Effects of blind spot monitoring systems on police-reported lane-change crashes

August 2017

Jessica B. Cicchino
Insurance Institute for Highway Safety

1005 N. Glebe Road, Suite 800
Arlington, VA 22201
+1 703 247 1500

iihs.org

ABSTRACT

Objective: To examine the effectiveness of blind spot monitoring systems in preventing police-reported lane-change crashes.

Methods: Poisson regression was used to compare crash involvement rates per insured vehicle year in police-reported lane-change crashes of all severities and with injuries in 26 U.S. states during 2009-2015 between vehicles with blind spot monitoring and the same vehicle models without the optional system, controlling for other factors that can affect crash risk.

Results: Crash involvement rates in lane-change crashes of all severities and with injuries were 14% and 23% lower, respectively, among vehicles with blind spot monitoring than those without. Although only the reduction in crashes of all severities reached statistical significance, the effect for injury crashes was consistently in the expected direction for 5 of the 6 manufacturers examined.

Discussion: Blind spot monitoring systems are effective in preventing police-reported lane-change crashes when considering crashes of all severities. If every U.S. vehicle in 2015 were equipped with blind spot monitoring that performed like the study systems, it is estimated that about 50,000 crashes and almost 16,000 injuries could have been prevented.

Keywords: Crash avoidance technology; collision warning; driver assistance system; side-view assist; blind spot detection; side blind zone alert; lane-change alert

INTRODUCTION

Collision avoidance technologies that warn, provide braking or steering assistance, or supplement a driver's perception of the environment have the potential to prevent a substantial number of crashes (Jermakian 2011). Some technologies currently deployed in the vehicle fleet have been living up to this potential and are proving effective in preventing real-world crashes. For example, forward collision warning with automatic emergency braking has been shown to cut police-reported rear-end crash rates in half (Cicchino, 2017).

Blind spot monitoring systems, which are also referred to as blind spot detection, blind spot warning, lane-change alert, side blind zone alert, or side-view assist, notify drivers when a vehicle in an adjacent lane is in their blind spot, typically with a visual alert in or near the corresponding side-view mirror. Some also warn of rapidly approaching vehicles in the adjacent lane. For simplicity purposes, these systems will be collectively referred to as blind spot monitoring systems throughout this paper. Warnings may intensify by blinking or beeping if drivers engage the turn signal when the system detects another vehicle. Systems were first offered as optional equipment on Volvo S80, V70, and XC70 models in model year 2006 but are now more widely available. In model year 2017, blind spot monitoring systems were offered on two-thirds of new vehicle series as optional (57%) or standard (9%) equipment (Highway Loss Data Institute, 2016e).

The Highway Loss Data Institute (HLDI) performed the first evaluation of the effectiveness of blind spot monitoring systems on real-world crashes. HLDI compared rates of property damage liability insurance claims, which cover damage caused by at-fault vehicles to other vehicles and property, between vehicles with optional blind spot monitoring systems from a number of manufacturers to the same vehicle models without the optional systems. On Acura, Mazda, Mercedes-Benz, and Volvo vehicles, where effects of blind spot monitoring systems could be isolated, vehicles with the systems had property damage liability claim rates that were 2%-11% lower than vehicles without; the 11% reductions each for Acura and Mazda vehicles were statistically significant, and the smaller reductions from other manufacturers were not (HLDI, 2012, 2016a, 2016d, 2017b). Blind spot monitoring systems were also examined for additional manufacturers, but since systems were always bundled with other collision avoidance systems on these vehicles, the effect of blind spot monitoring alone could not be determined (HLDI, 2016b, 2016c, 2017a).

Because HLDI's data do not have detailed information on the circumstances surrounding the crashes that result in insurance claims, analysts were not able to examine the effects of blind spot monitoring systems on the lane-change crashes they were designed to address. The goal of the current study is to evaluate the effects of blind spot monitoring systems on police-reported lane-change crashes in the United States.

