75.1	739.9
Double Use of Advanced Warning Signs for Curves or Intersections	13	\$			T					
Use of Optical Speed Bars	14	\$								
Install Chevron Signs	15	\$\$	\$	5	P	0.75	10.6	84.7	13.0	127.7
Install Arrow Signs at Horizontal Curve Locations	16	\$\$	-	10	P		27.9	222.8	34.1	336.1
Install Post-Mounted Delineators at Horizontal Curves	17	\$\$	-	10	P		5.3	42.4	6.5	63.9
Install Targeted Longitudinal Rumble Strips on the Outside of Horizontal Curves	18	\$\$			T	0.85				
Install Icy Curve Warning System	19	\$\$			E	0.82				
Improve Superelevation at Horizontal Curve Locations	20	\$\$\$\$			P					
Remove Compound Horizontal Curves	21	\$\$\$\$\$			T					
Modify Horizontal/Vertical Geometry	22	\$\$\$\$\$			P					
Cost: \$ = \$0 to \$5,000 \$\$ = \$5,001 to \$20,000 \$\$\$ = \$20,001 to \$50,000 \$\$\$\$ = \$50,001 to \$100,000 \$\$\$\$\$ = \$100,001 and up	NCHRP 500 Performance Rating <sup>20</sup> P - Proven T - Tried E - Experimental U - Unknown				*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd ***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders ****Narrower Conditions = 10-foot lanes and no shoulders					

**Table D-2. Intersections (signalized)**

SAFETY TREATMENT	For more information, visit page	COST			Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT- COST RATIO <sup>22</sup>	
		Initial Implementation	Ongoing Maintenance			NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*	Higher Volume**
Improve Traffic Signal Visibility (Larger Diameter Lens or Install Back Plate)	24	\$				P	0.85		
Provide Intersection Lighting	25	\$\$	\$	1		P	0.41-0.88	26.9	93.8
Install Pedestrian Signal Heads to Existing Signalized Intersections	26	\$\$				P			
Provide Flashing Beacons at Intersection Approaches	27	\$\$\$	\$	2		P		11.0	38.2
Use Raised Median to Restrict Turning Movements	28	\$\$\$-\$\$\$\$				P	0.61-1.09		
Install Priority Control Systems for Emergency Vehicles	29	\$\$\$-\$\$\$\$				T			
Provide Advanced Dilemma Zone Detection for Rural High Speed Signalized Approaches	30	\$\$\$-\$\$\$\$				P	0.61		
Implement J-Turns Along a Signalized Corridor	31	\$\$\$\$	\$	10		P		45.4	159.1
Install Acceleration or Deceleration Lanes	32	\$\$\$\$				P			
Install Right Turn Lane	33	\$\$\$\$\$	\$\$	10		P	0.77-0.96	4.9	16.9
Install Left Turn Lane	34	\$\$\$\$\$	\$\$	10		P	0.50-0.80	4.1	14.1
Install Offset (or Channelized) Left Turn Lane	35	\$\$\$\$\$	\$\$	10		P	0.80	4.1	14.1
Convert a Traditional Signalized Intersection into a Roundabout	36	\$\$\$\$\$	\$\$\$	10		P	0.26-0.82	4.8	16.6
Reconstruct At-Grade Intersection to Create an Interchange	37	\$\$\$\$\$	\$\$\$	10		P	0.43-0.64	0.1	0.4
<b>Cost:</b> \$ = \$0 to \$5,000 \$\$ = \$5,001 to \$20,000 \$\$\$ = \$20,001 to \$50,000 \$\$\$\$ = \$50,001 to \$100,000 \$\$\$\$\$ = \$100,001 and up	NCHRP 500 Performance Rating <sup>23</sup> P – Proven T – Tried E – Experimental U – Unknown				*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd				

