

Toolbox of Countermeasures and Their Potential Effectiveness for Roadway Departure Crashes



Introduction

This issue brief documents estimates of the crash reduction that might be expected if a specific countermeasure or group of countermeasures is implemented with respect to roadway departure crashes and other non-intersection crashes. The crash reduction estimates are presented as Crash Reduction Factors (CRFs).

Traffic engineers and other transportation professionals can use the information contained in this issue brief when asking the following types of question: Which countermeasures might be considered along a particular section of a highway that is experiencing a high number of roadway departure crashes? What changes in the number of roadway departure crashes can be expected with the implementation of the various countermeasures?

When selecting countermeasures to reduce the number and/or severity of roadway departure crashes, the practitioner should first consider countermeasures designed to reduce the likelihood of vehicles leaving the roadway. Next, the practitioner should select strategies which minimize the likelihood of crashing into an object or overturning if the vehicle travels beyond the edge of the shoulder. Finally, the practitioner should consider countermeasures which reduce the severity of the crash such as improving the design and application of barrier and attenuation systems.

When selecting countermeasures to reduce the number and/or severity of crashes associated with hazardous roadside obstacles, the practitioner should refer to the AASHTO Roadside Design Guide which recommends these design options in order of preference:

1. Remove the obstacle;
2. Redesign the obstacle so it can be safely traversed;
3. Relocate the obstacle to a point where it is less likely to be struck;
4. Reduce impact severity by using an appropriate breakaway device;
5. Shield the obstacle with a longitudinal traffic barrier designed for redirection or use a crash cushion; and
6. Delineate the obstacle if the above alternatives are not appropriate.

Crash Reduction Factors

A CRF is the percentage crash reduction that might be expected after implementing a given countermeasure. In some cases, the CRF is negative, i.e. the implementation of a countermeasure is expected to lead to a percentage increase in crashes.

One CRF estimate is provided for each countermeasure. Where multiple CRF estimates were available from the literature, selection criteria were used to choose which CRFs to include in the issue brief:

- Firstly, CRFs from studies that took into account regression to the mean and changes in traffic volume were preferred over studies that did not.
- Secondly, CRFs from studies that provided additional information about the conditions under which the countermeasure was applied (e.g. road type, area type) were preferred over studies



that did not.

Where these criteria could not be met, a CRF may still be provided. In these cases, it is recognized that the reliability of the estimate of the CRF is low, but the estimate is the best available at this time. The CRFs in this issue brief may be periodically updated as new information becomes available.

The *Desktop Reference for Countermeasures* lists all of the CRFs included in this issue brief, and adds many other CRFs available in the literature. A few CRFs found in the literature were not included in the *Desktop Reference*. These CRFs were considered to have too large a range or too large a standard error to be meaningful, or the original research did not provide sufficient detail for the CRF to be useful.

A CRF should be regarded as a generic estimate of the effectiveness of a countermeasure. The estimate is a useful guide, but it remains necessary to apply engineering judgment and to consider site-specific environmental, traffic volume, traffic mix, geometric, and operational conditions which will affect the safety impact of a countermeasure. The user must ensure that a countermeasure applies to the particular conditions being considered. The reader is also encouraged to obtain and review the original source documents for more detailed information, and to search databases such as the National Transportation Library (ntlsearch.bts.gov) for information that becomes available after the publication of this issue brief.

Presentation of the Crash Reduction Factors

In the Tables presented in this issue brief, the crash reduction estimates are provided in the following format:

CRF(standard error)^{REF}

The CRF is the value selected from the literature.

The standard error is given where available. The standard error is the standard deviation of the error in the estimate of the CRF. The true value of the CRF is unknown. The standard error provides a measure of the precision of the estimate of the true value of the CRF. A relatively small standard error indicates that a CRF is relatively precisely known. A relatively large standard error indicates that a CRF is not precisely known. The standard error may be used to estimate a confidence interval of the true value of the CRF. (An example of a confidence interval calculation is given below.)

The REF is the reference number for the source information.

As an example, the CRF for the countermeasure *remove or relocate fixed objects outside of clear zone* for all crashes is:

38(10)¹⁷

The following points should be noted:

- The CRF of 38 means that a 38% reduction in all crashes is expected after removing or relocating fixed objects outside of the clear zone.
- This CRF is bolded which means that a) a rigorous study methodology was used to estimate the CRF, and b) the standard error is relatively small. A CRF which is not bolded indicates that a less rigorous methodology (e.g. a simple before-after study) was used to estimate the CRF and/or the standard error is large compared with the CRF.
- The standard error for this CRF is 10. Using the standard error, it is possible to calculate the 95% confidence interval for the potential crash reduction that might be achieved by implementing the countermeasure. The 95% confidence interval is ± 2 standard errors from the CRF. Therefore, the 95% confidence interval for removing or relocating fixed objects outside of the clear zone is between 18% and 58% ($38 - 2 \times 10 = 18\%$, and $38 + 2 \times 10 = 58\%$).
- The reference number is 17 (Hovey and Chowdhury, as listed in the References at the end of this issue brief).

