Effectiveness of Centerline Rumble Strips and Cable Median Barriers

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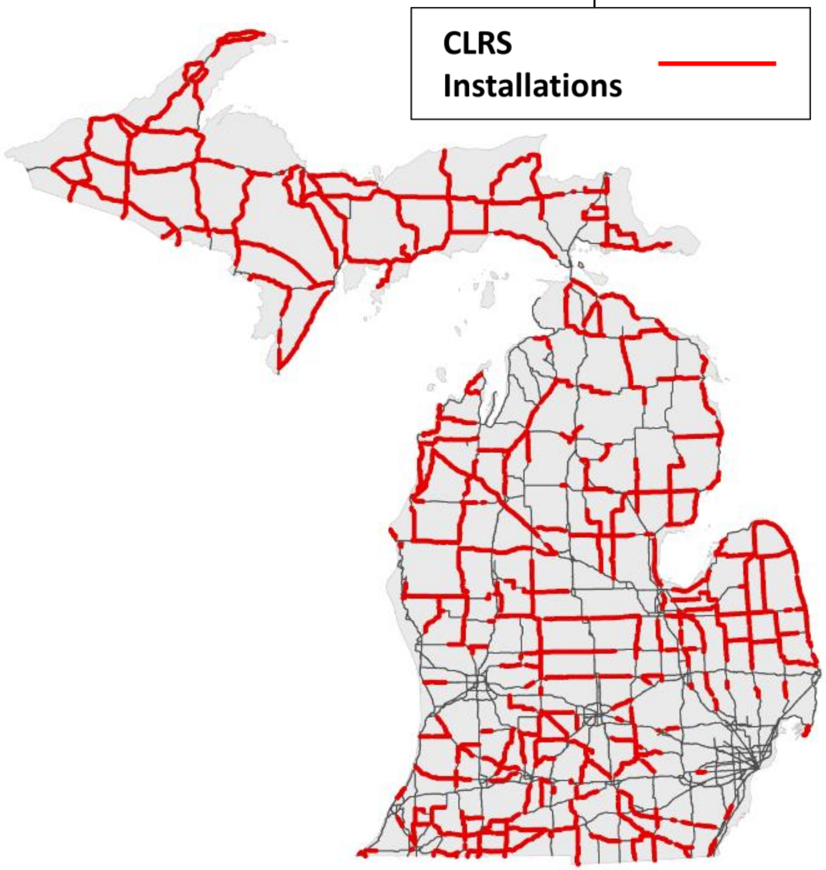
Lane Departure Crashes in Michigan

- From 2004 to 2007, lane departure crashes accounted for
  - 17.2% of all crashes in Michigan
  - 47.4% of fatal crashes in Michigan
- MDOT lane departure initiatives
  - Non-Freeways: 4000+ miles of rumble strips
  - Freeways: 300+ miles of cable median barriers

MDOT’s Non-Freeway Rumble Strip Initiative

- Statewide implementation on undivided trunklines from 2008-2010
  - CLRS
    - Speed limit of 55 mph
    - Paved roadway width > 20 ft
  - CLRS+SRS
    - Speed limit of 55 mph
    - Paved shoulders ≥ 6 ft wide



MDOT Rumble Strip Research Objectives

- Two-phase MDOT research
- Determine impact of CLRS on:
  - Driver behavior
  - Bicyclists
  - Noise
  - Crashes and injuries

Phase 1

Phase 2

RUMBLE STRIP EVALUATION #1:
Driver Behavior Impacts

Driver Behavior Study

- Before-and-after observational study of driver behavior on 10 roadways
  - Lateral placement within the travel lane
  - Encroachments onto the centerline
  - Encroachments onto the edgeline
  - Passing attempts
  - High risk behavior

Data Collection

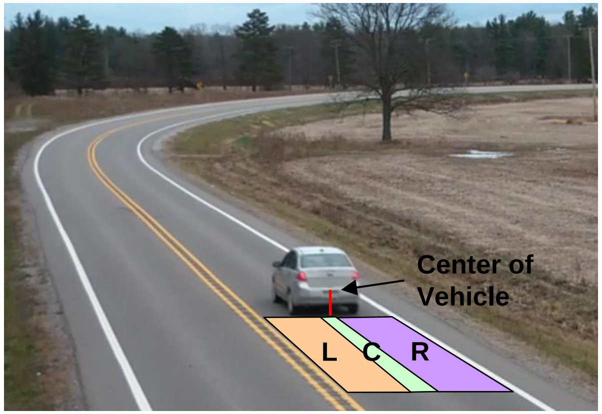
- Pole mounted HD video cameras
  - 20 ft high
  - 1000’ of roadway per camera
  - One camera for curves
  - Two opposing cameras in passing zones
  - 4 to 10 hours per location
  - Dry/daytime
  - Same location B & A

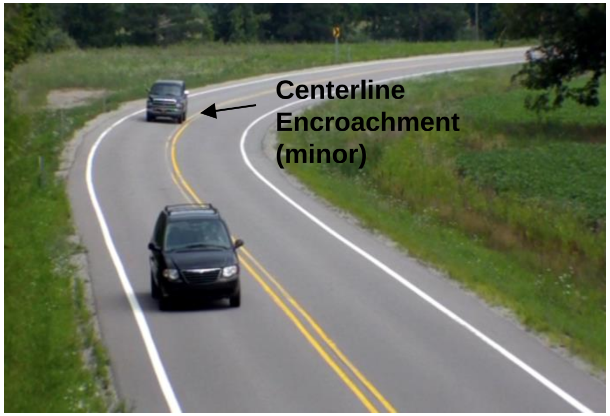
Passing Zone Data Extraction

- 700+ hours
- Manual review
- For each vehicle:
  - Was the vehicle in passing position?
  - Was a pass attempted?
  - Was the pass completed?
  - Was the pass aborted?
  - Other erratic behavior

Curve Data Extraction

- For each vehicle:
  - Left curve vs. right curve
  - Lateral lane position
    - Curve
    - Adjacent tangent section
  - Encroachments
    - Tire touch
    - Tire across





Measures of Effectiveness

- Passing Events
  - % attempting a passing maneuver
  - % aborting a passing maneuver
- Encroachments
  - % encroaching onto the centerline
  - % encroaching onto the edgeline
- Lane Positioning
  - % left
  - % center
  - % right

Passing Results

- ~78,000 total vehicular observations

MOE	Before RS	After RS	Significant?
Passing Attempts (as % of Total Vehicles)	1.6%	1.5%	No
Passing Attempts (as % of Vehicles in Passing Position)	9.9%	10.6%	No
Aborted Passing Attempts (as % of Total Passing Attempts)	2.3%	2.3%	No

Encroachment Results

- ~50,000 total vehicular observations

Geometry	EDGELINE Encroachments*			CENTERLINE Encroachments		
	Before	After	Significant?	Before	After	Significant?
Tangent	10.5%	6.6%	Yes	1.5%	0.6%	Yes
Left Curves	13.2%	4.5%	Yes	11.9%	1.5%	Yes
Right Curves	11.6%	6.6%	Yes	0.6%	0.4%	No

Reduced "Corner Cutting"

*Only sites where SRS were installed

Lane Positioning Results

CLRS-Only

Geometry	LEFT of Center			CENTERED			RIGHT of Center		
	Before	After	Significant?	Before	After	Significant?	Before	After	Significant?
Tangent	22.3%	18.6%	Yes	36.3%	48.4%	Yes	41.4%	33.0%	Yes
Left Curves	40.8%	19.4%	Yes	33.1%	54.9%	Yes	26.1%	25.7%	No
Right Curves	6.3%	7.1%	No	24.7%	45.3%	Yes	69.0%	47.6%	Yes

CLRS & SRS

Geometry	LEFT of Center			CENTERED			RIGHT of Center		
	Before	After	Significant?	Before	After	Significant?	Before	After	Significant?
Tangent	32.9%	9.6%	Yes	34.9%	68.7%	Yes	32.2%	21.6%	Yes
Left Curves	20.0%	4.5%	Yes	33.8%	72.5%	Yes	46.2%	22.9%	Yes
Right Curves	21.5%	1.8%	Yes	34.6%	67.5%	Yes	43.9%	30.7%	Yes