**Table D-3. Intersections (unsignalized)**

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO <sup>25</sup>			
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	4-LEG INTERSECTIONS		3-LEG INTERSECTIONS	
							Lower Volume*	Higher Volume**	Lower Volume*	Higher Volume**
Relocate an Existing Stop Bar on Minor Approach	40	\$			T					
Install Stop Ahead Pavement Markings	41	\$			P	0.44-0.69				
Install Advanced Intersection Warning Signs	42	\$			P					
Provide a Stop Bar on Minor-Road Approaches	43	\$	-	5	P		337.7	1175.8	287.1	1484.1
Improve Sight Distance within Sight Triangle	44	\$	\$	5	P	0.44-0.89	157.3	547.8	66.9	345.7
Provide Upcoming Road Names on Advanced Warning Signs	45	\$			T	0.90-0.99				
Install Retroreflective Strips on Sign Posts	46	\$			T					
Upgrade to Larger Stop Signs	47	\$			P					
Double Use of Stop Signs	48	\$			T					
Improve Sight Distance and Conspicuity at Railroad Grade Crossings	49	\$			T					
Install a Splitter Island	50	\$\$			T					
Channelization of Major and Minor Roads (Physical or Painted)	51	\$\$			P					
Provide Intersection Lighting	52	\$\$	\$	1	P		23.1	80.6	10.5	54.2
Install Dynamic Advanced Intersection Warning System	53	\$\$			P	0.10-0.76				
Upgrade Existing Railroad Crossing Hardware and Warning Systems	54	\$\$-\$\$\$			P	0.55				
Implement Lane Narrowing through Rumble Strips and Painted Median at Rural Stop-Controlled Approaches	55	\$\$-\$\$\$			T	0.60-0.80				

**Table D-4. Non-motorized user**

SAFETY TREATMENT	For more information, visit page	COST			Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO <sup>28</sup>			
		Initial Implementation	Ongoing Maintenance			NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrow Conditions****	Higher Volume**, Narrow Conditions****
Provide Crosswalks at Targeted Locations	73	\$				P & T					
Install Pedestrian Signal Heads to Existing Signalized Intersections	74	\$\$				P					
Construct Wildlife Fencing	75	\$\$				T					
Install Rectangular Rapid Flash Beacons (RRFBs)	76	\$\$				P					
Build Sidewalks	77	\$\$-\$\$\$				P					
Construct Adjacent Shared-Use Paths	78	\$\$-\$\$\$				P					
Construct Shared-Use Paved Shoulders for Horse & Buggy Road Users or Bicyclists	79	\$\$-\$\$\$				T					
Construct Exclusive Bicycle Lanes	80	\$\$-\$\$\$				T					
Install Curb Extensions	81	\$\$\$				T					
Install or Modify Culverts to Accommodate Wildlife Crossing	82	\$\$\$-\$\$\$\$				T					
Install Pedestrian Hybrid Beacons or High intensity Activated Crosswalks (HAWK)	83	\$\$\$-\$\$\$\$				P	0.712				
Construct Bicycle Trail Grade Separation Structures	84	\$\$\$\$\$				P					
Cost: \$ = \$0 to \$5,000 \$\$ = \$5,001 to \$20,000 \$\$\$ = \$20,001 to \$50,000 \$\$\$\$ = \$50,001 to \$100,000 \$\$\$\$\$ = \$100,001 and up	NCHRP 500 Performance Rating <sup>29</sup> P – Proven T – Tried E – Experimental U – Unknown		*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd ***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders ****Narrower Conditions = 10-foot lanes and no shoulders								

**Table D-5. Pavement and shoulder resurfacing**

SAFETY TREATMENT	For more information, visit page	COST			Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO <sup>30</sup>			
		Initial Implementation	Ongoing Maintenance			NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install a Safety Edge	86	\$	-	20	P	0.85-0.92	33.4	267.2	40.9	403.2	
Install Center Line Rumble Strips	87	\$	-	10	P	0.75-0.85	21.3	170.6	26.1	257.5	
Install Edge Line or Shoulder Rumble Strips	88	\$	-	10	P	0.78-0.90	58.6	469.0	71.8	707.7	
Install Transverse Rumble Strips	89	\$			P	0.76-0.91					
Regrade or Recondition Gravel Lanes	90	\$\$-			T						
Install Targeted Longitudinal Rumble Strips at Key Locations (Such as on the Outside of Horizontal Curves Only)	91	\$\$\$\$			T	0.85					
Install or Maintain a Graded Shoulder	92	\$\$\$\$			P	0.52					
Provide Turnout Areas	93	\$\$\$\$			T						
Improve Pavement Friction/Increase Skid Resistance	94	\$\$\$\$	-	10	P	0.25-0.60	3.3	26.7	4.1	40.3	
Add Paved Shoulder	95	\$\$\$\$	\$	2	P	0.86	n/a	n/a	0.5	4.5	
Widen Existing Travel Lanes by Two Feet or Less per Lane	96	\$\$\$\$	\$\$\$	10	P	0.95	n/a	n/a	0.3	2.8	
Install Passing or Climbing Lanes	97	\$\$\$\$	\$\$\$	10	P		0.3	2.3	0.4	3.5	
Increase Shoulder Width	98	\$\$\$\$			P	0.90-0.97					
Improve Superelevation at Horizontal Curve Locations	99	\$\$\$\$			P						
Cost: \$ = \$0 to \$5,000 \$\$ = \$5,001 to \$20,000 \$\$\$ = \$20,001 to \$50,000 \$\$\$\$ = \$50,001 to \$100,000 \$\$\$\$\$ = \$100,001 and up	NCHRP 500 Performance Rating <sup>31</sup> P – Proven T – Tried E – Experimental U – Unknown		*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd ***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders ****Narrower Conditions = 10-foot lanes and no shoulders								

