ABC Agency

ROADWAY DEPARTURE SAFETY IMPLEMENTATION PLAN

<Date>

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The **ABC Agency** developed this document to aid in the identification of potential countermeasures for roadway departure crashes. The content included in this report provides potential options to help reduce the number and severity of roadway departure crashes. The countermeasures noted in the report represent one set of recommendations for **ABC Agency** but are not the only possible countermeasure options for the noted sites or highways.

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AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
CMF	crash modification factor / function
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
HFST	high friction surface treatment
NHTSA	National Highway Traffic Safety Administration
RDSIP	Roadway Departure Safety Implementation Plan
RwD	roadway departure (crash)
SHSP	Strategic Highway Safety Plan
SPF	safety performance function
SVROR	Single Vehicle Run-off-road (crash)

EXECUTIVE SUMMARY

Introduce this Plan by summarizing some general statistics for the region. The following represents example text that could be updated to reflect the information for the agency and associated region.

From **<starting year>** to **<ending year>**, roadway departure crashes in **ABC Agency** accounted for approximately **<xx>** percent of statewide fatal crashes, yet only **<xx>** percent of total crashes occurred due to roadway departures. To address these severe crashes, the **ABC Agency** is developing a *Roadway Departure Safety Implementation Plan*, referred to as the Plan in this document. This document includes a summary of the data analysis and recommendations for improvements targeted at reducing these severe roadway departure crashes.

Provide a brief history, if known, related to past Roadway Departure Plans. This does not need to be more than a few sentences in length.

The evaluation approach documented in this Plan uses a combination of predictive safety assessment techniques and observed crash statistics as a way of comprehensively identifying candidate locations that are expected to benefit by the implementation of safety treatments. This Plan focuses on low-cost countermeasures suitable for widespread deployment. A wide variety of low-cost countermeasures may be considered. For the purposes of this Plan, **<insert number of selected treatments to assess here>** prospective treatments are the focus of this analysis.

Based on this analysis, this plan proposes treatments that collectively should result in a reduction of approximately **<xx>** fatal crashes per year and almost **<xx>** total RwD crashes per year for a **<x>**-year period based on the type and quantity of treatments outlined in the Plan. The following enhancements are critical components needed to achieve this crash reduction goal:

- The traditional approach of primarily relying on major improvements at high-crash roadway departure locations should be complimented with the systematic deployment of proven lower cost treatments.

- The treatments evaluated as part of this Plan focused on roadway departure crashes and ultimately will also help contribute to the national effort of Towards Zero Deaths. An additional way to reduce the number and severity of crashes is to similarly assess candidate countermeasures for other crash types.

- The following **<xx>** roadway departure countermeasures should be deployed based on a prioritization approach that optimizes construction with ongoing work efforts and emphasizes deployment at locations where there are greater opportunities to reduce crashes **<determine the treatments of preference and display in bullet list below>**:

- Centerline rumble stripes / strips.
- Edgeline rumble stripes / strips.
- 6" wide centerline pavement markings.
- 6" wide edgeline pavement markings.
- Centerline raised pavement markings.
- Edgeline raised pavement markings.
- Roadway lighting improvements.
- High Friction Surface Treatments.
- Static curve warning signs (standard).
- Enhanced curve warning system.
- Utility pole relocation.
- Remove or shield tree or fixed objects.
- Culvert End Treatment and Ditch improvement.
- Shoulder widening with drainage grading improvements
- Shoulder widening without drainage grading improvements
- Flattening median sideslopes.
- Add barrier.
- Upgrade or enhance barrier.
- Install median barrier.
- Education and enforcement campaigns.

This plan provides recommendations on how these safety enhancement strategies can be effectively implemented. An annual reduction of approximately **<xx>** fatal crashes per year requires an annual investment of approximately $**<xx>** million for each of the next **<x>** years. Following deployment and continuous maintenance of these treatments, the number of lives saved due to roadway departure crashes can be expected to continue to decrease on **ABC Agency** highways beyond the next **<x>** years.

For additional information about the FHWA Roadway Departure Focus State Initiative, contact Joseph Cheung, FHWA Office of Safety, at joseph.cheung@dot.gov. For additional information about the **ABC Agency** please contact **<insert agency contact person, title, and email address>**.

ROADWAY DEPARTURE SAFETY GOAL

BACKGROUND

<Jurisdiction represented by agency> roadway departure (RwD) fatal crashes account, on average, for approximately **<xx>** percent of all roadway fatal crashes within the **<State, Region, County, Parish, Other>**. Total and fatal **<name of jurisdiction>** crashes related to roadway departure generally account for around **<xx>** percent of the total roadway crashes (see table 1). Some of the causes for these crashes include a failure to maintain control, speed, impairment, and failure to obey traffic control devices.

Table 1. Total, RwD, and fatal crashes by year (2012 – 2016).

Year	All Crashes			Fatal Crashes		
	Total Crashes	RwD Crashes	Percent of Annual Total Crashes (%)	Total Fatal Crashes	Total Fatal RwD Crashes	Percent of Annual Total Fatal Crashes (%)
2012	153,084	20,935	14%	654	289	44%
2013	153,963	21,188	14%	651	303	47%
2014	156,813	21,175	14%	665	330	50%
2015	168,316	22,298	13%	698	229	33%
2016	173,539	21,766	13%	700	296	42%
Total	**805,715**	**107,362**	**13%**	**3,368**	**1,447**	**43%**

The values shown in this table are intended to demonstrate example content for a five-year period. For the purposes of this table, the years 2012 through 2016 have been used for demonstration purposes.

If appropriate, add a brief discussion about the agencies' strategic goals and related focus areas. If the agency has a Towards Zero, Destination Zero Deaths, or similar long-term target this should also be noted.

DEFINITION OF RWD CRASHES

A recently published Federal Highway Administration (FHWA) report titled *Federal Highway Administration Focus Area Data Definitions* provides an overview of the FHWA definition of RwD crashes.(1) In the early 2000s, the FHWA calculation for these crash types separately identified single-vehicle and multiple-vehicle crashes in an effort to avoid double counting crashes within the two broad categories. At that time, many transportation agencies defined a single-vehicle RwD crashes as a single vehicle run-off-road (SVROR) crash. These agencies expanded this definition for multiple-vehicle crashes as the following collision types:

- Front-to-front (i.e. head-on).
- Front-to-side, opposite direction (i.e. opposite direction angle crash).
- Sideswipe, opposite direction (i.e. opposite direction sideswipe crash).

In 2009, FHWA refined the criteria used to define RwD crashes by incorporating vehicle event disaggregation. Vehicle event disaggregation provided a sequence of up to six events specific to each vehicle involved in the crash and included elements such as "ran-off-road -- right" and "cross median/centerline." FHWA also excluded intersection crashes at that time, primarily because most RwD countermeasures are not applicable at intersections.

The new FHWA definition of a RwD crash is "a crash in which a vehicle crosses an edge line, a centerline, or leaves the traveled way." [(2)] The single change to the coding is to remove the intersection filter. FARS defines the vast majority of RwD events as those classified with a first harmful event for any involved vehicle as:

- Ran-off-road -- right (FARs code 63),
- Ran-off-road -- left (FARs code 64),
- Cross median (FARS code 65), or
- Cross centerline (FARS code 68).

The definition further includes a number of fixed object codes based on the idea that a vehicle must depart a roadway in order to collide with an object. These first harmful event codes are represented as the FARS fixed object codes 17, 19–43, 46, 52, 53, 57, and 59).[(3)] Finally, the RwD identification definition includes three additional event codes deemed to most likely be indicative of a RwD crash:

- Vehicle went airborne (FARS code 67),
- Re-entering roadway (FARS code 69), and
- End Departure (FARS code 71).

For this effort, the **ABC Agency** definition for RwD crashes is identified as a crash-level element coded as:

Identify the RwD crash codes here as defined for the jurisdiction.

The basis for the **ABC Agency** crash information included in this document is data for the **<x>**-year period extending from **<20xx to 20xx>**. The data summarized in this report represents crashes identified as RwD events as included in the **ABC Agency** crash database.

APPROACH

The goal of this Plan is to help reduce RwD fatal and serious injury crashes in **ABC Agency**. The Plan explores a variety of analysis techniques for optimizing and selecting study sites and their associated candidate safety enhancements. An effective and efficient Implementation Plan requires a strategic approach. In addition to support and facilitation of enforcement and training activities, deployment of safety treatments can enhance roadway safety at locations where RwD

crashes may be expected. This Plan blends traditional cluster-crash analysis techniques with state-of-practice predictive procedures to help identify locations where the deployment of safety treatments will provide the best opportunity to reduce these severe crashes in **ABC Agency**.

These data driven analysis approaches use historic (observed) crash data as a key element when evaluating safety performance. The companion Data package document included as standalone Appendix A provides detailed information about the steps used to develop the recommended treatments included in the Plan. The procedures use the observed crash data and, where sufficient data is available, predicted crashes to estimate the opportunity to reduce crashes at target locations. The Plan documents the potential impact of these improvements in terms of reducing total RwD crashes, injury crashes ("KABC" collisions), and fatal ("K").

Note: The crash severity should be adjusted based on the preferred format for the agency. As an example, due to small sample sizes, many agencies substitute "K" crashes with "KA" crashes. For the purposes of this generic template, "KABC" and "K" have been used.

In addition to the deployment of targeted safety treatments, **ABC Agency** will benefit from developing additional system-wide applications as well as prioritizing effective treatments as a routine part of facility maintenance and construction.

DISTRIBUTION OF ROADWAY DEPARTURE CRASHES

A review of RwD crash and injury severity data for **ABC Agency** can help to identify insights into the distribution and characteristics of these observed crashes. As a starting point, table 2 summarizes the individual roadway jurisdictions for **ABC Agency** roads.

Table 2. Jurisdiction for ABC Agency roads.

Roadway Category		Length (miles)
State System Roadways	Rural Interstate	528.4
	Rural Multilane Undivided	118.2
	Rural Multilane Divided	642.0
	Rural Two-lane	11,718.8
	Urban Interstate	490.3
	Urban Multilane Undivided	477.2
	Urban Multilane Divided	579.5
	Urban Two-lane	2,136.3
	Subtotal of State System Roads:	16,690.8
Local roadways		42,182.0
Total:		58,872.8

The values shown in this table are intended to demonstrate example State and local roadway categories for a State agency. If a RwD Plan is developed for a smaller region (i.e. DOT District, County, Parish, MPO, etc.), the roadway categories would need to be adjusted accordingly. The first paragraph following this table would similarly need to be updated.

ABC Agency road ownership includes State system facilities as well as local jurisdiction roadways. The **ABC Agency** road types include those categorized as rural, urban, and local facilities.

Table 3 summarizes the number of observed RwD crashes, by route and region type. During this five-year period, **<xx>** of the total **<xx>** RwD crashes occurred at locations identified as unknown. Of these crashes, **<xx>** involved at least one fatal injury.

Table 4 summarizes the collision types for RwD and total crashes by collision type. Head-on crashes made up 19 percent of the total RwD fatal crashes while 66 percent of the fatal crashes were single vehicle collisions. Table 5 further identifies the crash data based on the first harmful event. Common first harmful events included running off road to right or left, crossing median, hitting a tree, utility pole, or other fixed object, or hitting a Culvert End Treatment and Ditch. The first harmful event can be particularly useful when selecting candidate countermeasures, as it will help identify treatments that, if deployed, explicitly target these key conditions.

Table 3. RwD Crashes by route and region type (<20xx-20xx>).

Route	Region Type	RwD Crashes		RwD Fatal Crashes	
		Total RwD Crashes	Percent of Annual Total RwD Crashes (%)	Total RwD Fatal Crashes	Percent of Annual Total RwD Fatal Crashes (%)
Interstate/Freeway	Rural	6,385	6	103	7
	Urban	11,420	10	128	9
	Subtotal	17,805	16	231	16
Principal Arterial	Rural	2,636	3	54	4
	Urban	9,065	8	97	6
	Subtotal	11,701	11	151	10
Minor Arterial	Rural	4,924	4	99	7
	Urban	9,512	9	116	8
	Subtotal	14,436	13	215	15
Collector	Rural	17,378	16	382	26
	Urban	6,008	6	94	7
	Subtotal	23,386	22	476	33
Others	Rural	2,450	2	43	3
	Urban	458	< 1	5	< 1
	Unknown	940	1	4	< 1
	Subtotal	3,848	4	52	4
Unknown	Unknown	36,186	34	322	22
Total		**107,362**	**100**	**1,447**	**100**

The values shown in this table are intended to demonstrate the contrast between the percentage of annual total RwD crashes compared to the percentage for total RwD fatal crashes. A five-year period has been used for the purposes of this table and is based on the years 2012 through 2016.

Table 4. RwD and total crashes by collision type (<20xx-20xx>).

Collision Type	All Crashes			Fatal Crashes		
	Total Crashes	Total RwD Crashes	Percent of Total RwD Crashes (%)	Total Fatal Crashes	Total Fatal RwD Crashes	Percent of Total Fatal RwD Crashes (%)
Single Vehicle Crash	124,231	85,660	80	1,940	1,271	88
Sideswipe Same Direction	96,060	2,750	3	75	13	1
Rear End	285,528	2,428	2	322	21	1
Head On	12,358	1,198	1	385	73	5
Right Angle	109,829	1306	1	398	32	2
Other	177,709	14020	13	248	37	3
Total	**805,715**	**107,362**	**100**	**3,368**	**1,447**	**100**

xx

Table 5. RwD crashes by first harmful event (<20xx-20xx>).