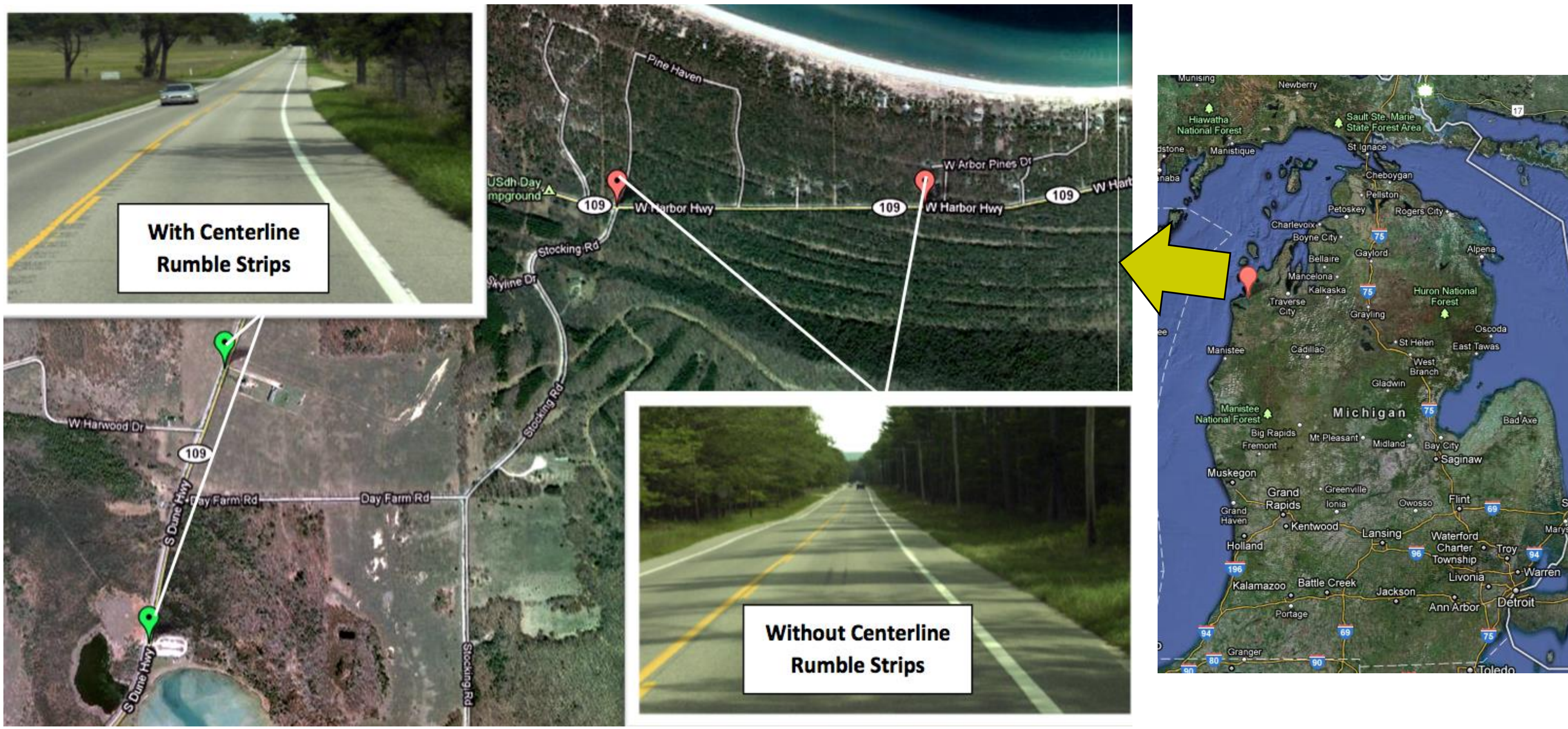
Conclusions - Driver Behavior

- Centerline rumble strips
  - Improve central lane positioning tendencies
  - Decrease centerline encroachments
    - "Corner-cutting" through left-curves
  - Do not negatively impact passing maneuvers
- Shoulder rumble strips (in addition to CLRS)
  - Additional improvements to central lane positioning
  - Decrease edgeline encroachments
    - "Corner-cutting" through right curves

RUMBLE STRIP EVALUATION #2:

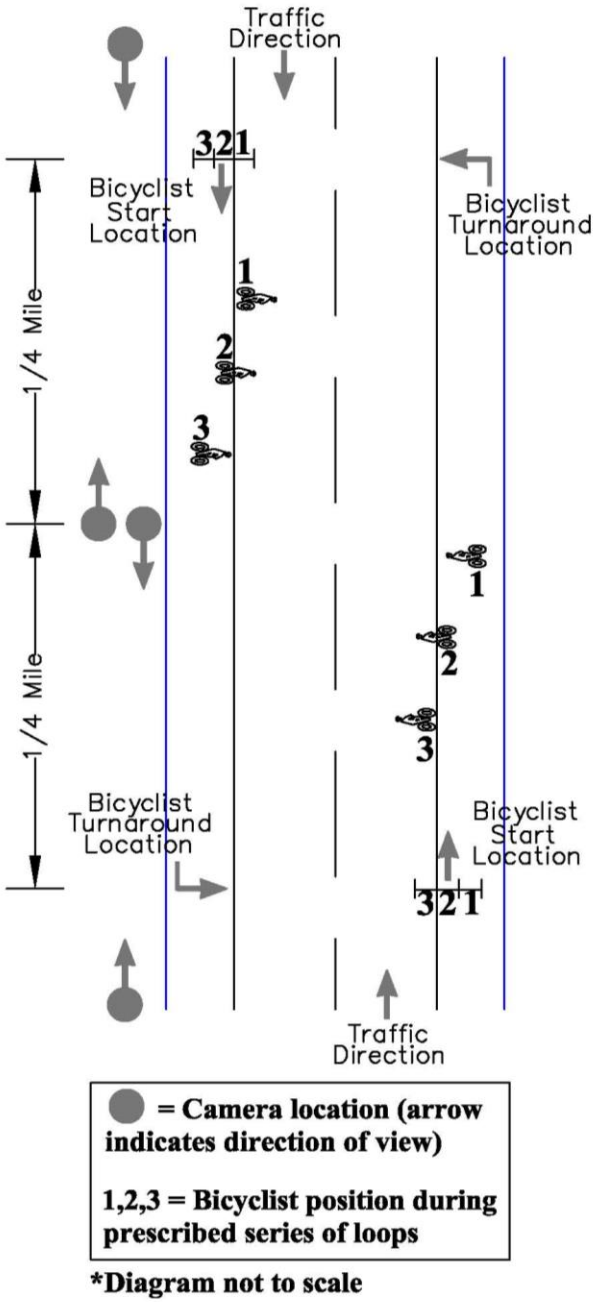
Impacts on Driver Behavior while Passing Bicyclists

M-109 Bicycle Study Site



Data Collection

- Four video cameras per site
- 2 WSU bikers per site
  - Continuous 1 mile loops
  - One biker always on either side
- 10 loops ridden in each position
  - Center of shoulder
  - Left shoulder edge
  - Right lane edge
- 5 hours



Data Extraction

- For each vehicle passing a bicyclist:
  - Bicyclist positioning within the lane or shoulder
  - Vehicle type
  - Number of cyclists
  - Opposing vehicle presence
  - Did the vehicle contact the centerline?
  - Did the vehicle cross at least halfway into the opposing lane?

Full CLRS Crossover

Group of Cyclists (No CLRS)

Bicycle Study Results

MOE	% of Vehicles w/o CLRS	% of Vehicles w/ CLRS	Percent Difference
Vehicle Contacted the Centerline	79.0%	71.1%	**-12.3%***
Vehicle Crossed at Least Halfway into Opposing Lane	19.7%	14.2%	**-19.2%***

* Statistically Significant

Conclusions – Bicyclist Impacts

- While passing bicyclists where CLRS are present, drivers are:
  - Less likely to contact or cross the centerline
    - Particularly for individual bicyclists
  - More likely to crowd the bicyclist
    - This increases the more leftward the bicyclists’ position
- “Share the Road” signs had little impact on the lateral positioning of vehicles

W11-1 / W16-1
Share the Road with Bicyclists assembly

RUMBLE STRIP EVALUATION #3:

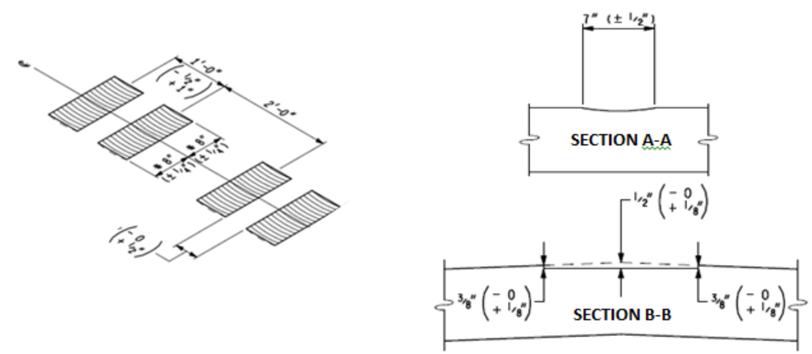
Roadside Noise Impacts

Field Study

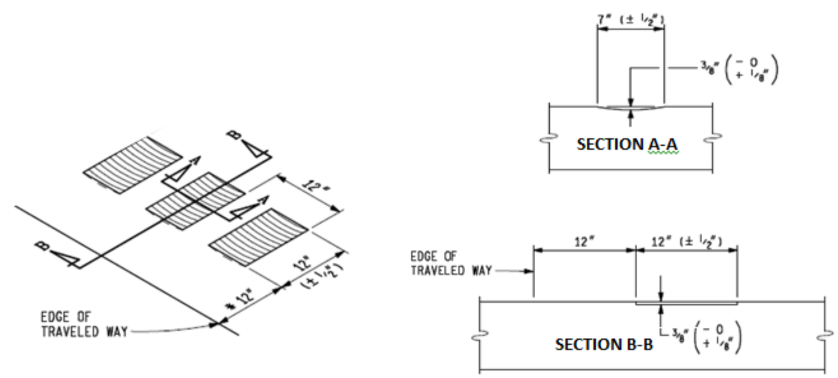
- 12 sites
- Chrysler minivan used as test vehicle (55 mph)
- 40 test vehicle passes per site
  - “Controlled pass-by” (CPB) method
  - 20 on CLRS
  - 20 off CLRS
  - Additional 20 passes on SRS (where present)
- Random truck pass-bys were also recorded
  - All were “off” rumble strips
- 3 center depth measurements per site