METHOD

Vehicles

Vehicle series and model years included in analyses are listed in Table 1. Study vehicles were limited to those where blind spot monitoring was offered as an optional feature and the presence or absence of the system on individual vehicles at the VIN (vehicle identification number) level was known. The study focused on vehicles with optional blind spot monitoring because these systems were rarely offered as standard equipment at the time of the study. VINs of Acura, Fiat Chrysler (Dodge, Jeep), General Motors (Buick, Cadillac, Chevrolet, GMC), Mazda,

Table 1. Study vehicle series and model years

Make	Series	Model years
Acura	MDX 4D 4WD	2010-2012
Acura	ZDX 4D 4WD	2010-2012
Buick	LaCrosse 4D 2WD	2014-2015
Buick	LaCrosse 4D 4WD	2014-2015
Buick	Regal 4D 2WD	2014-2015
Buick	Regal 4D 4WD	2014-2015
Cadillac	ATS 2D 2WD	2015
Cadillac	ATS 2D 4WD	2015
Cadillac	ATS 4D 2WD	2013-2015
Cadillac	ATS 4D 4WD	2013-2015
Cadillac	CTS 4D 2WD	2014-2015
Cadillac	CTS 4D 4WD	2014-2015
Cadillac	Escalade 4D 2WD	2015
Cadillac	Escalade 4D 4WD	2015
Cadillac	Escalade ESV 4D 2WD	2015
Cadillac	Escalade ESV 4D 4WD	2015
Cadillac	SRX 4D 2WD	2013-2015
Cadillac	XTS 4D 2WD	2013-2015
Cadillac	XTS 4D 4WD	2013-2015
Chevrolet	Impala 4D	2014-2015
Chevrolet	Suburban 4D 2WD	2015
Chevrolet	Suburban 4D 4WD	2015
Chevrolet	Tahoe 4D 2WD	2015
Chevrolet	Tahoe 4D 4WD	2015
Dodge	Charger 4D 2WD	2012
Dodge	Charger HEMI 4D 2WD	2011-2012
Dodge	Charger HEMI 4D 4WD	2011-2012
Dodge	Durango 4D 2WD	2011-2012
Dodge	Durango 4D 4WD	2011-2012
GMC	Yukon 4D 2WD	2015
GMC	Yukon 4D 4WD	2015
GMC	Yukon 4D XL 2WD	2015
GMC	Yukon 4D XL 4WD	2015
Jeep	Grand Cherokee 4D 2WD	2011-2012
Jeep	Grand Cherokee 4D 2WD	2011-2012
Mazda	3 4D	2012-2015
Mazda	3 5D	2014-2015
Mazda	3 SW	2012-2013
Mazda	6 4D 2WD	2009-2015
Mazda	CX-5 4D 2WD	2013-2015
Mazda	CX-5 4D 4WD	2013-2015
Mazda	CX-7 4D 2WD	2010-2012
Mazda	CX-7 4D 4WD	2010-2012
Mazda	CX-9 4D 2WD	2008-2015
Mazda	CX-9 4D 4WD	2008-2015
Mercedes-Benz	CL Class 2D 2WD	2008-2010
Mercedes-Benz	CL Class 2D 4WD	2009-2010
Mercedes-Benz	E Class 4D 2WD	2010
Mercedes-Benz	E Class 4D 4WD	2010
Mercedes-Benz	S Class Hybrid 4D 2WD	2010
Mercedes-Benz	S Class LWB 4D 2WD	2008-2010
Mercedes-Benz	S Class LWB 4D 4WD	2008-2010
Volvo	C30 3D 2WD	2008-2010
Volvo	C70 Convertible	2008-2010
Volvo	S40 4D 2WD	2008-2010
Volvo	S40 4D 4WD	2008-2010
Volvo	S80 4D 2WD	2007-2010
Volvo	S80 4D 4WD	2007-2010
Volvo	V50 SW 2WD	2008-2010
Volvo	V50 SW 4WD	2008-2010

Volvo	V70 SW 2WD	2008-2010
Volvo	XC60 4D 2WD	2010
Volvo	XC60 4D 4WD	2010
Volvo	XC70 SW 4WD	2008-2010
Volvo	XC90 4D 2WD	2007-2010
Volvo	XC90 4D 4WD	2007-2010

2D=two-door, 4D=four-door, 5D=five-door, 2WD=two-wheel drive, 4WD=four-wheel drive, LWB=long wheelbase

Mercedes-Benz, and Volvo vehicles equipped with optional crash avoidance features, including blind spot monitoring, were obtained from manufacturers.