Route	Region Type	RwD Crashes		Fatal RwD Crashes	
		Number	Percent of Annual Total (%)	Number	Percent of Annual Total (%)
Ran off road Right*	Rural	16,079	15	356	25
	Urban / Urbanized	13,039	12	216	15
	Unknown	10,998	10	120	8
	Subtotal	40,116	37	692	48
Ran off road Left*	Rural	5,625	5	113	8
	Urban / Urbanized	5,795	6	91	6
	Unknown	5,252	5	51	4
	Subtotal	16,672	16	255	18
Crossed Median/Centerline	Rural	5,113	5	152	11
	Urban / Urbanized	2,741	3	44	3
	Unknown	2,113	2	35	2
	Subtotal	9,967	9	231	16
Tree and other fixed object*	Rural	2,905	3	6	< 1
	Urban / Urbanized	512	< 1	8	< 1
	Unknown	846	< 1	16	1
	Subtotal	4,263	4	30	2
Utility Pole*	Rural	87	< 1	1	< 1
	Urban / Urbanized	596	< 1	2	< 1
	Unknown	1,199	1	3	< 1
	Subtotal	1,882	2	6	< 1
Culvert End Treatment and Ditch*	Rural	961	1	4	< 1
	Urban / Urbanized	1,246	1	1	< 1
	Unknown	2,736	3	18	1
	Subtotal	4,943	5	23	2
Other	Rural	3,003	3	49	3
	Urban / Urbanized	12,534	11	78	5
	Unknown	13,982	13	83	6
	Subtotal	29,519	27	210	14
Total		**107,362**	**100**	**1,447**	**100**
xx					

Note: Urban / Urbanized = population 5000 and above.

* Potential coding discrepancies are likely as vehicles that ran into poles, ditches, or trees first must have run off the road either to the right or left

The presence of street lighting can help reduce the number of nighttime crashes. Table 6 depicts the distribution of RwD crashes based on lighting conditions. As shown, approximately <xx> percent of the RwD crashes occurred during daylight conditions.

Table 6. RwD crashes by lighting condition (<20xx-20xx>).

Lighting Condition	All Crashes			Fatal Crashes		
	Total Crashes	Total RwD Crashes	Percent of Total RwD Crashes (%)	Total Fatal Crashes	Fatal RwD Fatal Crashes	Percent of Total RwD Fatal Crashes (%)
Daylight	579,698	53,197	50	1364	555	38
Dark (No Lighting)	66,087	29,831	28	1149	596	41
Dark (Lighting)	133,347	19,667	18	687	232	16
Dawn	7,341	1,675	2	64	27	2
Dusk	11,734	1,533	1	77	18	1
Unknown	7,508	1459	1	27	19	1
Total	**805,715**	**107,362**	**100**	**3,368**	**1,447**	**100**
xx						

As shown in table 7, <xx> percent of the total RwD crashes occurred on **ABC Agency** roads from **<20xx to 20xx>** when the pavement surface was dry. In fact, on average approximately <xx> percent of total RwD crashes and <xx> percent of fatal RwD crashes occurred during wet pavement conditions.

Table 7. RwD crashes by pavement surface condition (<20xx-20xx>).

Surface Condition	All Crashes			Fatal Crashes		
	Total Crashes	Total RwD Crashes	Percent of Total RwD Crashes (%)	Total Fatal Crashes	Total RwD Fatal Crashes	Percent of Total RwD Fatal Crashes (%)
Dry	677,665	79,286	74	2925	1226	85
Wet	121,013	25,897	24	404	195	13
Ice	507	214	0	5	1	0
Other	6,530	1,965	2	34	25	2
Total	**805,715**	**107,362**	**100**	**3368**	**1447**	**100**
xx						

SUMMARY OF RWD CRASH STATISTICS

Based on a review of the RwD crashes that occurred in **ABC Agency** during a **<x>**-year period, the following items directly influenced the recommended key components of this RwD Implementation Plan:

- A large number of crashes occurred on roads that were not part of the State-maintained system. The precise location of these crashes was not always available and is shown as "Unknown" in the summary tables (see table 3 as an example).
- Single vehicle and head-on crash types made up the majority of fatal RwD crashes (**<xx>** crashes) in **ABC Agency** at approximately **<xx>** percent of the total fatal RwD crashes (see table 4).
- The first harmful events common to RwD crashes in **ABC Agency** include running-off-road (to right or left), crossing median/centerline, colliding with a tree, utility pole, or other fixed object, or hitting a culvert or ditch (see table 5).
- Approximately 50 percent of the observed RwD crashes occurred during daytime conditions (see table 6).
- On average, about 24 percent of total RwD crashes and 13 percent of fatal RwD crashes occurred during wet pavement conditions (see table 7).

SUMMARY OF RWD COUNTERMEASURE DEPLOYMENTS

The **<AGENCY NAME>** can deploy a wide variety of potential techniques targeted at mitigating the number of RwD crashes or, when the crash cannot be avoided, limiting the level of crash severity. Additional definitions and details for each recommended countermeasure are included in table 8. Table 9 through table 13 collectively summarize these recommended countermeasures and their associated costs (where known).

The information contained in the following tables represents a summary strategy matrix that identifies the individual candidate countermeasures, reviews the associated costs expected for each treatment, and summarizes the annual estimated reduction in crashes for total RwD, K, and KABC collisions. The final column in these summary tables identifies the individual cost (in millions of dollars) required to save one life each year. The intent of this strategy matrix is to identify prospective treatments to program as part of a five-year initiative.

Table 8. Countermeasure description information and associated crash reductions.

Countermeasure Type	Beginning Page Number for Additional Information	Related CMF Values	Estimated Crash Reductions
Center rumble stripes/ strips	24	Table 16	Table 17
Edgeline rumble stripes/strips	27	Table 18	Table 19
6" wide centerline pavement markings	29	Table 20	Table 21
6" wide edgeline pavement markings	31	Table 22	Table 23
Centerline raised pavement markers	34	Table 24	Table 25
Edgeline raised pavement markers	37	Table 26	Table 27
Lighting improvements	39	Table 28	Table 29
High friction surface treatment	42	Table 30	Table 31
Static curve warning sign (standard)	45	Table 32	Table 33
Enhanced curve warning system	48	Table 34	Table 35
Utility pole relocation	50	Table 36	Table 37
Remove or shield tree or fixed objects	53	Table 38	Table 39
Culvert end treatment and ditch improvement	56	Table 40	Table 41
Shoulder widening with drainage grading improvements	58	Table 42	Table 43
Shoulder widening without drainage grading improvements	61	Table 44	Table 45
Flattening median sideslopes	64	Table 46	Table 47
Add barrier	65	Table 48	Table 49
Improve barrier	67	Table 50	Table 51
Install median barrier	69	Table 52	Table 53

As noted in the strategy matrix, **saving 19 to 20 additional lives per year** will require an approximate investment of $130 million over the next five-year period. This is equivalent to approximately $26 million per year for each of the five implementation years.

Table 9. RwD countermeasure strategy matrix for system rural roadways – five-year summary*.

System Rural Roadways						
Countermeasure	**Unit Cost**	**Estimated Number of Improve-ments (Length or Unit)**	**Associ-ated Cost ($ Million)**	**Annual Targeted RwD Crash Reduction**	**Annual Estimated Fatality Reduction**	**($ Million) Required to save one life annually**
Center rumble stripes/ strips	$475/mile	544.4	$0.26	71.56	1.68	$0.15
Edgeline rumble stripes/strips						
6" wide centerline pavement markings						
6" wide edgeline pavement markings						
Centerline raised pavement markers						
Edgeline raised pavement markers						
Lighting improvements						
High friction surface treatment						
Static curve warning sign (standard)						
Enhanced curve warning system						
Utility pole relocation						
Remove or shield tree or fixed objects	$30,000/ location	359	$10.77	15.85	0.33	$32.59
Culvert end treatment and ditch improvement						
Shoulder widening with drainage grading improvements						
Shoulder widening without drainage grading improvements						
Flattening median sideslopes						
Add barrier						
Improve barrier						
Install median barrier						
Education & Enforcement Campaigns						
Subtotal for Rural Roads (5-year cost)				--	--	--
Subtotal for Rural Roads (yearly cost)						

* The origin of CMFs varies, but they are generally based on values at the CMF Clearinghouse or in related publications as noted. The unit costs are based on values provided by and/or reviewed with the **<AGENCY NAME>** staff. These costs do not include right-of-way acquisitions or continuous routine maintenance.

Table 10. RwD countermeasure strategy matrix for system urban roadways – five-year summary*.

System Urban Roadways						
Countermeasure	**Unit Cost**	**Estimated Number of Improve-ments (Length or Unit)**	**Associ-ated Cost ($ Million)**	**Annual Targeted RwD Crash Reduction**	**Annual Estimated Fatality Reduction**	**($ Million) Required to save one life annually**
Center rumble stripes/ strips	$475/mile	0.0	--	--	--	--
Edgeline rumble stripes/strips						
6" wide centerline pavement markings						
6" wide edgeline pavement markings						
Centerline raised pavement markers						
Edgeline raised pavement markers						
Lighting improvements						
High friction surface treatment						
Static curve warning sign (standard)						
Enhanced curve warning system						
Utility pole relocation						
Remove or shield tree or fixed objects	$30,000/ location	217	$6.51	13.02	0.20	$32.77
Culvert end treatment and ditch improvement						
Shoulder widening with drainage grading improvements						
Shoulder widening without drainage grading improvements						
Flattening median sideslopes						
Add barrier						
Improve barrier						
Install median barrier						
Subtotal for Urban Roads (5-year cost)				--	--	
Subtotal for Urban Roads (yearly cost)						

* The origin of CMFs varies, but they are generally based on values at the CMF Clearinghouse or in related publications as noted. The unit costs are based on values provided by and/or reviewed with the **<AGENCY NAME>** staff. These costs do not include right-of-way acquisitions or continuous routine maintenance.

Table 11. RwD countermeasure strategy matrix for local rural roadways – five-year summary*.

Local Rural Roadways						
Countermeasure	**Unit Cost**	**Estimated Number of Improve-ments (Length or Unit)**	**Associated Cost ($ Million)**	**Annual Targeted RwD Crash Reduction**	**Annual Estimated Fatality Reduction**	**($ Million) Required to save one life annually**
Center rumble stripes / strips	$475/mile	3.91	$0.002	0.55	0.01	$0.34
Edgeline rumble stripes/strips						
6" wide centerline pavement markings						
6" wide edgeline pavement markings						
Centerline raised pavement markers						
Edgeline raised pavement markers						
Lighting improvements						
High friction surface treatment						
Static curve warning sign (standard)						
Enhanced curve warning system						
Utility pole relocation						
Remove or shield tree or fixed objects	$30,000/ location	13	$0.39	0.48	0.01	$63.84
Culvert end treatment and ditch improvement						
Shoulder widening with drainage grading improvements						
Shoulder widening without drainage grading improvements						
Flattening median sideslopes						
Add barrier						
Improve barrier						
Install median barrier						
Subtotal for Rural Roads (5-year cost)				--	--	--
Subtotal for Rural Roads (yearly cost)						

* The origin of CMFs varies, but they are generally based on values at the CMF Clearinghouse or in related publications as noted. The unit costs are based on values provided by and/or reviewed with the **<AGENCY NAME>** staff.

Table 12. RwD strategy matrix for local urban roadways – five-year summary*.

Local Urban Roadways						
Countermeasure	**Unit Cost**	**Estimated Number of Improve-ments (Length or Unit)**	**Associated Cost ($ Million)**	**Annual Targeted RwD Crash Reduction**	**Annual Estimated Fatality Reduction**	**($ Million) Required to save one life annually**
Center rumble stripes / strips	$475/mile	0	--	--	--	--
Edgeline rumble stripes/strips						
6" wide centerline pavement markings						
6" wide edgeline pavement markings						
Centerline raised pavement markers						
Edgeline raised pavement markers						
Lighting improvements						
High friction surface treatment						
Static curve warning sign (standard)						
Enhanced curve warning system						
Utility pole relocation						
Remove or shield tree or fixed objects	$30,000/ location	0	--	--	--	--
Culvert end treatment and ditch improvement						
Shoulder widening with drainage grading improvements						
Shoulder widening without drainage grading improvements						
Flattening median sideslopes						
Add barrier						
Improve barrier						
Install median barrier						
Subtotal for Urban Roads (5-year cost)				--	--	--
Subtotal for Urban Roads (yearly cost)						

* The origin of CMFs varies, but they are generally based on values at the CMF Clearinghouse or in related publications as noted. The unit costs are based on values provided by and/or reviewed with the **<AGENCY NAME>** staff.

Table 13. Summary of strategy matrix estimated costs and performance measures.

Description	Rural Roads	Urban Roads	Local Roads	Grand Total
Projected Five Year Metrics				
Cost ($ Million)				
Projected Annual Metrics				
Cost ($ Million)				
Targeted RwD Crash Reduction				
Estimated Reduction in K Crashes				
Estimated Reduction in KABC Crashes				
Funds Required to Save One Life ($ Million)				

The companion Data Analysis package (see Appendix A) document and companion spreadsheet is presented in the Strategy Matrix. The Data Analysis package also includes information related to the development of the **ABC Agency** RwD safety performance functions. Appendix A includes the above referenced Excel file that summarizes the strategy matrix calculations. In addition, appendix B includes an Excel file that ranks the individual State-system and local highway sections suitable for countermeasure deployment.

FIRST KEY ACTIONS

Successful implementation of RwD safety enhancements can involve activities that include development of enhanced guidelines for countermeasure selection, field evaluation of candidate locations, and prioritization of projects and associated funding. In addition, an effective safety enhancement program should incorporate identification of performance measures that will ultimately strengthen the effective selection of safety enhancement treatments. The following summary includes a list of key action items.