Objectives

- Determine increases in roadside noise associated with rumble strips
- Determine effects of:
  - Depth
  - Pavement type
  - Baseline noise



a. Centerline Rumble Strips



b. Shoulder Rumble Strips

Example Noise Measurement

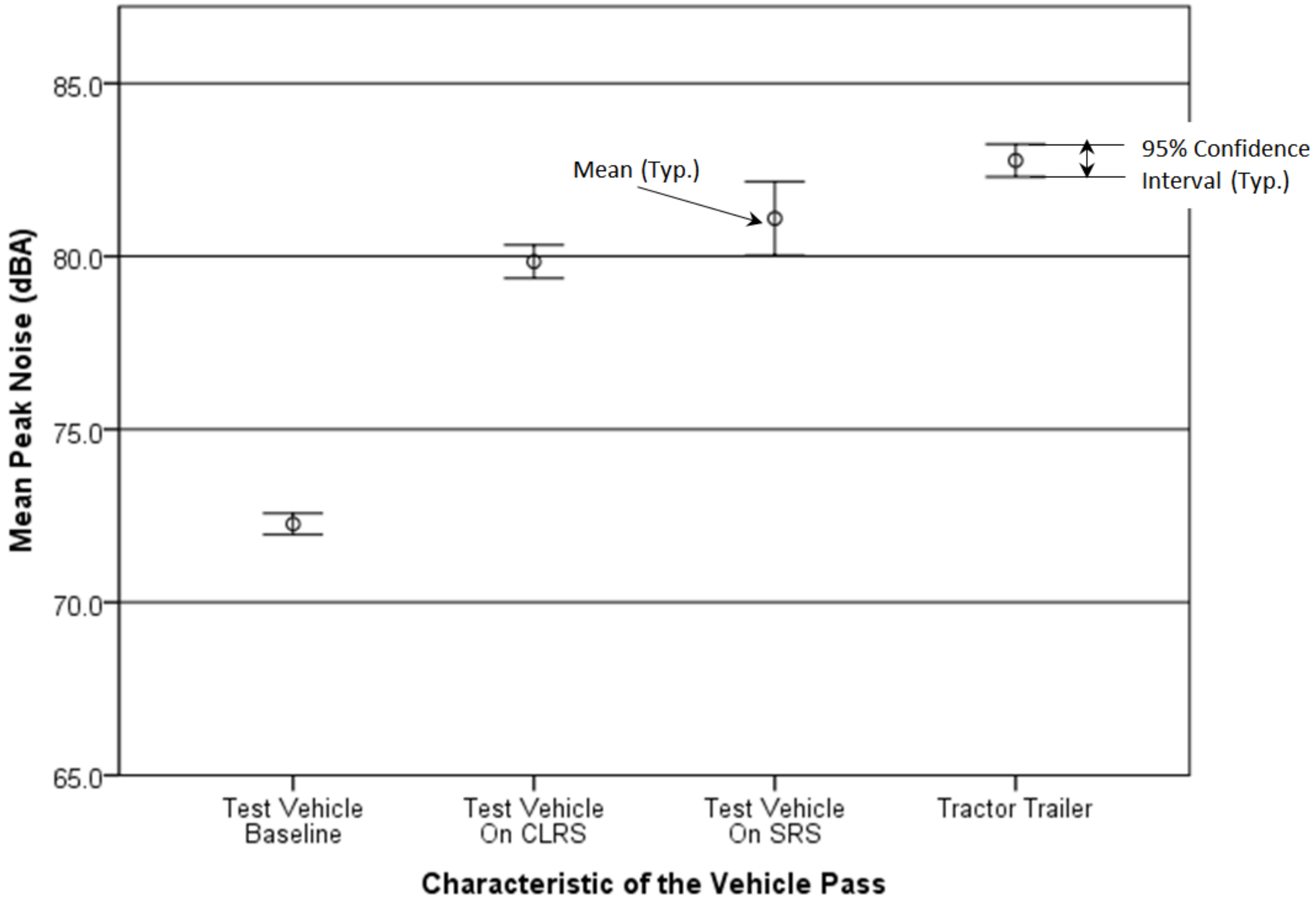
- Recorded peak noise (dBA) for each pass-by

Site Characteristics

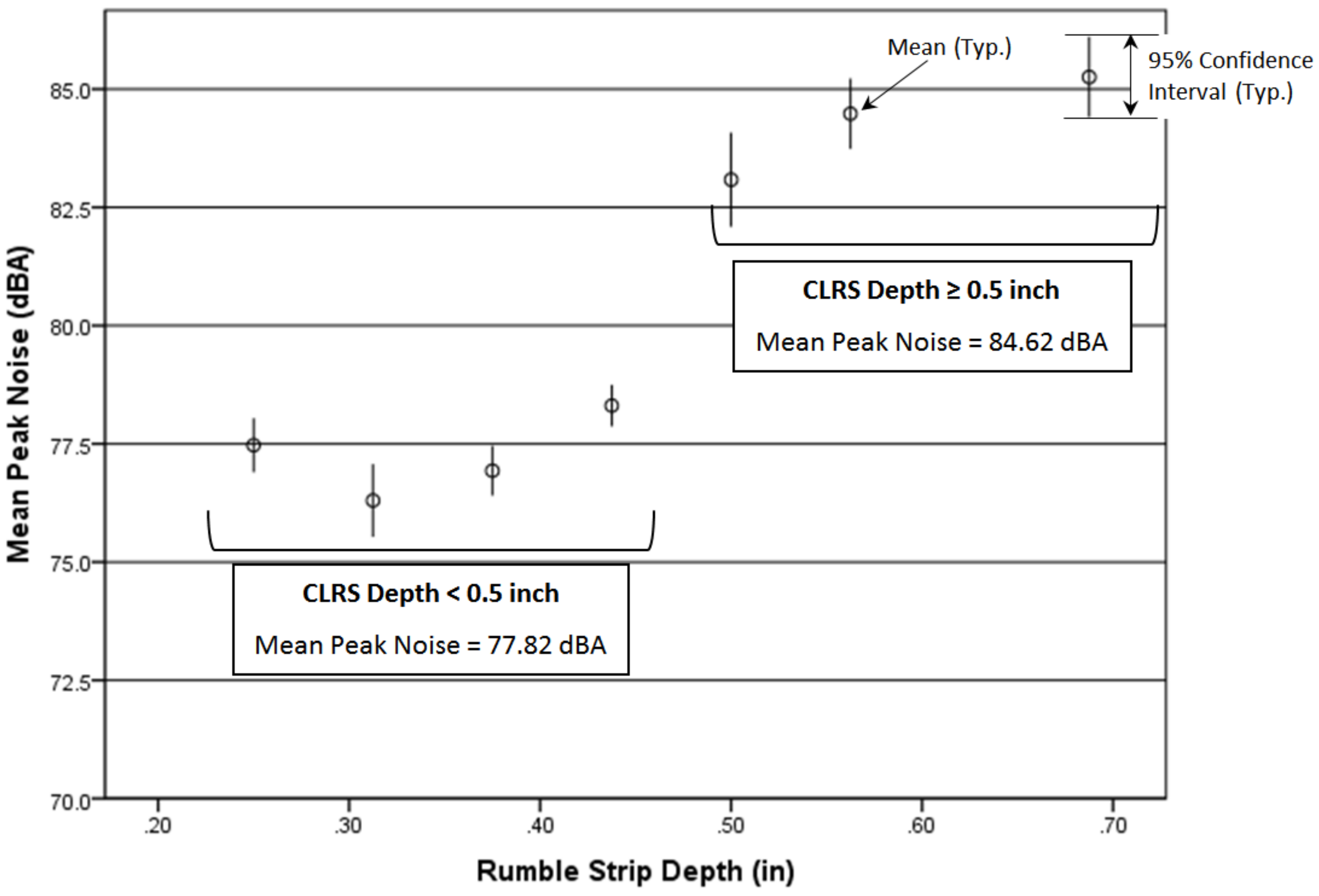
Highway	Pavement Type	Rumble Strip Type	Depth (in) (CLRS, SRS)
M-57 (A)	Chipseal	CLRS	0.25
M-57 (B)	Chipseal	CLRS	0.44
M-179	Chipseal	CLRS	0.69
M-72 (A)	Chipseal	CLRS	0.50
M-72 (B)	Chipseal	CLRS	0.56
M-28	Chipseal	CLRS	0.31
M-55	Chipseal	CLRS & SRS	0.38, 0.5
M-19	HMA	CLRS	0.44
M-136	HMA	CLRS	0.38
M-43	HMA	CLRS & SRS	0.56, 0.56
M-25	HMA	CLRS & SRS	0.44, 0.44
US-41	HMA	CLRS & SRS	0.44, 0.50

Avg. CLRS Depth = 0.45”
(same for chipseal and HMA)

