U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA

DOT HS 812 841 March 2020

Crash Avoidance Technology Evaluation Using Real-World Crash Data

DISCLAIMER

Suggested APA Format Citation:

Flannagan, C., & Leslie, A. (2020, March). *Crash avoidance technology evaluation using real-world crash data* (Report No. DOT HS 812 841). Washington, DC: National Highway Traffic Safety Administration.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 812 841		

Title and Subtitle	5. Report Date
Crash Avoidance Technology Evaluation Using Real-World Crash Data	March 2020
	6. Performing Organization Code
7. Authors Carol Flannagan and Andrew Leslie	8. Performing Organization Report No.
Performing Organization Name and Address University of Michigan Transportation Research Institute 2901 Baxter Rd. Ann Arbor, MI 48109	10. Work Unit No. (TRAIS)
	Contract or Grant No. DTHN2216R00075, Vehicle Electronics Systems Safety IDIQ
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE Washington, DC 20590	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Acknowledgements: The authors would like to acknowledge the invaluable help of Dr. Raymond J. Kiefer of General Motors. Without his help in obtaining data, explaining system design, packaging, and interfaces, and suggesting comparisons, this work could not have been done.

16. Abstract

This study used data on primarily optional safety content from 1.2 million General Motors (GM) vehicles linked to State police-reported crash data by Vehicle Identification Number to estimate field performance of a variety of new safety technologies. After linkage, there were 35,401 vehicles in our analysis dataset. This data included both an indication (presence/absence) of certain types of safety equipment on each vehicle, as well as a variety of crash descriptors at the crash, vehicle, and driver levels. Available covariates were also used to attempt to control for variables that might influence system-relevant crash involvement for the systems examined, including driver age and gender, speed limit, alcohol/drug presence, fatigue, weather, road surface condition, vehicle type, and vehicle model.

17. Key Words	18. Distribution Statement
	Document is available to the public from the National Technical Information Service, www.ntis.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	43	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

1 Executive Summary

This study used data on primarily optional safety content from 1.2 million General Motors (GM) vehicles linked to State police-reported crash data by Vehicle Identification Number (VIN) to estimate field performance of a variety of new safety technologies. After linkage, there were 35,401 vehicles in our analysis dataset. This data included both an indication (presence/absence) of certain types of safety equipment on each vehicle, as well as a variety of crash descriptors at the crash, vehicle, and driver levels. Available covariates were also used to attempt to control for variables that might influence system-relevant crash involvement for the systems examined, including driver age and gender, speed limit, alcohol/drug presence, fatigue, weather, road surface condition, vehicle type, and vehicle model.

Power analysis was presented in an earlier report from the same project, identifying the required sample size for different safety systems. Analyses in this report were conducted only on systems for which there was at least a large enough sample to detect a 25 percent reduction in relevant crashes. The estimated system effectiveness estimates are described in the next several paragraphs and summarized in Table 1-1 at the end of this Executive Summary.

In the description below, "significance" is defined using the standard p-value cutoff of 0.05. However, the estimates of effectiveness are reported for all systems, rather than treating non-significant estimates as though they are equal to zero. In many such cases, the estimated effectiveness was less than 25 percent and the dataset may not have included a large enough sample to detect smaller (but possibly true) differences. In the text, all reported effectiveness estimates are significant unless otherwise noted.

For forward (or frontal) collisions, Forward Collision Alert (FCA) produced an estimated 16 percent reduction in rear-end striking crashes and FAB (Front Automatic Braking), which is only offered with Adaptive Cruise Control (ACC), produced an estimated 45 percent reduction in the same crash type.

For lateral crashes, the analysis covered two types of such crashes and two sets of systems. For lane departure crashes, in which the vehicle leaves the lane or the road and crashes, lane keep assist (LKA) (which also includes lane departure warning functionality) showed an estimated 30 percent reduction in such crashes, whereas lane departure warning (LDW) alone showed a non-significant 3 percent reduction. In a large-scale telematic-based study of LDW usage, Flannagan et al. (2016) reported that, overall, vehicles' LDW systems were turned off 50 percent of the time, so this may contribute to the low LDW effectiveness. However, even if 50 percent of the vehicles in this study had LDW turned off, based on the observed results, the overall effectiveness would not be expected to be more than 6 percent. Lane Change Alert (packaged with Side Blind Zone Alert) was 32 percent effective in addressing lane-change crashes compared to 8 percent (non-significant) estimated effectiveness for Side Blind Zone Alert (SBZA) alone. While both systems provide side mirror alerts to help the driver avoid crashing into a moving vehicle detected in their side blind zone, the Lane Change Alert (with SBZA) system has a greater capability of alerting the driver to a vehicle that is rapidly approaching their side blind spot during a lane-change maneuver. The Lane Change Alert system has an extended sensor range, which appears to have notable benefits based on the observed results.

Finally, the pattern of results for backing crashes was somewhat more complex. Four systems were evaluated: rear automatic braking (RAB), rear cross-traffic alert (RCTA), rear park assist (RPA), and rear vision camera (RVC). Note that these systems are hierarchically related such that the more advanced systems such as RAB generally include all the other systems (e.g., RCTA, RPA, and RVC). Two models were developed, one with an interaction between age and equipment and one without that interaction. The no-interaction model estimated that rear automatic braking (RAB) is 83 percent effective, rear cross-traffic alert (RCTA) and rear park assist (RPA) are 56 percent and 50 percent effective, respectively, and rear vision camera (RVC) alone is 15 percent effective (non-significant). When the analysis was focused only on RVC and RPA for sedans, RPA alone was more effective than RVC alone, though both individual estimates were not significant. However, the combination produced a significant estimated 51 percent reduction in backing crashes.

With the interaction with age group included in the backing crashes analysis, the results showed that for older drivers (65 and older), the effectiveness of both RAB and RVC are much lower than for the younger driver group examined (younger than 65). For RVC this results in a non-significant estimated 38 percent *disbenefit* for older drivers. Since older drivers are overrepresented in backing crashes (Clarke et al, 2009), they should have more opportunity to benefit, though this does not itself indicate whether safety systems should be more or less effective for them. It is not clear whether the interaction will hold up in future studies. However, the effectiveness of backing crash systems for older drivers should be given particular attention going forward given the possibility that they use such technology differently.

In general, the pattern of results indicated that either brief, limited, vehicle control (e.g., a lane keep assist “nudge”) or more sustained, severe automatic vehicle control (e.g., FAB and RAB) resulted in substantially greater crash avoidance system benefit than “alert only” system counterparts (i.e., LDW, FCA, RPA, and RCTA). These “control” systems have the advantage of not strictly relying on drivers to respond to alerts in a timely and appropriate fashion (particularly in the case of forward and rear automatic braking) or to imminent crash situations that unfold quickly.

Finally, although the systems analyzed in this paper now have a combination of sufficient fleet penetration and/or sufficiently large benefits to evaluate, early indicators of field performance of new safety systems require very large datasets. A multi-OEM effort combined with a larger collection of State crash databases would allow for analysis of additional systems and would reduce the size of confidence intervals for all systems. We recommend an ongoing effort to collect and combine safety content data from multiple manufacturers, to link such data to a larger number of State crash databases, and to use the resulting dataset for ongoing assessment of the newest safety features as they enter the market and informing NHTSA (and global) New Car Assessment Programs (NCAPs).

Table 1-1. Summary of effectiveness estimates

Crash Type	System	Odds Ratio (95% confidence interval)	P Value (significant if less than 0.05)	Estimated Reduction	Findings Statistically Significant?
Frontal	Forward Collision Alert	0.84 [0.77,0.92]	0.000142	16%	Yes
	Forward Auto Braking with ACC	0.55 [0.41,0.74]	0.000061	45%	Yes
	Forward Auto Braking with Full Speed ACC	0.55 [0.43,0.71]	0. 000003	45%	Yes
Lane Departure	Lane Departure Warning	0.97 [0.90,1.05]	0.442	3%	No
	Lane Keep Assist with LDW	0.70 [0.51,0.96]	0.0281	30%	Yes
Blind Zone Alert	Side Blind Zone Alert (SBZA)	0.92 [0.75,1.12]	0.4045	8%	No
	Lane Change Alert with SBZA	0.68 [0.54,0.86]	0.00114	32%	Yes
	Pooled SBZA and Lane Change Alert (with SBZA)[1]	0.81 [0.70,0.95]	0.0109	19%	Yes
Backing	Rear Vision Camera	0.85 [0.54,1.35]	0.500	19%	No
	Rear Park Assist [2]	0.50 [0.39,0.65]	0.0000001	36%	Yes
	Rear Cross Traffic Alert[3]	0.44 [0.35,0.55]	0.0000001	55%	Yes
	Rear Automatic Braking[4]	0.17 [0.08,0.36]	0.000003	82%	Yes
	Rear Vision Camera + Rear Park Assist[5]	0.49 [0.34,0.71]	0.000143	51%	Yes

[1] Analysis was done by including vehicles equipped with *either* SBZA or LCA (with SBZA) in the "equipped" category.
[2] Includes front and rear park assist; in addition, many of these vehicles are also equipped with Rear Vision Camera.
[3] All vehicles are also equipped with rear park assist and rear vision camera or surround vision.
[4] All vehicles are also equipped with rear park assist, rear vision camera or surround vision, and rear cross-traffic alert.
[5] This analysis was conducted on sedans only to assess the independent contributions of RVC and RPA.