- The RwD Safety Implementation Plan should be presented to the **ABC Agency** leadership including representatives from the District Offices, Maintenance Division, Road Design Division, Traffic Engineering Division, Materials Control Soils and Testing Division, Planning Division, and Programming Division. If local roads are evaluated, the Plan should also be presented to LTAP leadership. The purpose of this activity is to share and review the Plan, obtain input, and identify action items towards a successful implementation of the Plan.
- An important aspect of this Plan will be the identification of sustained program funding to help pay for the cost of the safety enhancements while also enabling continued activities such as training, performance assessment, etc. Consequently, a helpful step is to assess funding sources, including HSIP, to determine ways to sustain the Plan in future years.
- Where feasible, the agency should identify and program safety treatments typically deployed as part of maintenance, design, and operations activities. For this Plan, system-wide treatments that occur as a matter of policy are assumed to have associated programmed annual costs and so these costs are not directly considered as part of this Plan.
- Due to the large number of RwD crashes occurring on rural roads, a successful implementation of RwD safety treatments should consider some systemic applications of safety treatments for these facilities. Though the Plan identified candidate locations for centerline and edgeline rumble strips, as an example, consideration should be given to widescale deployment of these and similar countermeasures that will provide uninterrupted treatments along entire corridors.
- To assess Plan effectiveness, the **ABC Agency** should explore ways to track performance before and after treatment deployment. This approach will enable identification of additional future cost effective treatments with known safety performance.

IDENTIFYING THE PROMISING HIGHWAY LOCATIONS TO ADDRESS WITH ROADWAY DEPARTURE COUNTERMEASURES

Where feasible, methods that collectively consider road types and their unique characteristics provide more reliable results than techniques that limit the analysis only to observed crashes at select locations. Consequently, this Plan recommends the following analysis methods to help the **ABC Agency** enhance their ongoing safety initiatives:

- Predictive safety assessment method for facilities where a RwD safety performance function and a crash modification factor for that road type are available. For the **ABC Agency** Plan, the RwD crash data is sufficient for the development of a RwD safety performance function for the following roadway facilities:
    - Rural two-lane roadway,
    - Rural multilane (divided) roadway,
    - Rural multilane (undivided) roadway,
    - Rural freeway,
    - Urban two-lane roadway,
    - Urban multilane (divided) roadway,
    - Urban multilane (undivided) roadway,
    - Urban freeway,
    - Local rural roadway, and
    - Local urban roadway.

    The resulting predictive approach enables an analysis that weights the observed crashes with statistically developed **predicted crashes** for an overall expected crash number. This weighted value, referred to as the **expected number of crashes** (before deployment of a treatment), can then be used, in conjunction with industry developed crash modification factors specifically focused on RwD crashes, to calculate the estimated reduction in the total number of RwD crashes (after treatment**). The term estimated is used to reference mathematical procedures that are not captured by the terms expected, predicted, or observed crashes.**
- For locations where RwD safety performance functions are not feasible or where a suitable CMF for RwD crashes is not available, the Plan incorporates safety assessment techniques that rely on the frequency of **observed crashes** at known high-crash locations as well as CMFs based on engineering judgment.
- Many opportunities exist for the system-wide deployment of safety treatments. For example, the systemic construction of rumble strips may occur as part of a resurfacing or

shoulder improvement project. The estimated RwD safety benefits included in this Plan do not directly address systemic treatments commonly deployed as a matter of policy.

REVIEW OF LOW-COST COUNTERMEASURES FOR THE ABC AGENCY HIGHWAYS

The goal of this Plan is to identify optimal locations and countermeasures that collectively can help to reduce the number and severity of RwD crashes in the **ABC Agency**. This initiative involves the identification of several potential low-cost, effective countermeasures targeted for the reduction of RwD crashes along **ABC Agency** roadway locations. The list of low-cost countermeasures is divided into categories that (1) first focus on keeping the vehicles on the roadway, (2) next target the provision of a safe roadside area, and (3) help to reduce crash severity in the event the crash occurs. The treatments evaluated in this Plan are as follows:

- Keep Vehicles on Roadway:
  - Centerline rumble stripes / strips.
  - Edgeline rumble stripes / strips.
  - Six-inch wide centerline pavement markings.
  - Six-inch wide edgeline pavement markings.
  - Centerline raised pavement markings.
  - Edgeline raised pavement markings.
  - Lighting improvements.
  - High friction surface treatments.
  - Static curve warning signs (standard).
  - Enhanced curve warning system.
- Provide for a Safe Recovery Area:
  - Utility pole relocation.
  - Remove or shield tree or fixed objects.
  - Culvert end treatment and ditch improvement.
  - Shoulder widening with drainage grading improvements.
  - Shoulder widening without drainage grading improvements.
  - Flattening median sideslopes.
- Reduce Crash Severity:
  - Add barrier.
  - Improve barrier.

  - Install median barrier.
  - **ABC Agency** bridge rail retrofit for MASH standards.
- Education and Enforcement Campaigns.

Though this Plan focuses on relatively low-cost treatments, it is likely that higher cost countermeasures may be options at some of the identified locations. Due to ongoing safety initiatives in **ABC Agency**, the **ABC Agency** may have constructed safety treatments at some of the identified locations. Consequently, this Plan further notes that the **ABC Agency** personnel should conduct field visits as part of the initial scoping activities to determine if the condition persists that initially triggered attention to each site due to RwD crash concerns.

The analysis summarized in this Plan assesses State system roadways divided into segments with a maximum length of two-mile. For local roads, the maximum segment lengths used for this analysis are one-mile. In many cases, the roadway section exceeds these upper bound length thresholds. For these locations, the analysis included in this Plan further divided these study corridor sections. Similarly, many roadway segments are considerably shorter than the targeted thresholds. Study segments, for the purposes of this analysis, represent corridor lengths that are greater than or equal to 0.1 miles in length and up to and including two-mile roadway sections. Though the Plan may identify a segment as a high crash corridor while excluding an adjacent study location, it is recommended that **ABC Agency** personnel **assess upstream and downstream locations during the site visit** to determine if the limits of the countermeasure application should be extended based on similar road conditions at these adjacent locations.

OVERVIEW OF INDIVIDUAL COUNTERMEASURE ANALYSIS

Table 15 provides an overview of the individual countermeasures and associated assessment techniques used for the safety analysis included in this Plan. The beginning content for the section titled “Components of Plan for Selecting Treatment Types and Thresholds” identifies the road types represented in this analysis.

Table 15 also shows some facility types that are not candidates for a specific treatment. For example, the placement of rumble strips in urban areas is generally discouraged due to the additional noise generated by these treatments. The toolbox of potential treatments that follows further identifies these treatment constraints where applicable.

As previously noted, for roadways where the safety performance functions are available, the Plan uses safety performance functions for total RwD crashes and then weights them with the observed crashes to estimate the expected number of RwD crashes prior to the application of a treatment. This method is more reliable than the traditional approach that only uses observed crashes, as the safety performance function considers all roads of similar types in the evaluation. This number of expected crashes represents the “before” condition. These “before” values can then be adjusted with a crash modification factor to estimate the “after” treatment condition

number of crashes. A description of this analysis approach is included in more detail in the companion Data Package document for this Plan. Table 15 depicts the more reliable predictive method analyses with a "P" indicator.

Table 15 further identifies assessments based solely on observed crashes by an "O" indicator. Locations where these observed crashes are used, instead of predicted crashes, occurs when a safety treatment features are not available in databases such as a roadway inventory database or a representative safety performance function could not be developed. For example, if a comprehensive utility pole database is not available then it is not feasible to screen for utility pole location characteristics. The best available information, therefore, is historic corridor crashes where vehicles impact roadside utility poles.

In some cases, a crash modification factor may not be applicable for the total RwD crash condition. For these treatments, the observed crash assessment method may also be used. As an example, the crash modification factor for improving lighting relies on nighttime-only conditions rather than the total RwD value. The companion Data Package (Appendix A and Appendix B) provides additional detail about the safety performance functions and their use for the underlying safety assessment.

Table 14. List of assessment techniques used.

No.	Countermeasure Strategy	State System Facilities						Local Roads	
		Rural			Urban			Rural Roadway	Urban Roadway
		Two-Lane	Multilane	Interstate	Two-Lane	Multilane	Interstate		
1	Center Rumble Stripes/Strips	P	P [undivided only]	NA	NA	NA	NA	P [undivided only]	NA
2	Edgeline Rumble Stripes/Strips	P	P	P	NA	NA	P	P	NA
3	6” Wide Centerline Pavement Markings	P	P [undivided only]	NA	P	P [undivided only]	NA	P	P
4	6” Wide Edgeline Pavement Markings	P	P	P	P	P	P	P	P
5	Centerline Raised Pavement Markings	P	P [undivided only]	NA	P	P [undivided only]	NA	P	P
6	Edgeline Raised Pavement Markings	P	P	P	P	P	P	P	P
7	Lighting Improvements	O [dark – not lighted]	O [dark – not lighted]	O [dark – not lighted]	O [dark – not lighted]	O [dark – not lighted]	O [dark – not lighted]	O [dark – not lighted]	O [dark – not lighted]
8	High Friction Surface Treatment	P	P	P	P	P	P	P	P
9	Static Curve Warning Sign (Standard)	P	P	P	P	P	P	P	P
10	Enhanced Curve Warning System	P	P	P	P	P	P	P	P
11	Utility Pole	O [pole crashes only]	O [pole crashes only]	O [pole crashes only]	O [pole crashes only]	O [pole crashes only]	O [pole crashes only]	O [pole crashes only]	O [pole crashes only]
12	Remove or shield tree or fixed objects	O [fixed object crashes only]	O [fixed object crashes only]	O [fixed object crashes only]	O [fixed object crashes only]	O [fixed object crashes only]	O [fixed object crashes only]	O [fixed object crashes only]	O [fixed object crashes only]

Table 14. List of assessment techniques (continued).

No.	Countermeasure Strategy	State System Facilities						Local Roads	
		Rural			Urban			Rural Roadway	Urban Roadway
		Two-Lane	Multilane	Interstate	Two-Lane	Multilane	Interstate		
13	Culvert End Treatment & Ditch Improvement	O [culvert and ditch crashes only]	O [culvert and ditch crashes only]	O [culvert and ditch crashes only]	O [culvert and ditch crashes only]	O [culvert and ditch crashes only]	O [culvert and ditch crashes only]	O [culvert and ditch crashes only]	O [culvert and ditch crashes only]
14	Shoulder Widening with Drainage Grading Improvements	P	P	P	P	P	P	P	P
15	Shoulder Widening without Drainage Grading Improvements	P	P	P	P	P	P	P	P
16	Flattening Median Sideslopes	NA	O [overturn and no barrier in median]	O [overturn and no barrier in median]	NA	O [overturn and no barrier in median]	O [overturn and no barrier in median]	O [overturn and no barrier in median]	O [overturn and no barrier in median]
17	Add Barrier	O [no barrier and ran off road to right]	O [no barrier and ran off road to right]	O [no barrier and ran off road to right]	O [no barrier and fixed object crash]	O [no barrier and ran off road to right]	O [no barrier and ran off road to right]	O [no barrier and ran off road to right]	O [no barrier and ran off road to right]
18	Improve Barrier	O [crash into existing barrier]	O [crash into existing barrier]	O [crash into existing barrier]	O [crash into existing barrier]	O [crash into existing barrier]	O [crash into existing barrier]	O [crash into existing barrier]	O [crash into existing barrier]
19	Install Median Barrier	NA	P [divided only]	P	NA	P [divided only]	P	P [divided only]	P [undivided only]
20	Education and Enforcement Campaigns	S	S	S	S	S	S	S	S

P = predictive method (weights observed crashes and predicted crashes for an expected number of crashes)
O = based on observed crashes
S = systemwide
NA = not applicable for road type considered

TOOLBOX OF IMPLEMENTATION PLAN SAFETY ENHANCEMENT TREATMENTS

A variety of candidate safety treatments are available to help reduce the number of severe injury RwD crashes that occur on **ABC Agency** roadways. For the purposes of this Plan, the data supports the countermeasures presented in this chapter. The recommended countermeasures include proven treatments, and, in many cases, treatments already deployed on **ABC Agency** roadways. The **ABC Agency** roadway inventory may not fully document the locations of existing safety treatments. Consequently, the Plan recommends that **ABC Agency** first assess the individual ranked sites to identify and remove locations where similar treatments have either already been deployed or are currently slated to be implemented. These ranked sites can be developed in a ranking spreadsheet tool, or the **ABC Agency** can provide an Appendix B document that provides ranking recommendations for the highest ranked sites for each potential safety countermeasure type.

This Plan explores the suitability of the list of countermeasures previously noted. The countermeasures do not include major infrastructure projects such as roadway reconstruction or major realignment since this type of enhancement, though effective, would be specific to a unique construction project at a location already known to be deficient.

Within this Plan, the estimates for effectiveness and cost for each treatment represent typical applications and **ABC Agency** representatives will need to make additional refinements based on unique field conditions. The following summaries review each potential safety treatment as it relates to **Name of Jurisdiction** applications.

CENTERLINE RUMBLE STRIPES / STRIPS

Centerline rumble stripes / strips are effective treatments for rural undivided highway locations where any noise generated by these treatments will not be disruptive to the surrounding community. Figure 1 shows an example of a rumble stripe where the placement of the pavement marking occurs directly on the rumble strip (making it a rumble stripe). Table 16 provides a typical value for a crash modification factor for head-on and sideswipe crashes based on the application of centerline rumble stripes/strips for rural two-lane highways. The study report titled NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips (2009) included data from Minnesota, Pennsylvania, and Washington. This report is available at:

Source: FHWA

Figure 1. Photograph. Centerline rumble stripe.

https://www.nap.edu/ catalog/14323/guidance-for-the-design-and-application-of-shoulder-and-centerline-rumble-strips.

Table 15. Centerline rumble stripes/strips CMF values.

Facility Type:	Rural two-lane highway	Crash Severity:	All
Crash Type:	Head-on & Sideswipe	CMF:	0.63 (Head-on & Sideswipe) 0.85 (assumed for RwD crashes)
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=3355 *Notes:* • The primary target crash identified in previous studies focused on head-on and sideswipe crashes. Currently, high quality safety performance functions are not available for these crash types and so the Plan utilizes a more generic conservative value of 0.85 for all RwD crashes for all facility types. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or most reliable rating. The centerline rumble stripes/strips head-on and sideswipe CMF value of 0.63 received a five-star rating at the CMF Clearinghouse.			