An indicator light in or near the appropriate side-view mirror was illuminated on all vehicles when a vehicle was detected in the blind spot. Additionally, systems on Fiat Chrysler, Mazda, and Mercedes-Benz vehicles warned with a beep if a vehicle was detected in the blind spot and the turn signal was activated. Systems varied in the extent to which the size of the adjacent lane zone covered exceeded the blind zone area, speed differentials at which vehicles could be detected, and in their ability to detect rapidly approaching vehicles.

Collision avoidance systems other than blind spot monitoring were offered on many study vehicles. Because lighting could potentially affect nighttime crashes of all types and because lane departure systems can increase turn signal use (LeBlanc et al., 2007), potentially influencing lane-change crash risk, analyses controlled for the presence or absence of different headlight and lane departure systems offered as optional equipment. When a manufacturer offered multiple headlight types, the base headlights were halogen; LED headlights were also standard on some General Motors models. The systems accounted for in the analyses were:

- General Motors: high-intensity discharge headlights, curve-adaptive high-intensity discharge headlights, high beam assist, cornering lamps, lane departure warning and lane-keeping assist (packaged with forward collision warning with or without autonomous emergency braking)
- Mazda: high-intensity discharge curve-adaptive headlights, high beam assist (packaged with forward collision warning), lane departure warning
- Mercedes-Benz: high-intensity discharge headlights, curve-adaptive high-intensity discharge headlights, high-beam assist, cornering lamps, night vision system, lane departure warning
- Volvo: high-intensity discharge curve-adaptive headlights, lane departure warning (packaged with forward collision warning with autonomous emergency braking)

Acura vehicles only offered a single headlight type. Fiat Chrysler offered the option of halogen or high-intensity discharge headlights, but their presence or absence on individual vehicles was unknown; thus, headlights were not accounted for in the analyses involving Fiat Chrysler vehicles.

Additional optional collision avoidance features were not accounted for in the analyses because they would not be expected to impact lane-change crashes. These features were sometimes, but not always, packaged with blind spot monitoring and included forward collision warning with autonomous emergency braking on Acura vehicles; rearview cameras, parking sensors (rear or both front and rear), rear automatic emergency braking, and active parallel parking assistance on other General Motors vehicles; rearview cameras and rear parking sensors on Fiat Chrysler vehicles; low-speed autonomous emergency braking, rear cross-traffic alert, and rearview cameras on Mazda vehicles; forward collision warning with autonomous emergency braking, precharged brakes, front and rear

parking sensors, rearview cameras, and active parallel parking assistance on Mercedes-Benz vehicles; and forward collision warning, rearview cameras, and rear parking sensors on Volvo vehicles. Blind spot monitoring always came packaged with rear cross-traffic alert on General Motors study vehicles and with forward collision warning and rear cross-traffic alert on Fiat Chrysler study vehicles.

Crash data

Police-reported crash data were obtained from 26 states that released the VINs of the vehicles involved in crashes with their data. Available crash data with VINs varied by state. Data included 2009-2013 crashes in Nevada and Rhode Island; 2009-2015 crashes in Delaware, Idaho, Louisiana, Missouri, South Dakota, and Tennessee; 2010-2013 crashes in Indiana; 2011-2015 crashes in Mississippi; 2010-2015 crashes in Florida, Georgia, Iowa, Kansas, Michigan, Minnesota, Nebraska, New Jersey, Oklahoma, Pennsylvania, Texas, Utah, Washington, Wisconsin, and Wyoming; and 2014-2015 crashes in Maryland.

Lane-change crashes were defined as multiple-vehicle crashes where the subject vehicle was changing lanes or merging prior to the crash. Additionally, when point of initial impact was available or when direction of vehicle travel prior to the crash was available in two-vehicle crashes, lane-change crashes considered relevant to blind spot monitoring excluded those in which the subject vehicle rear ended another vehicle and or the two vehicles involved were initially traveling in opposite or perpendicular directions. In two-vehicle crashes, a rear-end strike was defined as a crash involvement when the crash type was a rear end, the initial impact to the subject vehicle was to the front, and the initial impact to the struck vehicle was to the rear; in rear-end crashes involving three or more vehicles, the initial impact point to the struck vehicle was not considered.