2 Research Approach

2.1 Introduction

One of the challenges in automotive safety is the speed at which new vehicle safety systems are coming on the market. It is difficult to measure the safety benefit of these systems in a timely way so that manufacturers and agencies can prioritize system development and/or inclusion in NHTSA and various global New Car Assessment Programs (NCAPs). Although systems may be tested in simulation, on test tracks, and on public roads prior to release, crash data are critical to understanding achieved safety benefits in the field.

A study by the Insurance Institute for Highway Safety (IIHS) illustrates the challenges associated with measuring the field performance of these systems (IIHS Status Report, 2012); particularly if circumstances surrounding the crash is not known. The report showed benefits of some systems such as Forward Collision Warning, but there was wide variation across make/models in their study, leading to mixed conclusions about benefits. Furthermore, results for adaptive headlamps indicated a puzzling 5- to 10 percent reduction in all property damage and bodily injury liability claims, even though only 7 percent of all police-reported crashes occur at night.

A more recent insurance loss-based study of a number of General Motors active safety and headlighting systems (HLDI, 2017) showed significant reductions in overall claims (either collision or property damage liability or both) for forward alerts, forward braking, side alerts, parking alerts with and without rear-vision camera, rear (or reverse) automatic braking, and High Intensity Discharge (HID) and steerable HID headlamps. Intellibeam headlamps were associated with a significant increase in overall claims.

In both of these insurance claims-based studies, the data did not include information about the crash type or conditions (e.g., time of day was not available for headlighting analysis), and as a result, the analyses looked at effectiveness on *overall* claims (irrespective of crash circumstances). An example of a more focused approach to estimating effectiveness using information on crash circumstance is one taken by Dang (2007) looking at effectiveness of Electronic Stability Control (ESC). Because Dang (2007) used crash data linked to safety content (with respect to ESC), Dang was able to separate relevant crashes from irrelevant crashes. Relevant crashes are those that can plausibly be influenced by a given technology. More recently, in a series of Insurance Institute for Highway Safety (IIHS) studies examining police-reported crashes employing data from multiple manufactures, Cicchino (2016, 2017a, 2017b) has shown benefits for forward collision warning, autonomous emergency braking, lane-departure prevention, and blind spot warning systems. In these studies, the effect of these systems on specific relevant crashes were evaluated using a Poisson rate model, where insured-vehicle-years was the denominator for the rates.

To build a database suitable for analyzing safety benefits of vehicle features (e.g., to support NHTSA NCAP decision-making), we need a substantial number of crashes from State crash databases linked with vehicle safety content. Much of the content of interest is optional, so vehicle manufacturers are the definitive source of this information. The Center for the Management of Information for Safe and Sustainable Transportation (CMISST) at UMTRI houses a large number of State crash databases that provide 17-character Vehicle Identification Number (VIN). With vehicle manufacture support, these VINs can be matched to build information to identify the specific content on the millions of vehicles that crash in these States each year. By combining crashes matched to multiple manufacturers' safety content, we can build a large enough dataset to estimate safety benefits in an effective and timely manner.

The overall goal of this project was to amass a large database with a wide variety of safety content information. The purpose of the database was to enable analysis to estimate the safety benefits of various vehicle safety systems. The project included a data sufficiency report where we conducted power analyses prior to gathering all of the data and conducting subsequent analyses. For those systems where a sufficient number of crashes was available, we then conducted analyses of the field performance of those systems.

This report reviews the project in general and provides the results of the data analyses. The first section describes the methods; including data collection, analysis methods, and a summary of the data sufficiency report. This is followed by a statistical analysis of the results, and discussion of findings.

2.2 Methods

2.2.1 Data

To build the safety content database, we require both crash data and VIN-linked safety content. Since most vehicles equipped with advanced crash avoidance systems are new, we need large samples of both to maximize the number of linkable cases.

VIN-linked safety content data. For this project, we teamed with General Motors (GM), which agreed to provide VIN-linked safety content (indicating the presence/absence of content) for a wide variety of Model Year 2013-2015 makes, models, and active safety (crash avoidance) systems.

Safety content indicated by GM included all of the systems listed in Table 2-1. The content falls generally into four categories: forward collision avoidance systems, lateral collision avoidance systems, rear (backing) collision avoidance systems, and advanced headlighting systems.

Table 2-1. Systems included in safety content data from GM

Forward Collision Avoidance Systems	Lateral Collision Avoidance Systems
Forward Collision Alert (FCA)	Lane Departure Warning (LDW)
Front Automatic Braking (FAB) (includes FCA & ACC)	Lane Keep Assist (LKA; includes LDW)
FCA Camera Only	Side Blind Zone Alert (SBZA)
Adaptive Cruise Control (ACC; above 16 mph)	Lane Change Alert (LCA; includes Side Blind Zone Alert)
Full-Speed Range ACC (can brake to stop and work in "stop and go" traffic)	
Rear Collision Avoidance Systems	**Advanced Headlighting Systems**
Rear Vision Camera (RVC)	IntelliBeam Headlamps
Surround Vision (SV)	Halogen Headlamps
Rear Parking Assist (RPA)	High-Intensity Discharge (HID) Headlamps
Front and Rear Parking Assist (FRPA)	Steerable HID Headlamps
Automatic Parking Assist (APA)	Light-Emitting Diode (LED) Headlamps
Rear (Reverse) Automatic Braking (RAB)	
Rear Cross Traffic Alert (RCTA)	

The following provides brief descriptions of the systems evaluated. (The reader is encouraged to examine the more detailed descriptions provided by General Motors in Appendix A.) Forward Collison Alert (FCA) provides alerts if a front-end collision situation is imminent with a vehicle the driver is following, or when the driver is following much too closely. If the Front (or Forward) Automatic Braking (FAB) system detects that a front-end collision situation is imminent, and the driver has not already applied the brakes (e.g., in response to the FCA alert), FAB may automatically apply the brakes. Note FAB-equipped vehicles include FCA, as well as Adaptive Cruise Control (ACC), where the cruise control speed is automatically adapted in order to maintain a driver-selected following gap with the vehicle ahead.

Among lateral avoidance systems, Lane Departure Warning (LDW) provides alerts to help unintentionally drifting out of the lane when the turn signal is not activated. Along similar lines, Lane Keep Assist (LKA) provides gentle steering wheel turns (and LDW alerts if necessary) to further help unintentionally drifting out of the lane when the driver is not actively steering or the turn signal is not activated. (Note the LKA system is not the same as Lane Centering, which automatically keeps the vehicle in a set position within the lane). Side Blind Zone Alert (SBZA) provides side mirror alerts when a moving vehicle is detected in the side blind zone, whereas Lane Change Alert (LCA) add the capability of providing such alerts when a vehicle is rapidly approaching the side blind zone (due to a longer sensing range than SBZA).

Finally, the following backing and parking systems were examined, which operate in Reverse gear under low-speed backing conditions. Rear Vision Camera provides a camera view of the area behind the vehicle. Rear Cross-Traffic Alert (RCTA) provides alerts when left- or right-cross traffic is approaching. Rear Park Assist (RPA) provides distance-to-object alerts to objects directly behind the vehicle, whereas Rear (or Reverse) Automatic Braking (RAB) may also automatically apply the brakes and works at higher speeds than RPA.

2.2.2 Data Obtained

Safety Content Data. GM provided UMTRI with safety content shown in Table 2-1 for 1,215,618 vehicles from MY 2013 to MY 2015. All vehicles were from make-models that offer Front (or Forward) Automatic Braking, or FAB (GM's name for Automatic Emergency Braking systems) as an available option on at least one trim level. Hence, these data included vehicles equipped with none of the safety systems under evaluation.

Crash data. UMTRI was able to obtain crash data from 13 States that provide 17-character VIN. The States, years, and status of databases in CMISST's collection are given in Table 2-2. Data from Tennessee 2016 was from the first two quarters and Maryland 2014 data could not be used in the analysis. (In 2014, Maryland changed its police accident report form, including the coding of initial impact location. During the changeover year, two sets of codes coexisted making this impact variable unusable.) The original plan called for obtaining 16-17 States for crash years 2012 to 2015, including some provided by NHTSA.