Controlled Pass-by Results



CLRS Depth Effects



Other Noise Effects

- Greater noise on chipseal pavements vs. HMA
  - Additional 2.6 decibels
  - Same effect on or off rumble strips
- Depth effect is greater on HMA than chipseal
  - HMA: 2.3 decibels per 1/16 inch
  - Chipseal: 1.4 decibels per 1/16 inch

In-Vehicle Noise

- How much noise is necessary to warn drivers?
  - No specific recommendations for rumble strips
  - 10 to 15 decibel increase above ambient provides sufficient warning stimulus (train horn literature)
  - Above 15 decibel increase may elicit startle response

In-Vehicle Noise, dBA Increases Above Ambient

Pavement Type	1/4”	5/16”	3/8”	7/16”	1/2”	9/16”	5/8”	11/16”
HMA	13.3	13.5	13.8	14.0	14.3	14.6	14.8	15.1

Recommended RS Depth

Regression Results for Roadside Noise during CPB

Pavement Type	CPB Off Rumble Stips (dB_A)	Predicted Peak Roadside Noise (50’) during CLRS Contact (dB_A)							
		1/4”	5/16”	3/8”	7/16”	1/2”	9/16”	5/8”	11/16”
HMA	70.4	72.9	75.2	77.5	79.8	82.2	84.5	86.8	89.1
Chipseal	72.1	78.1	79.5	81.0	82.4	83.9	85.3	86.8	88.2

Trucks (off RS)

- Depths between 3/8” and 5/8” are recommended
  - Adequate in-vehicle noise
  - Roadside noise controlled
  - Allows for chipseal without re-milling

RUMBLE STRIP EVALUATION #4:

Safety Impacts (Phase 2 Evaluation)

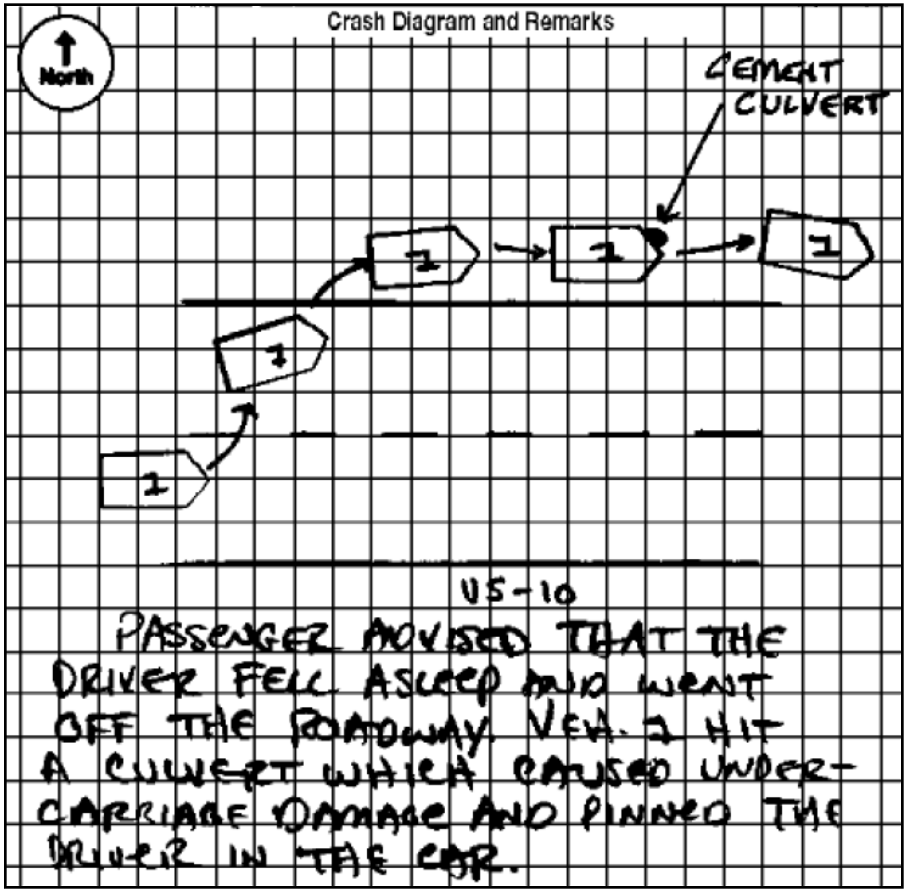
Rumble Strip Segments

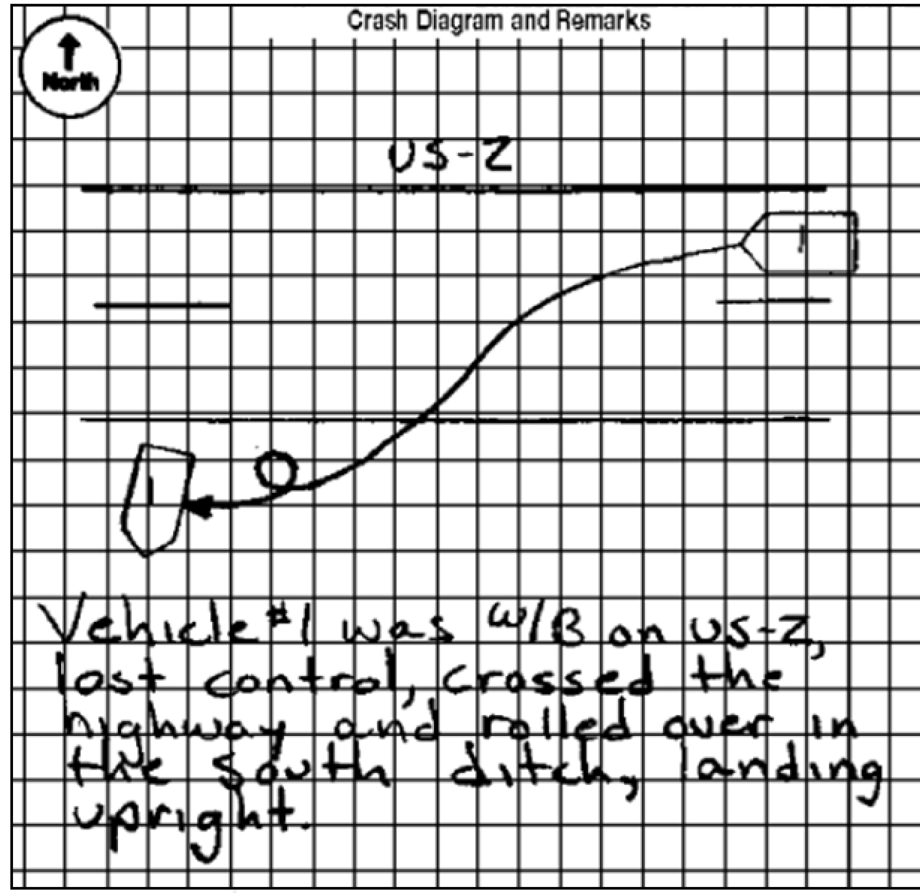
- Confirmation of rumble strip installation
  - Installation dates and start/end points
  - 1,249 segments and 4,078 centerline miles
- Data obtained for each confirmed segment
  - Sufficiency data
  - Other geometric data
  - Traffic volumes
  - Target crashes

Target Crash Identification

- Queried non-intersection crashes 3 years before and after installation (exclude install yr)
  - 70,000+ candidates
- Manual review of UD-10
  - Diagram & description
  - Re-assignment of crash type
- Target crash definition
  - Cross-centerline crash preventable by CLRS
  - 6,000+ resulting target crashes

Target Crash Examples





Empirical Bayes Results

Crash Category	Segments with CLRS Only			Segments with CLRS/SRS		
	Before	After	% Reduction (EB Analysis)	Before	After	% Reduction (EB Analysis)
Total Crashes	26,578	23,428	**15.8**	10,810	9,372	**17.2**
Target Crashes	2,780	1,911	**27.3**	1,195	745	**32.8**
Target – Wet Pavement	293	143	**52.9**	139	54	**55.6**
Target – Wintry Pavement	1,426	1,206	**1.4**	599	500	**4.6**
Target – Passing	306	166	**42.8**	126	83	**35.7**
Target – Impaired Driving	334	225	**28.8**	126	78	**39.9**
Target – Fatal	80	41	**44.2**	27	15	**51.4**
Target – A injury	205	145	**32.0**	113	61	**32.5**
Target – B injury	332	187	**39.3**	119	81	**53.7**
Target – C injury	403	307	**27.9**	202	114	**35.2**
Target – PDO	1,760	1,231	**16.2**	734	474	**28.5**

Conclusions – Safety Impacts

- CLRS reduced target cross-centerline crashes, particularly injury and fatal crashes
- Crash reductions were most pronounced where both CLRS and SRS were installed
- Reductions during adverse weather conditions reinforce anecdotal evidence that rumble strips improve lane-keeping during inclement weather
- Reductions involving passing or impaired drivers suggest improvements to high risk behavior

Benefit/Cost Ratio

- Installation Costs
  - 12 cents/ft
  - 10 year replacement cycle
  - $455,700 annually
- Crash Benefits
  - 400+ crashes prevented annually
  - $26,774,000 annually
- Benefit/Cost Ratio
  - 3% discount rate: B/C = 53
  - 7% discount rate: B/C = 38

