Driver performance at horizontal curves: Bridging critical research gaps to increase safety

Road Safety and Simulation International Conference
8-10 June 2022

Presented by Alyssa Ryan and Emily Hennessy

Contributions from Chengbo Ai, Wooseong Kwon, Cole Fitzpatrick, and Michael Knodler

THE UNIVERSITY OF ARIZONA
COLLEGE OF ENGINEERING
Center for Applied Transportation Sciences

UMassAmherst
College of Engineering
Civil and Environmental Engineering

RSS 2022
8th Road Safety & Simulation International Conference
Road Safety and Digitalization

There is a need to develop prioritization methods for investment allocation at horizontal curves for effective and comprehensive ***safe mobility.***

Literature Review

Safety at Horizontal Curves

- Crash rates on horizontal curves at 1.5 to 4 times higher than those of tangent sections of roadway *(Fink & Krammes, 1995)*
- Fatality rates are 3 times higher on horizontal curves compared to all roads and account for approximately 25% of all people who die each year on U.S. roadways *(Hummer et al., 2010; Torbic et al., 2004)*
- Curved sections of roadway represent a higher risk to drivers due to increased vehicular centripetal forces, increased driver demand, and roadway characteristics *(Hummer et al., 2010)*
- Horizontal curves are also associated with roadway departure crashes, which occur on two-lane rural highways four times as frequently as on comparable tangent segments *(Glennon et al., 1985)*

Literature Review

Safety and Horizontal Curve Properties

- The safety performance of horizontal curves differs with respect to traffic volumes, segment lengths, and additional roadway features *(Gooch et al., 2018)*
- Safety risk on horizontal curves has been found to be influenced by the curve deflection angle, super-elevation, road surface friction, distance to and radius of adjacent curves, use of signage, and radius *(Elvik, 2019)*
- The shorter the mean distance between horizontal curves of a given radius, the lower the crash rate *(Elvik, 2019)*
- Neighboring curves of sharper curves, or those with a smaller radius, were found to be associated with a lower crash rate than those neighboring curves with a larger radius *(Elvik, 2019)*

Literature Review

Driver Behavior and Horizontal Curves

- Curve negotiation requires increased attention, creating a higher driver workload as they evaluate geometric factors before adapting speed and steering to the new roadway condition *(McDonald & Ellis, 1975)*
- The theory of risk homeostasis suggests all people adjust their behavior in response to their desired level of perceived risk *(Gibreel et al., 1999; Fink & Krammes, 1995)*

Literature Review

Driver Behavior and Horizontal Curves

- Speeds have been found to be underestimated by drivers at curves, particularly during the approach sections *(Milošević & J. Milić, 1990; Retting & Farmer, 1998)*
- Sharper curves and curves with shorter available sight distances are perceived as less favorable to drivers in simulations *(Moreno et al., 2013)*
- Drivers drive at higher speeds through wider curves on rural roads *(Calvi, 2015)*

Horizontal Curve Countermeasures

- Edge lines along curves have been shown to visually guide driver steering and reduce crashes *(Coutton-Jean et al., 2009; Taylor et al., 1972)*
- Research has indicated that advance warning signs at curves, even with advisory speed plates, do not provide an adequate safety improvement *(Coutton-Jean et al., 2009; Taylor et al., 1972)*
- An extensive analysis of two-lane two-way rural roads which concluded that applying crash modification factors to tangent sections does not adequately model the safety performance of horizontal curves *(Gooch et al., 2018)*

The most beneficial countermeasure for a curve is not always implemented or is implemented inefficiently **due to a lack of full understanding of driver behavior at curves compared to tangent roadway segments.**

Problem Statement

This research identified the factors that impact safety at curve locations compared to tangent segment locations using a novel dataset.