Table 2-2. State crash datasets obtained

STATES WITH 17-CHARACTER VIN	YEAR RANGE
Alabama*	2012-2017
Florida	2012-2015
Georgia	2012-2014
Idaho	2012-2015
Kansas	2012-2015
Louisiana	2012-2015
Maryland	2012-2015
Michigan	2012-2016
Missouri	2012-2015
Nebraska	2012-2015
New Mexico	2012-2014
Tennessee	2012-2016
Utah	2012-2015

On receipt from GM of the VIN-linked build codes, UMTRI used the VINs (with safety content indicated) from GM and the State crash databases to link these two datasets. The safety content analysis database was then limited to vehicles in the State crash database that were successfully matched to VINs with safety content information. Thus, the dataset does not necessarily represent a random sample of each State's crashes. Instead, the dataset is designed to compare crash performance with and without particular safety system content.

2.2.3 Analysis Approach

Our analytical approach to estimating the effectiveness of each system is to compare "system-relevant" crashes to a baseline (control) crash type for vehicles equipped or not-equipped with each system. This method is known as *quasi-induced exposure* because crash data are used to infer vehicle exposure (similar to vehicle-miles traveled) (Keall & Newstead, 2009). The system-relevant crash types should be reduced by an effective system, whereas control crashes should only reflect driving exposure of the group of vehicles (i.e., and not be increased or decreased by the system).

For example, to look at the effectiveness of the rear vision camera (RVC) system, we would select backing crashes as the system-relevant crash. For the control crash, we use "rear-end struck" (as opposed to "rear-end striking" crashes), which is defined as a rear-end crash type with rear damage to the vehicle. A vehicle in this "control" crash type is generally considered to be not at fault, though fault is not specified in these databases per se. Moreover, rear-end struck crashes should not be affected by the RVC system. Rear-end-struck crashes are often used as controls in this type of analysis since this control crash type has the desirable quality of being primarily influenced by driving exposure, rather than driver riskiness (Keall & Newstead, 2009).

* Alabama data was provided by the Center for Advanced Public Safety at the University of Alabama through grants from the Alabama Department of Economic and Community Affairs and the Alabama Department of Transportation.

More generally, rear-end struck crashes are used here as the control crash across all the safety system evaluated.

Using these two crash types (system-relevant and control), a crude odds ratio might be constructed from a table like Table 2-3 below. Variables *a, b, c* and *d* represent counts of crashes in the dataset. The odds ratio, $OR = \left(\frac{a}{c}\right) / \left(\frac{b}{d}\right)$ represents the (crude) relative odds of a backing crash for vehicles with a rear vision camera, compared to those without a rear vision camera.

Table 2-3. Hypothetical 2X2 table for computing crude odds ratio of backing-crash reduction associated with Rear Vision Camera (RVC) systems

		System Presence	
		Rear Vision Camera (RVC)	**No RVC**
Crash Type	System-Relevant	a	b
	Control	c	d

The crude odds ratio represents the basic conceptual structure of the analysis approach, but does not address potential important confounder variables. For example, since ownership of certain vehicle make/models may predict involvement in certain crash types, a difference in driver demographics for drivers of equipped vehicles with a given safety system versus drivers of vehicles not equipped with a given safety system could potentially masquerade as a system effect, or alternatively, mask a safety effect associated with the system.

To account for a wide variety of potential confounder variables, we used logistic regression to perform multivariate analyses of the outcome variable (relevant versus control crash type). The covariates considered in each model were the following.

- Driver Age (<25, 25-64, 65+)
- Driver Gender (male, female)
- Speed Limit (in mph)
- Alcohol/Drug Presence (yes, no)
- Fatigue (present, absent)
- Weather (clear/cloudy versus other)
- Road Surface Condition (dry versus wet/icy/other)
- Vehicle Type (sedan, small utility, utility)
- Vehicle Model (as a random effect)

Of these covariates, driver age and gender, as well as safety system presence (and type) were included in every model regardless of significance, based on the following rationale: Age and gender represent minimum characteristics of drivers that need to be accounted for to help eliminate the effects of purchase decisions and driving style, and safety systems are the focus of the study. Thus, these predictors are included *a priori* and we are interested in their effects whether significantly different from zero or not.

For the other variables, those that were significant at an $\alpha = 0.05$ significance level (during backward selection) were included in the model. Except where the model fit did not converge (the maximum likelihood search process could not find a model that was enough better than neighboring models to be considered stable), we included make/model as a random effect. In doing so, we account for differences in effectiveness by make/model as well as basic demographic differences in drivers for each make/model (which could affect the tendency to get into certain crash types independent of the system).

The outcome variable was defined based on the system being evaluated. Table 2-4 gives the crash types that were used for analysis in this study, along with their specific definitions which were constructed and based upon variables available in the State datasets that could be best used to define the various system-relevant crashes and the control crash (i.e., rear-end struck).

Table 2-4. Crash definitions for system-relevant and control crashes by crash type

Crash Type	Control and System-Relevant Crash Types For Each Crash Category	Crash Definition
Rear-end Struck	All (control)	Manner of Crash = Rear-end AND Initial Contact Point on Vehicle = Rear
Rear-end Striking	Frontal (relevant)	Manner of Crash = Rear-end AND Initial Contact Point on Vehicle = Front
Lane-Departure	Lane Departure (relevant)	Manner of Crash = Sideswipe OR Harmful Event = Run off road, Cross centerline, Cross median
Lane-Change	Lane Change (relevant)	Motor Vehicle Maneuver/Action = Lane Change AND Manner of Crash = Same-direction Sideswipe OR Manner of Crash = Rear-end AND Initial Contact Point on Vehicle = Rear
Backing	Backing (relevant)	Motor Vehicle Maneuver/Action = Backing AND Initial Contact Point on Vehicle = Rear

2.2.4 Data Sufficiency Analyses

An early report deliverable in the project was to conduct a series of power analyses to identify which safety systems would likely be analyzable and how much data would be needed to detect differences of various magnitudes. These analyses are reported in Flannagan et al. (2017), and further updates were provided in Flannagan and Leslie (2017).

Data sufficiency depends on the specific system being analyzed, since some systems have higher fleet penetration than others and some crash types are more common than others. Power is the probability of rejecting the null hypothesis given a specific effect size, sample size, alpha level, and reference proportion (i.e., the expected proportion of relevant crashes without the system present). Although the actual analysis reported later in the paper involved multivariate modeling to adjust for effects of other covariates, power analyses could only be done for the simple crude odds ratio (i.e., the 2x2 table crossing safety system present/absent with crash system-relevant/not system-relevant).

The power of the chi-square independence test is given by

$$1 - \beta = F_{df,\lambda}(x_{crit}) \qquad (1)$$

where F is the cumulative distribution function (cdf) for the noncentral chi-square distribution, x_{crit} is the critical value for a given value of α, and $\lambda = w^2 n$ is the noncentrality parameter where w is the effect size and n is the sample size. The required sample size is a function of the base rate of the relevant crash (compared to the control crash), so power calculations were done for different reference rates for each system evaluated.

Needed sample size was calculated using SAS PROC POWER for each analysis. Sample sizes for 80 percent power were calculated for assumed true ORs of 0.5, 0.75, and 0.95 for each system. The resulting sample size requirements were presented in Table 3 of the Data Sufficiency Report (Flannagan & Leslie, 2017), which is reproduced in Table 2-5 below (with feature names either spelled out or adapted to maintain consistency with this report). Green cells indicate that the sample was expected to be sufficient (based on predicted sample size) and red cells indicate that the sample size would likely be insufficient. The expected total sample size was 34,571 crashes. Some systems such as FCA radar and FCA camera only were not analyzed separately (in some cases because different active systems were always offered together), but the power analysis was still done individually for each system.

Table 2-5. Data Sufficiency Report (Flannagan & Leslie, 2017) Table 3 (adapted for this report): Necessary sample size for 80 percent power and assumed true OR*†

Power	80%		
Assumed Odds Ratio	**0.5**	**0.75**	**0.95**
Forward Collision Alert – Radar part of feature*	847	4653	144606
Forward Collision Alert w/ Front Automatic Braking	847	4653	144606
Forward Collision Alert - Camera Only*	312	1728	53775
Forward Collision Alert – Camera Only or Camera and Radar*	304	1653	51357
Adaptive Cruise Control	1782	9396	289170
Full-Speed Range Adaptive Cruise Control	1443	7917	245661
Rear Vision Camera	846	4050	115371
Surround Vision	9307	43419	1204826
Rear Parking Assist	1144	5416	152380
Front & Rear Parking Assist	951	4539	128406
Automatic Park Assist	8436	39294	1090242
Rear Automatic Braking	5684	26362	732109
Rear Cross Traffic Alert	940	4440	125400
Lane Keep Assist with Lane Departure Warning	3724	21014	678566
Lane Departure Warning	300	1700	54425
Side Blind Zone Alert	448	2394	72926
Lane Change Alert with Side Blind Zone Alert	464	2465	74849
Intellibeam Headlamps	63271	283123	7648661
Halogen Headlamps	28832	132392	3649584
HID Headlamps	48020	215880	5854352
Steerable HID Headlamps	66502	297373	8028661
LED Headlamps	198803	883881	23714797

*These systems were analyzed together (i.e., all FCA, including radar- and camera-based), but were separated in the data sufficiency report.
†Green cells indicate those with sufficient expected sample size and red cells indicate those with insufficient expected sample size.