Using the Tables

The CRFs for roadway departure crashes and other non-intersection crashes are presented in six tables which summarize the available information. The Tables are:

Table 1: Barrier Countermeasures

Table 2: Bridge Countermeasures

Table 3: Geometric Countermeasures

Table 4: Median Countermeasures

Table 5: Roadside Countermeasures

Table 6: Signs/Markings/Operational Countermeasures

The following points should be noted:

- Where available, separate CRFs are provided for different crash severities. The crash severities are: all, fatal/injury, fatal, injury, or property damage only (PDO).
- Where available, road type information is provided.
- Where available, daily traffic volume (vehicles/day) is provided.
- Blank cells mean that no information is reported in the source document.
- For additional information, please visit the FHWA Office of Safety website (safety.fhwa.dot.gov).

Legend

CRF(standard error)^{REF}

CRF is a crash reduction factor, which is an estimate of the percentage reduction that might be expected after implementing a given countermeasure. A number in bold indicates a rigorous study methodology and a small standard error in the value of the CRF. Standard error, where available, is the standard deviation of the error in the estimate of the CRF.

REF is the reference number for the source information.

Additional crash types identified in the *Other Crashes* column are:

a: Sideswipe b: Night c: Right-angle d: Left-turn e: Wet pavement f: Overturn g: Pedestrian h: Right-turn i: Animal
j: Parking k: Wet weather l: Head-on/sideswipe m: Snow n: Truck-related o: Speed related

Table 1: Barrier Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Improve guardrail	All			18 ⁹			41 ⁹	23 ⁹	f 41 ⁹	<5,000/lane
	All			9 ⁹	32 ⁹		27 ⁹	18 ⁹	f 27 ⁹	>5,000/lane
	All				26 ⁹					
	Fatal Injury		All	50 ¹ 35 ⁹						
Install animal fencing	All								i 80 ⁹	
	Injury								i 91 ⁹	
	PDO								i 61 ⁹	
Install barrier (concrete) inside and outside curve	Fatal/Injury			39 ⁹						
Install guardrail (as shield for rocks and posts)	All			14 ⁹				100 ⁹		
	Injury			31 ⁹						
Install guardrail (as shield for trees)	Fatal			65 ⁹						
	Injury			51 ⁹						
Install guardrail (at culvert)	All			27 ⁹						
Install guardrail (at ditch)	Injury			26 ⁹						
Install guardrail (at embankment)	All		All		7(31) ⁴					
	Fatal		All		44(10) ⁴					
	Injury			42 ⁹						
	Injury		All		47(5) ⁴					
Install guardrail (inside curves)	Fatal/Injury			28 ⁹						
Install guardrail (outside curves)	Fatal/Injury			63 ⁹						
Install impact attenuators	All			29 ⁹	45 ⁹					
	Fatal	All	All	75 ¹				69(28) ⁴		
	Injury	All	All	50 ¹				69(10) ⁴		
	PDO							46(30) ⁴		
Replace guardrail with a softer material (concrete→steel→wire)	Fatal		All		41(31) ⁴					
	Injury		All		32(10)⁴					

Table 1 (continued on page 5)

Table 2: Bridge Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Install bridge lighting	All			59 ⁹						
Install delineators (on bridges)	All			43 ⁹						
Install guardrail (at bridge)	All			22 ⁹			37 ⁹		f 41 ⁹	<5,000/lane
	All			20 ⁹			32 ⁹		f 32 ⁹	>5,000/lane
	All								k 50 ⁹	
	Fatal Injury			90 ⁹ 45 ⁹						
Repair bridge deck	All		14 ⁹							
Replace bridge (general)	All		All	45 ¹						
Replace bridge (2-lane)	All			45 ⁹						
Upgrade bridge parapet	All			5 ⁹						
Upgrade bridge railing	All			20 ⁹						
	Fatal			76 ⁹						
	Injury			61 ⁹						
	PDO			50 ⁹						
Widen bridge	All			45 ⁹	44 ⁹	45 ⁹		45 ⁹	a 49 ⁹	
	Fatal/Injury			92 ⁹						
	PDO			95 ⁹						
Widen bridge (18 to 24 ft)	All			68 ⁹						
Widen bridge (18 to 30 ft)	All			93 ⁹						
Widen bridge (20 to 24 ft)	All			56 ⁹						
Widen bridge (20 to 30 ft)	All			90 ⁹						
Widen bridge (22 to 24 ft)	All			36 ⁹						
Widen bridge (22 to 30 ft)	All			86 ⁹						