Point of impact was unavailable in three states (Mississippi, Washington, and Wisconsin), and direction of travel was unavailable in four (Louisiana, Mississippi, Nevada, and Oklahoma). In the states where they were available, initial impact point and direction of travel were missing in 3% and 5%, respectively, of crashes involving study vehicles. Seven states (Georgia, Mississippi, Missouri, Nevada, Pennsylvania, Tennessee, Texas) did not code when a vehicle was merging prior to the crash. In these states, only crash involvements where the subject vehicle was changing lanes were considered. Because Texas did not code movement prior to the crash, vehicles in Texas were deemed to be in lane-change crashes if "changed lanes while unsafe" was a contributing factor for that vehicle to the crash.

Exposure data

Data on vehicle exposure and characteristics of the vehicle's garaging location (density of registered vehicles in the ZIP code where the vehicle is garaged) and rated driver on the vehicle's insurance policy (age, gender, marital status, insurance risk level) were obtained from HLDI. HLDI's database includes information on approximately 85% of insured U.S. passenger vehicles. Exposure was expressed as insured vehicle years. Crash and insurance exposure data were merged by matching VINs within states. Crashes that occurred in a different state than where a vehicle was insured were not included in the analyses.

Regression models

Poisson regression was used to model lane-change crash involvement rates per insured vehicle year for vehicles with blind spot monitoring compared with vehicles without the system, controlling for a number of factors that can affect crash risk. Models used a logarithmic link function. Two regressions were constructed for each manufacturer, one that modeled lane-change crashes of all severities and one that modeled lane-change crashes with injuries. This resulted in a total of 12 separate regressions.

Models controlled for rated driver age (15-34, 35-54, 55-69, 70+, unknown), gender, marital status, and insurance risk level (standard risk, nonstandard risk, unknown); state; calendar year; and registered vehicle density per square mile (0-499, 500+) in the ZIP code where the vehicle is garaged. These covariates were chosen for consistency with previous analyses examining the effects of blind spot monitoring systems on insurance claim rates (HLDI 2012, 2016a, 2016c, 2016d, 2017b). A single variable capturing the vehicle series and model year was included to restrict estimates of effects within series and model year, preventing confounding of collision avoidance feature effects with other vehicle design changes that may occur between model years. Finally, binary variables indicating the presence or absence of blind spot monitoring, headlight, and lane departure systems were also included.

Suppose C_i represents the number of crash involvements, E_i represents exposure (i.e., insured vehicle days), and S_i represents the presence or absence of blind spot monitoring for vehicle i. Assuming C_i is a Poisson random variable with mean $E_i\lambda_i$, the statistical models were specified as $\log \lambda_i = \beta 0 + \beta 1(S_i) + \beta 2(\text{covariates})$. $\text{Exp}(\beta 1)$ represented a rate ratio comparing crash involvement rates for vehicles with blind spot monitoring to vehicles without. Over-dispersion in the Poisson models was controlled for by estimating a scale parameter in SAS (i.e., PSCALE) and adjusting statistics accordingly. Negative binomial models were considered but were ultimately not used because they did not converge (i.e., data were too sparse for algorithm to produce estimates) in every case.

Pooled estimates

Effects were pooled across automakers using meta-analysis methods. Random effects models were used because the implementation of blind spot monitoring varied across manufacturers.

Rate ratios were log-transformed. A weight was assigned to each estimate as follows:

$$w_i = \frac{1}{v_i + \sigma_\theta^2}$$

where v_i represents the estimate's variance and σ_θ^2 is a function of the Q statistic that represents the systematic variation among the estimated effects. The pooled effect for blind spot monitoring was calculated as follows:

$$\overline{y} = exp\left(\frac{\sum_{i=1}^{g} w_i y_i}{\sum_{i=1}^{g} w_i}\right)$$

where exp is the exponential function, y_i is the logarithm of each effect estimate, w_i is each estimate's weight, and g is the total number of estimates. Thus, because weights were primarily based on the inverse variance of the respective estimates, estimates with high variance (those with large confidence intervals, typically because of a

small number of crashes or little exposure) contributed less to the pooled effect than estimates with low variance (those with small confidence intervals).