For all systems, small effects (5% reduction in crashes) were not 80 percent likely to be detected with the expected sample size. However, larger effect sizes (e.g., 25%+) were 80 percent likely to be detected with the expected sample size for most systems. The category of systems that could not be analyzed was advanced headlighting systems because the relevant crash type, pedestrian struck at night, is very rare and thus a large number of crashes would be required to match a sufficient number of relevant crashes. As a result, we did not further pursue the headlighting analysis. The other two systems deemed unlikely to meet power requirements were surround vision and automatic parking assist because the fleet penetration of these systems is currently very low.

3 Results

3.1 Sample

Although we obtained data from fewer States than anticipated and NHTSA Crash Data Acquisition Network (CDAN) data was not able to be used, the final sample size of matched vehicles in crashes was 35,401, slightly higher than the expected sample size of 34,571. This was due to a higher-than-expected overall match rate (expected: 0.18%; observed: 0.23%), as well as the addition of 2016 data from three States (Michigan, Tennessee, Alabama) and “up-to-date” 2017 data from Alabama. The newer data tends to have a higher match rate because all of the MY 13-15 vehicles should be on the road for the full year after their model year (i.e., many 2015 vehicles are sold during 2015 and are thus not being driven, but they are on the road for all of 2016).

Table 3-1 gives a more detailed breakdown of the sample size for relevant and control crashes for each system evaluated in this study.

Table 3-1. Sample size details for each system tested

Category	System Present	Sample Size	
		Relevant	Control
Forward	None	2,316	4,520
	Forward Collision Alert (FCA)	1,591	3,774
	Front Automatic Braking (FAB) and Adaptive Cruise Control (ACC) (speeds>25 mph)	70	242
	FAB+ Full-Speed ACC	93	336
Lane Departure	None	3,134	4,530
	Lane Departure Warning (LDW)	2,695	4,224
	Lane Keep Assist (w/ LDW)	62	134
Lane Change	None	515	4,682
	Side Blind Zone Alert (SBZA)	275	2,506
	Lane Change Alert (w/SBZA)	114	1,624
Backing	None	219	1,689
	Rear (or Reverse) Automatic Braking (RAB)	35	403
	Rear Cross Traffic Alert (w/o RAB)	217	2,638
	Rear Park Assist or Front and Rear Park Assist (without RCTA or RAB)	319	3,902

Category	System Present	Sample Size	
		Relevant	Control
	Rear Vision Camera (without any of above backing systems)	10	245

3.2 Analysis of Forward Collision Avoidance

Table 3-2 gives a high-level summary of the features of the forward collision avoidance system analyses. The three systems evaluated were Forward Collision Alert (FCA), Front Automatic Braking (FAB) with standard Adaptive Cruise Control (ACC) and FAB with Full-Speed (Range) ACC, which can bring the vehicle to a stop if necessary. The reference group for analysis was "Unequipped" or no forward collision avoidance system present. The total sample size shown in the bottom of Table 3-2 refers to the number of both equipped and non-equipped vehicles involved in either system-relevant or control crashes.

Table 3-2. Summary of features of forward collision avoidance system analyses

Characteristic	Value
Systems Evaluated	FCA, FAB with ACC, and FAB with Full-Speed ACC
Relevant Crash Type	Rear-end striking
Control Crash Type	Rear-end struck
Total sample size	12,942

Covariates that were retained in the model, all of which were significant, include driver age and gender, speed limit, driver distraction, driver fatigue, road surface, and driver alcohol/drug involvement. The random effect for vehicle make/model was also included.

Of particular interest, the results of the system effects are shown in Figure 3-1. (There were no significant interactions of the forward collision avoidance system with any other covariates.) All three types of forward collision avoidance systems evaluated produced significant benefits. FAB systems (with either type of ACC) resulted in an estimated 45 percent reduction in system-relevant frontal crashes, while FCA resulted in an estimated 16 percent reduction in such crashes. Details of the model are provided in Appendix B.

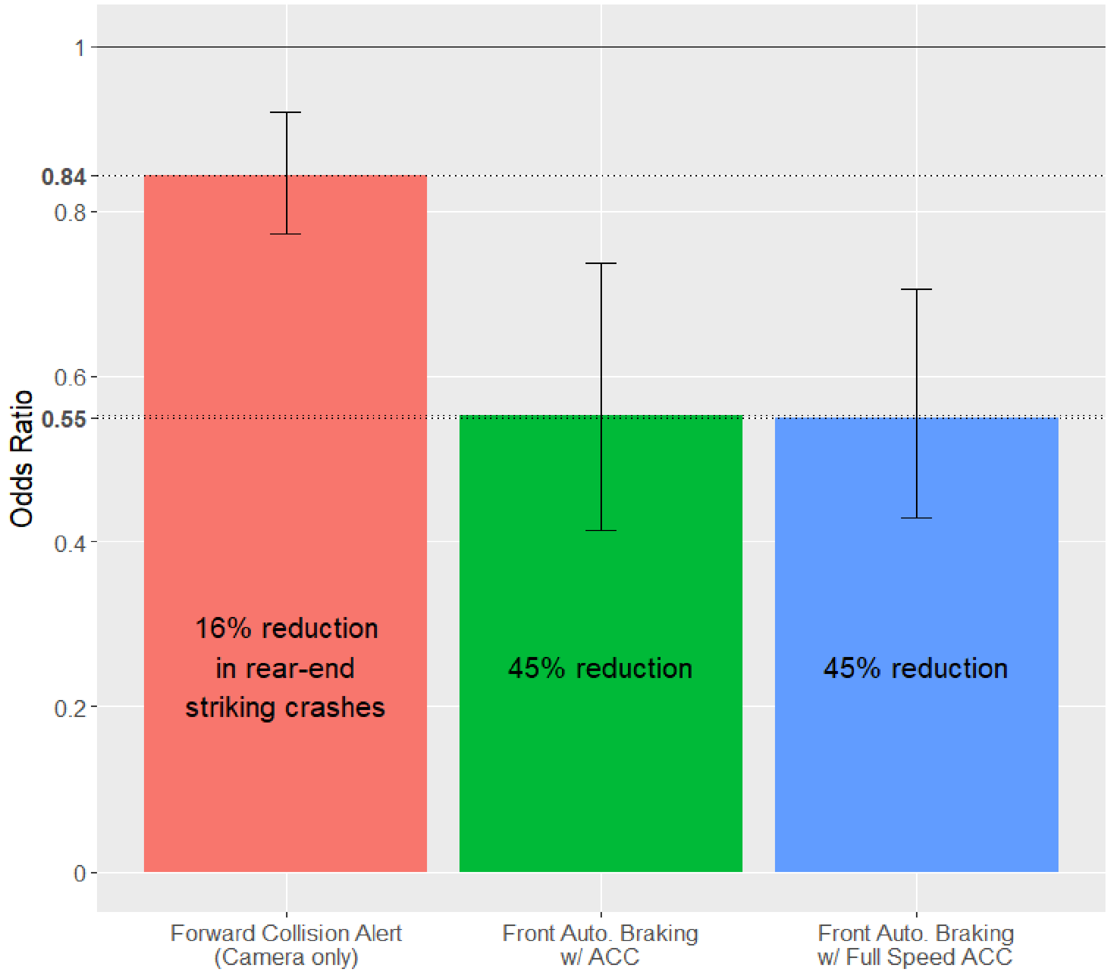

Figure 3-1. Estimated odds ratios and confidence intervals for forward collision avoidance systems.

3.3 Analysis of Lane Departure Collision Avoidance

Table 3-3 gives a high-level summary of the features of the lane departure collision avoidance analyses. The two systems evaluated were Lane Departure Warning (LDW) and Lane Keep Assist (LKA) systems. Note the latter system includes LDW functionality as well. The reference group for analysis was "Unequipped" or no lane departure collision avoidance system (i.e., no LDW or LKA with LDW) present.

Table 3-3. Summary of features of lane departure collision avoidance system analyses

Characteristic	Value
Systems Evaluated	LDW, LKA (includes LDW)
Relevant Crash Type	Lane Departure
Control Crash Type	Rear-end struck
Total sample size	14,779

Covariates that were retained in the model, all of which were significant, include driver age and gender, speed limit, driver fatigue, and driver alcohol/drug involvement. The random effect for vehicle make/model was also included.

The results of the system effects are shown in Figure 3-2. (There were no significant interactions of the lane departure collision avoidance system with any other covariates.) The LKA system showed a significant estimated 30 percent reduction in relevant crashes. For LDW, the estimated reduction was a non-significant 3 percent reduction. Note that since the sample size for LDW is large (CI is narrow) and the estimated benefit is small, establishing this relative small level of reduction reliably would require a substantially larger sample (e.g., see Table 2-5). Details of the model are provided in Appendix B.