**Table D-6. Pavement marking**

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO <sup>32</sup>			
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Provide a Stop Bar on Minor Road Approaches	101	\$	\$	5	P		337.7	1175.8	287.1	1484.1
Install Stop Ahead Pavement Markings	102	\$			P	0.44-0.69				
Relocate an Existing Stop Bar on Minor Approach	103	\$			T					
Use of Optical Speed Bars	104	\$								
Install Raised Pavement Markers	105	\$-\$			T	≤0.76				
Install Edge Line Markings	106	\$	-	5	P	0.56-0.62	27.9	222.8	34.1	336.1
Install Center Line Markings	107	\$	-	5	P	0.67	35.1	281.0	43.0	424.0
Install Wider Pavement Markings (With or Without Rumble Strips)	108	\$			E	0.65-0.96				
Implement Lane Narrowing Through Rumble Strips and Painted Median at Rural Stop-controlled Approaches	109	\$-\$-\$			T	0.60-0.80				
Install Center Line and Edge Line Markings	110	\$	-	5	P		16.5	132.1	20.2	199.3
Convert a Four-Lane Two-Way Road into a Three-Lane Road With One Lane in Each Direction of Travel Plus a Continuous Two-Way Left Turn Lane (Road Diet)	111	\$-\$-\$-\$			P	0.71-0.95				
Convert a Four-Lane Two-Way Road into a Five-Lane Road with Two Lanes in Each Direction of Travel Plus a Continuous Two-Way Left Turn Lane OR Convert a Two-Lane Two-Way Road into a Three-Lane Road Plus a Continuous Two-Way Left Turn Lane	112	\$-\$-\$-\$			T					
<b>Cost:</b> \$ = \$0 to \$5,000 \$\$ = \$5,001 to \$20,000 \$\$\$ = \$20,001 to \$50,000 \$\$\$\$ = \$50,001 to \$100,000 \$\$\$\$\$ = \$100,001 and up	<b>NCHRP 500 Performance Rating<sup>33</sup></b> P - Proven T - Tried E - Experimental U - Unknown		*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd ***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders ****Narrower Conditions = 10-foot lanes and no shoulders							

**Table D-7. Roadside**

SAFETY TREATMENT	For more information, visit page	COST			Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO <sup>34</sup>			
		Initial Implementation	Ongoing Maintenance			NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install a Safety Edge	114	\$	-	20	P	0.85-0.92	33.4	267.2	40.9	403.2	
Improve Sight Distance by Controlling Roadside Vegetation	115	\$\$-\$			T						
Convert Culvert Headwalls to Traversable End Treatments	116	\$\$-\$			P						
Remove Guardrail	117	\$\$-\$			U						
Install or Maintain a Graded Shoulder	118	\$\$\$			P	0.52					
Relocate Select Hazardous Utility Poles	119	\$\$\$-\$\$\$\$			P	≤0.71					
Install Median Guardrail	120	\$\$\$-\$\$\$\$									
Modify End Treatments of Existing Guardrail	121	\$\$\$-\$\$\$\$			P						
Install Impact Attenuation Devices at Select Roadside Hazard Locations (Such as Exposed Bridge Columns)	122	\$\$\$-\$\$\$\$			P	0.31-0.54					
Remove or Shield Obstacles in Clear Zone	123	\$\$\$\$	\$\$	5	P	≤0.71	3.3	26.7	4.6	45.2	
Increase Shoulder Width	124	\$\$\$\$-\$\$\$\$\$			P	0.90-0.97					
Widen Existing Median or Construct Median	125	\$\$\$\$-\$\$\$\$\$			P						
Install Median Cable Barrier	126	\$\$\$-\$\$\$\$			P	0.71					
Flatten Road Sideslope	127	\$\$\$\$	-	10	P	0.58	n/a	n/a	0.2	1.9	
Create or Increase Clear Zone	128	\$\$\$\$	-	-	P	0.56-0.87	1.0	7.9	1.5	14.6	
Add Paved Shoulder	129	\$\$\$\$	\$\$	2	P	0.86	n/a	n/a	0.5	4.5	
Install Concrete Median Barrier	130	\$\$\$\$			P						
<b>Cost:</b> \$ = \$0 to \$5,000 \$\$ = \$5,001 to \$20,000 \$\$\$ = \$20,001 to \$50,000 \$\$\$\$ = \$50,001 to \$100,000 \$\$\$\$\$ = \$100,001 and up	<b>NCHRP 500 Performance<sup>35</sup> Rating</b> P – Proven T – Tried E – Experimental U – Unknown		*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd ***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders ****Narrower Conditions = 10-foot lanes and no shoulders								