Ninety-five percent confidence intervals were computed using the following equation:

$$95\%\ CI = exp\left[\left(\frac{\sum_{i=1}^{g} w_i y_i}{\sum_{i=1}^{g} w_i}\right) \pm 1.96 \times {}^{1}\Big/\sqrt{\sum_{i=1}^{g} w_i}\right]$$

Effect estimates indicated that vehicles with blind spot monitoring significantly lower crash involvement rates than comparison vehicles when estimates and their 95% confidence intervals were less than 1. Percentage reductions were expressed as the rate ratio minus 1, multiplied by 100.

RESULTS

Study vehicles were involved in 154,811 crashes of all severities and 37,077 injury crashes. Of these, 4,620 crashes of all severities (3% of total) and 568 injury crashes (2% of all injury crashes) were lane-change crashes. Few (4%) lane-change crashes with injuries involved serious injuries (i.e., A on the KABCO scale), and none were fatal. For the subset of these that were lane-change crashes, Table 2 presents descriptive measures on raw crash count and involvement rates that do not control for various exposure factors (described below) that may impact crash risk. It should be noted that raw crash counts associated with fewer insured vehicle years yield less reliable estimates of crash rates.

Table 2. Crash involvement rates in lane-change crashes of all severities and with injuries among vehicles with and without blind spot monitoring systems (not controlling for factors that can affect crash risk)

Manufacturer	Has blind spot monitoring	Insured vehicle years	All severities		Injury crashes	
			Crashes	Rate (x10,000)	Crashes	Rate (x10,000)
Acura	Yes	29,130	27	9.3	3	1.0
	No	192,599	227	11.8	26	1.4
Fiat Chrysler	Yes	76,208	82	10.8	10	1.3
	No	512,500	641	12.5	86	1.7
General Motors	Yes	284,719	386	13.6	44	1.5
	No	196,541	380	19.3	44	2.2
Mazda	Yes	584,541	674	11.5	89	1.5
	No	863,325	1412	16.4	174	2.0
Mercedes-Benz	Yes	21,188	20	9.4	4	1.9
	No	172,923	227	13.1	28	1.6
Volvo	Yes	109,925	121	10.0	10	0.9
	No	357,577	423	11.8	50	1.4
All manufacturers	Yes	1,105,711	1310	11.8	160	1.4
	No	2,295,465	3310	14.4	408	1.8
	Total	3,401,176	4620	13.6	568	1.7

Poisson regression models examining the effects of blind spot monitoring controlling for state, calendar year, registered vehicle density of the vehicle garaging location, vehicle series/model year combination, vehicle headlight and lane departure systems, and the age, gender, marital status, and insurance risk of the rated driver are summarized in Table 3. Blind spot monitoring reduced lane-change crash involvement rates in crashes of all severities by 14 percent on average, and crash involvement rates in injury crashes by 23 percent. Only the effect for crashes of all severities reached statistical significance.

Table 3. Adjusted rate ratios from Poisson regression models examining the effects of blind spot monitoring on involvement rates in lane-change crashes

	Rate ratio (95% confidence interval)	
Analysis	All severities	Injury crashes
Acura	0.89 (0.28, 2.83)	0.91 (0.28, 3.02)
Fiat Chrysler	0.98 (0.71, 1.35)	0.70 (0.34, 1.44)
General Motors	0.82 (0.51, 1.30)	0.58 (0.23, 1.46)
Mazda	0.80 (0.68, 0.94)	0.91 (0.55, 1.51)
Mercedes-Benz	0.73 (0.26, 2.07)	*
Volvo	1.05 (0.77, 1.43)	0.66 (0.32, 1.37)
Combined blind spot effect	0.86 (0.76, 0.98)	0.77 (0.56, 1.06)

*not enough data to produce estimate; Mercedes is not included in combined effect

DISCUSSION

Consistent with prior research with insurance claims (HLDI, 2016a, 2017b), the current results indicate that blind spot monitoring is reducing the lane-change crashes it was designed to address when considering crashes of all severities. Effects for injury crashes were also in the expected direction for the five manufacturers for which effects could be estimated, but the overall effect did not reach statistical significance.