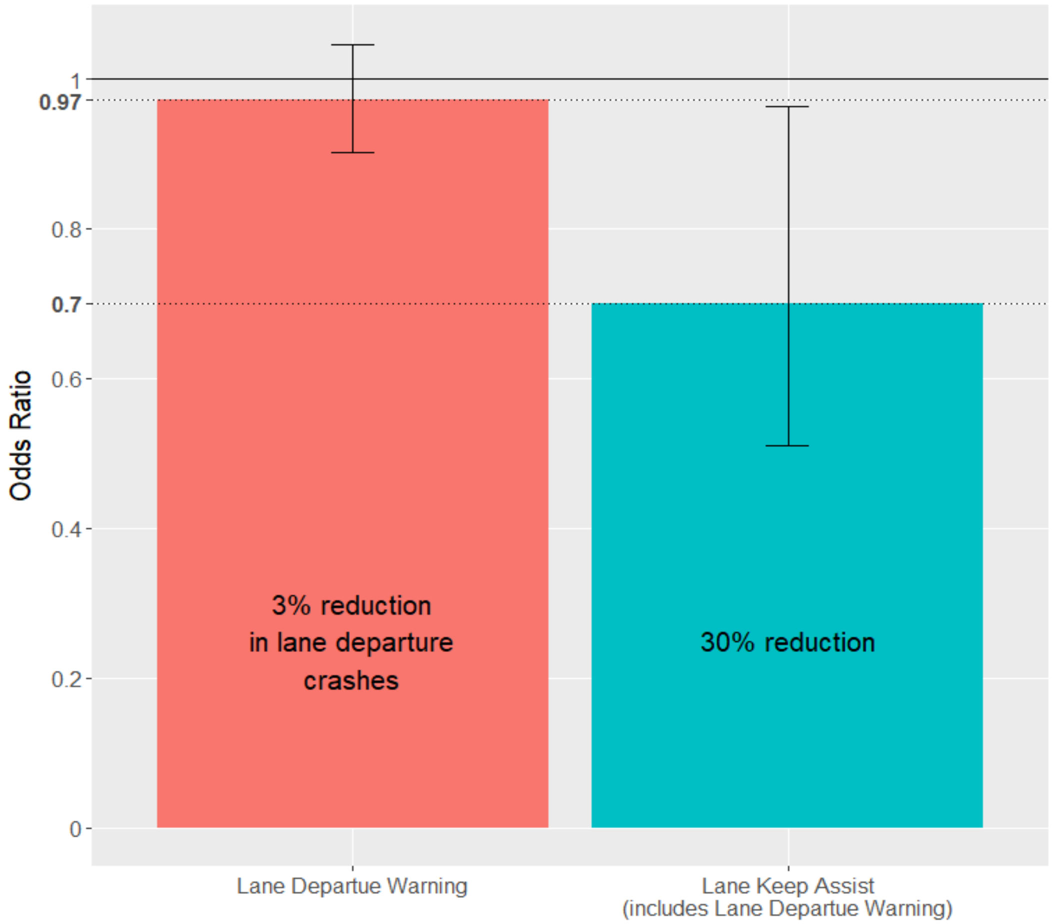

Figure 3-2. Estimated odds ratios and confidence intervals for forward collision avoidance systems.

3.4 Analysis of Lane Change Collision Avoidance

Table 3-4 gives a high-level summary of the features of the lane change collision avoidance system analyses. The two systems evaluated were Side Blind Zone Alert (SBZA) and Lane Change Alert with SBZA (LCA with SBZA). The reference group for analysis was "Unequipped" or no lane change collision avoidance system (i.e., no SBZA or LCA with SBZA) present.

Table 3-4. Summary of features of lane change collision avoidance system analyses

Characteristic	Value
Systems Evaluated	SBZA, LCA with SBZA
Relevant Crash Type	Lane change
Control Crash Type	Rear-end struck
Total sample size	9,716

Covariates that were retained in the model, all of which were significant, include driver age and gender, speed limit, driver distraction, driver alcohol/drug involvement, and vehicle type. The random effect for vehicle make/model was included (but was estimated to be zero in the pooled model discussed below).

The results of the system effects are shown in Figure 3-3. (There were no significant interactions of the lane change collision avoidance system with any other covariates.) In the first model, we separated the effects of SBZA and LCA (with SBZA), which are shown in the first two bars (red and green), respectively. LCA (with SBZA) resulted in a substantially larger and significant 32 percent reduction in relevant crashes compared to SBZA, which had an estimated and non-significant 8 percent reduction.

To enable a more direct comparison to State crash database results from another recent study by the Insurance Institute for Highway Safety (Cicchino, 2017a), we also generated a pooled estimate of the benefits of SBZA and LCA, which is also shown in Figure 3-3 on the right. That estimate (which is essentially a weighted average of the individual system estimates, weighted by system prevalence) is a significant 19 percent reduction. This compares well to the results from IIHS, which estimated a non-significant 18 percent reduction for GM vehicles and a significant 14 percent reduction when pooling data across manufacturers (only 1 of the 6 manufacturers showed an effect).

Because the two systems produced a different pattern of results in the current analysis, we prefer the non-pooled model. The details for this model are provided in Appendix B.

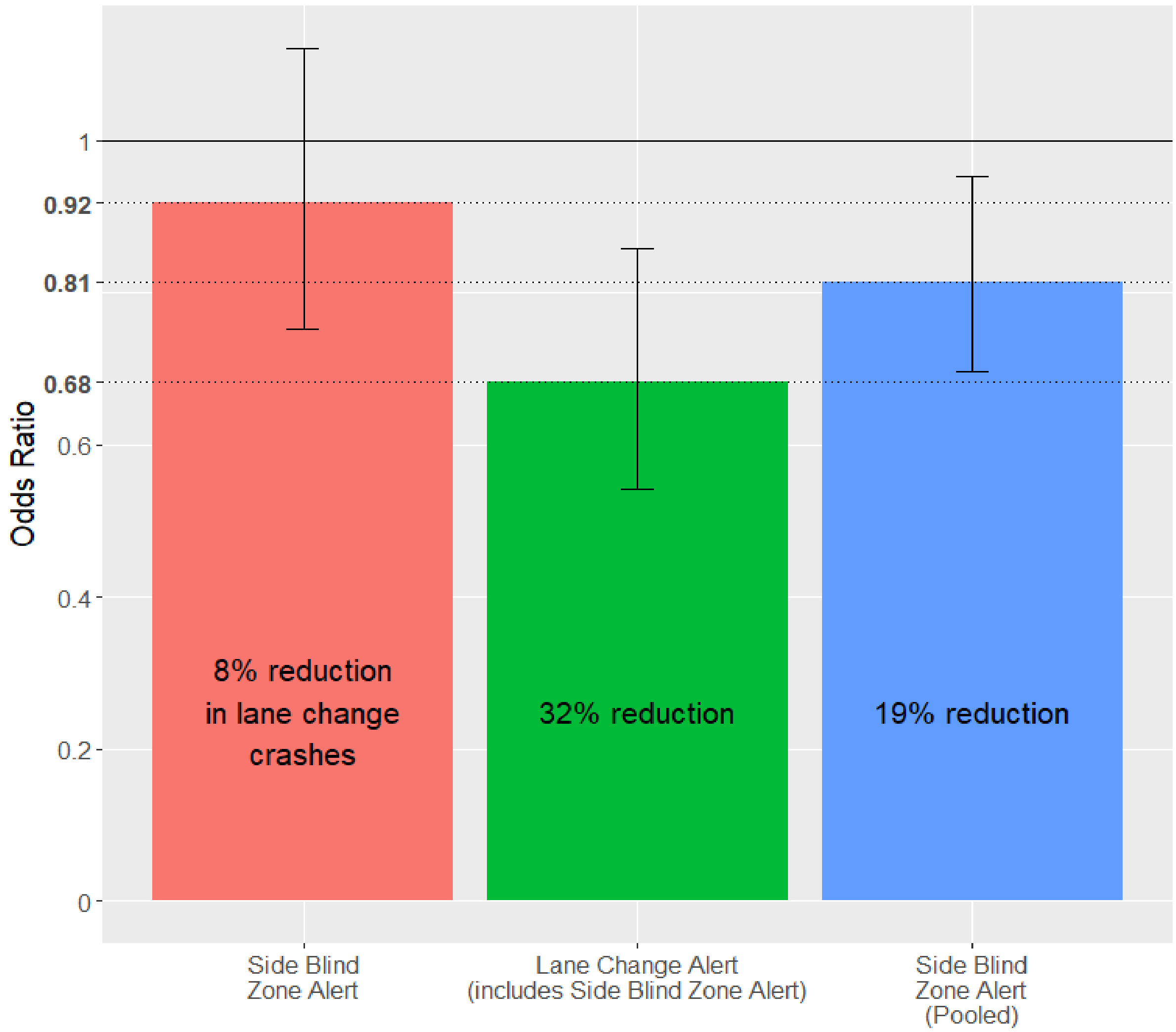

Figure 3-3. Estimated odds ratios and confidence intervals for lane-change collision avoidance systems.