**Table D-8. Signing**

SAFETY TREATMENT	For more information, visit page	COST			Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO <sup>36</sup>			
		Initial Implementation	Ongoing Maintenance			NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume <sup>*</sup> , Optimal Conditions <sup>***</sup>	Higher Volume <sup>**</sup> , Optimal Conditions <sup>***</sup>	Lower Volume <sup>*</sup> , Narrower Conditions <sup>****</sup>	Higher Volume <sup>**</sup> , Narrower Conditions <sup>****</sup>
Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting	132	\$	-	5	P	0.66	63.1	490.4	75.1	739.9	
Install Curve Warning Signs	133	\$	\$	5	P	0.70	33.8	270.1	43.5	428.4	
Install Retroreflective Strips on Sign Posts	134	\$			T						
Double Use of Advanced Warning Signs for Curves or Intersections	135	\$			T						
Provide Upcoming Road Names on Advanced Warning Signs	136	\$			T	0.90-0.99					
Install Advanced Intersection Warning Signs	137	\$			T						
Upgrade to Larger Stop Signs	138	\$			P						
Double Use of Stop Signs	139	\$			T						
Use of Supplemental Warning Signs	140	\$			T						
Install Chevron Signs	141	\$\$	\$	5	P	0.75	10.6	84.7	13.0	127.7	
<b>Cost:</b> \$ = \$0 to \$5,000 \$\$ = \$5,001 to \$20,000 \$\$\$ = \$20,001 to \$50,000 \$\$\$\$ = \$50,001 to \$100,000 \$\$\$\$\$ = \$100,001 and up	<b>NCHRP 500 Performance Rating<sup>37</sup></b> P – Proven T – Tried E – Experimental U – Unknown				*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd ***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders ****Narrower Conditions = 10-foot lanes and no shoulders						

**Table D-9. Vertical curves**

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO <sup>38</sup>			
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install Advanced Intersection Warning Signs	143	\$			P					
Install Dynamic Advanced Intersection Warning System	144	\$\$			P	0.10-0.76				
Modify Horizontal/Vertical Geometry	145	\$\$\$\$			P					
Relocate Driveways, Entrances, and Intersections	146	\$\$\$\$			T					
<b>Cost:</b> \$ = \$0 to \$5,000 \$\$ = \$5,001 to \$20,000 \$\$\$ = \$20,001 to \$50,000 \$\$\$\$ = \$50,001 to \$100,000 \$\$\$\$\$ = \$100,001 and up	<b>NCHRP 500 Performance Rating<sup>39</sup></b> P - Proven T - Tried E - Experimental U - Unknown		*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd ***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders ****Narrower Conditions = 10-foot lanes and no shoulders							

# Appendix E

Source: F. Gross, P. P. Jovanis, and K. Eccles, "Safety Effectiveness of Lane and Shoulder Width Combinations on Rural, Two-Lane, Undivided Roads," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2103, no. 1, pp. 42-49, 2009.