Table 3: Geometric Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Flatten crest vertical curve	All	All	All	20(19) ¹⁷						
	Fatal/Injury	All	All	51(19) ¹⁷						
	Fatal/Injury	Rural	2-lane	50 ¹⁸						
Flatten horizontal curve	All			39 ⁹						
	All				90 ⁹	67 ⁹	73 ⁹	68 ⁹	f 73 ⁹	<5,000/lane
	All				79 ⁹	64 ⁹	24 ⁹	87 ⁹	f 24 ⁹	>5,000/lane

Table 3 (continued on page 6)

Table 3 (continued)
Geometric Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Flatten horizontal curves (10 to 5 degrees)	All			45 ⁹						
Flatten horizontal curves (15 to 5 degrees)	All			63 ⁹						
Flatten horizontal curves (20 to 10 degrees)	All			48 ⁹						
Flatten side slopes	All			43 ⁹						<5,000/lane
	All			45 ⁹						>5,000/lane
	All				10 ⁹			62 ⁹		
Flatten side slopes (11 to 8 degrees)	All			8 ⁹					g 14 ⁹	
	All								h 14 ⁹	
Flatten side slopes (14 to 9 degrees)	Injury	Rural	2-lane	22(4) ⁴						
	PDO	Rural	2-lane	24(2) ⁴						
	All			7 ⁹					g 12 ⁹	
	All								h 12 ⁹	
Flatten side slopes (18 to 9 degrees)	All	Rural	2-lane	11 ⁹					g 19 ⁹	
	All								h 19 ⁹	
Flatten side slopes (18 to 11 degrees)	All			8 ⁹					g 14 ⁹	
	All								h 14 ⁹	
Flatten side slopes (18 to 14 degrees)	Injury	Rural	2-lane	42(4) ⁴						
	PDO	Rural	2-lane	29(4) ⁴						
	All			5 ⁹					g 8 ⁹	
	All								h 8 ⁹	
Flatten side slopes (27 to 9 degrees)	All			12 ⁹					g 21 ⁹	
	All								h 21 ⁹	
Flatten side slopes (27 to 11 degrees)	All			9 ⁹					g 15 ⁹	
	All								h 15 ⁹	
Flatten side slopes (27 to 14 degrees)	All			6 ⁹					g 10 ⁹	
	All								h 10 ⁹	
Flatten side slopes and remove guardrail	All	All	All	42(58) ¹⁷						
Improve gore area	All			25 ⁹						
Improve horizontal and vertical alignments	All			58 ⁹						
Improve longitudinal grade	All			49 ⁹						
	Fatal/Injury			87 ⁹						
	PDO			83 ⁹						
Improve superelevation	All			40 ⁹	50 ⁹					
Improve superelevation (for drainage)	All			45 ⁹						
Increase number of lanes	All								d 71 ⁹	
	All			20 ⁹		38 ⁹	42 ⁹		a 38 ⁹	<5,000/lane
	All								c 35 ⁹	<5,000/lane
	All								f 42 ⁹	<5,000/lane
	All			31 ⁹		44 ⁹	52 ⁹		a 44 ⁹	>5,000/lane
	All								c 45 ⁹	>5,000/lane
	All								f 52 ⁹	>5,000/lane
	Fatal			39 ⁹						
Injury			23 ⁹							

Table 3 (continued on page 7)