3.5 Analysis of Backing Collision Avoidance

Table 3-5 gives a high-level summary of the features of the backing collision avoidance system analyses. The systems evaluated include rear vision camera (RVC), rear park assist (RPA), rear cross traffic alert (RCTA) and rear automatic braking (RAB). Note that these categories are hierarchical. Thus, first, RAB also includes the other backing systems. Second, RCTA always includes RVC (with a few exceptions that have Surround Vision) and generally includes either RPA or Front and Rear Park Assist (FRPA). Third, except for a small number of cases, RPA generally includes RVC. (Also note RPA was combined with the Front and Rear Park Assist feature, and only backing crashes were analyzed for this latter feature.) The reference group for analysis was “Unequipped” or no backing collision avoidance system (i.e., no RVC, RPA, FRPA, RCTA, or RAB present).

Table 3-5. Summary of features of backing collision avoidance system analyses

Characteristic	Value
Systems Evaluated	RVC, RPA (or FRPA), RCTA, and RAB
Relevant Crash Type	Backing crashes (rear damage)
Control Crash Type	Rear-end struck
Total sample size	9,677

Covariates that were retained in the model, all of which were significant, include driver age and gender, road surface condition, driver alcohol/drug involvement, and vehicle type. Unlike previous analyses, speed limit was omitted from the model because it is not relevant to backing. The random effect for vehicle make/model was included as well. The nature of the observed vehicle type effect is that larger SUVs have a higher base propensity to be involved in backing crashes than sedans (which were no different than the one small SUV available for analysis), independent of any backing crash avoidance systems on the vehicle.

The results of the backing collision avoidance system effects are shown in Figure 3-4. Although most of the vehicles are equipped with a RVC, a relatively small proportion of the sample were equipped with *only* an RVC. For these vehicles, the estimated benefit was a non-significant 15 percent reduction in backing crashes. RPA, RCTA, and RAB produced estimated 50 percent, 56 percent, and 83 percent reductions in backing crashes, respectively. The confidence interval on the RAB estimate excludes RVC and RPA (includes FRPA) and nearly excludes RCTA, in spite of a relatively small sample size for the equipped RAB group. Note that since the grouping was done hierarchically, the effect of RAB may include contributions from other systems (e.g., RCTA, RPA, FRPA, RVC) found on RAB-equipped vehicles. Similarly, the effect of RCTA includes the effects of other systems (e.g., RPA, FRPA, RVC) found on RCTA-equipped vehicles.

In following up this analysis with an investigation of interactions, we noted a significant interaction between age group and backing collision avoidance system type. In this model, we simplified age group to 65 and older (65+) versus younger than 65 (<65) and had to drop the random effect of vehicle model because the model did not converge. As shown in Figure 3-5, drivers under 65 showed a significant 55 percent benefit of RVC and benefits of other systems that are generally similar to the population as a whole (from Figure 3-4). However, the 65+ age groups showed a non-significant disbenefit of RVC and a non-significant 52 percent benefit of RAB. Both of these observed age effects produce lower benefits than when all ages are pooled. The details of both models are provided in Appendix B.

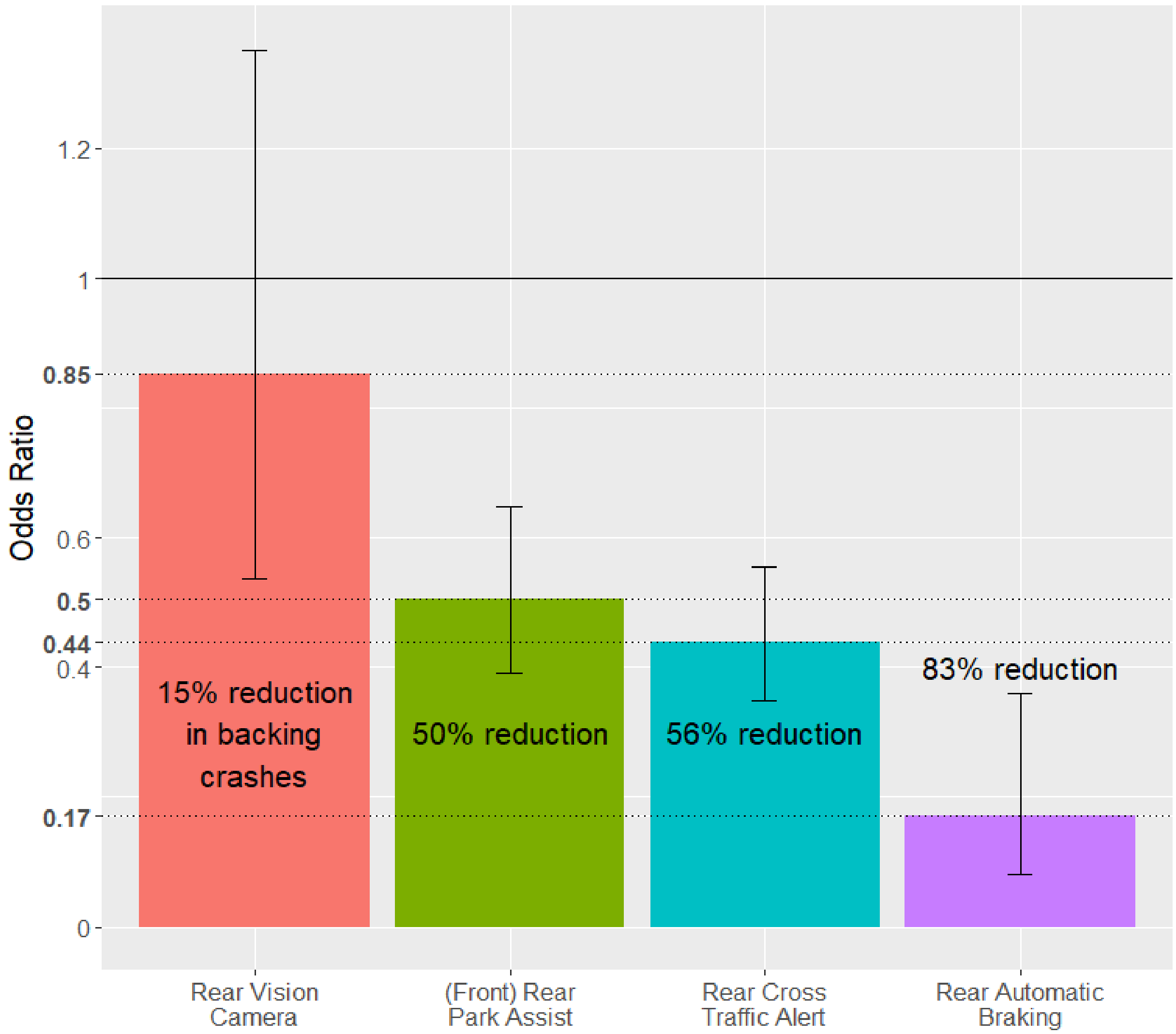

Figure 3-4. Estimated odds ratios and confidence intervals for lane change collision avoidance systems.