**Table E-1. Low-Volume roads and safety audits**

Issue	Promising Low-Cost Measure	Guidebooks	Photo
Cross section	<p>Improve shoulders:</p> <ul style="list-style-type: none"> <li>- Add or widen paved shoulder</li> <li>- Stabilize unpaved shoulders</li> </ul> <p>Install rumble strips or stripes:</p> <ul style="list-style-type: none"> <li>- Install center line rumbles</li> <li>- Install shoulder or edge line rumbles</li> </ul>	N/A	
Horizontal curves	<p>Improve delineation:</p> <ul style="list-style-type: none"> <li>- Install advance curve warning (with or without advisory speed)</li> <li>- Install center line and edge line pavement markings</li> <li>- Install chevrons or post-mounted delineators</li> </ul> <p>Upgrade existing signs:</p> <ul style="list-style-type: none"> <li>- Replace old signs with fluorescent yellow signs</li> <li>- Replace old signs with signs that are more retroreflective</li> </ul> <p>Improve surface friction:</p> <ul style="list-style-type: none"> <li>- Overlay curve with high-friction treatment (e.g., NovaChip)</li> </ul>	<p>Low-Cost Treatments for Horizontal Curve Safety (FHWA-SA-15-084)</p> <p>NCHRP Report 500 Series: Volume 7</p>	
Roadside hazards	<ol style="list-style-type: none"> <li>1. Remove the obstacle</li> <li>2. Redesign the obstacle so it can be safely traversed</li> <li>3. Relocate the obstacle to a point where it is less likely to be struck.</li> </ol> <p>Relocation is often accomplished by moving objects further from the road; however, there can also be strategic relocation without moving the object further from the road. For example, roadway departure crashes on horizontal curves tend to be more frequent on the outside of the curve. As such, an object is less likely to be struck if it is moved to the inside of the curve</p> <ol style="list-style-type: none"> <li>4. Reduce impact severity by using an appropriate breakaway device</li> <li>5. Shield the obstacle with a longitudinal traffic barrier designed for redirection, or use a crash cushion</li> <li>6. Delineate the obstacle if the above alternatives are not appropriate.</li> </ol>	AASHTO's Roadside Design Guide	

<p>Intersections</p>	<p>Enhance driver expectation of intersections:</p> <ul style="list-style-type: none"> <li>- Provide adequate sight distance to intersection and</li> <li>- Install “Stop Ahead” pavement markings and signs</li> </ul> <p>Enhance conspicuity of signs and pavement markings:</p> <ul style="list-style-type: none"> <li>- Increase size of stop signs</li> <li>- Double-up stop signs</li> <li>- Replace old and faded signs and pavement markings</li> </ul> <p>Improve line of sight at the intersection: clear sight triangles</p> <p>Use access management strategies: reduce conflict points by installing turn lanes and consolidating driveways.</p>	<p>Strategies to Address Nighttime Crashes at Rural, Unsignalized Intersections</p> <p>NCHRP Report 500 Series: Volume 5</p>	
<p>Pedestrians and bicyclists</p>	<p>Provide designated pedestrian and bicycle facilities:</p> <ul style="list-style-type: none"> <li>- Install or widen paved shoulder to at least 4 feet for use by pedestrians and bicyclists (this can be accomplished, in part, by narrowing the lane width to the extent possible in regard to the presence of heavy vehicles)</li> <li>- Construct a shared-use path enhance driver awareness of pedestrians and bicyclists:</li> <li>- Install appropriate warning signs to indicate the presence of pedestrians, bicyclists, and crossings</li> <li>- Enhance conspicuity of pedestrian crossings and bicycle facilities</li> </ul>	<p>Pedestrian Safety Guide and Countermeasure Selection System</p> <p>Bicycle Countermeasure Selection System</p>	
<p>Animals</p>	<p>Enhance driver awareness of animals:</p> <ul style="list-style-type: none"> <li>- Install appropriate warning signs to indicate the presence of animals and animal crossings</li> <li>- Clear roadside vegetation to enhance the visibility of animals along the roadside and to discourage animals from grazing along roads</li> </ul> <p>Reduce the number of potential conflict points with livestock:</p> <ul style="list-style-type: none"> <li>- Install animal fencing.</li> <li>- Enact and enforce laws to prohibit grazing within the right-of-way</li> <li>- Educate owners about animal control laws and liability</li> </ul> <p>Reduce the number of potential conflicts with wildlife: construct wildlife crossings (i.e., overpasses and underpasses) along primary migratory and feeding routes</p>	<p>Critter Crossings website</p>	

## Appendix F

Source: R. Sperry, J. Latterell, and T. McDonald, "Best Practices for Low-Cost Safety Improvements on Iowa's Local Roads," Center for Transportation Research and Education, 2008.