Although blind spot monitoring is proving effective, the size of its effect on lane-change crashes was relatively modest. This may be because of the primary mechanism by which the system works. Blind spot monitoring provides drivers with additional information to supplement their vision and also draws attention to side-view mirrors, where vehicles in the blind spot can be detected (Kiefer and Hankey, 2008); drivers must respond to the system appropriately to prevent a crash. Other collision avoidance systems that actively control or brake the vehicle to avoid a crash, such as electronic stability control and front automatic emergency braking, have demonstrated higher estimates of effectiveness (Cicchino, 2017; Farmer, 2006; Fildes et al., 2015). Some current production blind spot monitoring systems provide light braking or steering to keep a vehicle within the lane if another vehicle is detected in the blind spot, and the effectiveness of such systems is unknown.

Among individual manufacturers, the size of the effect of blind spot monitoring on the target crash type was sometimes smaller than expected given the size of the effect of the system on property damage liability insurance claims in prior research from HLDI. Estimates for individual manufacturers in the current study were relatively imprecise (i.e., had large confidence intervals), and it is also possible that true effect sizes for individual manufacturers are higher or lower than estimated here. That said, it is interesting to note that Acura's and Mazda's

blind spot monitoring systems were each associated with significant 11% reductions in property damage liability claim rates in HLDI's (2016a, 2017b) studies. In the current study, Acura's system reduced police-reported lane-change crashes of all severities nonsignificantly by 11%, and Mazda's significantly by 20%. It would be expected that the magnitude of the effects on lane-change crashes would be larger than they were to result in an 11% reduction in property damage liability claims, given that lane-change crashes comprised only 3% of all police-reported crashes in this sample. It has been estimated that more than half of the lane-change crashes that occur may be unreported to police (Wang and Knipling, 1994), and it is possible that lane-change crashes make up a larger proportion of property damage liability claims than of all police-reported crashes if many lane-change crashes are reported to insurers but not to police, which could explain some of the difference.

The activation status of systems at the time of the crash was unknown, but observed (Reagan et al., 2017) and self-reported (Braitman et al. 2010; Cicchino and McCartt, 2015) evidence indicates that drivers with blind spot monitoring systems overwhelmingly keep the systems turned on. Drivers tend to report high satisfaction with blind spot monitoring systems and report higher trust in them than in other types of collision avoidance and driver assistance systems (Kidd et al., 2017).

This study is not without limitations. Crash counts were too small to compare blind spot monitoring systems with different characteristics, such as those that provide a beeping warning when the turn signal is activated and those that warn only with a visual cue, or those that can and cannot detect rapidly approaching vehicles. System characteristics varied by manufacturer, and this could have contributed to the differing pattern of effect sizes by manufacturer seen in this study. Blind spot monitoring was an optional feature. Vehicles with it more often had other collision avoidance systems and typically cost more than vehicles without. Systems not accounted for in the analyses, such as forward collision warning/braking and backing assistance systems, were not expected to affect lane-change crashes. Although analyses controlled for lighting and lane departure systems that could potentially affect lane-change crash risk, as well as characteristics of the rated driver and insurance policy, it is possible that drivers of vehicles with and without the system differed even after controlling for these factors.

Like other types of collision avoidance systems, blind spot monitoring systems appear to be effective in preventing the types of crashes they were designed to address. In 2015, about 350,000 passenger vehicle lane-change crashes relevant to blind spot monitoring were reported to the police in the United States that resulted in nearly 70,000 injuries. If every U.S. passenger vehicle in 2015 had been equipped with a blind spot monitoring that performed like those on the study vehicles, about 50,000 police-reported crashes could have been prevented. Although not significant, the effect on lane-change crashes with injuries suggests that almost 16,000 injuries in these crashes may have been prevented in 2015 if all U.S. passenger vehicles were equipped with a similarly-performing system.