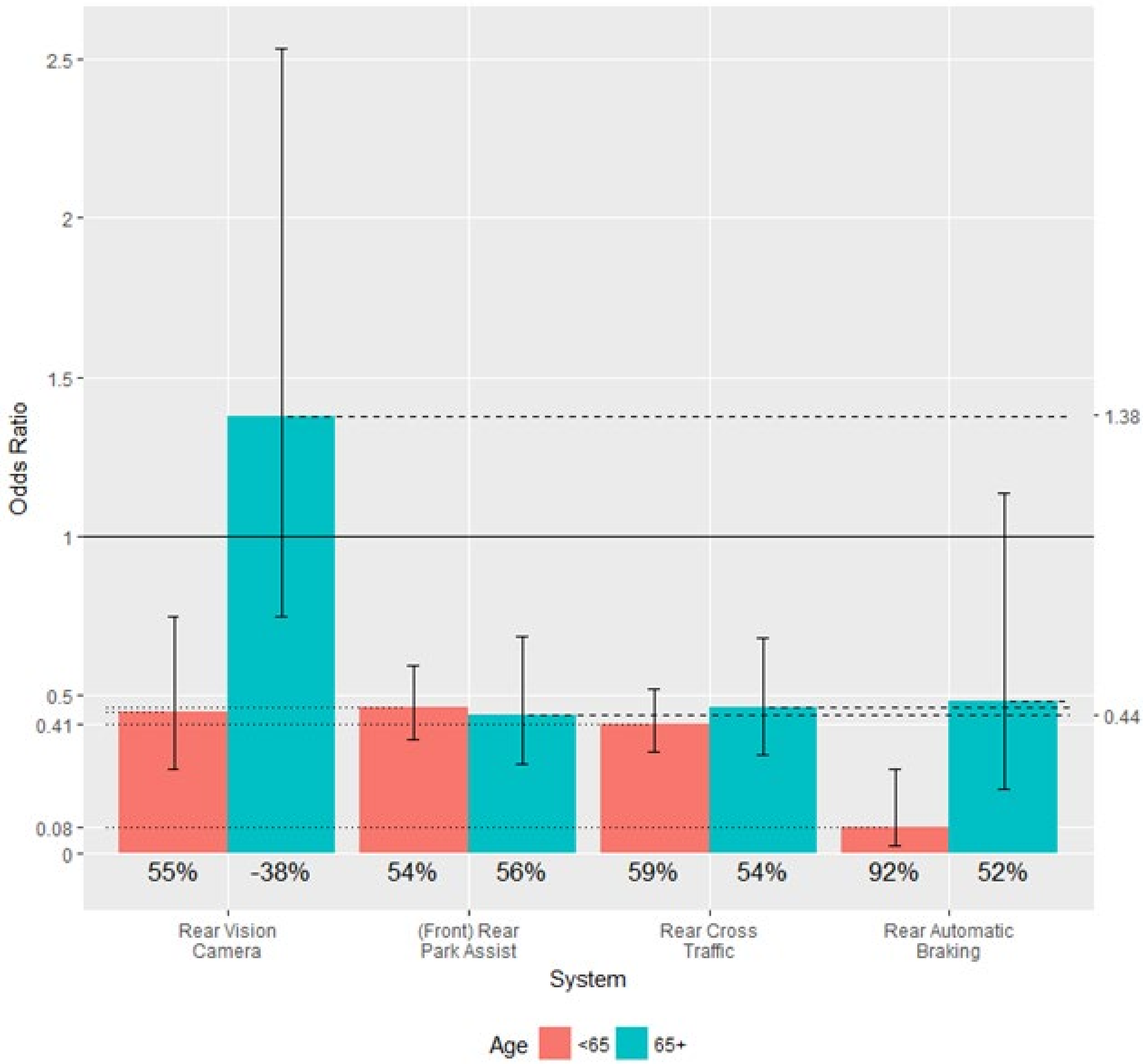

Figure 3-5. Estimated odds ratios for interaction of age group by backing collision avoidance system. Red numbers indicate dis-benefit and green numbers indicate benefit.

Finally, a separate model focused only on the comparison of the RVC and RPA backing collision avoidance systems (excluding vehicles with RAB or RCTA), which appear in all possible combinations in sedans in this dataset. For this "sedan only" dataset, we analyzed the specific contributions of RVC and RPA to backing crash reductions. The model included driver age, driver gender, road surface condition, and alcohol involvement, along with the random effect for vehicle model. (In this analysis, there were no significant interactions of the backing collision avoidance system with any other covariates.)

Figure 3-6 shows the results of the analysis. When compared to vehicles with no backing collision avoidance systems, RVC alone and RPA alone both resulted in non-significant estimated 11 percent and 36 percent reductions in backing crashes, respectively. In contrast, the combination of RVC and RPA (without RCTA or RAB) resulted in a significant estimated 51 percent reduction in backing crashes.

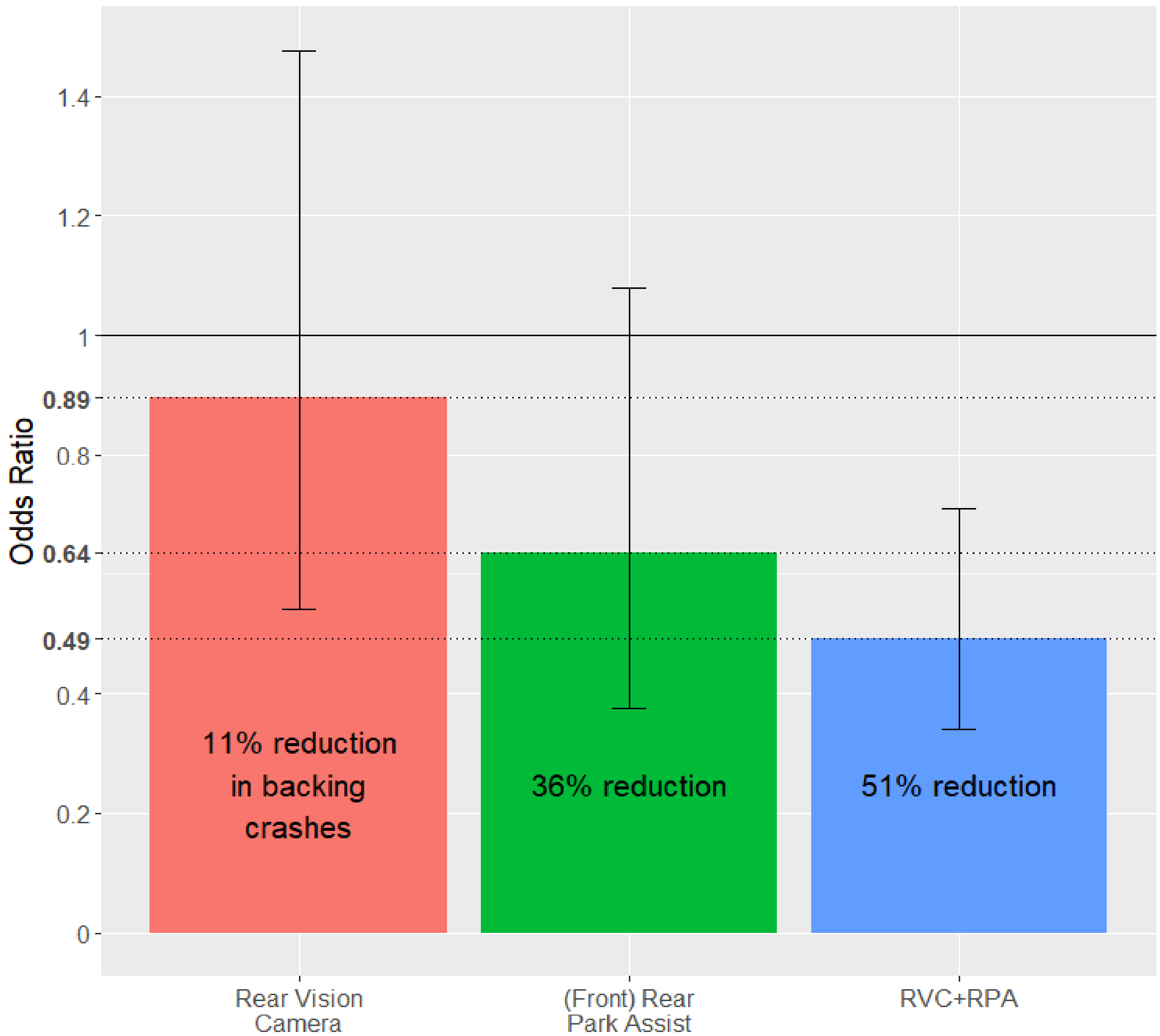

Figure 3-6. Estimated odds ratios and confidence intervals for RVC and RPA.

4 Discussion

This study used data on safety system content (i.e., with presence/absence of content indicated) for 1.2 million GM vehicles linked to State crash data by VIN to estimate the field effectiveness of these safety systems. Various covariates were used to attempt to control for variables that might influence system-relevant crashes for the systems examined, including driver age and gender, speed limit, alcohol/drug presence, fatigue, weather, road surface condition, vehicle type (sedan, small utility, utility), and vehicle model (treated as a random effect).

In spite of some difficulties in getting the planned additional State crash data, the observed match rate for the two datasets was higher than predicted, and thus the actual sample size ended up surprisingly close to the expected sample size. As a result, power was sufficient for the analyses that had been originally planned in the Data Sufficiency Report (Flannagan & Leslie, 2017). A summary of all analysis results is shown in Table 4-1.

Table 4-1. Summary of effectiveness estimates

Crash Type	System	Odds Ratio (95% confidence interval)	P Value (significant if less than 0.05)	Estimated Reduction	Findings Significant?
Frontal	Forward Collision Alert	0.84 [0.77,0.92]	0.000142	16%	Yes
	Forward Auto Braking with ACC	0.55 [0.41,0.74]	0.000061	45%	Yes
	Forward Auto Braking with Full Speed ACC	0.55 [0.43,0.71]	0. 000003	45%	Yes
Lane Departure	Lane Departure Warning	0.97 [0.90,1.05]	0.442	3%	No
	Lane Keep Assist with LDW	0.70 [0.51,0.96]	0.0281	30%	Yes
Blind Zone Alert	Side Blind Zone Alert (SBZA)	0.92 [0.75,1.12]	0.4045	8%	No
	Lane Change Alert with SBZA	0.68 [0.54,0.86]	0.00114	32%	Yes
	Pooled SBZA and Lane Change Alert (with SBZA)[6]	0.81 [0.70,0.95]	0.0109	19%	Yes

[6] Analysis was done by including vehicles equipped with *either* SBZA or LCA (with SBZA) in the "equipped" category.