Table 3 (continued)
Geometric Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Increase number of lanes (continued)	PDO			27 ⁹	50 ⁹	50 ⁹	53 ⁹		a 64 ⁹	
	PDO								c 46 ⁹	
	PDO								d 67 ⁹	
Install acceleration/deceleration lanes	All			26 ⁹			75 ⁹		a 75 ⁹	
Install channelized lane	All			67 ⁹			93 ⁹			
	PDO			62 ⁹						
Install climbing lane (where large difference between car and truck speed)	Fatal/Injury	Rural	2-lane	33 ¹⁸						
Install passing/climbing lane	All	All	All	20 ¹						
	Fatal/Injury	Rural	2-lane	33 ¹⁸						
Install shoulder	All			9 ⁹						
Install shoulder bus lanes	Fatal/Injury					50 ⁹			a 27 ⁹	
	Fatal/Injury								c 34 ⁹	
	Fatal/Injury								d 42 ⁹	
	PDO				27 ⁹	86 ⁹			a 8 ⁹	
	PDO								c 31 ⁹	
	PDO								d 57 ⁹	
Install truck escape ramp	All			18 ⁹	75 ⁹		33 ⁹			
Lengthen culverts	All			44 ⁹						
Narrow cross section (4 to 3 lanes with two-way left turn lane)	All	Urban	4-lane highway	37(1) ¹¹			31(2) ¹¹		c 37(1) ¹¹	8,000 - 17,400
	All	Urban	4-lane highway						d 24(2) ¹¹	8,000 - 17,400
	Fatal/Injury	Urban	4-lane highway	0(2) ¹¹						8,000 - 17,400
	PDO	Urban	4-lane highway	46(1) ¹¹						8,000 - 17,400
Reduce horizontal curve angle	All			38 ⁹						
Reduce shoulder width (6 ft to 0 ft)	All	Rural	2-lane	-12(3) ¹⁴						
Reduce shoulder width (6 ft to 1 ft)	All	Rural	2-lane	-17(6) ¹⁴						
Reduce shoulder width (6 ft to 2 ft)	All	Rural	2-lane	-11(2) ¹⁴						
Reduce shoulder width (6 ft to 4 ft)	All	Rural	2-lane	-6(2) ¹⁴						
Reduce shoulder width (6 ft to 5 ft)	All	Rural	2-lane	-2(2) ¹⁴						
Resurface pavement and improve superelevation	All			28 ⁹					e 51 ⁹	
Stabilize shoulder	All			25 ⁹						
Stabilize shoulder and dropoff	All	All	All	25 ¹						
Widen lane (add 1 ft to both sides)	All				12 ⁹	12 ⁹			a 12 ⁹	
Widen lane (add 2 ft to both sides)	All				23 ⁹	23 ⁹			a 23 ⁹	
Widen lane (add 3 ft to both sides)	All				32 ⁹	32 ⁹			a 32 ⁹	
Widen lane (add 4 ft to both sides)	All				40 ⁹	40 ⁹			a 40 ⁹	
Widen lane (initially less than 9 ft)	Fatal/Injury	Rural	2-lane	28 ¹⁸						400 - 2,000
Widen lane (initially between 9 ft and 10.75 ft)	Fatal/Injury	Rural	2-lane	16 ¹⁸						400 - 2,000
Widen lanes	All			50 ⁹	49 ⁹	70 ⁹		5 ⁹	a 52 ⁹	
	All								f 5 ⁹	

Table 3 (continued on page 8)

Table 3 (continued)
Geometric Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Widen shoulder (from 6 to 7 ft)	All	Rural	2-lane	-1(4) ¹⁴						
Widen shoulder (from 6 to 8 ft)	All	Rural	2-lane	4(2) ¹⁴						
Widen shoulder (from 6 to 9 ft)	All	Rural	2-lane	21(6) ¹⁴						
Widen shoulder (from 6 to >9 ft)	All	Rural	2-lane	18(3) ¹⁴						
Widen shoulder (initially less than 1 ft)	Fatal/Injury	Rural	2-lane	25 ¹⁸						400 - 2,000
Widen shoulder (initially between 1 ft and 3.3 ft)	Fatal/Injury	Rural	2-lane	13 ¹⁸						400 - 2,000
Widen shoulder (paved)(from 0 to 2 ft)	All				16 ⁹			16 ⁹		
Widen shoulder (paved)(from 0 to 4 ft)	All				29 ⁹			29 ⁹		
Widen shoulder (paved)(from 0 to 6 ft)	All				40 ⁹			40 ⁹		
Widen shoulder (paved)(from 0 to 8 ft)	All				49 ⁹			49 ⁹		
Widen shoulder (unpaved)(from 0 to 2 ft)	All				13 ⁹			13 ⁹		
Widen shoulder (unpaved)(from 0 to 4 ft)	All				25 ⁹			25 ⁹		
Widen shoulder (unpaved)(from 0 to 6 ft)	All				34 ⁹			34 ⁹		
Widen shoulder (unpaved)(from 0 to 8 ft)	All				43 ⁹			43 ⁹		

Table 4: Median Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Install median	All	All	All	15 ¹						
	Injury	Rural	Multilane	12(3) ⁴						
	Fatal/Injury	Rural	2-lane	-94(56) ⁴						
	Injury	Urban	Multilane	22(2) ⁴						
	Fatal/Injury	Urban	2-lane	39(10) ⁴						
	PDO	Rural	Multilane	18(3) ⁴						
	PDO	Rural	2-lane	-128(55) ⁴						
Install median (flush)	All			44 ⁹					d 72 ⁹	<5,000/lane
	All			52 ⁹					d 78 ⁹	>5,000/lane
	Fatal			90 ⁹						
Install median barrier	All								c 58 ⁹	<5,000/lane
	All								c 54 ⁹	>5,000/lane
	All	All	All	19 ⁹	35 ⁹					
	All		Multilane divided	86(3) ¹⁷						
	All		Multilane divided	-24(3) ⁴						
	Fatal		Multilane divided	43(10) ⁴						
	Injury			40 ⁹						
	Fatal/Injury	All	All	88(5) ¹⁷						
Injury		Multilane divided	30(6) ⁴							

Table 4 (continued on page 9)