In the **ABC Agency**, the centerline rumble stripes/strips can be applied to rural two-lane as well as rural undivided multilane highways. The placement of a milled centerline rumble stripe/strip requires full depth pavement so that the construction of the treatment does not undermine the integrity of the roadway. This plan assumes that centerline rumble stripes/strips can only be considered for **ABC Agency** rural two-lane facilities if the **overall pavement width is from 24 to 28 ft and the posted speed limit is 50 mph or greater**. For rural multi-lane undivided facilities, centerline rumble stripes/strips can be considered **for roadways with the posted speed limit of 50 mph or greater**. The placement of a centerline rumble stripe is dependent on the presence of centerline pavement marking.

The Appendix B spreadsheet summarizes potential sites where a centerline rumble strip may be considered. The Plan ranks the sites based on how much the observed number of crashes exceeded the expected number of crashes for each location based on the predictive method.

Table 17 summarizes the approximate length of improvements, associated treatment costs, and anticipated reduction in crashes estimated to result from the placement of centerline rumble stripes/strips. The Plan for deploying recommended centerline rumble stripe/strip applications is expected to reduce total crashes by approximately xx crashes per year. This crash reduction also equates to approximately one to two fatal crashes each year. Prior to deployment of this treatment, local agency personnel should conduct a site inspection to confirm that this treatment is suitable and is not already present at the subject location.

Table 16. Estimated RwD crash reductions for centerline rumble strips at undivided facilities.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment -- RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane	531.9	$0.253	0.02	0.47	70.58	1.65	33.10
Rural multilane undivided	12.5	$0.006	0.03	0.39	0.98	0.03	0.38
Rural Subtotal:	544.4	$0.259	--	--	71.56	1.68	33.48
Locally Owned or Maintained							
Local Rural	3.9	$0.002	0.01	0.36	0.55	0.01	0.20
Local Subtotal:	3.9	$0.002	--	--	0.55	0.01	0.20
Grand Total	548.3	$0.261	--	--	72.11	1.68	33.68

Notes:

- For installing centerline rumble strips at locations with opposite direction sideswipe and head-on crashes, assumes improvement of 50% and 10% of identified system and local locations, respectively.
- Cost estimates based on $475 per mile.
- CMF value of 0.85 used for installing centerline rumble strips for RwD target crashes.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis). Treatment not considered for divided roadways or urban locations.

Suggested implementation is as follows:

1. A statewide database for existing centerline rumble stripes/strips is not available. Consequently, the Plan assumes that these rumble strips are not present. Prior to initiating improvement projects, **ABC Agency** should inspect the candidate sites and confirm that the sites are viable options for this treatment. To overcome this potential limitation, the Plan assumes that only 50 percent of the identified State system locations can be addressed and only 10 percent of the local sites can be addressed. Following the site inspections, **ABC Agency** may elect to adjust this assumption. As part of the field evaluation, **ABC Agency** staff should confirm the minimum pavement width. This value should include the roadway and the shoulder widths.

2. The recommended application for centerline rumble stripes/strips is restricted to roadways at rural locations only; however, it is possible that facilities classified as urban could be potential candidates for future centerline rumble stripes/strips. The rural locations are ranked in the Appendix B spreadsheet and should be used as a starting point for programming future improvement sites. **ABC Agency** staff may want to explore the potential for deploying this treatment at select urban locations where the noise generated by the rumble stripes/strips will not adversely impact the property owners along the corridor.

EDGELINE RUMBLE STRIPES / STRIPS

Edgeline or shoulder rumble stripes or strips can effectively alert a driver who inadvertently exits his or her travel lane. These treatments are appropriate for non-curbed (typically rural) roadways. Figure 2 depicts roadways with example edgeline/shoulder rumble stripe/strip applications. Table 18 summarizes known safety performance for edgeline rumble stripes/strips.

Edgeline Rumble Stripe Edgeline/Shoulder Rumble Strip

Source: FHWA

Figure 2. Photograph. Edgeline rumble stripe/strip.

Table 17. Edgeline rumble stripes/strips CMF values.

Facility Type:	Rural two-lane highway	Crash Severity:	All severity levels
Crash Type:	Run-off-road	CMF:	0.84
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=3442#commentanchor *Notes:* • The primary facility type identified in previous studies focused on rural two-lane highways for run-off-road crashes at all severity levels. The CMF value of 0.84 has been assumed for these rural two-lane highways as well as for rural multilane highway applications. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The edgeline rumble stripe/strip CMF value of 0.84 received a five-star rating at the CMF Clearinghouse.			

This treatment is appropriate for rural **ABC Agency** two-lane highways with a **pavement width of 25 ft or greater, paved shoulder width greater than 1 ft, and posted speed limit of 50 mph or greater.** For rural multilane highways, this treatment is appropriate for roadways with **paved shoulder widths greater than 1 ft and a posted speed limit of 50 mph or greater**. To be effective, the placement of milled edgeline rumble stripes/strips requires full depth pavement so that the construction of the treatment does not undermine the integrity of the roadway.

Table 19 summarizes a proposed improvement plan for edgeline rumble stripe/strip application. The Plan for deploying the recommended edgeline rumble stripe/strip applications is expected to reduce total crashes by approximately xx crashes per year. This crash reduction also equates to approximately two to three fatal crashes each year. Prior to deployment of this treatment **ABC Agency** personnel should conduct a site inspection to confirm that this treatment is suitable and is not already present at the subject location.

Table 18. Estimated RwD crash reductions for edgeline rumble stripes/strips at rural locations.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural multilane undivided							
Rural multilane divided							
Rural Interstate							
Rural Subtotal:			-	-			
Urban Interstate							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For installing edgeline rumble strips at locations with RwD, assumes improvement of 50% and 10% of identified system and local locations, respectively. With the exception of interstates, the analysis excludes urban locations.
- Cost estimates based on $565 per mile per edge.
- CMF value of 0.84 used for installing edgeline rumble strips.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis).

Suggested implementation is as follows:

1. A statewide database for existing edgeline rumble stripes/strips is not available. Consequently, the Plan assumes that these rumble strips are not present. Prior to initiating improvement projects, **ABC Agency** should inspect the candidate sites and confirm that the sites are viable options for this treatment. To overcome this potential limitation, the Plan assumes that only 50 percent of the identified State system locations can be addressed and only 10 percent of the local sites can be addressed. Following the site

inspections, **ABC Agency** may elect to adjust this assumption. As part of the field evaluation, **ABC Agency** staff should confirm the minimum pavement width.

2. The recommended application for edgeline rumble stripes/strips is restricted to roadways at rural locations only; however, it is possible that facilities classified as urban could be potential candidates for future centerline rumble stripes/strips. The rural locations are ranked in the Appendix B spreadsheet and should be used as a starting point for programming future improvement sites. **ABC Agency** staff may want to explore the potential for deploying this treatment at select urban locations where the noise generated by the rumble stripes/strips will not adversely impact the property owners along the corridor.

SIX-INCH WIDE CENTERLINE PAVEMENT MARKINGS

The application of standard as well as wider pavement marking can help to provide positive guidance to the driver so that he or she does not deviate from the active travel lane. This treatment can be constructed individually (just a centerline) or in conjunction with wider edgeline pavement markings (resulting in centerline and edgeline pavement markings). The application can occur at rural as well as urban locations.

Source: FHWA

Figure 3. Photograph. Six-inch centerline pavement markings.

Table 20 demonstrates that the use of a wider centerline pavement marking does marginally reduce crashes (by approximately three percent). The treatment, however, in conjunction with companion pavement marking (i.e. four-inch or six-inch edgelines), is likely to help further reduce the number of crashes. The available CMF values primarily target all crashes on rural two-lane highways.

Table 19. Six-Inch wide centerline pavement marking CMF values.

Facility Type:	Rural two-lane highway	Crash Severity:	All severity levels
Crash Type:	All	CMF:	0.97
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=83#			

Note:

- The primary facility type identified in previous studies focused on rural two-lane highways for all crash types and severity levels. The CMF value of 0.97 has been assumed for all road types.
- The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The six-inch wide centerline pavement marking CMF value of 0.97 received a three-star rating at the CMF Clearinghouse.

Table 21 summarizes the proposed improvement plan for six-inch centerline pavement marking applications. The Plan for deploying the recommended six-inch centerline pavement marking is expected to reduce total crashes by approximately xx crashes per year. This crash reduction also equates to a reduction of one fatal crash approximately every xx years.

Suggested implementation is as follows:

1. The use of six-inch wide centerline pavement markings is new to the **ABC Agency**. Consequently, the Plan assumes that these wider pavement markings are not present. Prior to initiating improvement projects, **ABC Agency** should inspect the candidate sites and confirm that the sites are viable options for this treatment. The Plan assumes that only 40 percent of the identified State system locations can be addressed and only 10 percent of the local sites can be addressed. Following the site inspections, **ABC Agency** may elect to adjust this assumption.

Table 20. Estimated RwD crash reductions for six-inch wide centerline pavement markings at rural locations.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- Rural and urban 2-lane roadways considered for this evaluation must have a pavement width of 24 ft or greater.
- For installing 6" wide centerline pavement markings at identified locations, the Plan assumes improvement of 40% of identified locations State system facilities and 10% of local facility candidate sites.
- Cost estimates based on $4510 per mi.
- CMF value of 0.97 used for installing 6" wide centerline stripes.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis). Treatment not considered for divided roadways.

SIX-INCH WIDE EDGELINE PAVEMENT MARKINGS

The goal of an edgeline is to help delineate the edge of the roadway and ultimately minimize or reduce RwD crashes. The use of six-inch wide edge lines will further emphasize the edges of the travel area. Edgelines are appropriate at locations that also have centerline marking if the width of the road is sufficient to support motor vehicle travel in two directions. The application of edgelines can occur at rural as well as urban locations, though engineers often design urban roadways with raised curb so that the curb line is used for roadway edge delineation in lieu of an edgeline pavement marking.

Source: FHWA

Figure 4. Photograph. Six-inch wider edgeline pavement markings.

Table 22 demonstrates that the use of a wider edgeline pavement marking helps to reduce single vehicle crashes by approximately 17 percent. The available CMF values primarily target all single vehicle crash types, though most of the related research has focused on rural two-lane highways.

Table 21. Six-inch wide edgeline pavement marking CMF values.

Facility Type:	Rural two-lane highway	Crash Severity:	All severity levels
Crash Type:	Single Vehicle	CMF:	0.63 to 0.83 (Install wider edgelines 4 in to 6 in)
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=4736# and http://www.cmfclearinghouse.org/detail.cfm?facid=4737#			

Notes:

- The primary facility type identified in previous studies focused on rural two-lane highways for single vehicle crashes and severity levels. The CMF value ranged from 0.63 to 0.83. For this Plan, the more conservative value of 0.83 has been assumed for all road types.
- The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The six-inch wide edgeline pavement marking CMF value of 0.83 received a four-star rating at the CMF Clearinghouse.

The Appendix B spreadsheet summarizes potential sites where a wider edgeline pavement marking may be considered. The Plan ranks the sites based on how much the observed number of crashes exceeded the expected number of crashes for each location using the predictive safety assessment approach. This information is expanded upon in the Appendix A summary. Table 23 summarizes a proposed improvement plan for six-inch edgeline pavement marking applications. The Plan for deploying the recommended six-inch edgeline pavement marking is expected to reduce total crashes by approximately xx crashes per year. This crash reduction also equates to a reduction of approximately xx fatal crashes each year.

Table 22. Expected RwD crash reductions for six-inch wide edgelines.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Interstate							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- Rural and urban roads considered for this treatment must have a pavement width of 25 ft or greater.
- For installing 6" wide edgeline pavement markings at locations with RwD crashes, assumes improvement of 40% and 10% for identified system and local sites, respectively.
- Cost estimates based on $4510 per mile per edge. Each undivided segment assumed to have two edges and divided roads assumed to have four edges. Local roads assumed to have only two edges per facility.
- CMF value of 0.83 used for installing 6" wide centerline stripes.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes during the five-year period (using predictive analysis).

Suggested implementation is as follows:

The use of six-inch wide edgeline pavement markings is new to ABC Agency. Consequently, the Plan assumes that these wider pavement markings are not present. Prior to initiating improvement projects, **ABC Agency** should inspect the candidate sites and confirm that the sites

are viable options for this treatment. The Plan assumes that only 40 percent of the identified State system locations can be addressed and only 10 percent of the local sites can be addressed. Following the site inspections, **ABC Agency** may elect to adjust this assumption.

CENTERLINE RAISED PAVEMENT MARKINGS

The application of centerline raised pavement markings can complement existing centerline striping while also enhancing the positive guidance provided for the driver so that he or she does not deviate from the active travel lane. This treatment can be positioned on the pavement surface or, in regions with frequent snow, can be embedded so that it is snowplow able. For the purposes of the **ABC Agency** Plan, the treatment is assumed to be a surface epoxy coated treatment. The application can occur at rural or urban locations.

Table 24 demonstrates that the use of centerline raised pavement markings provide a crash reduction of approximately 15 percent.

© TTI

Figure 5. Photograph. Centerline raised pavement markings.

Table 23. Centerline raised pavement marking CMF values.

Facility Type:	Rural Principal Arterial, Freeways, Expressways	Crash Severity:	All
Crash Type:	All	CMF:	0.81 (AADT < 60,000) 0.87 (AADT ≥ 60,000) Used 0.85 value
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=5496 and http://www.cmfclearinghouse.org/detail.cfm?facid=5498 *Notes:* • The primary target crash identified in previous studies focused on all crashes. Currently, high quality safety performance functions are available based on a **ABC Agency** study that evaluated the addition of both centerline and edgeline raised pavement markers. This Plan utilizes a value of 0.85 for all RwD crashes for all facility types. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or most reliable rating. The raised pavement marking CMF value of 0.81 and 0.87 each received a five-star rating at the CMF Clearinghouse.			