Evaluating Safety Impacts of MDOT's High-Tension Cable Median Barrier Installation Program

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Introduction

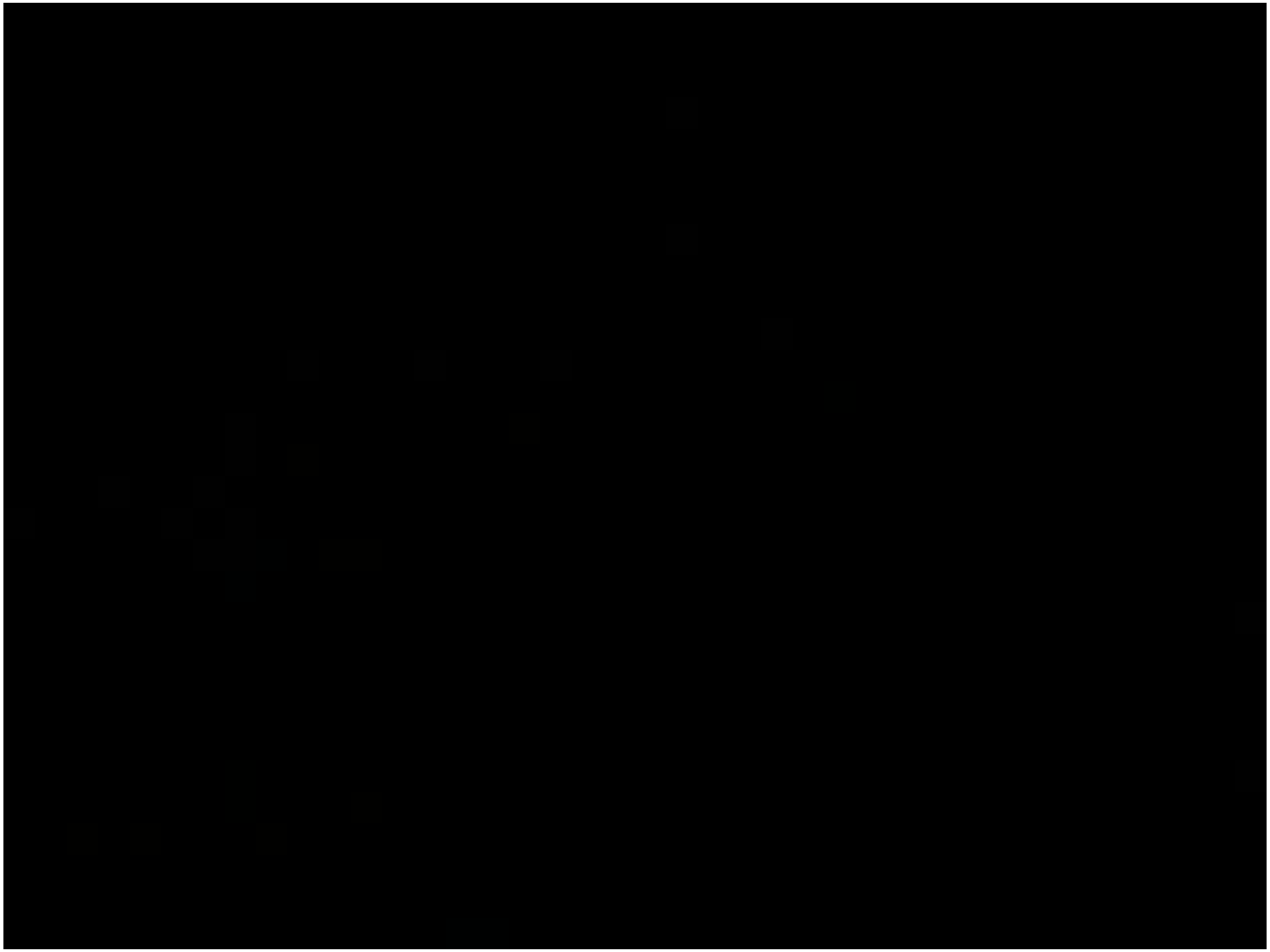
- Cross median crashes on freeways tend to lead to severe injury outcomes:
  - In Michigan, 683 head on crashes in interstates from 2008-2012, resulting in 33 fatalities and 78 incapacitating injuries
- Primary countermeasure to reduce these crashes is median barrier installation:
  - Concrete Barrier
  - Beam Guardrail
  - Cable Barrier

Cable Median Barrier

- Deflects laterally to absorb collision force
- Can be installed on up to 4:1 cross slopes
- Relatively easy to repair
- Cheaper to install than concrete or beam

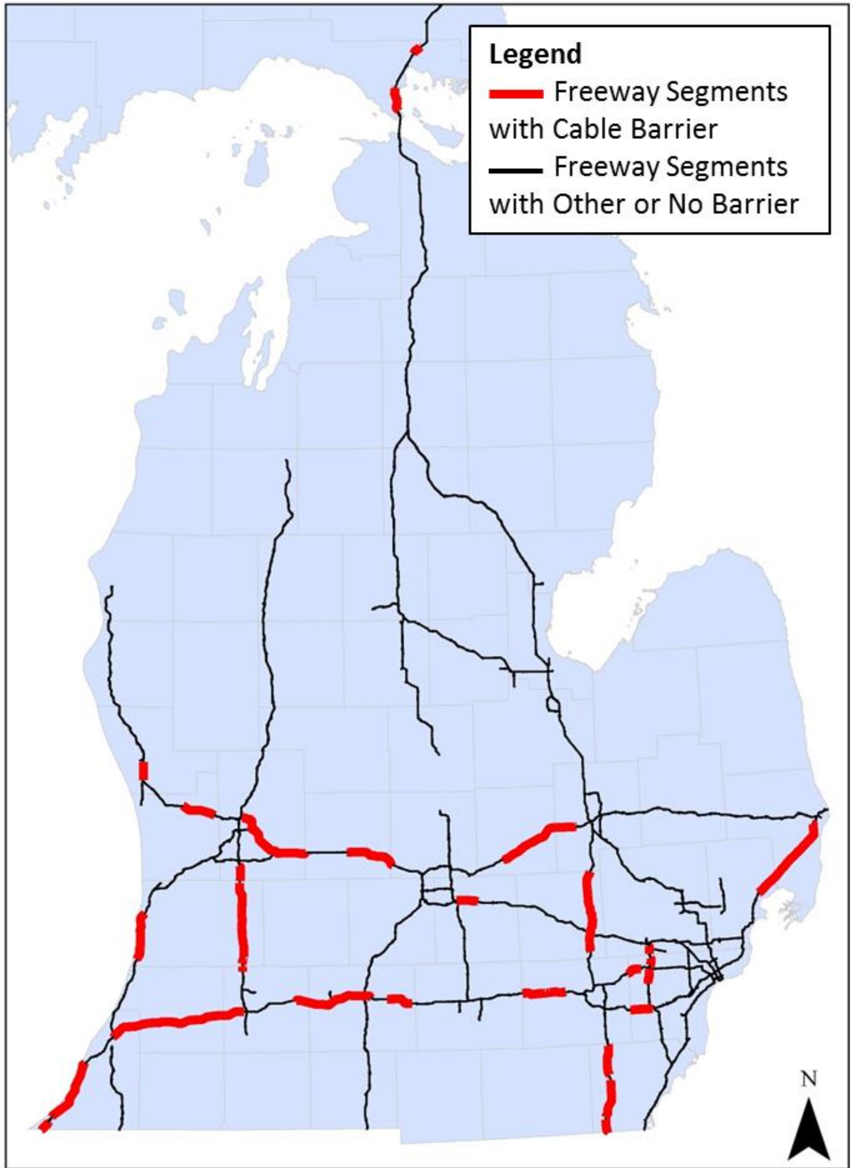
<u>Costs compared to other barrier types (data from WA):</u>
Cable barrier: $46 per foot
'W-beam' guardrail: $53 per foot
Concrete barrier: $187 per foot

Cable Barrier Strike



MDOT Cable Median Barrier Program

- Since 2008, MDOT has installed 300+ miles of cable median barrier on freeways with a high number of fatal cross-median crashes

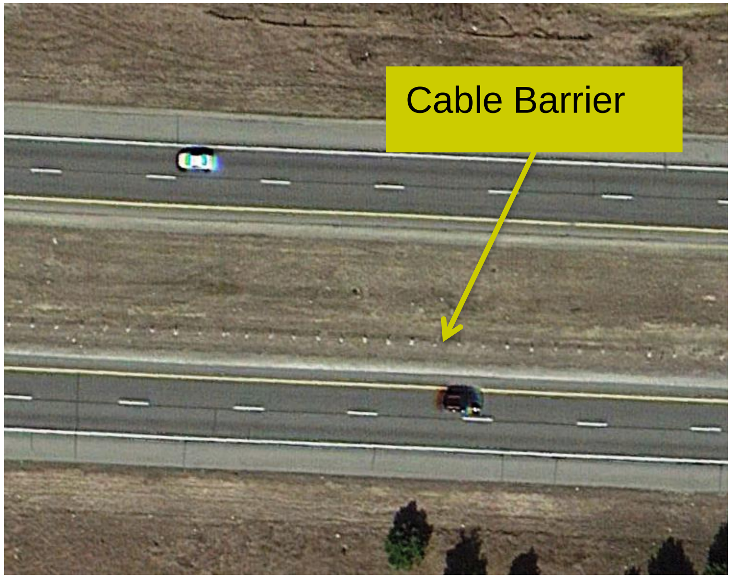


Data Collection – Installation Data

- MDOT provided installation data for all sections of cable median barrier, including:
  - Route number and MDOT region
  - Physical Road (PR) start and end points
  - Install date
  - Cable median type

