Safety Effects of Horizontal Curve Pavement Marking Warning Symbols on Two-lane Rural Highways

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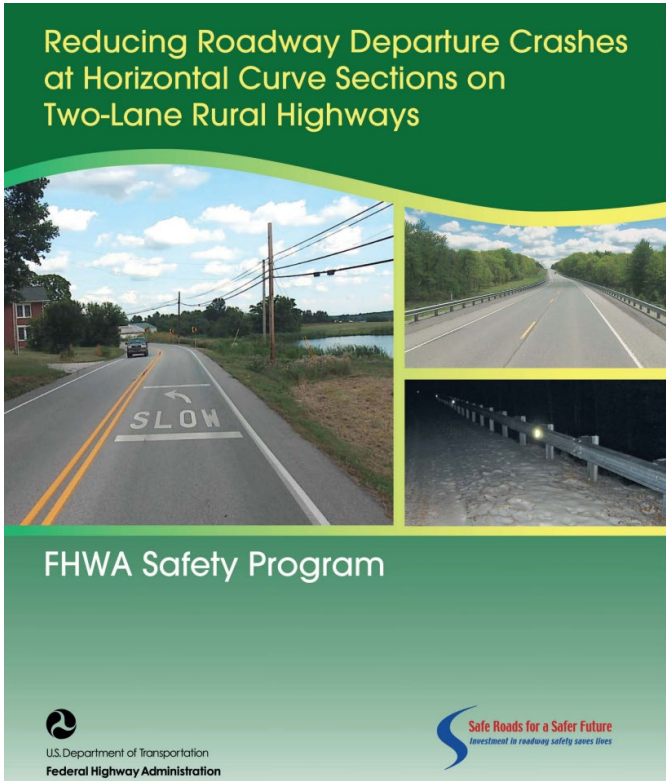


Roadway Departure Crashes

- Vehicle “crosses an edge line or a centerline, or otherwise leave the traveled way” (FHWA)
- Crash statistics (2016)
  - 7.28 millon police-reported crashes
  - 37,461 fatalities
  - 3.1 million injuries
  - More than 50 percent of fatalities → roadway departure crashes

Where are roadway departure crashes most likely to occur?

Source: Albin, R., et al. *Low-Cost Treatments for Horizontal Curve Safety 2016* (FHWA).

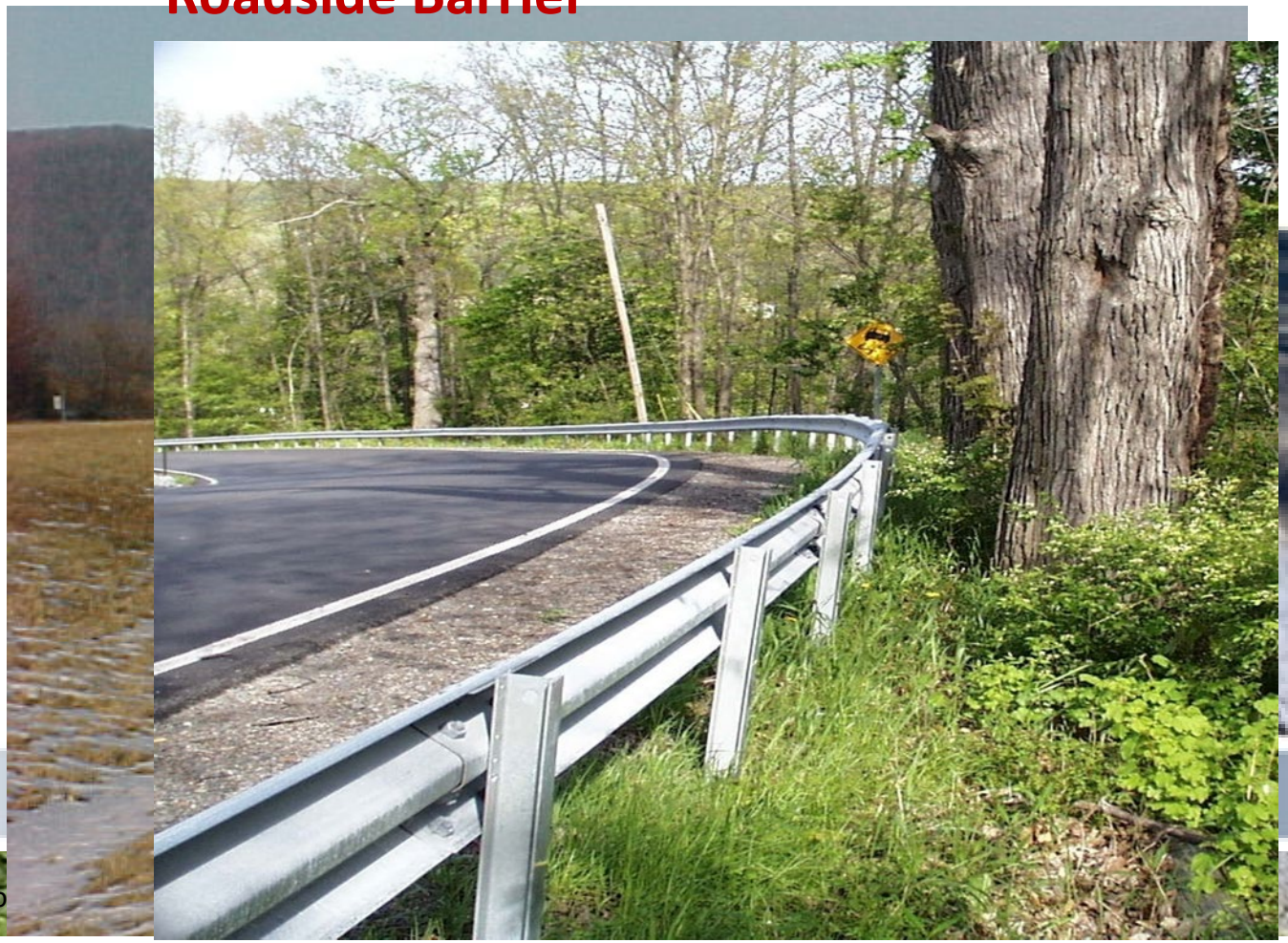
Strategies to Mitigate Roadway Departure Crashes