Table 25 summarizes the proposed improvement plan for centerline raised pavement marking applications. The Plan for deploying the recommended treatment is expected to reduce total crashes by approximately xx crashes per year. This crash reduction also equates to a reduction of one to two fatal crashes each year.

Suggested implementation is as follows:

1. Information about locations with centerline raised pavement markings already present was not available at the time of Plan development. The Plan assumes that these pavement markings are not present. Prior to initiating improvement projects, **ABC Agency** should inspect the candidate sites and confirm that the sites are viable options for this treatment. To overcome this potential limitation, the Plan assumes that only 40 percent of the identified State system locations can be addressed and only 10 percent of the local sites can be addressed. Following the site inspections, **ABC Agency** may elect to adjust this assumption.

2. As previously noted, the most common application of centerline raised pavement markings is to apply the treatment to the pavement surface using an epoxy. At high traffic locations, placement where heavy vehicles may regularly traverse over the markers, or locations prone to extreme winter weather, consideration may be given to the use of embedded pavement markers. These types of installations are considerably more expensive than those used for standard pavement markers. This Plan assumes the more common and less expensive application.

Table 24. Estimated RwD crash reductions for centerline raised pavement markings.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural multilane undivided							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For installing raised pavement markers at locations with opposite direction sideswipe and head-on crashes, assumes improvement of 40% and 10% of identified system and local locations, respectively.
- Cost estimates based on $475/mi.
- CMF value of 0.85 used for installing centerline raised pavement markers. Published literature varies regarding the effectiveness of these RPMs on crash reduction, but when used for enhanced visibility as well as a "surrogate" profile rumble strip, the CMF for centerline rumbles strips seems reasonable.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis). Treatment not considered for divided roadways or urban locations.

EDGELINE RAISED PAVEMENT MARKINGS

The application of edgeline raised pavement markings can complement existing edgeline striping while also enhancing the positive guidance provided for the driver so that he or she does not deviate from the active travel lane. This treatment can be positioned on the pavement surface or, in regions with frequent snow, can be embedded so that it is snowplow able. For the purposes of the **ABC Agency** Plan, the treatment is assumed to be a surface epoxy coated treatment. The application can occur at rural or urban locations

Table 26 demonstrates that the use of edgeline raised pavement markings provide a crash reduction of approximately 15 percent.

Table 25. Edgeline raised pavement marking CMF values.

Facility Type:	Rural Principal Arterial, Freeways, Expressways	Crash Severity:	All
Crash Type:	All	CMF:	0.81 (AADT < 60,000) 0.87 (AADT ≥ 60,000) Used 0.85 value
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=5496 and http://www.cmfclearinghouse.org/detail.cfm?facid=5498 *Notes:* • The primary target crash identified in previous studies focused on all crashes. Currently, high quality safety performance functions are available based on a **ABC Agency** study that evaluated the addition of both centerline and edgeline raised pavement markers. This Plan utilizes a value of 0.85 for all RwD crashes for all facility types. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or most reliable rating. The raised pavement marking CMF value of 0.81 and 0.87 each received a three-star rating at the CMF Clearinghouse.			

Table 27 summarizes the proposed improvement plan for edgeline raised pavement marking applications. The Plan for deploying the recommended treatment is expected to reduce total crashes by approximately xx crashes per year. This crash reduction also equates to a reduction of two to three fatal crashes each year.

Table 26. Estimated RwD crash reductions for edgeline raised pavement markings.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural multilane undivided							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Interstate							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For installing edgeline raised pavement markers at locations with RwD crashes, assumes improvement of 40% and 10% of identified system and local locations, respectively.
- Cost estimates based on $475/mi per edge. Each undivided segment assumed to have two edges and divided roads assumed to have four edges. Local roads assumed to have only two edges per facility.
- CMF value of 0.85 used for installing edgeline raised pavement markers. Published literature varies regarding the effectiveness of these RPMs on crash reduction, but when used for enhanced visibility as well as a "surrogate" profile rumble strip, the CMF for edgeline rumbles strips seems reasonable.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis).

Suggested implementation is as follows:

1. Information about locations with edgeline raised pavement markings already present was not available at the time of Plan development. The Plan assumes that these pavement markings are not present. Prior to initiating improvement projects, **ABC Agency** should inspect the candidate sites and confirm that the sites are viable options for this treatment. To overcome this potential limitation, the Plan assumes that only 40 percent of the identified State system locations can be addressed and only 10 percent of the local sites can be addressed. Following the site inspections, **ABC Agency** may elect to adjust this assumption.

2. As previously noted, the most common application of edgeline raised pavement markings is to apply the treatment to the pavement surface using an epoxy. At high traffic locations, placement where heavy vehicles may regularly traverse over the markers, or locations prone to extreme winter weather, consideration may be given to the use of embedded pavement markers. These types of installations are considerably more expensive than those used for standard pavement markers. This Plan assumes the more common and less expensive application.

LIGHTING IMPROVEMENTS

The strategic positioning of streetlights at critical locations, such as intersections or sharp horizontal curves (as depicted in Figure 6), can help to enhance roadway visibility and therefore reduce nighttime collisions. Transportation agencies often install lighting at locations with a pattern of nighttime RwD crashes or conditions where this type of crash is likely. For rural areas, an agency can encounter challenges deploying lighting if electrical service is not available at more remote locations. As the number of lanes, access points, changes in horizontal or vertical alignment, or parking increases, the demand for lighting increases.

Source: FHWA

Figure 6. Photograph. Adding lighting improvements at key isolated locations.

Table 28 demonstrates that the addition of lighting improvements reduces nighttime crashes by approximately 17 to 28 percent. The available CMF values primarily target nighttime crashes for all roadway facilities.

Table 27. CMF values for lighting improvements.

Facility Type:	All	Crash Severity:	ABC and O
Crash Type:	Nighttime	CMF:	0.72 (ABC Severity) 0.83 (O Severity) [Used a CMF value of 0.80]
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=192 and http://www.cmfclearinghouse.org/detail.cfm?facid=193 *Notes:* • Previous studies have focused on all facility types, but the target crash type is a nighttime crash with injury or property damage only crash severity. The CMF value ranged from 0.72 to 0.83. For this Plan, the value of 0.80 has been assumed for all road types. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The highway lighting CMF values of 0.72 and 0.83 received four-star ratings at the CMF Clearinghouse.			

The Appendix B spreadsheet summarizes potential sites where lighting improvements may be considered. The Plan ranked sites based on the frequency of observed crashes during nighttime conditions where supplemental lighting was not available. This information is expanded upon in the Appendix A summary. Table 29 summarizes a proposed plan for lighting improvements. The plan for deploying the recommended street lighting is expected to reduce total crashes by approximately seven crashes per year.

Suggested implementation is as follows:

1. The basis for the Plan recommendation to install lighting improvements is to reduce nighttime RwD crashes. Because lighting may require supplemental power, a first step towards implementation it to determine if and where lighting can be supported by solar power versus hardwired electrical power. For rural locations that require physical electrical wiring, **ABC Agency** should inspect the sites to determine how or if this service can be provided. Prior to initiating improvement projects, **ABC Agency** staff should inspect the candidate sites and confirm that the sites are viable options for this treatment. To overcome this potential limitation, the Plan assumes that only 40 percent of the identified locations can be addressed. Following the site inspections, **ABC Agency** may elect to adjust this assumption.

2. A common strategy for adding lighting is to share poles with other utilities so that the department can minimize the number of roadside fixed objects. If, for example, electrical service is available it may also be practical to coordinate with the power company or

owner of the existing poles to mount lighting standards on their poles. **ABC Agency** should explore if this option is acceptable and, if deemed appropriate, coordinate with regional utility companies to determine common locations identified during the ranking process that correspond to identified share pole locations.

3. If solar powered lights are determined to be practical, **ABC Agency** should finalize specifications for the lights and determine suitable locations based on the ranked sites included in the Appendix B spreadsheet.

Table 28. Estimated RwD nighttime crash lighting improvements for sites with no previous lighting.

Facility Type	Estimated Number of Locations	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural multilane divided							
Rural Interstate							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane divided							
Urban Interstate							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For lighting installation or improvements, assumes improvement of 5% of identified system and local locations. This low distribution is due to limited authority of lighting installations (particularly on State facilities).
- Cost estimates based on $30,000 per location (assumes 3 lights for each identified location).
- CMF value of 0.80 used for lighting improvements.
- Based on an elevated observed crash level threshold of 10 to 19 crashes into a utility pole or light support within a 5-year period.

HIGH FRICTION SURFACE TREATMENTS

High Friction Surface Treatment (HFST) is an innovative pavement treatment that incorporates the application of high-quality calcined bauxite aggregate to the pavement surface using a polymer binder. This pavement treatment is an effective way to improve friction at intersection and sharp horizontal curve locations where standing water is likely to occur or where the pavement friction is not suitable. HFST can be an effective alternative at locations with sharp horizontal curvature and insufficient superelevation, because HFST can be constructed in lieu of more costly alternatives like geometric changes that require a flatter horizontal curve or superelevation wedge construction. This application then results in enhanced skid resistance and helps vehicles maintain their path at critical locations. HFST can provide enhanced road surface performance for both wet and dry pavements. HFST can also provide improved friction at ramp locations with abrupt speed changes.

The common influential factors of horizontal curvature (specifically required superelevation run-off and run-out) as well as vertical curvature can work together to limit pavement surface friction. For this implementation plan, calculations for candidate locations for HFST in the **ABC Agency** per the computations below are based on prospective locations that are likely to have flat spots (due to inadequate superelevation and vertical grade interactions) and that do not maintain an effective slope of 2 percent or greater. These locations have been calculated based on the superelevation run-off and run-out length at the point of curvature and point of tangency for horizontal curves using available horizontal curve information (e.g., design speed, curve radius, maximum superelevation). The location where the cross-slope has a value of zero (at the superelevation transition) can then be contrasted to the known vertical grade information at that specific milepoint. If the vertical grade at a milepoint with a zero cross-slope value is between -2% and 2%, the horizontal curve may be a location that may be subjected to standing water during rain events. The analysis method used for identifying these candidate flat spots is described as follows:

1. Calculate the length of run-out for each curve using the equation in figure 7:

$$L = \frac{Slope\ Change \times W \times Lane\ Factor}{Equivalent\ Maximum\ Relative\ Slope}$$

Figure 7. Equation. Calculation for the length of run-out for each curve.

Where,

L = length of superelevation run-out (mile);

W = lane width (ft);

Slope Change = change in vertical slope (ft/ft);

Lane Factor can be found in the **ABC Agency** Design Manual (2017 July Version, page 4-19).

2. Calculate the milepost (MP) of level point (MP of PC – 0.8 * length of run-out).
3. Check the vertical grade of the MP of level point.
4. Determine if potential drainage issue exists (i.e., flag as drainage issue if vertical grade is between -2% and 2%).

Source: FHWA

Figure 8. Photograph. High friction surface treatment.

Table 30 notes that High Friction Surface Treatments have shown impressive safety-related results. Currently additional data is being collected by FHWA to develop a more mature and fully vetted crash modification factor for this treatment. Consequently, the observed crash reductions that range from 57 up to 90 percent conservatively support a crash modification value of 0.70.

Table 29. CMF values for high friction surface treatments.

Facility Type:	All	Crash Severity:	All
Crash Type:	All crashes at high risk locations (see discussion below)	CMF:	0.70
Additional Information: https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/high_friction/ *Notes:* As noted in the previous text, an overall CMF for high friction surface treatment is preliminary. This relatively new treatment type has already proven to be effective, but studies are currently underway to better quantify the safety effectiveness. By its nature, the typical			

application of a high friction surface treatment occurs at a high crash location with good existing pavement conditions. Applications are commonly located at horizontal curves with small radii, steep vertical approaches at intersections, or ramps with abrupt changes in speed. As part of the site analysis, **ABC Agency** should assess the quality of the existing pavement. Studies report remarkable results including crash reductions by as much as 57 to 90 percent. One cited study at the FHWA link above notes that this treatment can reduce crashes by approximately 31 percent. Consequently, this Plan uses a conservative value of CMF=0.70.

Table 31 summarizes a proposed improvement plan for High Friction Surface Treatment applications for **ABC Agency** facilities. The Plan for deploying the recommended High Friction Surface Treatment applications is expected to reduce total crashes by approximately 16 crashes per year. This crash reduction also equates to approximately one fatal crashes every four years.

Table 30. Predicted RwD crash reductions for high friction surface treatment applications.

Facility Type	Estimated Number of Improvements	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural multilane undivided							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Interstate							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For the installation of high friction surface treatments, assumes improvement of only 2% of identified locations.
- Cost estimates based on $35 per square yard with an assumed typical application that is 30 feet wide and 1500 feet long. Only one application assumed per location.
- CMF value of 0.70 used for high friction surface treatment improvements.
- Selection of system facilities based on sites where the observed number of crashes exceeds the expected number of crashes by 20%. For local roads, identified sites experienced 4 or more RwD crashes.

Suggested implementation is as follows:

1. The placement of HFST should be targeted for locations where the road surface friction is not sufficient for vehicles to adequately maintain their path, particularly during wet weather conditions. HFST should only be used at locations where the existing pavement surface is in good condition. For this application, "good condition" refers to where there is not any evidence of pavement deficiencies that would indicate compromised integrity of the pavement structure. Common applications of HFST are at curve locations where the pavement surface does not always maintain proper drainage or at high speed intersections with steep vertical approaches. The sites identified as part of this plan are based on locations with horizontal curve transitions that do not maintain a two percent effective grade throughout the transition region.

2. The data used to identify potential locations is based on an assumed horizontal curve superelevation transition length as defined in the standard highway standards. Prior to implementing this treatment, it would be advisable for **ABC Agency** staff to conduct field evaluations to confirm site suitability and priority.