**Table F-1. Best Practices for low-cost safety improvements on Iowa's local roads**

Type	Highway Classification(s)
<b>Signing and Delineation</b>	Use of 36 in. Signs on Paved Roadways (Warnings, Stop Ahead, and Stops) Replacing Yield Signs with Stop Signs at Y Intersections Use of Chevrons (in Lieu of) Double Arrow for Extra Emphasis Nighttime Sign Surveys Flags on (Oversize) Stop (and/or Warning) Signs Object Markers—Marking Hazards Delineators—Marking Alignment or a Hazard Post-Mounted Delineators and Chevrons (Curves) Large Advance Street Signing Larger 8 in. Street Names Signs Adding Large Arrow Sign to Curve Warning Flashing Beacons (Red) Flashing Beacons (Yellow) Solar-Powered Flashing Beacons (Red or Yellow) Utility Pole Delineation Blinker Signs Sign Sheeting Alternatives
<b>Traffic Calming</b>	Summary of Treatment Effectiveness Speed Displays Lane Width Reduction with Channelizers Speed Limit on Pavement Pavement Marking with Convergent Chevrons 2-6 Shoulder Marking to Reduce Perceived Width of Traveled Way Speed Humps or Tables Optical Speed Bars for Speed Reduction Optical Speed Bars (for Speed Reduction at Curves) Red Painted Pavement Markings
<b>Pavement Marking and</b>	Rumble Striping (Research project in 2008) Rumble Striping on New PC Overlay Project

Type	Highway Classification(s)
<b>Rumble Strips/Stripes</b>	Painted Edge lines on Two-Lane Paved Roads Wider Longitudinal Pavement Markings (Edge lines) Milled in Centerline Pavement Markings Shoulder and Edge line Rumble Strips Centerline Rumble Strips Advance Rumble Strips for Stop Signs on Paved Roadways Curve Advance Warning on Pavement
<b>Roadside and Clear Zone</b>	Mowing Entire ROW (Paved Roads) Mowing/Clearing Railroad ROW (with permission) Safety Dikes (Ramps) at T Intersections Flattening Slopes of Entrances and Drives Maintenance Shouldering/Flattening Slopes County Entrance Slope Survey Data from Iowa DOT Removal of Hazard(s) in Clear Zone Utility Pole Relocation
<b>Guardrail and Barriers</b>	Reflective Tape on Guardrail Reflective Paint on Guardrail Roadside Cable Barrier Roadside Beam Guardrail High Tension Cable Guardrail (Medians)
<b>Lighting</b>	Destination Lighting Intersection Lighting
<b>Pavements and Shoulders</b>	Adding 2 ft of Additional Paving at Curves Recycling (4 in.) and Resurfacing (3 in.) at 24 ft Width and Marking Pavements at 22 ft Width Skid Resistant Treatments and Overlays Safety Edge Attachment for ACC Paving
<b>Intersections</b>	Offset Right-Turn Lane Roundabouts
<b>Railroad Crossings</b>	Channelizers for Lane Guidance and at Railroad Crossings Medians at Railroad Crossings Stop Signs at Railroad Crossings
<b>Bridges and Culverts</b>	Guardrail at Culvert Ends Guardrail at Bridge Ends
<b>Miscellaneous</b>	Crash Study Methodology Resource Allocation Strategy Creating Positive Relationships with Law Enforcement

# Appendix G

## STC Synthesis Survey

---

### Introduction

The University of Kentucky has been awarded project LTRC-2PF "Synthesis on the Contributing Factors and Effective Countermeasures for Low Volume Roadway Fatality Rates in the Southeast" from the Louisiana Transportation Research Center. The research goals are to summarize contributing factors on low volume roads (LVR) crashes based on prior domestic and international research; identify countermeasures implemented to address LVR safety; and document countermeasure effectiveness in addressing LVR safety. Note that LVRs are defined here as roads with volumes less than 2,000 vehicles per day.

To this end, we are conducting a survey that will solicit input of state transportation agencies to help identify current practices regarding countermeasures and applications in addressing LVR safety. Moreover, we are seeking to identify agencies that have implemented countermeasures across a range of contexts and possibly have evaluated their effectiveness.

We are interested in soliciting your participation in the survey. Your assistance in this matter will help our research and aid making the results more relevant to future practice.

---

*Questions and the available responses are shown below with the number of responses received indicated in parenthesis.*

Q1 What is your designation?