Ryan, Hennessy, Ai, Kwon, Fitzpatrick, Knodler (2022)

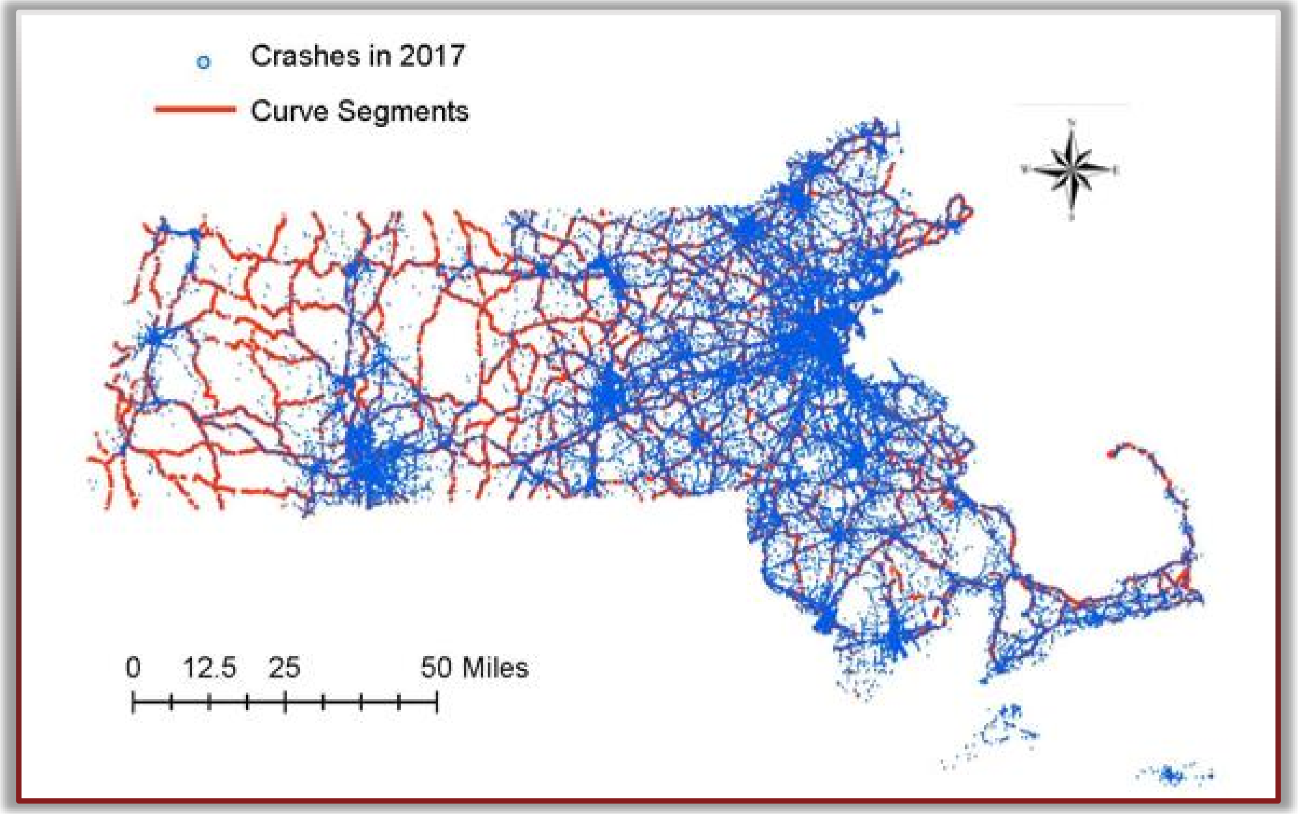
Methodology

Horizontal Curve Data Acquisition/Development

- Novel horizontal curve data was derived from Massachusetts vehicle GPS trajectory data in a process established in the literature *(Ai & Tsai, 2015)*
- Trajectory data was segmented and clustered into tangent sections or one of the four following types of horizontal curves: simple, compound, reverse, and spiral
- Once categorized, the curves were fitted to applicable circular or spiral radii and used for this analysis

Methodology

Other Data Acquisition



- Crash data from Massachusetts IMPACT data tool from 2014-2017
- Roadway inventory data from MassDOT

Methodology
Spatial Analysis

- Tangent segments created using Massachusetts road data and curve data
- Crashes within a 200-foot buffer of each segment were considered correlated with that segment *(Labi, 2011; Pulugurtha and Sambhara, 2011; Khan et al., 2013)*
- Crash values were assigned using the EPDO crash method of Massachusetts (21:1 weighting method) *(Ryan et al., 2022)*