STATIC CURVE WARNING SIGN (STANDARD)

Often horizontal curves have visibility issues due to their geometry, roadway configuration, roadside landscape, and a variety of other potentially problematic roadway elements. To enhance the visibility of a horizontal curve, a variety of signing options are available. Curve warning signs are needed at locations with an advisory speed that is at least ten mph below the posted speed limit. Similarly, curve warning signs may be appropriate due to geometric features including length, radius, shoulders, or roadside features. In some instances, an unexpected feature may be located within the curve such as an intersection, geometric change, or similar. These example characteristics demonstrate the wide variety of issues that ultimately may trigger the need to install static curve warning signs.

Source: FHWA

Figure 9. Photograph. Application of curve warning signs.

Table 32 indicates that deployment of static curve warning signs reduces crashes from 30 up to 44 percent. For conservative applications that encompass rural two-lane highways, the Plan analysis used a crash modification factor of 0.70.

Table 31. CMF values for static curve warning signs.

Facility Type:	Not specified	Crash Severity:	ABC
Crash Type:	Varies	CMF:	Varies ranging from 0.56 (run off road) up to 0.70
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=71 and http://www.cmfclearinghouse.org/detail.cfm?facid=1910			

Notes:

- Previous studies have focused on all facility types with varying crash types and injury levels. The CMF values ranged from 0.56 (for run-off-road crash types at principal arterials, freeways, and expressways) to 0.70 (for all crash types and unspecified road types). For this Plan, the conservative value of 0.70 has been assumed for all road types.
- The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The study that generated a CMF for static curve warning signs for higher speed arterials and freeways scored a three-star rating at the CMF Clearinghouse. The CMF for all crash types, unspecified road types, and injury crashes only received one-star rating.

The Appendix B spreadsheet summarizes potential sites where static curve warning signs may be considered (see Table A-26 for specific criteria). The Plan ranks the sites based on observed crash information for rural roadways associated with RwD crashes at horizontal curve locations.

Table 33 summarizes a proposed improvement plan for deploying a static curve warning sign treatment. The Plan for deploying these static curve warning signs is expected to reduce rural crashes at horizontal curve locations by approximately 165 crashes per year. This equates to a reduction of approximately two to three fatal crashes each year.

Suggested implementation is as follows:

1. The placement of static curve warning signs should be targeted for locations where the curve radius, roadway superelevation, posted speed, advisory speed, and/or roadside environment may be configured in such a way that that a driver is surprised by the road geometry or has a challenge navigating the corridor. The data used to identify potential locations included some, but not all, of these potential contributing factors. Consequently, a first step in implementing this treatment is for **ABC Agency** staff to conduct field evaluations using the prioritized list of sites included in Appendix B to confirm the need for these supplemental curve warning signs.

2. At locations where a driver needs additional warning, enhanced curve warning systems are recommended (see the next treatment in this Plan). Often, an agency deploys static curve warning signs and then ultimately adds enhanced features such as flashing beacons or larger signs if the problem persists. For this reason, implementation of the static curve warning signs and the enhanced curve warnings systems should be assessed together and only one initial treatment deployed per location.

Table 32. Predicted RwD crash reductions based on the addition of static curve warning signs.

Facility Type	Estimated Number of Locations	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- Static horizontal curve signage based on 40% and 10% of system and local road locations, respectively.
- Cost estimates based on $3000 per location (assumed to be one application per section).
- CMF value of 0.70 used for static horizontal curve sign improvements.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis).

ENHANCED CURVE WARNING SYSTEM

The road features that trigger static curve warning signs also apply to enhanced curve warning systems. An enhanced curve warning system can incorporate larger signs, better advanced warning, and in some cases companion flashing beacons to further enhance the curve warning system.

Source: FHWA

Figure 10. Graphic. Enhanced curve warning systems.

Table 34 notes that crash modification factors vary for the enhanced curve warning sign treatment; however, a conservative value assumes an approximate 30-percent reduction in RwD crashes. This equates to a crash modification factor of 0.70.

Table 33. CMF values for enhanced curve warning signs.

Facility Type:	Arterials, Freeways, and Expressways	Crash Severity:	All
Crash Type:	Run-off-road	CMF:	Varies but in range of 0.59 up to 0.73 (Conservative value of CMF = 0.70 used)
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=1856 and http://www.cmfclearinghouse.org/detail.cfm?facid=1874 *Notes:* • Previous studies have focused on all higher speed roads (arterials, freeways, and expressways) with run-off-road crash types and all injury levels. The CMF values ranged from 0.59 to 0.73. For this Plan, the conservative value of 0.70 has been assumed for all road types. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The study that			

generated a CMF=0.59 for the enhanced curve warning system received four stars and the CMF = 0.73 received three stars.

The Appendix B spreadsheet summarizes potential sites where enhanced curve warning system configurations may be considered. The Plan ranks the sites based on an evaluation of predicted crashes. The analysis focused on RwD crashes at horizontal curve locations.

Table 35 summarizes a proposed improvement plan for deploying enhanced curve warning signs. The Plan for deploying these curve warning treatments is expected to reduce rural crashes at horizontal curve locations by approximately 17 crashes per year. This equates to a reduction of approximately one fatal crash every three to four years.

Table 34. Estimated RwD crash reductions for implementation of enhanced curve warning signs.

Facility Type	Estimated Number of Locations	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural multilane undivided							
Rural multilane divided							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- Candidate sites for enhanced horizontal curve signage assumes 20% and 5% of system and local roads, respectively.
- Cost estimates based on $3300 per one location.
- CMF value of 0.70 used for enhanced curve warning sign applications.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis).

Suggested implementation is as follows:

1. The placement of enhanced curve warning signs should be targeted for locations where the curve radius, roadway superelevation, posted speed, advisory speed, and/or roadside environment are configured in such a way that that a driver is surprised by the road geometry or has a challenge navigating the corridor. The data used to identify potential locations for this Plan considered rural locations with a horizontal curve radius of 1,000 ft or less (per the Manual on Uniform Traffic Control Devices Table 3F-1). A first step in implementing this treatment is for **ABC Agency** staff to conduct field evaluations using the prioritized list of sites included in Appendix B to confirm the need for these supplemental curve warning signs.

2. At locations where a driver needs additional warning but where the location may not warrant extra signage or illumination, the use of static curve warning signs may be sufficient (see previous treatment). Often, an agency deploys static curve warning signs and then ultimately adds enhanced features such as flashing beacons or larger signs if the problems persist. For this reason, **ABC Agency** staff should assess the implementation of the enhanced curve warning systems and the static curve warnings signs at the same time and only deploy one initial treatment per location.

UTILITY POLE RELOCATION

As shown in figure 11, the close lateral placement of utility poles near active traffic can result in severe roadway departure crashes. The only way to eliminate these potential hazards is to relocate the utility poles to locations where they no longer create a risk. This treatment can be challenging when the pole is located in the right-of-way where multiple users share the pole. Where feasible, relocation of the poles laterally can help to reduce the frequency and severity of crashes. Table 36 identifies source information for potential crash modification factors for utility pole relocation. Due to significant variability in pole positions prior to relocation, the estimated safety implications vary. The Plan assigned crash reductions of approximately 29 percent.

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Figure 11. Photograph. Candidate relocation for utility pole (urban environment).

Table 35. CMF values for utility pole relocation.

Facility Type:	All facilities (Rural Undivided for CMF shown)	Crash Severity:	Not specified
Crash Type:	Fixed Object Crashes	CMF:	0.40 to 0.64 for a 5' to 10' lateral shift 0.71 (per FHWA)
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=5240# and https://safety.fhwa.dot.gov/hsip/hrrr/manual/sec47.cfm *Notes:* • Previous studies have focused on rural undivided crashes into fixed objects. One study that evaluated the lateral offset of utility poles resulted in a crash modification function that contrasts the offset before and after the utility pole relocation. For this study, a lateral shift of ten feet is equivalent to a CMF value of 0.40 and a shift of five feet equates to a CMF of 0.64. The FHWA roadside HSIP manual website (noted above) notes a CMF that is less than or equal to 0.71. For this Plan, the conservative value of 0.71 has been assumed for all road types. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The study that generated the crash modification function received a three-star rating.			

The Appendix B spreadsheet summarizes potential sites where utility pole relocation may be considered. The Plan ranks the sites based on observed crash information associated with RwD crashes into utility poles. This information is expanded upon in the Appendix A summary. Table 37 summarizes a proposed improvement plan for utility pole relocations. The Plan for relocating utility poles is expected to reduce pole crashes by approximately 4 crashes per year.

Table 36. Estimated number of RwD crashes based on utility pole relocation.

Facility Type	Estimated Number of Affected Locations	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural multilane divided							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Interstate							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Note:

- For utility pole relocation, assumes improvement of 10% of identified locations (both State system and local roads).
- Cost estimates based on $10,000 per location and assume 5 or fewer pole relocations per site with a maximum cost of approximately $2000 per pole.
- CMF value of 0.71 used for the utility pole analysis.
- Based on a crash level threshold of 4 crashes into a utility pole or light support within a 5-year period.

Suggested implementation is as follows:

1. Utility poles located in close proximity to the roadway can also behave as fixed objects subject to RwD crashes if their placement is not carefully considered. For many locations, existing utility poles preceded agency management. In other instances, the utility poles have been located as far from the roadway as practical for the surrounding terrain. Consequently, the lateral relocation of utility poles may not always be practical and an agency should consider shielding them. The ownership of a utility pole can also vary and more than one utility, including lighting, may depend on the specific utility pole placement. To determine feasibility of relocation, therefore, **ABC Agency** staff should first identify the pole owners and agencies sharing the pole and assess potential for relocation of these fixed objects. The **ABC Agency** could also work with agencies to identify safer placement locations of relocated utility poles. For this Plan, the identified locations are based on sites with a history of RwD crashes into utility poles (see list in Appendix B spreadsheet).

2. Often crashes into a single utility pole shift upstream and downstream over time. This trend suggests the likelihood that there are multiple poles collectively located too close to the road. When this trend is observed, the **ABC Agency** staff should consider initiating a project to relocate (or shield) all of the utility poles along a corridor. During field visits, inspectors can identify these issues by inspecting poles upstream and downstream of the identified corridor locations. Strong indications of this trend would be marks on the poles where a vehicle has scrubbed against the pole and left a scar. **ABC Agency** should consider prioritizing these utility pole corridors for improvement projects.

REMOVE OR SHIELD TREE OR FIXED OBJECTS

At locations where fixed objects are located on the roadside, an errant vehicle that inadvertently exits the roadway may impact these trees or fixed objects if they are positioned too close to the active travel way. When feasible, an agency should completely remove these fixed objects. In many cases, however, the objects may be a large number of trees and removal is simply not practical. For these locations, the agency should shield the trees that cannot be removed.

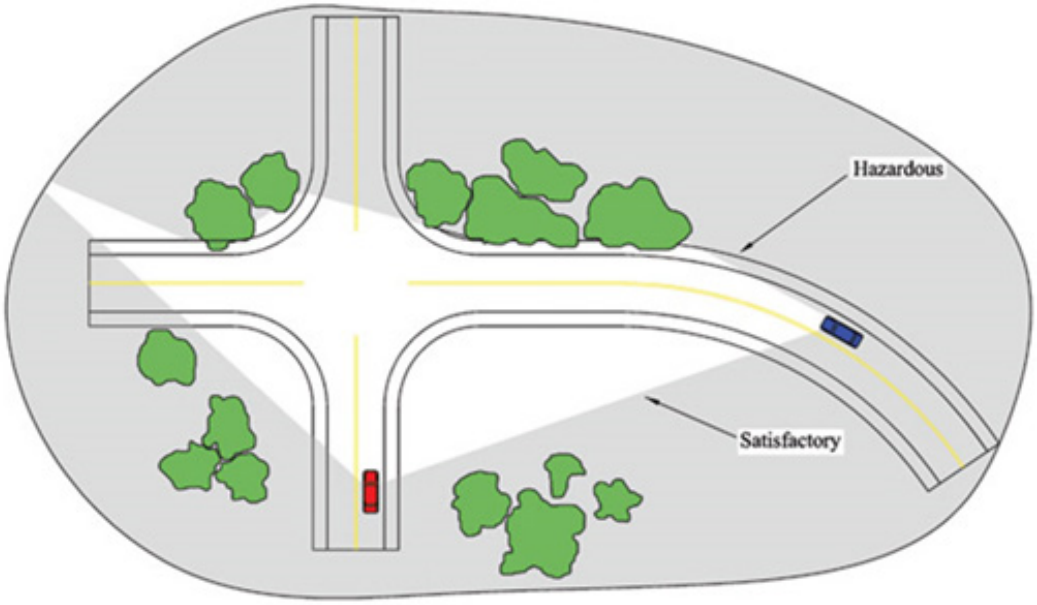

Figure 12. Graphic. Remove or shield trees or fixed objects.

Table 38 summarizes the safety performance resulting from removing or shielding trees or fixed objects. As shown, the published research varies substantially about the expected reduction in crashes, but a conservative expectation is an approximate reduction of 50 percent for fixed object crashes.

Table 37. CMF values to remove or shield trees or fixed objects.

Facility Type: All	Crash Severity: All
Crash Type: Fixed Object, All	CMF: 0.71 (Fixed Objects)
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=2724 http://www.cmfclearinghouse.org/detail.cfm?facid=1044 https://safety.fhwa.dot.gov/hsip/hrrr/manual/sec47.cfm#s47j	
Notes: • Previous studies have resulted in values that vary dramatically. Studies report CMF values of 0.03 (when applied only to fixed object crashes) and 0.62 (all crashes). A conservative CMF of 0.71 is suggested as part of the HSIP manual. For this analysis, the Plan utilizes a conservative CMF value of 0.71 as applied to fixed object crashes. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The CMF = 0.03 received a two-star rating, while the CMF = 0.62 received a three-star rating.	