Data Collection – Geometric Data

- Used MDOT Sufficiency File to obtain relevant data for freeway segments including:
  - Median type and width
  - Shoulder type and width
  - Number of lanes and width
- Other relevant data collected manually using Google Earth and Street View



Data Collection – Other Relevant Data

- AADT (from MDOT Sufficiency File)
- Installation (engineering+construction) Costs
- Maintenance/Repair Costs
- Annual Precipitation and Snowfall (NOAA)

Data Collection – Target Crashes

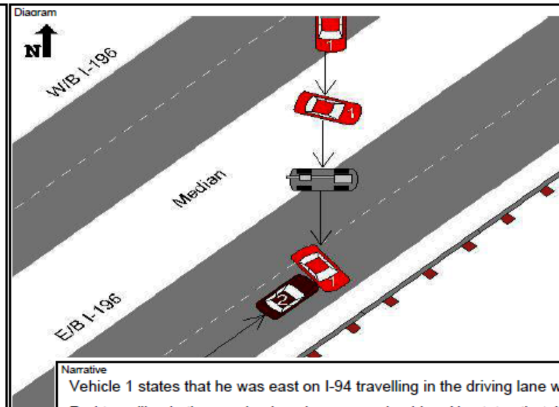
- Identify median-involved crashes at cable median barrier locations (2004-2013 data):
  - Prior to cable barrier installation
  - After cable barrier installation
    - Exclude construction year
- Identify crashes on freeway sections with:
  - Concrete barrier
  - Traditional guardrail
  - No median barrier (w/ median < 100 ft.)

Data Collection – Manual UD-10 Review

Narrative

Veh. #1 left the roadway on W/B I-196 for an unknown reason. Veh. #1 entered the median and then rolled over into the path of E/B Veh. #2. Driver #1 was deceased at the scene. Driver #2 had right foot and elbow pain, a deep laceration to the hand, left shoulder pain and numerous glass lacerations.

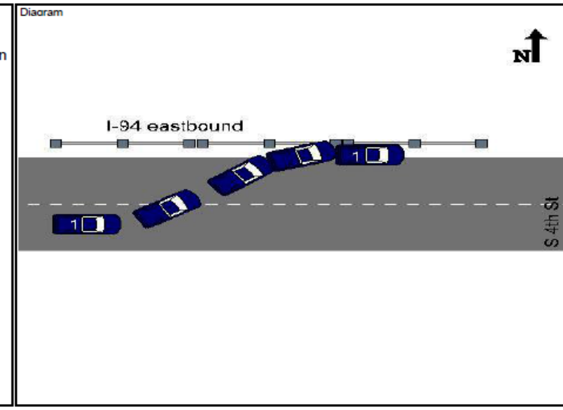
Diagram



Narrative

Vehicle 1 states that he was east on I-94 travelling in the driving lane when a Red travelling in the passing lane began passing him. He states that Jeep began to lose control and turn sideways coming into his lane. He states that to avoid hitting the jeep he hit his brakes which caused him to spin on the icy roads. He lost control and hit the cable barriers. There was not any contact between the red Jeep and Vehicle 1. The driver of vehicle one complained of minor injury. He was transported to Bronson by Pride Care. No citation was issued as the crash was clearly caused by the red Jeep coming into Vehicle 1 lane forcing him to take evasive action. There was no other information on the red Jeep.

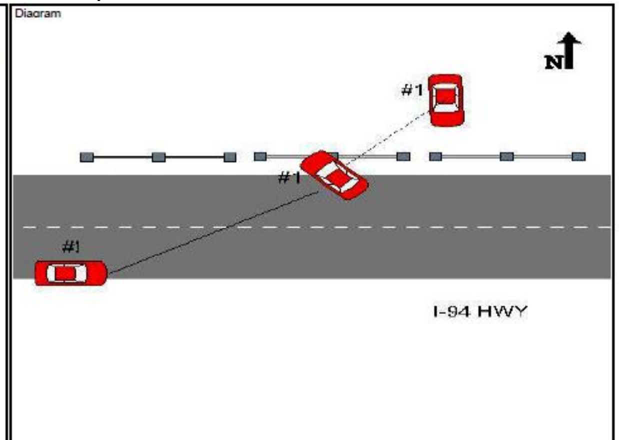
Diagram



Narrative

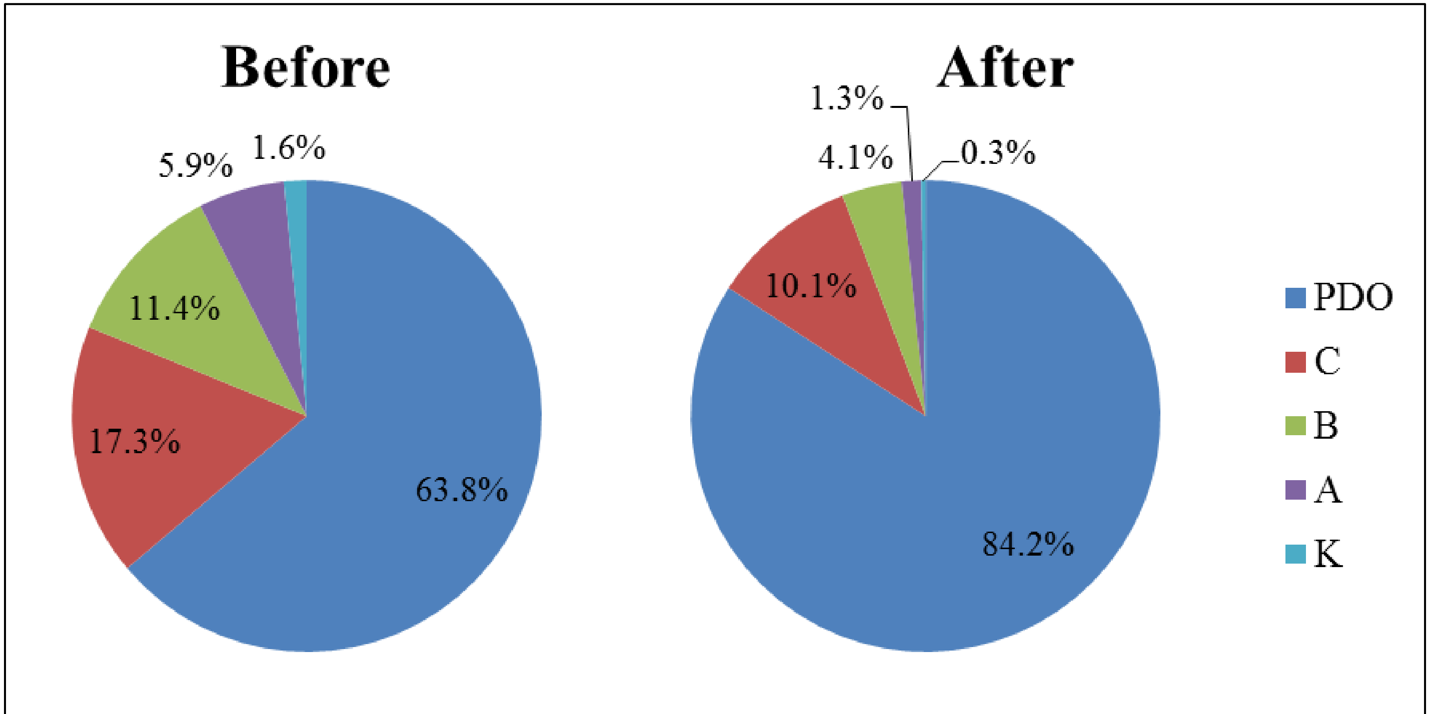
#1 advised he is unsure of what occurred. He states he drove slightly onto the right shoulder and then lost control of his vehicle. From evidence on scene, U/O determined that #1 did run off the road onto the right shoulder where he lost control of the vehicle, traveled across both lanes of travel, striking the median guard cables. At this point the vehicle, slid under the guard cables into the ditch. Impact with the cables and support pole caused heavy damage to the vehicle.