- Designer (1)
- Traffic engineer (2)
- Safety engineer (4)
- Other (Please Define) (3) \_\_\_\_\_

Q2 What is your primary area of practice?

- Program Development (1)
- Planning (2)
- Design Construction (3)
- Operations (4)
- Maintenance (5)
- Safety analysis (8)
- Other: (7) \_\_\_\_\_

Q3 What is your agency?

- State DOT (1)
- City (2)
- County (3)
- Other: (4) \_\_\_\_\_

Q4 What is the extent of LVRs that your agency supervised? (Provide estimated mileage; Note that LVRs are roads with an AADT of 2,000 vpd or less)

\_\_\_\_\_

Q5 Are there any policies that your agency has in place for addressing safety concerns for LVRs?

- Yes (1)
- No (2)

*Display This Question:*

*If Are there any policies that your agency has in place for addressing safety concerns for LVRs? = Yes*

Q5a Please describe any policies your agency has in place for addressing safety concerns for LVRs.

\_\_\_\_\_

Q6 Regarding safety evaluations for LVRs, does your agency use any of the following practices?

- Cost-benefit estimations (1)
- Road Safety Audits (2)
- Highway Safety Manual Crash Prediction Models (3)
- Local road safety plans (5)
- Other (Please describe) (4)

\_\_\_\_\_

Instruction Please check the Safety Improvements you have installed to address safety concerns on LVRs (volumes < 2,000).

**Q9 Clear Zone**

- Flatten side slopes (1)
  - Increase clear zone (2)
  - Widen shoulders (3)
  - Convert a non-traversable culvert headwall into a traversable culvert headwall (4)
  - Mow (5)
  - Modify end treatments at existing guardrail (6)
  - Remove fixed objects (trees, power poles, structures, etc.) (7)
  - Relocate fixed objects (trees, power poles, structures, etc.) (10)
  - Shield fixed objects (trees, power poles, structures, etc.) (11)
  - Convert non-crash-worthy roadside hardware (such as guardrail) to crash-worthy. (8)
  - Other (Please specify) (9) \_\_\_\_\_
- 

**Q10 Geometric Improvements**

- Climbing lane (1)
  - Passing lane (2)
  - Right-turn lane (3)
  - Left-turn lane (4)
  - Driveway deceleration lane (5)
  - Two-way left-turn lane (6)
  - Re-alignment (8)
  - Offset T-intersections (9)
  - Other (Please specify) (7) \_\_\_\_\_
-

**Q11 Pavement Surface Treatments**

- Centerline rumble strips (1)
- Edgeline rumble strips (2)
- Rumble strips on approaches to intersections or horizontal curves (3)
- Shoulder texturing (4)
- High friction surface improvements (5)
- Other (Please specify) (7) \_\_\_\_\_

**Q12 Pavement Markings**

- Add on-lane pavement markings (painted curve arrow, slow speeds, etc.) (1)
- Improve visibility or retro-reflectivity of pavement marking (2)
- Add pavement markings (e.g., edge lines or center lines) (3)
- Install raised pavement (4)
- Markers (5)
- Reapply existing pavement markings because they have faded (6)
- Other (Please specify) (8) \_\_\_\_\_

**Q13 Sign Improvements**

- Install advance warning sign for intersections (1)
  - Install horizontal alignment signs (2)
  - Install advance traffic control warning signs (3)
  - Delineators (4)
  - Use of fluorescent yellow sheeting on warning signs (7)
  - Install retro-reflective strips on sign posts (14)
  - Double use of warning signs for curves or intersections (15)
  - Increased sign size (16)
  - Install post-mounted delineators at curves (17)
  - Add flags on stop sign (18)
  - Flashing beacon on stop sign (8)
  - Flashing beacon on warning sign (9)
  - In-rail reflectors for guardrail and bridge rail (11)
  - Reflective corner caps on signs (contrasting colors) (12)
  - Other (Please specify) (13) \_\_\_\_\_
- 

**Q14 Signal Improvements**

- Install retro-reflective backplates on signal heads (1)
  - Increased signal head size (12") (2)
  - LED indicators (4)
  - Signal timing improvements (5)
  - Add flashing beacons at intersections (6)
  - Provide advanced dilemma zone detections (7)
  - Other (Please specify) (3) \_\_\_\_\_
-