Table 4 (continued)
Median Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Install median barrier (cable)	All		Highway (3-lane)	-34(74) ⁴						
	Fatal	Rural	Highway			92 ⁶				
	Injury		Highway (3-lane)	26(84) ⁴						
	Injury		Multilane divided	29(11) ⁴						
Install median barrier (concrete)	Injury		Multilane divided	-15(36) ⁴						
	Fatal			90 ⁹						
	Injury			10 ⁹						
Install median barrier (steel)	Injury		Multilane divided	35(8) ⁴						
Install or upgrade median barrier near gore area	All			17 ⁹	56 ⁹		39 ⁹			<5,000/lane
Install raised median	All			20 ⁹		75 ⁹			g 25 ⁹	

Table 5: Roadside Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
Install frontage road	All			40 ⁹						
Install snow fencing	All								m 53 ⁹	
Remove poles by burying utility lines	All			40 ⁹						
Remove obstacles on curves to improve sight distance	Fatal/Injury	Rural	2-lane	5 ¹⁸						
Remove or relocate fixed objects outside of clear zone	All	All	All	38(10) ¹⁷						
	All			18 ⁹					f 42 ⁹	<5,000/lane
	All			17 ⁹					f 44 ⁹	>5,000/lane
	All							65 ⁹		
	All	Urban						20 ⁹		
	All					71 ⁹				
	Fatal/Injury	All	All	38(13) ¹⁷						
Widen clear zone (add 5 ft)	All							13 ⁹		
Widen clear zone (add 8 ft)	All							21 ⁹		
Widen clear zone (add 10 ft)	All							25 ⁹		
Widen clear zone (add 15 ft)	All							35 ⁹		
Widen clear zone (add 20 ft)	All							44 ⁹		

Table 6: Sign/Marking/Operational Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
SIGNS										
Implement sign corrections to MUTCD standards	Injury	Urban	Local	15(10) ⁴						
	PDO	Urban	Local	7(6) ⁴						
Install chevron signs on horizontal curves	All			35 ⁹						
	Fatal/Injury	Rural	2-lane	20 ¹⁸						
Install curve advance warning signs	All			30 ⁹	30 ⁹	29 ⁹				
	Fatal			55 ⁹						
	Fatal/Injury	Rural	2-lane	10 ¹⁸						
	Injury PDO			30(71) ⁴ 8(76) ⁴						
Install curve advance warning signs (advisory speed)	All			29 ⁹						
	Injury			13(9) ⁴						
	PDO			29(23) ⁴						
Install curve advance warning signs (flashing beacon)	All			30 ⁹						
Install delineators (general)	All			11 ⁹	34 ⁹	67 ⁹			a 67 ⁹	
	All								b 25 ⁹	
Install dynamic/variable accident warning signs	Injury		Freeway	44(17) ⁴			16(10) ⁴			
Install dynamic/variable queue warning signs	PDO		Freeway				-16(15) ⁴			
Install dynamic/variable speed warning signs	All			46(17) ⁴						
	Injury			41(62) ⁴						
Install guide signs (general)	All			15 ⁹						
Install guideposts or barrier reflectors	Fatal/Injury	Rural	2-lane	8 ¹⁸						
Install illuminated signs	All			15 ⁹						
Install lane assignment signs	All						10 ⁹		a 20 ⁹	
Install nonvehicular (animal) reflectors	All			10 ⁹					b 25 ⁹	
Install pavement condition warning signs	All	All	All						k 20 ¹	
	All			5 ⁹					e 20 ⁹	
Install post-mounted delineators (curves)	All	All	All						b 30 ¹	
	All			25 ⁹						
Install post-mounted delineators (tangents and curves combined)	Injury	Rural	2-lane	-4(10) ⁴						
	PDO	Rural	2-lane	-5(7) ⁴						
PAVEMENT										
Improve pavement friction	All								g 10 ⁹	
Improve pavement friction (groove shoulder)	All			22 ⁹						
Improve pavement friction (grooving)	All			37 ⁹	41 ⁹		54 ⁹	36 ⁹	f 54 ⁹	<5,000/lane
	All			21 ⁹	40 ⁹		35 ⁹	19 ⁹	f 35 ⁹	>5,000/lane
	All								e 64 ⁹	<5,000/lane
	All								e 54 ⁹	>5,000/lane
Improve pavement friction (increase skid resistance)	Fatal/Injury	Rural	2-lane						e 30 ¹⁸	

Table 6 (continued on page 11)