Diagram



Before and After Evaluation

- Total target crashes:
  - Before period: 3,784
  - After period: 4,090



Before and After Crash Rates

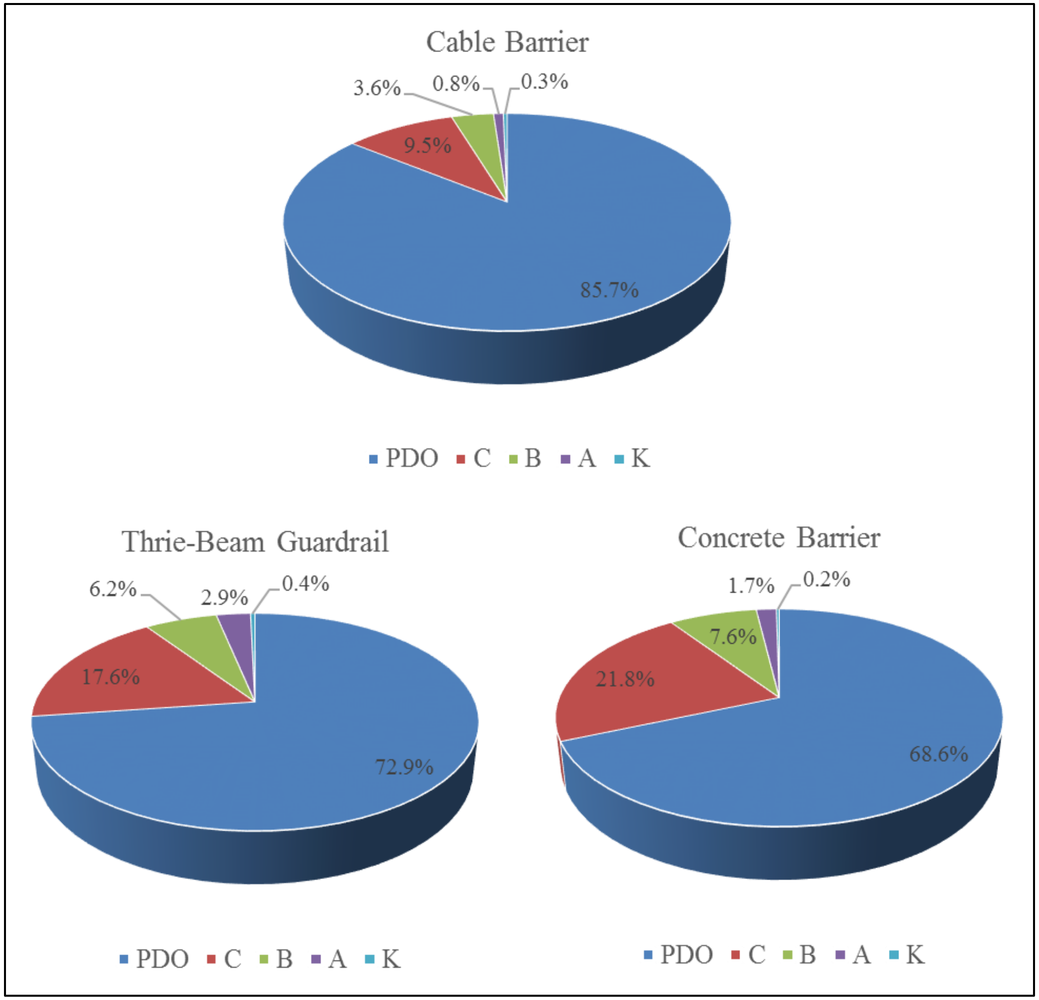
Crash Severity/Type	Average Annual Crash Rate (crashes per 100 MVMT)		
	Before Period	After Period	Percent Change
All Target Crashes	15.60	34.88	123.6%
Target PDO & C Crashes	12.90	32.85	154.7%
Target B Crashes	1.85	1.33	-28.1%
Target K & A Crashes	1.15	0.58	-49.6%
Median Crossover Crashes	2.66	0.35	-86.8%
Target Rollover Crashes	4.88	2.42	-50.4%

Cable Barrier Performance

Cable Barrier Crash Outcome Scenario		After Period Cable Barrier Strikes by Type and Severity						Percent of Total Cable Barrier Crashes
		PDO	C	B	A	K	TOTAL	
Contained by cable barrier in median	No.	2,861	291	101	21	6	3,280	89.3%
	%	87.2%	8.9%	3.1%	0.6%	0.2%	100.0%	
Struck cable barrier and re-directed back onto travel lanes	No.	222	36	16	4	2	280	7.6%
	%	79.3%	12.9%	5.7%	1.4%	0.7%	100.0%	
Penetrated cable barrier but contained in median	No.	55	16	11	4	0	86	2.3%
	%	64.0%	18.6%	12.8%	4.7%	0.0%	100.0%	
Penetrated cable barrier and entered opposing lanes (struck opp. veh)	No.	0	3	0	1	1	5	0.1%
	%	0.0%	60.0%	0.0%	20.0%	20.0%	100.0%	
Penetrated cable barrier and entered opposing lanes (did not strike opp. veh)	No.	10	4	5	1	3	23	0.6%
	%	43.5%	17.4%	21.7%	4.3%	13.0%	100.0%	
Total Cable Barrier Crashes	No.	3,148	350	133	31	12	3,674	100.0%
	%	85.7%	9.5%	3.6%	0.8%	0.3%	100.0%	

Comparison with Other Barrier Types

- Thrie-beam: 2,339 target crashes (210 mi.)
- Concrete barrier: 11,925 target crashes (226 mi.)



Comparison With Other Barrier Types

Barrier Type	Percent Vehicles Contained in Median	Percent Vehicles Penetrating	Percent Vehicles Re-Directed Back onto Travel Lanes
Cable Barrier	89.3%	3.1%	7.6%
Thrie-Beam	83.4%	0.8%	15.8%
Concrete Barrier	68.9%	0.1%	31.1%

Crash Type	Cable Barrier		Thrie-Beam Guardrail		Concrete Barrier	
	No.	%	No.	%	No.	%
Single-Vehicle	3,214	87.5%	1,891	80.8%	9,244	77.5%
Multi-Vehicle	460	12.5%	448	19.2%	2,681	22.5%
Total	3,674	100.0%	2,339	100.0%	11,925	100.0%

Development of SPFs

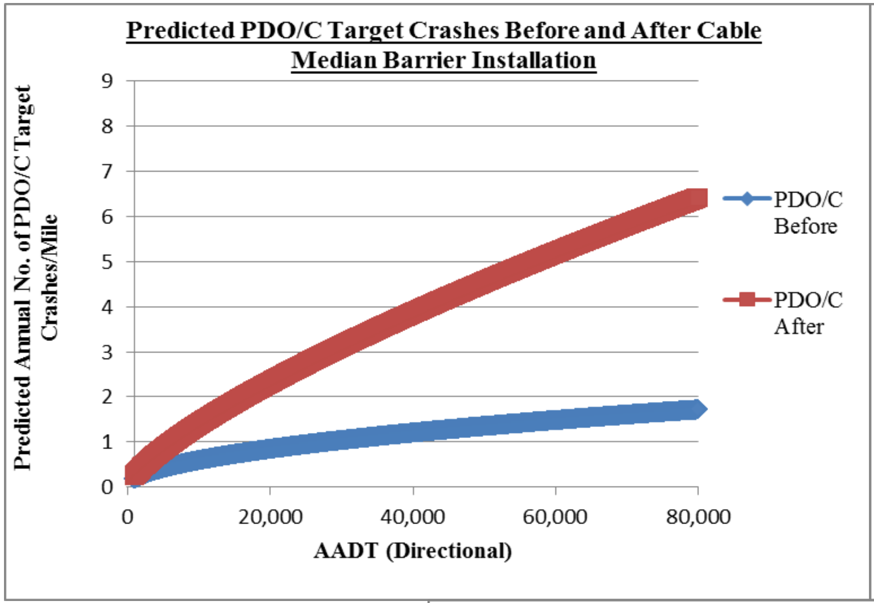
- Safety Performance Functions (SPFs) developed:

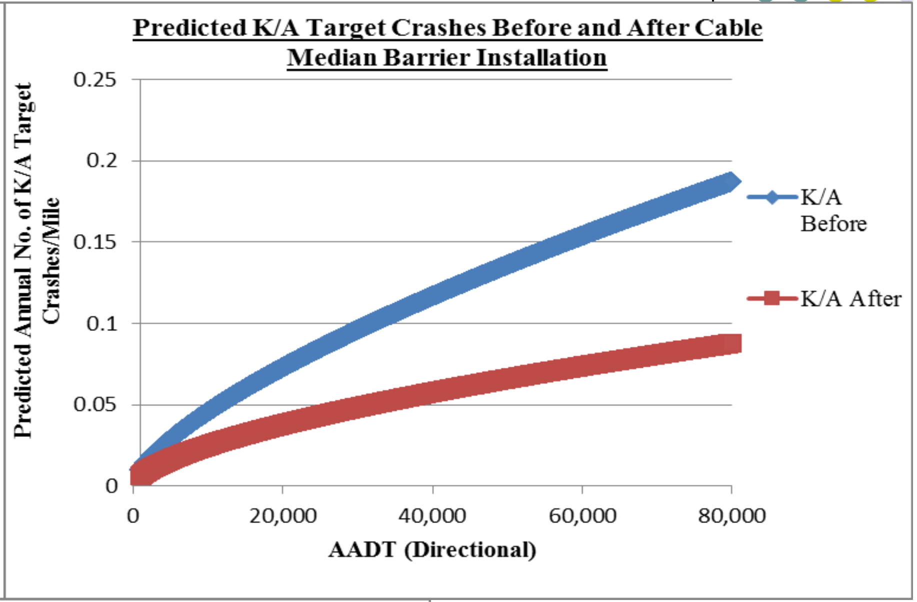
$$\lambda_i = X_{Li} EXP(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2\mathrm{i}} + +\beta_k X_{ki})$$