- Keep vehicles on the roadway
- Reduce crash probability
- Minimize crash severity

Roadway Departure Countermeasures

Clear Zones

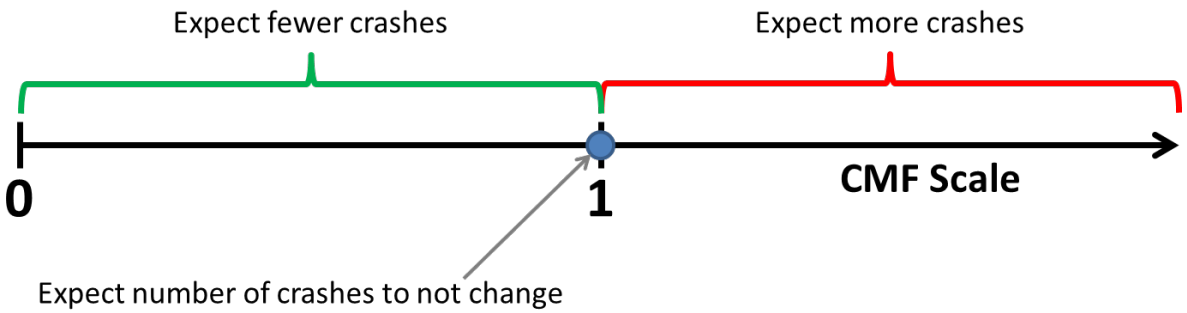
Roadside Barrier



Horizontal Curve Pavement Marking Warning Symbol

Background

- One previous safety evaluation
  - Crash modification factors
    - 0.616 for total crashes
    - 0.649 for nighttime crashes
    - Evaluation included 12 sites and 67 crashes in “after” period



- Operational evaluations
  - 7 percent (2.4 mph) reduction in operating speed on suburban highway (1 site)
  - No change in mean or 85th-percentile operating speeds on two-lane rural highways

Evaluation Objectives

- Develop Crash Modification Factors for marking
  - Focus on two-lane rural highways

- Use Empirical Bayes (EB) observational before-after methodology

EB Methodology

- Step 1: Predict what safety performance would have been in “after” period without countermeasure
- Step 2: Estimate safety performance in “after” period with countermeasure
- Step 3: Compare Steps 1 and 2

Step 1: Predict what safety performance would have been in "after" period without countermeasure ($\sum N_{EB,After}$)

- Reference group used to estimate safety performance function (SPF)

$$Annual\ crashes/mile = L^{\beta_{Length}} \times AADT^{\beta_{AADT}} \times \exp(\beta_0 + \beta_1\ \beta_1 + \ldots + \beta_1$$

L = segment length (miles)
AADT = average annual daily traffic (veh/day)
β = regression coefficients
X = site-specific features

Combine SPF with reported crashes to estimate expected number of crashes "before" treatment → adjust for length of "after" period and traffic volume differences in before and after periods for "after" period safety performance

Step 2: Estimate safety performance in "after" period with countermeasure ($\sum N_{Obs,After}$)

- Number of reported (observed) crashes over analysis period at locations with countermeasure

Step 3: Compare Steps 1 and 2

$$\frac{\sum N_{EB,After}}{\sum N_{Obs,After}}$$

Empirical Setting

- Treatment installations between 2006 – 2012
  - 263 horizontal curves with symbol
- Reference group: 21,902 curves without symbol
- Crash data: 2005 – 2013
- Roadway and traffic volume data: 2005 - 2013

Data Summary (Continuous Variables)

Reference Group

Variable	Mean	S.D.	Min	Max
AADT	2597	2395	100	15,998
Length (mi)	0.082	0.066	0	0.567
Shoulder width (ft)	3.571	1.890	0	12
Degree of curve	7.724	8.416	0.852	94.307
Total crashes	0.104	0.389	0	12
Fatal + injury crashes	0.057	0.267	0	7
ROR crashes	0.069	0.293	0	7
Nighttime crashes	0.040	0.214	0	6
Nighttime ROR crashes	0.031	0.185	0	4
Nighttime fatal + injury crashes	0.021	0.150	0	3