Table 6 (continued)
Sign/Marking/Operational Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
PAVEMENT										
Improve pavement friction (overlay)	All			13 ⁹		43 ⁹		43 ⁹	a 43 ⁹	<5,000/lane
	All			20 ⁹		61 ⁹		34 ⁹	a 61 ⁹	>5,000/lane
	All								c 23 ⁹	
	All								e 23 ⁹	<5,000/lane
	All								e 50 ⁹	>5,000/lane
	Fatal/Injury				28 ⁹		12 ⁹		d 41 ⁹	
	PDO				29 ⁹	30 ⁹	21 ⁹		a 27 ⁹	
	PDO								c 31 ⁹	
								d 34 ⁹		
Improve pavement friction (curve overlay)	All			17 ⁹		86 ⁹			e 51 ⁹	
Improve pavement friction (resurface with deicing additives)	All					31 ⁹				
Improve pavement friction (resurface with open grade mix)	All			75 ⁹		90 ⁹		93 ⁹	a 90 ⁹	
	All								e 91 ⁹	
Improve pavement friction (skid treatment with overlay)	Fatal/Injury								g 3 ⁹	
Install centerline rumble strips	All	Rural	2-lane	14(5) ⁴					l 21(12) ⁴	5,000 - 22,000
	All	Rural	2-lane highway			55 ¹⁶				
	Fatal	Rural	2-lane highway			68 ¹⁶				
	Injury	Rural	2-lane	15(8) ⁴					l 25(15) ⁴	5,000 - 22,000
	Injury (minor)	Rural	2-lane highway			26 ¹⁶				
	Injury (major)	Rural	2-lane highway			33 ¹⁶				
Install or upgrade curbing	All	All						50 ⁹		
Install shoulder rumble strips	All	All	Freeway		18(7) ¹³					
	All	Rural	All		34 ²¹					
	All	Rural	Arterial		16 ²¹					
	All	Rural	Between ramps		34 ²¹					
	All	Rural	Freeway		21(10) ¹³					
	All	Rural	Highway		27(22) ¹⁰					
	All	Rural	Highway		38 ²¹					
	All	Rural	Multilane divided	16 ⁵	10 ⁵					
	All	Rural	3-lane		36 ²¹					
	All	Rural	2-lane		13(8) ¹⁹					>4,000
	Fatal/Injury	Rural	2-lane		18(12) ¹⁹					>4,000
	Injury	All	Freeway		13(12) ¹³					
	Injury	Rural	Freeway		7(16) ¹³					
	Injury	Rural	Multilane divided	17 ⁵	22 ⁵					
Install shoulder rumble strips on illuminated highways	All	Rural	All		41 ²¹					
Install shoulder rumble strips on unilluminated highways	All	Rural	All		31 ²¹					
Pave shoulder	All			15 ⁹		86 ⁹			b 62 ⁹	

Table 6 (continued on page 12)

Table 6 (continued)
Sign/Marking/Operational Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
MARKINGS										
Delineate multiple lanes (painted lane lines)	All	Urban	Multilane	18(22) ⁸						
Install centerline markings	All			33 ⁹						
	Injury	All	2-lane	1(6) ⁸						
Install chevron converging pattern markings on pavement	PDO	All	2-lane	-1(5) ⁸						
	All	Urban		38(6) ¹²						
Install edgelines and centerlines	Injury		Freeway	56(26) ⁴						
	All	Rural	Undivided	-3(21) ²						1,000 - 4,000
Install edgelines, centerlines and delineators	Injury	All	All	24 (11) ⁸						
	Injury	All	All	45 (11) ⁸						
Install edgeline markings	All			44 ⁹			45 ⁹	66 ⁹	f 45 ⁹	<5,000/lane
	All			38 ⁹			50 ⁹	59 ⁹	f 50 ⁹	>5,000/lane
	All				30 ⁹					
	Injury			15 ⁹						
	PDO			8 ⁹						
Install edgeline markings (from 4 to 6 in)	Injury	Rural	2-lane	3(4) ⁸						
	PDO	Rural	2-lane	3(11) ⁸						
Install edgeline markings (8 in)	Injury	Rural	2-lane	-5(8) ⁸						
	PDO	Rural	2-lane	1(15) ⁸						
Install raised pavement markers (snowplowable) where DOC = degree of curvature	All	Mostly Rural	4-lane freeway						b -13(14) ³	≤20,000
	All	Mostly Rural	4-lane freeway						b 33(21) ³	<60,000
	All	Mostly Rural	4-lane freeway						b 6(21) ³	20,001 - 60,000
	All	Mostly Rural	2-lane, DOC>3.5						b -43 (9) ³	≤5,000
	All	Mostly Rural	2-lane, DOC>3.5						b -26 (10) ³	5,001 - 15,000
	All	Mostly Rural	2-lane, DOC>3.5						b -3(11) ³	15,001 - 20,000
	All	Mostly Rural	2-lane, DOC<3.5						b -16 (3) ³	≤5,000
	All	Mostly Rural	2-lane, DOC<3.5						b 1 (5) ³	5,001 - 15,000
	All	Mostly Rural	2-lane, DOC<3.5						b 24 (7) ³	15,001 - 20,000
REGULATORY										
Install no-passing line	All			53 ⁹		40 ⁹			a 40 ⁹	
Prohibit on-street parking	All	Urban	Arterial (64ft)	42(8) ⁴				40 ⁹		30,000
	All			22 ⁹						
	Injury	Urban	Arterial	20(5) ⁴						
	Injury	Urban	Arterial (64ft)	35(14) ⁴						30,000
	PDO	Urban	Arterial	27(2) ⁴						
Reduce mean speed by 5% through speed limit change and enforcement	PDO	Urban	Arterial (64ft)	48(1) ⁴						30,000
	Fatal	All	All	17(5) ⁴						
	Injury	All	All	7(3) ⁴						
Reduce mean speed by 10% through speed limit change and enforcement	PDO	All	All	5(4) ⁴						
	Fatal	All	All	32(9) ⁴						
	Injury	All	All	15(5) ⁴						
PDO	All	All	10(8) ⁴							