Crash Severity	Costs	% of all crashes in MA	Weighting Factor
Fatal Crashes	$14,482,300	0.2%	21
Incapacitating Injury Crashes	$860,700	2.0%	
Non-Incapacitating Injury Crashes	$260,800	12.0%	
Possible Injury Crashes	$165,000	16.0%	
Property Damage Only Crashes	$15,600	70.0%	1
TOTAL		100.0%	

https://www.mass.gov/doc/2016-top-crash-locations-report/download

Methodology

Modeling

- Generalized linear regression model predicting **EPDO crash points per mile on each segment**
- Included AADT, roadway operation (one-way or two-way), and segment type (horizontal curve or tangent)
- Interaction between the segment type and other factors included in final model
- **Log transformation of the EPDO rate plus one** included in model due to exponential increase in crashes and to account for segments with EPDO values of zero per mile

Methodology

Modeling

Final Dataset

324,336 segments

15.5% curve segments

Final Model

$$log(EPDO\ crashes\ per\ mile + 1) \sim (segment\ type * roadway\ operation) + (segment\ type * AADT)$$

Results

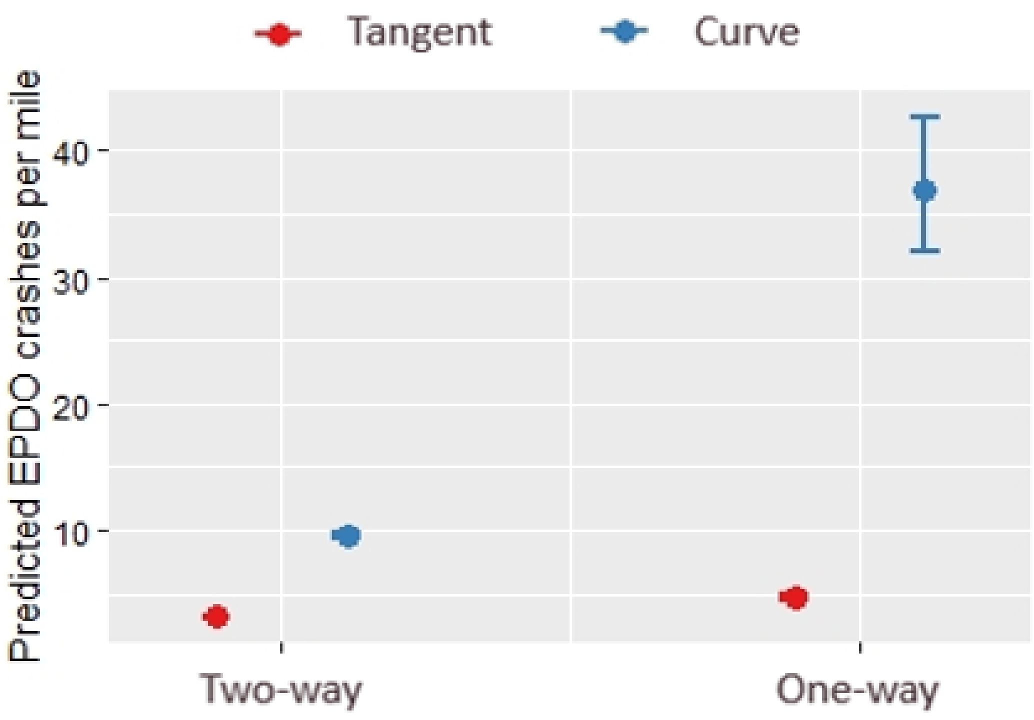
Model Coefficient Summary

Term	Coefficient	Standard Error of Coefficient	P-Value
Constant	0.522	0.0068	0.000
Segment type (reference = tangent)	0.468	0.0168	0.000
Roadway operation (reference = two-way)	0.416	0.0266	0.000
AADT	0.000053	0.0000004	0.000
Segment type * Roadway operation	0.935	0.0785	0.000
Segment type * AADT	0.000056	0.000001	0.000

Ryan, Hennessy, Ai, Kwon, Fitzpatrick, Knodler (2022)