Treatment Group (Before)

Variable	Mean	S.D.	Min	Max
AADT	2802	2491	100	15,998
Length (mi)	0.075	0.063	0.010	0.471
Shoulder Width (ft)	3.600	1.972	0	12
Degree of curve	10.017	13.163	0.854	94.558
Total crashes	0.044	0.242	0	3
Fatal + injury crashes	0.019	0.152	0	2
ROR crashes	0.020	0.142	0	1
Nighttime crashes	0.017	0.131	0	1
Nighttime ROR crashes	0.012	0.110	0	1
Nighttime fatal + injury crashes	0.008	0.090	0	1

Data Summary (Categorical Variables)

Variable	Proportion (%)	
	Reference Group	Treatment Group (Before)
Posted speed limit ≥ 50 mph	41.6	39.3
Passing zones present	18.2	16.4
Centerline rumble strips present	20.5	21.5
Shoulder rumble strips present	7.9	6.9
RHR = 4 or 5	73.9	72.0
RHR = 6 or 7	18.6	24.4

Safety Performance Functions

Variable	Crash Types and Severities					
	Total	Fatal+Injury	ROR	Nighttime	Nighttime ROR	Nighttime Fatal+Injury
Natural log of AADT	0.762***	0.727***	0.574***	0.730***	0.621***	0.707***
Natural log of length	0.823***	0.817***	0.835***	0.778***	0.784***	0.777***
Posted Speed 50-55 mph	-0.047**	-0.040	-0.005	-0.035	-0.050	-0.037
Year = 2005	-0.841***	-0.761***	-0.959***	-0.864***	-0.925***	-0.791***
Year = 2006	-0.214***	-0.139**	-0.214***	-0.124*	-0.095	-0.038
Year = 2007	-0.195***	-0.186***	-0.247***	-0.224***	-0.224***	-0.269***
Year = 2008	-0.028	-0.025	-0.014	-0.033	-0.003	-0.044
Year = 2009	-0.058	-0.023	-0.059	-0.161**	-0.159**	-0.175**
Year = 2010	-0.053	0.012	-0.049	-0.090	-0.044	-0.049
Year = 2011	-0.013	-0.056	-0.023	0.006	-0.011	-0.053
Year = 2012	-0.449***	-0.391***	-0.455***	-0.491***	-0.488***	-0.468***
Degree of curve	0.039***	0.038***	0.039***	0.037***	0.038***	0.036***
Shoulder width (ft)	-0.058***	-0.051***	-0.068***	-0.062***	-0.068***	-0.055***
Passing zone present	-0.085***	-0.085**	-0.112***	-0.045	-0.084*	-0.023
Centerline rumble strips	0.084***	0.094***	0.146***	0.108***	0.124***	0.144***
Shoulder rumble strips	-0.024	-0.042	-0.027	-0.058	-0.086	-0.120
Roadside hazard rating = 4 or 5	0.014	0.003	0.022	-	-	-
Roadside hazard rating = 6 or 7	0.035	0.024	0.096	-	-	-
Constant	-5.981***	-6.361***	-4.865***	-6.746***	-6.101***	-7.249***
Overdispersion Parameter (α)	1.724***	1.885***	0.516***	1.690***	1.787***	1.948***
ρ^2	0.0880	0.0785	0.0699	0.0747	0.0634	0.0659
* indicates p-value < 0.05, ** indicates p-value < 0.01, *** indicates p-value < 0.001						

EB Results

Crash Type	Total Crashes	Fatal + Injury Crashes	ROR Crashes	Nighttime Crashes	Nighttime ROR Crashes	Nighttime Fatal + Injury Crashes
θ	0.652	0.693	0.769	0.708	0.745	0.771
Stdev(θ)	0.115	0.144	0.140	0.157	0.176	0.211
θ 95% lower bound	0.426	0.411	0.495	0.400	0.399	0.358
θ 95% upper bound	0.877	0.975	1.044	1.015	1.090	1.185
$\sum N_{Obs,after}$	62	38	52	29	24	17
$\sum N_{EB,after}$	93.652	53.848	66.578	40.309	31.714	21.632
$\sum VAR(N_{EB,after})$	141.138	53.527	66.513	26.418	16.270	8.721

CMFs

Total Crashes = 0.652
Fatal + Injury Crashes = 0.693
ROR Crashes = 0.769*
Nighttime Crashes = 0.708*
Nighttime ROR Crashes = 0.745*
Nighttime Fatal + Injury Crashes = 0.771*

**Not statistically significant at 95th-percentile*

Past Research

Total Crashes = 0.616
Nighttime Crashes = 0.649

Conclusions

- Horizontal curve pavement marking warning symbol is associated with fewer total and fatal+injury crashes on two-lane rural highways in Pennsylvania.
- Study assumes pavement marking symbols will retain visibility over time.
- Consider evaluation of same symbol at other locations (e.g., freeway ramps, multi-lane highways).

Thank you!

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