Table 6 (continued on page 13)

Table 6 (continued)
Sign/Marking/Operational Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
REGULATORY (CONTINUED)										
Reduce mean speed by 15% through speed limit change and enforcement	Fatal	All	All	44(14) ⁴						
	Injury	All	All	22(8) ⁴						
	PDO	All	All	15(12) ⁴						
LIGHTING										
Improve lighting	All								b	37 ⁹
	Fatal	All	Freeway	73(71) ⁴						
	Fatal	All	Highway	69(36) ⁴						
	Fatal	Rural	Highway	73(72) ⁴						
	Fatal	Urban	Highway	63(52) ⁴						
	Injury	All	Freeway	27(12) ⁴						
	Injury	All	Highway	28(6) ⁴						
	Injury	Rural	Highway	20(12) ⁴						
	Injury	Urban	Highway	31(7) ⁴						
	PDO	All	Freeway	32(26) ⁴						
	PDO	All	Highway	18(7) ⁴						
	PDO	Rural	Highway	30(43) ⁴						
	PDO	Urban	Highway	16(8) ⁴						
Install lighting at interchanges	All	All	All	50(17) ¹⁷						
	Fatal/Injury	All	All	26(38) ¹⁷						
OPERATIONAL										
Add two-way left-turn lane	All		All	8(16) ¹⁷						
	All				37 ⁹	36 ⁹	36 ⁹		c	20 ⁹
	All								d	33 ⁹
	All								g	19 ⁹
	Fatal/Injury		All	20(25) ¹⁷	90 ⁹	67 ⁹	32 ⁹		a	32 ⁹
	Fatal/Injury								c	31 ⁹
	Fatal/Injury								d	17 ⁹
	Injury			20 ⁹						
	PDO			35 ⁹	16 ⁹	64 ⁹	38 ⁹		a	37 ⁹
	PDO								c	23 ⁹
	PDO								d	38 ⁹
Convert from two-way to one-way traffic	All			43 ⁹						
Implement crossover at work zone	All		4-lane divided	0 ⁷						6,800 - 38,000
Implement single lane closure at work zone	All		4-lane divided	-56 ⁷						20,000 - 41,500
Improve drainage patterns	All			32 ⁹						
	All								e	40 ⁹
Install sidewalk	All								g	74 ⁹
Reconfigure lanes within existing pavement width (two to three in one direction)	All		2-lane	32 ⁹			46 ⁹		a	46 ⁹
	All		2-lane						d	46 ⁹
	Injury		2-lane	59 ⁹						

Table 6 (continued on page 14)

Table 6 (continued)
Sign/Marking/Operational Countermeasures

Countermeasure(s)	Crash Severity	Area Type	Road Type	All Crashes	Run-off-Road Crashes	Head-on Crashes	Rear-end Crashes	Fixed Object Crashes	Other Crashes	Daily Traffic Volume (vehicles/day)
OPERATIONAL (CONTINUED)										
Reconfigure lanes within existing pavement width (four to five in one direction)	All	Urban	Freeway	-11(5) ⁴						77,000 - 126,000
	Fatal/Injury	Urban	Freeway	-11(8) ⁴						77,000 - 126,000
	All	Urban	Freeway	-3(8) ⁴						77,000 - 126,000
Reconfigure lanes within existing pavement width (five to six in one direction)	Fatal/Injury	Urban	Freeway	-7(13) ⁴						77,000 - 126,000
	All								g 17 ²⁰	
Remove unwarranted signals										