Results

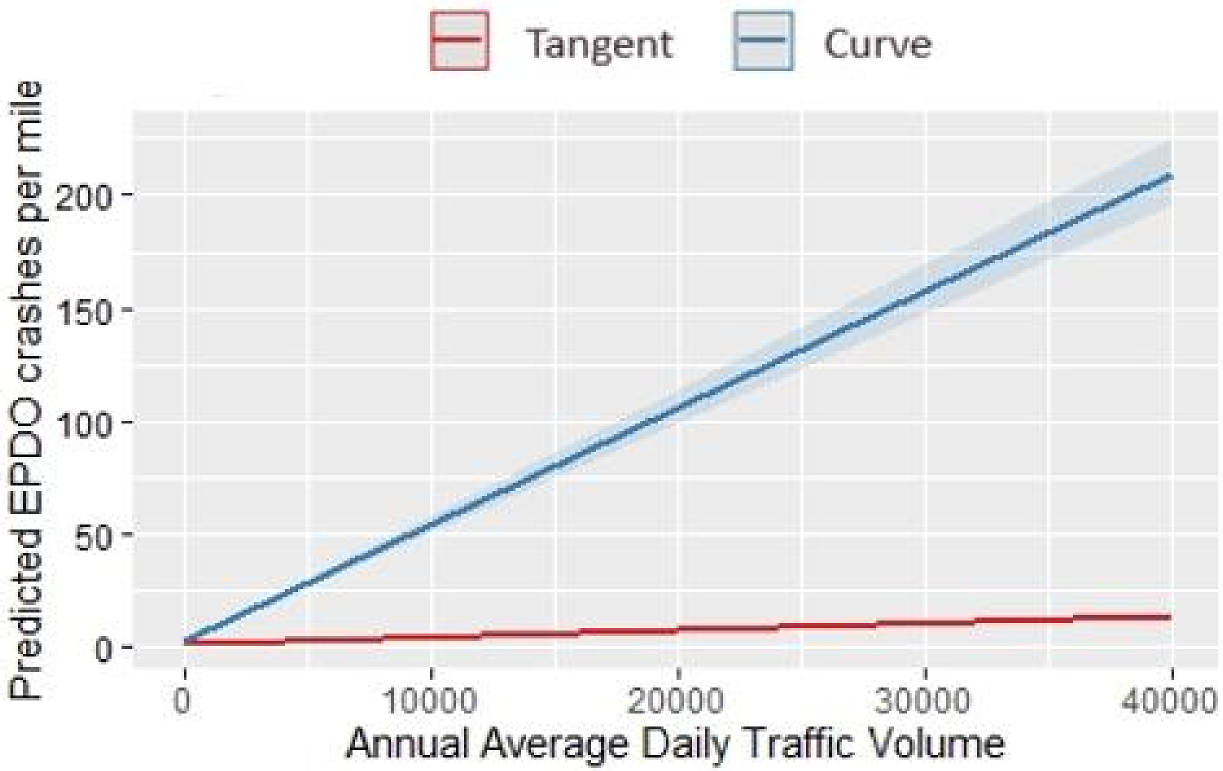
Segment type * Roadway operation



Ryan, Hennessy, Ai, Kwon, Fitzpatrick, Knodler (2022)

Results

Segment type * AADT



Ryan, Hennessy, Ai, Kwon, Fitzpatrick, Knodler (2022)

Conclusions

- **Several factors cause horizontal curves to have a higher crash point value** related to driver performance, including the **increased task load and demand required at curve segments compared to tangent segments**
- Curve segments have an **increased rate of crashes per mile** with an **increasing AADT** compared to tangent segments
- Curve segments along **one-way operations** are of increased safety concern for drivers compared to tangent segments and **two-way operations**

Safety countermeasures that are developed for horizontal curves should focus on these locations and consider these human factors considerations

Ryan, Hennessy, Ai, Kwon, Fitzpatrick, Knodler (2022)

CONTACT:

Alyssa Ryan, PhD
alyssaryan@arizona.edu
Assistant Professor, University of Arizona

Emily Hennessy, PE
ehennessy@umass.edu
PhD Student, University of Massachusetts Amherst