**Q15 Wildlife Control**

- Methods to control wildlife management (1)
- Reflectors to alert wildlife of approaching vehicles (2)
- Sign (with or without flashers) to alert drivers of wildlife (3)
- Other (Please specify) (4) \_\_\_\_\_

**Q17** Are there any countermeasures that your agency has used that are not listed above?

\_\_\_\_\_

Instruction Based on your experience, please score the potential effectiveness of each of the following countermeasures using a scale (integers) from:

1 (very effective) to  6 (not effective at all)

**Q30 Clear Zone**

- 1 Flatten side slopes (1)
- 1 Increase clear zone (2)
- 1 Widen shoulders (3)
- 1 Convert a non-traversable culvert headwall into a traversable culvert headwall (4)
- 1 Mow (5)
- 1 Modify end treatments at existing guardrail (6)
- 1 Remove fixed objects (trees, power poles, structures, etc.) (7)
- 1 Relocate fixed objects (trees, power poles, structures, etc.) (10)
- 1 Shield fixed objects (trees, power poles, structures, etc.) (11)
- 1 Convert non-crash-worthy roadside hardware (such as guardrail) to crash-worthy. (8)
- 1 Other (Please specify) (9)

**Q31 Geometric Improvements**

- 1 Climbing lane (1)
- 1 Passing lane (2)
- 1 Right-turn lane (3)
- 1 Left-turn lane (4)
- 1 Driveway deceleration lane (5)
- 1 Two-way left-turn lane (6)
- 1 Re-alignment (8)
- 1 Offset T-intersections (9)
- 1 Other (Please specify) (7)

**Q32 Pavement Surface Treatments**

- 1 Centerline rumble strips (1)
- 1 Edgeline rumble strips (2)
- 1 Rumble strips on approaches to intersections or horizontal curves (3)

- 1 Shoulder texturing (4)
- 1 High friction surface improvements (5)
- 1 Other (Please specify) (7)

**Q33 Pavement Markings**

- 1 Add on-lane pavement markings (painted curve arrow, slow speeds, etc.) (1)
- 1 Improve visibility or retro-reflectivity of pavement marking (2)
- 1 Add pavement markings (e.g., edge lines or center lines) (3)
- 1 Install raised pavement (4)
- 1 Markers (5)
- 1 Reapply existing pavement markings because they have faded (6)
- 1 Other (Please specify) (8)

**Q34 Sign Improvements**

- 1 Install advance warning sign for intersections (1)
- 1 Install horizontal alignment signs (2)
- 1 Install advance traffic control warning signs (3)
- 1 Delineators (4)
- 1 Use of fluorescent yellow sheeting on warning signs (7)
- 1 Install retro-reflective strips on sign posts (14)
- 1 Double use of warning signs for curves or intersections (15)
- 1 Increased sign size (16)
- 1 Install post-mounted delineators at curves (17)
- 1 Add flags on stop sign (18)
- 1 Flashing beacon on stop sign (8)
- 1 Flashing beacon on warning sign (9)
- 1 In-rail reflectors for guardrail and bridge rail (11)
- 1 Reflective corner caps on signs (contrasting colors) (12)
- 1 Other (Please specify) (13)

**Q35 Signal Improvements**

- 1 Install retro-reflective strips on sign posts (1)
- 1 Increased signal head size (12") (2)
- 1 LED indicators (4)
- 1 Signal timing improvements (5)
- 1 Add flashing beacons at intersections (6)
- 1 Provide advanced dilemma zone detections (7)
- 1 Other (Please specify) (3)

**Q36 Wildlife Control**

- 1 Methods to control wildlife management (1)
- 1 Reflectors to alert wildlife of approaching vehicles (2)
- 1 Sign (with or without flashers) to alert drivers of wildlife (3)
- 1 Other (Please specify) (4)

Q26 Please identify three cases where some of the countermeasures noted above have been implemented then describe their effectiveness:

- Case 1 (1) \_\_\_\_\_
- Case 2 (2) \_\_\_\_\_
- Case 3 (3) \_\_\_\_\_

Q37 Please provide your name and contact information in case we have additional clarification questions;

- Name (1) \_\_\_\_\_
- Email (2) \_\_\_\_\_
- Phone (7) \_\_\_\_\_

Q38 What AADT does your state use as a cutoff for paved LVRs?

\_\_\_\_\_

Q39 What AADT does your state use as a cutoff for unpaved LVRs?

---

End of Block: Default Question Block

---