The Appendix B spreadsheet summarizes potential sites where removing or shielding trees or fixed objects may be considered. The Plan ranks the sites based on observed crash information associated with RwD crashes into utility poles. This information is expanded upon in the Appendix A summary. Table 39 summarizes a proposed improvement plan for removing or shielding these roadside objects. The Plan for removing or shielding trees or fixed objects is expected to reduce fixed object crashes by approximately 30 crashes per year. This crash reduction also equates to a reduction of approximately one fatal crash every two years.

Table 38. Estimated RwD crash reduction based on removal or shielding of trees or fixed objects.

Facility Type	Estimated Number of Candidate Locations (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane	246	$7.38	0.02	0.47	9.33	0.22	4.37
Rural multilane undivided	2	$0.06	0.03	0.39	0.06	< 0.01	0.02
Rural multilane divided	19	$0.57	0.02	0.42	0.63	0.01	0.27
Rural Interstate	92	$2.76	0.02	0.33	5.83	0.10	1.93
Rural Subtotal:	359	$10.77	-	-	15.85	0.33	6.59
Urban 2-lane	19	$0.57	0.01	0.36	0.75	0.01	0.27
Urban multilane undivided	29	$0.87	0.01	0.35	1.11	0.01	0.39
Urban multilane divided	38	$1.14	0.01	0.34	1.60	0.02	0.54
Urban Interstate	131	$3.93	0.02	0.40	9.58	0.16	3.82
Urban Subtotal:	217	$6.51	-	-	13.02	0.20	5.03
Locally Owned or Maintained							
Local Rural	13	$0.39	0.01	0.36	0.48	0.01	0.16
Local Subtotal:	13	$0.39	-	-	0.48	0.01	0.16
Grand Total (On and Off System):	589	$17.67	-	-	29.35	0.54	11.77

Notes:

- For removal or shielding of trees or fixed objects, assumes improvement of 10% of identified locations.
- Cost estimates based on $30,000 per location.
- CMF value of 0.71 used for the tree/fixed object tree analysis.
- Based on a crash level threshold of 5 to 9 crashes into a tree or fixed object within a 5-year period.

Suggested implementation is as follows:

1. The placement of fixed objects in the clear recovery zone can result in an increase in the number of fixed object crashes. For isolated fixed objects, removal of the item is recommended; however, in many cases there are a series of objects and it is not practical to entirely remove the objects. In this scenario, it may be appropriate to shield them. This Plan identified sites where recurring fixed object crashes persist for rural and urban locations. As a first implementation step, **ABC Agency** staff should review the prioritized sites included in the Appendix B spreadsheet and determine if any of these locations overlap with proposed improvement or safety enhancement projects. For any of these overlapping sites, the removal or shielding of the fixed object should be addressed as part of these projects. If overlapping projects are not identified, the **ABC Agency** should

systematically being to address these sites by initiating projects to relocate (or shield) these fixed objects.

2. This Plan also included a countermeasure to relocate utility poles (see previous treatment) and a variety of treatments to add or improve barriers. **ABC Agency** staff can explore these treatments collectively and one or more may potentially be considered for a given site; therefore, the **ABC Agency** should assess this treatment at the same time as these other treatments so that safety initiatives can be combined and duplication of efforts can be minimized.

CULVERT END TREATMENT AND DITCH IMPROVEMENT

A preferred drainage treatment is to locate culverts and drainage ditches so that they are not located immediately adjacent to active travel lanes and, consequently do not pose threats to roadway users. In many cases, however, the available right-of-way constrains the placement of these drainage features. When this occurs, transportation professionals should design culvert end treatments and associated drainage ditches that are located in close proximity to a road so that they are traversable.

Source: FHWA

Figure 13. Photograph. Roadside culvert and treatment and associated ditch improvement.[6]

Table 40 summarizes published resources associated with the safety of culvert end treatment and ditch improvements; however, this proven treatment does not have a designated crash modification factor. For this reason, this Plan uses an estimated assumption that 50 percent of crashes related to culverts and ditches will be eliminated if these treatments are improved so that they are traversable or shifted laterally so that they no longer pose a threat to drivers of errant vehicles.

Table 39. CMF values for culvert end treatment and ditch improvement.

Facility Type:	Not Specified	Crash Severity:	All
Crash Type:	Culvert end treatment and ditch RwD crashes	CMF:	None documented – since proven treatment assume CMF=0.50 (culvert end treatment and ditch related crashes)
Additional Information: https://safety.fhwa.dot.gov/hsip/hrrr/manual/sec47.cfm *Note: Due to the unique site characteristics that govern this type of treatment, a CMF is not available but as noted in the FHWA HSIP Manual (see link above), this is a proven treatment.*			

The Appendix B spreadsheet summarizes potential sites where improving culvert end treatments and associated ditch sideslopes may be considered. The Plan ranks the sites based on observed crash information associated with RwD crashes into culverts or ditches. Appendix A expands on this information. Table 41 summarizes a proposed improvement plan for minimizing culvert or ditch related RwD crashes. The Plan for this treatment is expected to reduce RwD crashes by approximately 142 crashes per year. This crash reduction also equates to a reduction of approximately two to three fatal crashes each year.

Suggested implementation is as follows:

1. The placement of culverts is common at driveway locations where the culvert aligns with the roadside ditch. In addition, often a culvert is positioned laterally across the road. The common issue associated with these treatments is that the orientation of the culvert treatments or the slopes associated with the roadside ditches have the potential to become roadside hazards. For this Plan, candidate locations where culvert end treatment and ditch-related crashes occur are priorities in the Appendix B spreadsheet. Prior to initiating an improvement project, **ABC Agency** staff should examine the individual sites and determine feasibility of improvement. The relocation of a roadside ditch, for example, may not be feasible and a site evaluation can help make this determination. Where possible, however, culvert end treatments should be modified to be traversable, shielded, or outside of the roadside clear zone.

2. For locations where the relocation of the roadside ditch is not feasible or where a culvert cannot be modified or extended, an alternative option may be to shield the roadside areas with a barrier. For this reason, **ABC Agency** should explore this culvert end treatment and ditch improvement implementation plan at the same time as they consider the add barrier treatment option.

Table 40. Estimated RwD crash reductions for culvert end treatment and ditch improvement.

Facility Type	Estimated Number of Candidate Locations (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural multilane undivided							
Rural multilane divided							
Rural Interstate							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Interstate							
Urban Subtotal:							
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For culvert or ditch improvement, assumes improvement of 30% and 5% of identified system and local roadways, respectively.
- Cost estimates based on $1000 per location.
- CMF value of 0.50 used for the culvert end treatment and ditch analysis.
- Based on a crash level threshold of 4 crashes into a culvert end treatment or ditch within a 5-year period.

SHOULDER WIDENING WITH DRAINAGE GRADING IMPROVEMENTS

Roadways with minimal shoulder widths do not provide space for errant vehicles that exit their travel lane to correct their path (while still on a paved surface). Shoulders also provide a benefit for disabled vehicles to safely exit the active travel lanes. Consequently, providing wider shoulders can be an effective safety treatment. In many cases, however, a roadside ditch or other drainage feature will be affected due to this type of widening. When this occurs, the treatment should consider the shoulder widening and the drainage improvements collectively.

Table 42 summarizes published resources associated with the safety of shoulder widening (this CMF is the same with or without the added cost of drainage improvements). This Plan used an

estimated assumption that 39 percent of crashes related to shoulder widths will be eliminated if the shoulders are widened to meet State guideline recommendations.

Table 41. Shoulder widening with drainage grading improvements CMF values.

Facility Type:	Not Specified	Crash Severity:	All
Crash Type:	Run-off-road, Single Vehicle	CMF:	0.61 [Run off road, single vehicle] 0.62 [all crash types]
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=6659 and http://www.cmfclearinghouse.org/detail.cfm?facid=6661 *Notes:* • The primary facility type identified in previous studies focused on a variety of roadway types and all severity levels. The CMF value of 0.61 has been assumed for shoulder widening activities. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The shoulder widening CMF values of 0.61 and 0.62 both received a four-star rating at the CMF Clearinghouse. For the purposes of this Plan, the CMF=0.61 value has been used.			

The Appendix B spreadsheet summarizes potential sites where widening the shoulder should be considered. The Plan ranks the sites based on predicted crash information. Table 43 summarizes a proposed improvement plan for minimizing RwD crashes associated with narrow shoulders. The Plan for this treatment is expected to reduce RwD crashes by approximately 75 crashes per year. This crash reduction also equates to the elimination of approximately one fatal crash each year.

Table 42. Estimated RwD crash reductions for shoulder widening with drainage grading improvements.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For widening highway shoulders with drainage grading improvements, the Plan assumes improvement of 10% and 5% of identified system and local locations, respectively.
- Cost estimates based on $80,000 per mile for two lane or local roads up to $200,000 per mile for multilane roads.
- CMF value of 0.61 used for installing Shoulder widening with drainage grading improvements.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis) by 20% or more.

Suggested implementation is as follows:

The widening of roadway shoulders and upgrade of adjacent drainage is generally considered to be a rural issue; however, a small number of urban sites that do not have raised curb with an enclosed drainage system could also be viable candidates for this type of a treatment. For this Plan, candidate locations that would benefit from shoulder widening and associated drainage improvements are included in the Appendix B spreadsheet. The need for drainage improvements is a site-specific issue. Prior to initiating an improvement project, **ABC Agency** staff should examine the individual sites and determine feasibility of improvement and assess if the shoulder widening can be accomplished without drainage grading improvements. If the drainage improvements are not required, then the next treatment (shoulder widening without drainage grading improvements) should be implemented.

SHOULDER WIDENING WITHOUT DRAINAGE GRADING IMPROVEMENTS

Roadways with minimal shoulder widths do not provide space for errant vehicles that exit their travel lane to correct their path (while still on a paved surface). Shoulders also provide a benefit for disabled vehicles to safely exit the active travel lanes. Consequently, providing wider shoulders can be an effective safety treatment. In many cases, however, a roadside ditch or other drainage feature will be affected due to this type of widening. When this occurs, the treatment should consider the shoulder widening and the drainage improvements collectively (see previous treatment). In other cases, the road sideslope may be relatively flat and this grade can accommodate shoulder widening without significant drainage improvements.

Figure 14. Photograph. Shoulder pavement candidate.

Table 44 summarizes published resources associated with the safety of shoulder widening (this CMF is the same with or without the added cost of drainage improvements). This Plan used an estimated assumption that 39 percent of crashes related to shoulder widths will be eliminated if the shoulders are widened to meet State guideline recommendations.

Table 43. Shoulder widening without drainage grading improvements CMF values.

Facility Type:	Not Specified	Crash Severity:	All
Crash Type:	Run-off-road, Single Vehicle	CMF:	0.61 [Run off road, single vehicle] 0.62 [all crash types]
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=6659 and http://www.cmfclearinghouse.org/detail.cfm?facid=6661 *Notes:* • The primary facility type identified in previous studies focused on a variety of roadway types and all severity levels. The CMF value of 0.61 has been assumed for shoulder widening activities. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The shoulder widening CMF values of 0.61 and 0.62 both received a four-star rating at the CMF Clearinghouse. For the purposes of this Plan, the CMF=0.61 value has been used.			

The Appendix B spreadsheet summarizes potential sites where widening the shoulder should be considered. The Plan ranks the sites based on predicted crash information. Table 45 summarizes a proposed improvement plan for minimizing RwD crashes associated with narrow or no shoulders. The Plan for this treatment is expected to reduce RwD crashes by approximately 56 crashes per year. This crash reduction also equates to the elimination of approximately one fatal crash each year.

Suggested implementation is as follows:

The widening of roadway shoulders is generally considered to be a rural issue; however, a small number of urban sites that do not have raised curb could also be viable candidates for this type of a treatment. For this Plan, candidate locations that would benefit from shoulder widening and that do not require additional drainage improvements are included in the Appendix B spreadsheet. The need for drainage improvements is a site-specific issue. Prior to initiating an improvement project, **ABC Agency** staff should examine the individual sites and determine feasibility of improvement and assess if the shoulder widening can be accomplished without drainage grading improvements. If the drainage improvements are required, then the previous treatment (shoulder widening with drainage grading improvements) should be implemented.

Table 44. Estimated RwD crash reductions for shoulder widening without drainage grading improvements.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural Subtotal:			-	-			
Urban 2-lane							
Urban multilane undivided							
Urban multilane divided							
Urban Subtotal:			-	-			
Locally Owned or Maintained							
Local Rural							
Local Urban							
Local Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For widening highway shoulders without drainage grading improvements, the Plan assumes improvement of 10% and 2% of identified system and local locations, respectively.
- Cost estimates based on $65,000 for two lane or local roads up to $165,000 for multilane roads.
- CMF value of 0.61 used for widening shoulders without drainage grading improvements.
- Analysis based on locations where the observed number of crashes exceeded the expected number of crashes (using predictive analysis) by 20% or greater.

FLATTENING MEDIAN SIDESLOPES

In some instances, such as extreme terrain locations, an errant vehicle cannot safely traverse the adjacent median sideslope. This trend tends to occur when the ratio of vertical to horizontal slopes is steeper than one foot vertically for every three feet horizontally. If this steeper grade is sustained, an errant vehicle may not be able to recover and could overturn. Table 46 demonstrates that flattening median sideslopes can result in a reduction of approximately 42 percent of overturn crashes.

Table 45. CMF values for flattening median sideslopes.

Facility Type:	Divided roadway	Crash Severity:	All
Crash Type:	Overturn / Rollover	CMF:	0.58 (per FHWA) 0.91 (cross median, fixed object, and run-off-road) [Used CMF = 0.91]
Additional Information: https://safety.fhwa.dot.gov/hsip/hrrr/manual/sec47.cfm and http://www.cmfclearinghouse.org/detail.cfm?facid=6914			
Notes: • Flattening sideslopes is a potential treatment for the roadside slope adjacent to the paved surface. The FHWA reference above notes that this type of improvement is appropriate on the outside of horizontal curves, locations where the roadside sideslopes exceed values of a 1 (Vertical):3 (Horizontal) slope, or sites experiencing overturn crashes. The FHWA site suggests a CMF value of approximately 0.58 may be suitable for flattening roadway sideslopes. This Plan uses the CMF Clearinghouse value of 0.91. • Research documented in NCHRP Report 794: Median Cross-Section Design for Rural Divided Highways notes a CMF value of 0.91 for cross median, fixed object, and run-off-road crashes at rural divided highway locations. The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The CMF = 0.91 received a three-star rating.			