ACKNOWLEDGEMENTS

The author would like to thank Adrian Lund, Chuck Farmer, and David Zuby of the Insurance Institute for Highway Safety, and Matt Moore of the Highway Loss Data Institute, for their input that improved the design and statistical methods used in this study. She is also grateful to Lisa Henke of the Highway Loss Data Institute, who provided exposure and vehicle feature data, and Jason Rubinoff and JoAnn Wells of the Insurance Institute for

Highway Safety for their assistance in obtaining and formatting state crash data. Pennsylvania data used herein was supplied by the Pennsylvania Department of Transportation. The Pennsylvania Department of Transportation specifically disclaims responsibility for any analyses, interpretations, or conclusions drawn in this publication. This work was supported by the Insurance Institute for Highway Safety.

REFERENCES

Braitman K. A., McCartt A. T., Zuby D. S., Singer J. (2010). Volvo and Infiniti drivers' experiences with select crash avoidance technologies. *Traffic Injury Prevention,* 11(3), 270-278.

Cicchino J. B. (2017). Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accident Analysis & Prevention,* 99(Pt A), 142-152.

Cicchino J. B., McCartt A. T. (2015). Experiences of model year 2011 Dodge and Jeep owners with collision avoidance and related technologies. *Traffic Injury Prevention,* 16(3), 298-303.

Farmer C. M. (2006). Effects of electronic stability control: an update. *Traffic Injury Prevention,* 7(4), 319-324.

Fildes B., Keall M., Bos N., Lie A., Page Y., Pastor C., Pennisi L., Rizzi M., Thomas P., Tingvall C. (2015). Effectiveness of low speed autonomous emergency braking in real-world rear-end crashes. *Accident Analysis & Prevention,* 81:24-29.

Highway Loss Data Institute. (2012). Volvo collision avoidance feaures: initial results. *HLDI Bulletin,* 29(5).

Highway Loss Data Institute. (2016a). Acura collision avoidance features: a 2016 update. *HLDI Bulletin,* 33(19).

Highway Loss Data Institute. (2016b). Buick collision avoidance features: an update. *HLDI Bulletin,* 33(18).

Highway Loss Data Institute. (2016c). Fiat Chrysler collision avoidance features: initial results. *HLDI Bulletin,* 33(2).

Highway Loss Data Institute. (2016d). Mercedes-Benz collision avoidance features: a 2016 update. *HLDI Bulletin,* 33(23).

Highway Loss Data Institute. (2016e). *Vehicle information report, HLDI facts and figures: 1981-2017 vehicle fleet.* Arlington, VA.

Highway Loss Data Institute. (2017a). 2013–16 Subaru collision avoidance features. *HLDI Bulletin,* 34(10).

Highway Loss Data Institute. (2017b). Mazda collision avoidance features: 2007–16. *HLDI Bulletin,* 34(8).

Jermakian J. S. (2011). Crash avoidance potential of four passenger vehicle technologies. *Accident Analysis & Prevention,* 43(3), 732-740.

Kidd D. G., Cicchino J. B., Reagan I. J., Kerfoot L. B. (2017). Driver trust in five driver assistance technologies following real-world use in four production vehicles. *Traffic Injury Prevention,* 18(S1), S44-S50.

Kiefer R. J., Hankey J. M. (2008). Lane change behavior with a side blind zone alert system. *Accident Analysis & Prevention,* 40(2), 683-690.

LeBlanc D. J., Sayer J., Winkler C., Bogard S., Devonshire J. (2007). Field test results of a road departure crash warning system: driver utilzation and safety implications. In: *Proceedings of the Fourth International Driving Symposim on Human Factors in Driver Assessment, Training and Vehicle Design*.

Reagan I. J., Cicchino J. B., Kerfoot L. B., Weast R. A. (2017). *Crash avoidance and driver assistance technologies – are they used?* Arlington, VA: Insurance Institute for Highway Safety.

Wang J. S., Knipling R. R. (1994). *Lane change/merge crashes problem size assessment and statistical description* (DOT HS 808 075). Washington, DC: National Highway Traffic Safety Administration.