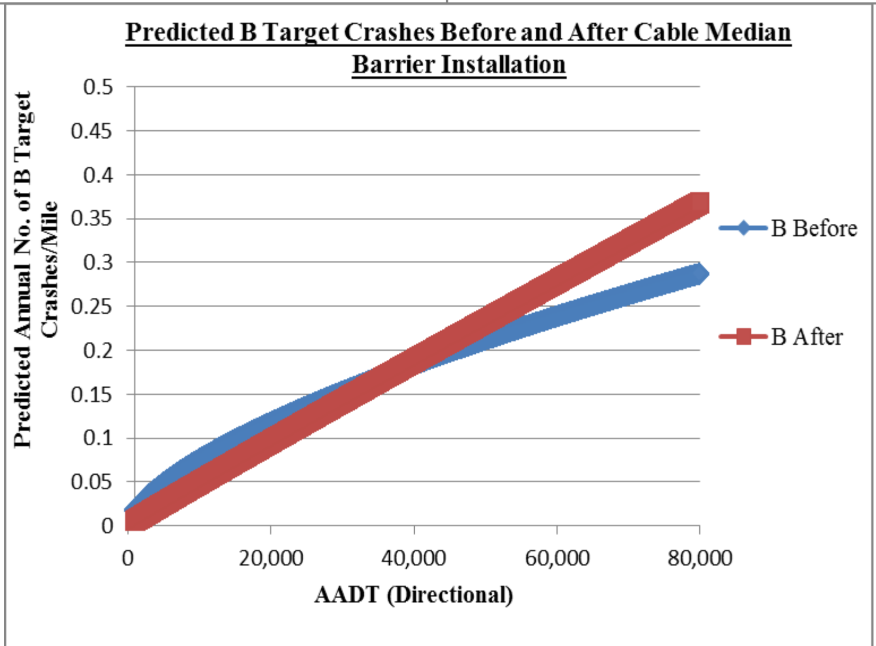
Where:

- λ_i = Predicted number of crashes/yr per segment
- X_{Li} = length of segment in miles
- β_0 = Intercept term
- β_i = estimable parameters
- X_i = Explanatory variables (AADT, median width, etc..)

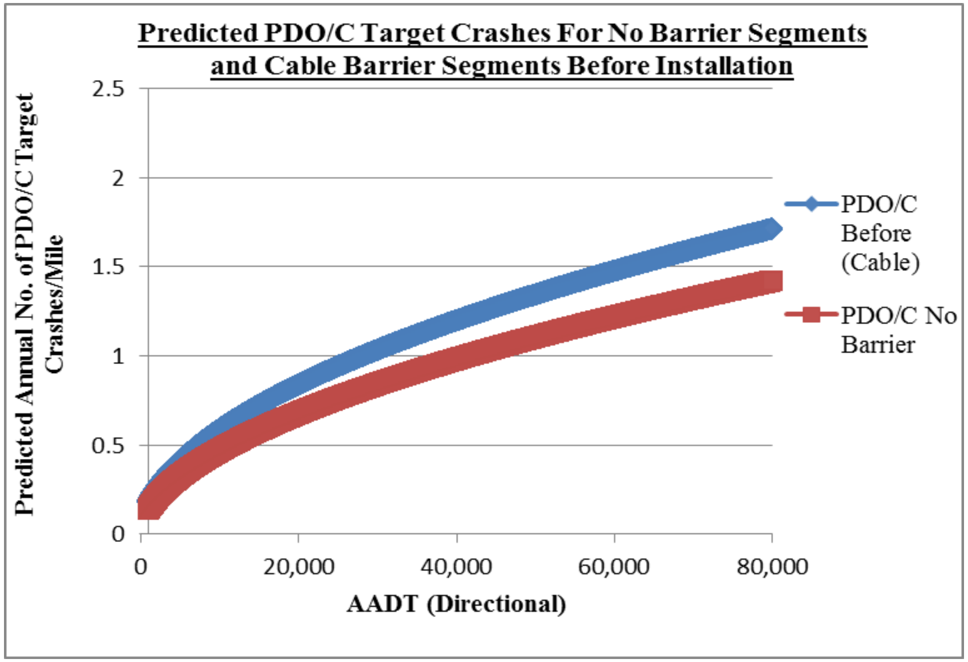
SPF Results – Crash Severity

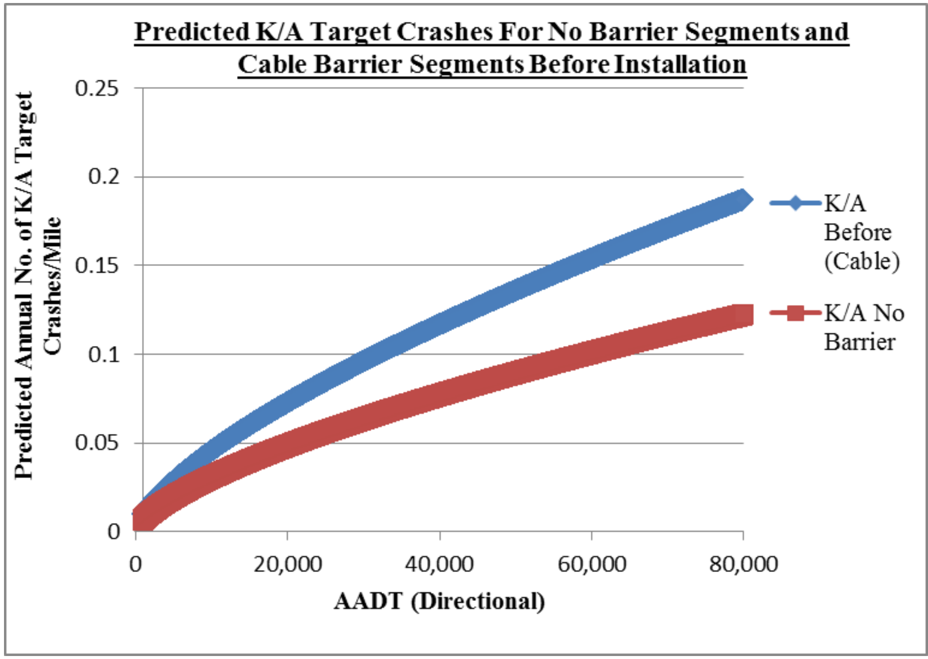






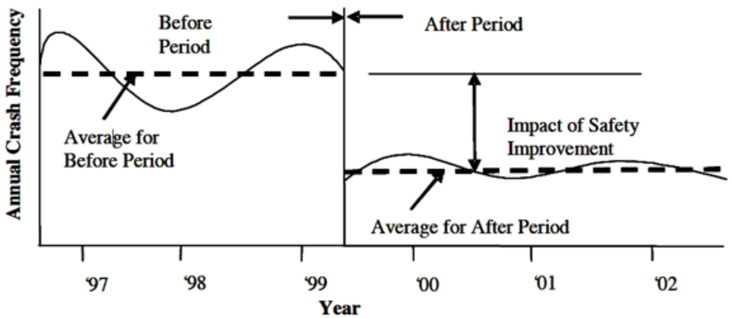
SPF Results – Control Segments (w/o barrier)





Evaluation of Effectiveness – Empirical Bayes Analysis

- Determine the best estimate of safety effectiveness of installing cable median barrier:
  - Before and After Empirical Bayes Design



- Accounts for possible regression-to-the-mean effect and selectivity bias
- Uses combination of actual pre-installation crashes and predicted crashes from regression model

Evaluation of Effectiveness – CMFs from EB analysis

- Crash modification factors (CMFs) were developed using EB analysis:
  - PDO/C Crashes: 155 percent increase
  - B Crashes: 1 percent increase
  - K/A Crashes: 33 percent decrease

Factors Affecting PDO/C-injury Crashes

Criterion	Values	Percent Change in PDO/C Crashes
Number of lanes	2 lanes	Baseline
	3 or more lanes	39.7% decrease
Lateral clearance	More than 20.0 ft	Baseline
	10.0 to 20.0 ft	58.2% increase
	Less than 10.0 ft	144.2% increase
Snowfall	0.0 to 39.9 inches	Baseline
	40.0 to 49.9 inches	27.3% increase
	50.0 to 69.9 inches	70.2% increase
	70.0 inches or above	122.3% increase
Horizontal Curvature	No Curve	Baseline
	Curve w/ radius 2,500-3500 feet	70.2% increase
	Curve w/ radius <2,500 feet	104.2% increase

Economic Analysis

- Cable Barrier Costs:
  - Installation: $155,622 per mile
  - Maintenance/Repair: $849 per repair (crash)

- “Blended” Crash Costs:
  - PDO/C/B crash: $9,100 per crash
  - K or A injury: $258,300 per person

- Time-of-Return: 13.36 years

Conclusions

- Cable median barriers 97% effective in preventing penetrations
- Cross-median crash rate reduced 87% after cable barrier installation
- Cable barrier resulted in fewer injuries and lower rate of re-direction onto roadway compared with other barrier types
- K/A crashes reduced by 33%
- Cable barrier is cost effective solution to reducing cross-median crashes

Questions?

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