References

1. Agent, K. R., Stamatiadis, N., and Jones, S., "Development of Accident Reduction Factors." KTC-96-13, Kentucky Transportation Cabinet, (1996)
2. Al-Masaeid, H. R. and Sinha, H., "An Analysis of Accident Reduction Potentials of Pavement Marking." Journal of Transportation Engineering, ASCE, (1993) pp. 723-736.
3. Bahar, G., Mollett, C., Persaud, B., Lyon, C., Smiley, A., Smahel, T., and McGee, H., "NCHRP Report 518: Safety Evaluation of Permanent Raised Pavement Markers." Washington, D.C., Transportation Research Board, National Research Council, (2004)
4. Bahar, G., Parkhill, M., Hauer, E., Council, F., Persaud, B., Zegeer, C., Elvik, R., Smiley, A., and Scott, B. "Prepare Parts I and II of a Highway Safety Manual: Knowledge Base for Part II". Unpublished material from NCHRP Project 17-27. (May 2007)
5. Carrasco, O., McFadden, J., and Chandhok, P., "Evaluation of the Effectiveness of Shoulder Rumble Strips on Rural Multi-lane Divided Highways In Minnesota." 83rd Transportation Research Board Annual Meeting, Washington D.C., (2004)
6. Chandler, B., "Eliminating Cross-Median Fatalities: Statewide Installation of Median Cable Barrier in Missouri." TR News, No. 248, Washington, D.C., Transportation Research Board of the National Academies, (2007) pp. 29-31.
7. Dudek, C. L., Richards, S. H., and Buffington, J. L., "Some Effects of Traffic Control on Four-Lane Divided Highways." Transportation Research Record 1086, Washington, D.C., Transportation Research Board, National Research Council, (1986) pp. 20-30.
8. Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004)
9. Gan, A., Shen, J., and Rodriguez, A., "Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects." Florida Department of Transportation, (2005)
10. Garder, P. and Davies, M., "Safety Effect of Continuous Shoulder Rumble Strips on Rural Interstates in Maine." 2006 TRB 85th Annual Meeting: Compendium of Papers CD-ROM, Vol. TRB#06-2219, Washington, D.C., (2006)
11. Gates, T. J., Noyce, D. A., Talada, V., and Hill, L., "The Safety and Operational Effects of "Road Diet" Conversion in Minnesota." 2007 TRB 86th Annual Meeting: Compendium of Papers CD-ROM, Vol. TRB#07-1918, Washington, D.C., (2007)
12. Griffin, L. I. and Reinhardt, R. N., "A Review of Two Innovative Pavement Patterns that Have Been Developed to Reduce Traffic Speeds and Crashes." Washington, D.C., AAA Foundation for Traffic Safety, (1996)
13. Griffith, M. S., "Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways." Transportation Research Record 1665, Washington, D.C., Transportation Research Board, National Research Council, (1999) pp. 28-33.
14. Gross, F. and Jovanis, P. P., "Estimation of Safety Effectiveness of Changes in Shoulder Width using Case-Control and Cohort Methods." 2007 TRB 86th Annual Meeting: Compendium of Papers CD-ROM, Vol. TRB#07-2762, Washington, D.C., (2007)
15. Harwood, D. W., Council, F. M., Hauer, E., Hughes, W. E., and Vogt, A., "Prediction of the Expected Safety Performance of Rural Two-Lane Highways." FHWA-RD-99-207, McLean, Va., Federal Highway Administration, (2000)
16. Hirasawa, M., Takuda, T., Asano, M., and Saito, K., "Developing Optimal Centerline Rumble Strips and Evaluating Their Safety Benefits on National Highways in Hokkaido, Japan." 2006 TRB 85th Annual Meeting: Compendium of Papers CD-ROM, Vol. TRB#06-1968, Washington, D.C., (2006)
17. Hovey, P. W. and Chowdhury, M., "Development of Crash Reduction Factors." 14801(0), Ohio Department of Transport, (2005)
18. Montella, A., "Safety Reviews of Existing Roads: a Quantitative Safety Assessment Methodology." Washington, D.C., Vol. TRB#05-1295, (2005)
19. Patel, R. B., Council, F. M., and Griffith, M. S., "Estimating the Safety Benefits of Shoulder Rumble Strips on Two Lane Rural Highways in Minnesota: An Empirical Bayes Observational Before-After Study." 2007 TRB 86th Annual Meeting: Compendium of Papers CD-ROM, Vol. TRB#07-1924, Washington, D.C., (2007)
20. Persaud, B., Hauer, E., Retting, R. A., Vallurupalli, R., and Mucci, K., "Crash Reductions Related to Traffic Signal Removal in Philadelphia." *Accident Analysis and Prevention*, Vol. 29, No. 6, Oxford, N.Y., Pergamon Press, (1997) pp. 803-810.
21. Smith, E. B. and Ivan, J. N., "Evaluation of Safety Benefits and Potential Crash Migration Due to Shoulder Rumble Strip Installation on Freeways in Connecticut." 2005 TRB 84th Annual Meeting: Compendium of Papers CD-ROM, Vol. TRB#05-1299, Washington, D.C., (2005)