The Appendix B spreadsheet summarizes potential sites where flattening median sideslopes at locations that do not have median barrier may be considered. The Plan focuses on divided multilane highways and ranks the sites based on observed crash information associated with rollover RwD crashes at these locations. Appendix A expands on this information. Table 47 summarizes a proposed improvement plan for minimizing crashes that occur at these steep median sideslope locations. Due to the limited number of sites identified, this treatment can be expected to result in a reduction of approximately one crash each year.

Table 46. Estimated RwD crash reductions due to flattening median sideslopes.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Urban Interstate							
Urban Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For flattening median sideslopes, one site (an urban interchange) had 20 to 29 RwD crashes during a five-year period and so this site is suggested as the best potential candidate for this treatment. Based on cost effectiveness, this is the only initial recommendation for this treatment.
- Cost estimates of $792,000 per mile (based on $150 per foot x 5280 feet).
- CMF value of 0.91 used for flattening median sideslope analysis.

Suggested implementation is as follows:

1. The identification of candidate improvement locations included in this Plan is based on locations that are divided highways where currently median barrier is not present and where rollover crashes occur. Prior to initiating these improvement efforts, ABC Agency staff should examine the identified locations to determine the feasibility of flattening the sideslopes. The Appendix B spreadsheet identifies these candidate sites, but this Plan is based on an assumption that one specific urban interstate site can be improved. **ABC Agency** staff may want to assess this assumption and modify it following this field inspection step.

2. Flattening the sideslope for an existing median can introduce additional issues including drainage modification, removal of existing fixed objects, and substantial import of suitable soil material. Consequently, the **ABC Agency** staff should consider evaluation of the treatment in conjunction with that of adding median barrier to minimize redundant assessments. It may also be appropriate to consider only one of the treatment options, and this joint assessment will help to identify the optimal solution.

ADD BARRIER

In the event that roadway improvements cannot prevent a vehicle from inadvertently exiting the roadway, the **ABC Agency** should design the roadside environment to minimize crash severity. One common way to reduce crash severity is to install roadside barriers. Table 48 notes that the addition of a barrier can result in an approximate 16 percent reduction in run-off-road crashes. For this analysis the barrier type cost is based on guardrail.

Table 47. CMF values for adding barrier

Facility Type: Varies (2 to 5 lanes)	Crash Severity: KABC
Crash Type: Run-off-road	CMF: 0.84
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=8348#commentanchor *Note:* The CMF Clearinghouse includes a variety of "add barrier" studies and the associated CMF values differ substantially for the varying studies. Consequently, the CMF=0.84 value is used because it is from a United States evaluation and developed using reliable statistical procedures. The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The CMF = 0.84 received a four-star rating.	

The Appendix B spreadsheet summarizes sites where the potential addition of roadside barrier is expected to help minimize crashes. The Plan ranks the sites based on observed crash information associated with rural and urban locations associated with RwD crashes at locations where barrier is not currently present. Appendix A expands on this information. Table 49 summarizes a proposed improvement plan for adding barrier at locations with run-off-road crashes where barrier is not currently present.

Table 48. Estimated RwD crash reductions due to adding barrier.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural 2-lane							
Rural Interstate							
Rural Subtotal:			-	-			
Urban Interstate							
Urban Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For adding barrier at locations with crashes into trees, poles, or other fixed objects, assumes improvement of 5% and 2% of identified system and local roadways.
- Cost estimates based on $700,000 per mile.
- CMF value of 0.84 used for adding barrier.
- Based on a crash level threshold of 2 crashes due to rollover/overturn within a 5-year period.

IMPROVE BARRIER

Locations with steep roadside terrain or heavily wooded land are often shielded by roadside barrier. In many cases, barrier is constructed and remains in place for many years. In other cases, barrier is frequently impacted and the department of transportation is required to maintain the barrier. In addition, over time the design of an effective barrier may change. These design modifications could require barrier reconstruction or improvement. Recently the United States began a transition from NCHRP 350 barrier crash criteria from the 2016 AASHTO Manual for Assessing Safety Hardware (MASH). For this treatment to improve barrier, the improvements should be designed for the current criteria for the location.

Table 50 notes that improving barrier to current standards can be estimated to reduce run-off-road crashes by approximately 33 percent.

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Figure 15. Photograph. Improve barrier to current standards.

Table 49. CMF values for improving barrier to current standards.

Facility Type: Not specified	Crash Severity: ABC, KABC
Crash Type: Run-off-road	CMF: 0.67 to 0.68 (used 0.67)
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=41 and http://www.cmfclearinghouse.org/detail.cfm?facid=5551 *Notes:* • Studies included general sites (0.67) as well as rural multilane divided locations (0.68). This Plan utilized the slightly more conservative value of 0.68. The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or more reliable rating. The CMF=0.67 study received a two-star rating, while the CMF=0.68 received a four-star rating. • Due to the recent transition in the United States from NCHRP 350 barrier crash criteria to the requirements identified in the 2016 AASHTO *Manual for Assessing Safety Hardware* (MASH), it is not clear how this shift will influence related CMFs. The cited CMF studies pre-dated the new 2016 MASH criteria. In all cases, any barrier improvements should be designed for current standards.	

The Appendix B spreadsheet summarizes potential sites where barrier is present but continues to be a location with barrier-related crashes. The Plan ranks the sites based on observed crash information associated with rural and urban locations associated with RwD crashes at locations where barrier is not currently present. Appendix A expands on this information.

Table 51 summarizes a proposed improvement plan for improving barrier at locations with run-off-road crashes into existing barrier.

Table 50. Estimated RwD crash reductions due to improving barrier.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Rural Interstate							
Rural Subtotal:			-	-			
Urban multilane undivided							
Urban Interstate							
Urban Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- The Plan assumes improvement of 1% and 2% of identified system and local locations, respectively.
- Cost estimates based on $700,000 per mile.
- CMF value of 0.67 used for improving barrier.
- Based on a crash level threshold of 30 to 49 RwD crashes within a 5-year period.

INSTALL MEDIAN BARRIER

The installation of a median barrier is a reasonable treatment at locations where the maintaining agency cannot practically flatten the median sideslope or relocate fixed objects outside of the median area. Table 52 notes that an approximate reduction of 65 percent for cross median crashes at locations with median barrier installations.

Table 51. CMF values for installing median barrier.

Facility Type:	Divided	Crash Severity:	All
Crash Type:	Cross median RwD	CMF:	0.31 to 0.35 (varies) [Used 0.35]
Additional Information: http://www.cmfclearinghouse.org/detail.cfm?facid=5445# and http://www.cmfclearinghouse.org/detail.cfm?facid=7091#			
Notes: • The primary median barrier target crash identified in previous studies focused on cross median crashes at divided highways. CMF values range from 0.31 for to 0.35. • The FHWA CMF Clearinghouse uses a five-star rating scale to represent CMF quality where a value of five represents the highest or most reliable rating. The median barrier CMF value of 0.31 received a five-star rating at the CMF Clearinghouse and the CMF value of 0.35 received a three-star designation. The plan uses the more conservative 0.35 CMF value.			

The Appendix B spreadsheet summarizes potential sites where a median barrier is not currently present. Appendix A expands on this information. Table 53 summarizes a proposed improvement plan for installing median that would result in a reduction of approximately five to six crashes per year.

Table 52. Estimated RwD crash reduction due to installing median barrier.

Facility Type	Estimated Length of Improvements (mi)	Construction Cost ($ Million)	Ratio of Type K to RwD Crashes	Ratio of Type KABC to RwD Crashes	After Treatment – RwD Crashes		
					Annual Targeted RwD Crash Reduction	Annual Estimated K Crash Reduction	Annual Estimated KABC Crash Reduction
On State System							
Urban multilane divided							
Urban Interstate							
Urban Subtotal:			-	-			
Grand Total (On and Off System):			-	-			

Notes:

- For installing median barrier at locations that currently do not have existing barrier treatments, assumes improvement of 40% and 10% of identified system and local roadways.
- Cost estimates based on $700,000 per mile.
- CMF value of 0.35 used for adding barrier.
- Based on a crash level where the observed number of crashes is greater than the number of expected crashes before installation of the median barrier.

EDUCATION AND ENFORCEMENT CAMPAIGNS

A wide variety potential education and enforcement campaigns can help raise driver awareness and ultimately contribute to a reduction in RwD crashes. For the purposes of this Plan, each of the **ABC Agency** districts will receive $xx for a total allocation of $xx.

MASH UPGRADE FOR ABC AGENCY BRIDGE RAIL RETROFIT

Due to the recent change in crash testing standards, several **ABC Agency** bridge rails require retrofit to MASH standards in the near future. This is an ongoing research project and so will be systematically applied to all applicable facilities. At this time, there is no current safety assessment method or estimated cost per site for this new treatment.

PERFORMANCE MEASURES

As the implementation of safety treatments occurs over time, assessing performance measures is an effective way to assess ongoing success with the Plan. This observation can then help **ABC Agency** refine future proven safety treatments. Two types of performance measures may be considered:

1. Production performance measures that track the implementation of treatments can be used to assess the quantity of efforts expended toward reaching future safety goals.

2. Effectiveness performance measures that evaluate the effectiveness of the individual treatments can compare the estimated to actual safety metrics.

Table 54 provides an example format for evaluating production performance measures. The measures shown would be updated based on the individual treatment implementation activities. Table 55 provides one example template that could be used for tracking the effectiveness performance measures that are specifically targeted at reducing crashes.

Table 53. Example production performance measures table.

Treatment	Measure	Target Initiation Timeline	Annual Completion
Center Rumble Stripes/Strips		TBD	Actual results
Edgeline Rumble Stripes/Strips		TBD	Actual results
6” Wide Centerline Pavement Markings		TBD	Actual results
6” Wide Edgeline Pavement Markings		TBD	Actual results
Lighting Improvements		TBD	Actual results
High Friction Surface Treatment		TBD	Actual results
Static Curve Warning Sign (Standard)		TBD	Actual results
Enhanced Curve Warning System		TBD	Actual results
Utility Pole		TBD	Actual results
Remove or shield tree or fixed objects		TBD	Actual results
Culvert End Treatment and Ditch Improvement		TBD	Actual results
Flattening Median Sideslopes		TBD	Actual results
Add Barrier		TBD	Actual results
Improve Barrier		TBD	Actual results
Install Median Barrier with a mow strip		TBD	Actual results
TBD = To Be Determined			

Table 54. Example effectiveness performance measures table.

Countermeasure	Year Improvements Implemented	Year Evaluation Plan Developed	Year Evaluation Completed	Estimated Crash Reduction	Actual Crash Reduction
Center Rumble Stripes/Strips					
Edgeline Rumble Stripes/Strips					
6” Wide Centerline Pavement Markings					
6” Wide Edgeline Pavement Markings					
Centerline Raised Pavement Markings					
Edgeline Raised Pavement Markings					
Lighting Improvements					
High Friction Surface Treatment					
Static Curve Warning Sign (Standard)					
Enhanced Curve Warning System					
Utility Pole					
Remove or shield tree or fixed objects					
Culvert End Treatment and Ditch Improvement					
Shoulder Widening with Drainage Grading Improvements					
Shoulder Widening without Drainage Grading Improvements					
Flattening Median Sideslopes					
Add Barrier					
Improve Barrier					
Install Median Barrier					

SUMMARY

Due to recent economic improvements in the United States, the number of crashes has continued to increase. Over the last decade, the transportation profession has continued to learn more about the effectiveness of individual safety treatments and their associated effectiveness. With this added knowledge about how these countermeasures can contribute to crash reductions, this implementation Plan is intended to assist the **ABC Agency** with determining how to target valuable safety resources in an effort to further reduce the number and severity of RwD crashes. This Plan specifically focuses on lower cost treatments that the **ABC Agency** can deploy at numerous sites where RwD crashes are likely.

The focus of this plan is on identification of candidate countermeasures, deployment levels, and costs that collectively result in an estimated 19 to 20 lives saved with a corresponding 1090 prevented RwD crashes (see table 9, table 10, table 11, and table 12).

REFERENCES

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3. National Highway Traffic Administration. *Fatality Analysis Reporting System (FARS) Analytical User's Manual 1975-2016.* Report No. DOT HS 812 447, NHTSA, U.S. Department of Transportation, Washington, D.C., 2017.

4. Preston, H., R. Storm, J.D. Bennett, and B. Wemple. *Systemic Safety Project Selection Tool*. Report No. FHWA-SA-019, FHWA, U.S. Department of Transportation, Washington, D.C., 2013.

5. American Association of State Highway and Transportation Officials (AASHTO). *Highway Safety Manual.* AASHTO, 2010.

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APPENDIX A

Appendix A is a separate PDF document that contains the **ABC Agency** crash data analysis for the period extending from 2012 to 2016. This Roadway Departure Implementation Plan is based on this analysis. Appendix A includes a summary of the **ABC Agency** RwD network screening SPFs (for facilities where there was an adequate sample size for SPF development).

APPENDIX B

Appendix B includes three separate Microsoft Excel files. The file named *Countermeasures_matrix.xls* provides information used to develop the strategy matrix and the benefit-cost evaluation. The second and third spreadsheets (titled *Candidate_Sites_State.xls* and *Candidate_Sites_Local.xls*) provides information on individual highway locations for the various countermeasures. The individual sites are further identified by a ranking for application of a treatment based on the analysis summarized in the Appendix A document.

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