Crash Type	System	Odds Ratio (95% confidence interval)	P Value (significant if less than 0.05)	Estimated Reduction	Findings Significant?
Backing	Rear Vision Camera	0.85 [0.54,1.35]	0.500	19%	No
	Rear Park Assist [7]	0.50 [0.39,0.65]	0.0000001	36%	Yes
	Rear Cross Traffic Alert[8]	0.44 [0.35,0.55]	0.0000001	55%	Yes
	Rear Automatic Braking[9]	0.17 [0.08,0.36]	0.000003	82%	Yes
	Rear Vision Camera + Rear Park Assist[10]	0.49 [0.34,0.71]	0.000143	51%	Yes

For the forward collision avoidance systems analyzed, both the forward collision alert (FCA) and front automatic braking (FAB) were beneficial. FCA produced an estimated 16 percent reduction in system-relevant rear-end striking crashes. Furthermore, FAB, which is always offered with FCA and adaptive cruise control (ACC), produced an estimated 45 percent reduction in the same system-relevant crash type (independent of whether vehicle was equipped with regular ACC or full-speed range ACC). In comparison, when data were combined across multiple manufacturers, results from Cicchino (2016) indicated that FCA and FAB were associated with significant reductions in rear-end striking crashes of 23 percent and 49 percent, respectively (ACC type was not examined).

For lateral crashes, our analysis covered two types of such crashes and two sets of systems. For lane departure crashes, in which the vehicle leaves the lane or the road and crashes, lane keep assist (LKA) (which includes lane departure warning (LDW) functionality) showed a significant estimated 30 percent reduction in such crashes, whereas LDW only showed a non-significant 3 percent reduction. In comparison, results from Cicchino (2017b) indicated that LDW was associated with a significant 11 percent reduction in lane departure crashes when results were combined across multiple manufacturers (with GM results showing a corresponding non-statistically significant 13% benefit). It should be noted that in a large-scale study of LDW usage, Flannagan et al. (2016) reported that 50 percent of the time LDW systems were turned off, so this may contribute to the low LDW effectiveness. Hence, even if 50 percent of the vehicles in this study had LDW turned off, based on the observed results, the overall effectiveness would not be expected to be more than 6 percent.

In addressing lane change crashes, Lane Change Alert (LCA) with Side Blind Zone Alert (SBZA) was 32 percent effective (significant) compared to 8 percent (non-significant) estimated effectiveness for SBZA. In an additional "pooled" analysis, which combined SBZA and LCA

[7] Includes front and rear park assist; in addition, many of these vehicles are also equipped with Rear Vision Camera.
[8] All vehicles are also equipped with rear park assist and rear vision camera or surround vision.
[9] All vehicles are also equipped with rear park assist, rear vision camera or surround vision, and rear cross-traffic alert.
[10] This analysis was conducted on sedans only to assess the independent contributions of RVC and RPA.

(with SBZA) data, results indicated a 19 percent benefit. Corresponding "pooled" results from Cicchino (2017a) indicated a significant 14 percent reduction in lane change crashes when results were combined across multiple manufacturers with various SBZA and LCA systems (with GM results showing a corresponding non-statistically significant 18% benefit). More generally, the magnitude of these effectiveness results, as well as those observed here for FCA and FAB, correspond well to those observed in previous Insurance Institute for Highway Safety (IIHS) studies conducted by Cicchino (2016, 2017a, 2017b) using State crash police-report databases.

Finally, the pattern of results for backing crashes was somewhat more complex. We developed two models, one without an interaction between age and backing collision avoidance equipment, and one including this interaction. The former (non-interaction model) estimated statistically significant reductions in backing collision for the rear automatic braking (RAB), rear cross traffic alert (RCTA), and rear park assist (RPA; which includes Front and Rear Park Assist) systems of 83 percent, 56 percent, and 50 percent, respectively. In contrast, the estimated effectiveness of the rear vision camera (RVC) system alone was non-significant at 15 percent effective. Note that these systems are hierarchically related such that the more advanced systems such as RAB generally include all of the other systems (e.g., RCTA, RPA, and RVC). When we focused analysis on RVC and RPA for sedans without either RAB or RPA, RPA alone was more effective than RVC alone, though both estimates were not significant (nor were they statistically different from each other), but the combination of both RVC and RPA (without either RCTA or RAB) produced a significant estimated 51 percent reduction in backing crashes.

In the model where we included the interaction with age group (<65 versus 65+) and backing collision avoidance equipment, we observed no difference in effective estimates for RPA and RCTA. In contrast, we observed in this analysis that for the older group examined, the effectiveness of both RAB and RVC were much lower than for younger group examined. For RVC this actually results in a non-significant estimated 38 percent disbenefit for older drivers. Since older drivers are overrepresented in backing crashes (Clarke et al., 2009), they should have more opportunity to benefit, though this does not itself indicate whether safety systems should be more or less effective for them.

We were unable to find many papers on how older drivers make use of backing assistance systems. One study of a small number of older drivers with RVC-equipped vehicles showed that older drivers were able to incorporate RVC scanning into their backing process (Mueller et al., 2017). This, and the fact that RAB, a largely automated crash prevention system (which can be overridden by the driver), showed less effectiveness for older drivers makes these results somewhat surprising. At this point, we are not confident that the interaction is not spurious. However, we do think that the effectiveness of backing crash systems for older drivers should be given particular attention in studies going forward.

While the specific effects for older drivers is difficult to interpret and may or may not be replicated in the future, the general results for backing-crash preventions systems are consistent with prior research. Flannagan et al. (2016) evaluated GM RPA and RVC from model years 2008-2010 and found a 52 percent of RVC that was separated from the effect of RPA. In this study, the specific comparison of RPA and RVC suggests that RVC and RPA have separate benefits (both non-significant in our analysis) that are approximately additive in combination (the combination was significant).

In general, the pattern of results indicated that either brief, limited, vehicle control (e.g., a lane keep assist "nudge") or more sustained, severe automatic vehicle control (e.g., FAB and RAB) resulted in substantially greater crash avoidance system benefit than "alert only" system counterparts (i.e., LDW, FCA, RPA, and RCTA). These "control" systems have the advantage of not strictly relying on drivers to respond to alerts in a timely and appropriate fashion (particularly in the case of forward and rear automatic braking) or to imminent crash situations that unfold quickly.

For lane change crashes, the LCA (with SBZA) system was found to be notably more effective than the SBZA system. While both systems provide side mirror alerts to help the driver avoid crashing into a moving vehicle detected in their side blind spot (or zone), the LCA (with SBZA) system has a greater capability of alerting the driver to a vehicle that is rapidly approaching their side blind spot during a lane-change maneuver due to an extended sensor range, which appears to have notable benefits based on the observed results.

Finally, although the systems analyzed in this paper now have a combination of sufficient fleet penetration and/or sufficiently large benefits to evaluate, early indicators of field performance of new safety systems require very large datasets. A multi-OEM effort combined with a large collection of State crash databases would allow for analysis of additional systems and would reduce the size of confidence intervals for all systems. We recommend an ongoing effort to collect and combine safety content data from multiple manufacturers, to link such data to a larger number of State crash databases, and to use the resulting dataset for ongoing assessment of the newest safety features as they enter the market and informing NHTSA (and various global) New Car Assessment Programs (NCAPs).

5 References

Cicchino, J. B. (2016). *Effectiveness of forward collision warning systems with and without autonomous emergency braking in reducing police-reported crash rates.* Arlington, VA: Insurance Institute for Highway Safety.

Cicchino, J. B. (2017a, August). *Effects of blind spot monitoring systems on police-reported lane-change crashes.* Arlington, VA: Insurance Institute for Highway Safety.

Cicchino, J. B. (2017b, August). *Effects of lane departure warning on police-reported crash rate*. Arlington, VA: Insurance Institute for Highway Safety.

Clarke, D. D., Ward, P., Truman, W., & Bartle, C. (2009). *Collisions involving older drivers: An in-depth study* (Road Safety Research Report no. 109). London, UK: Department for Transport.

Flannagan, C. A., Kiefer, R. J., Bao, S., LeBlanc, D. J., & Geisler, S. P. (2014) Reduction of backing crashes by production rear vision camera systems. *Journal of Ergonomics* S3:008. doi: 10.4172/2165-7556.S3-008.

Flannagan, C., LeBlanc, D., Bogard, S., Nobukawa, K., Narayanaswamy, P., Leslie, A., … Lobes, K. (2016, February). *Large-scale field test of forward collision alert and lane departure warning systems* (Report No. DOT HS 812 247). Washington, DC: National Highway Traffic Safety Administration. Available at https://www.nhtsa.gov/sites /nhtsa.dot.gov/files/812247b-lanedeparturewarningsystems.pdf.

Flannagan, C., Narayanaswamy, P., & Leslie, A. (in press). *Crash avoidance technology evaluation using real-world crash data: Data sufficiency report*. Washington, DC: National Highway Traffic Safety Administration.

Flannagan, C., Narayanaswamy, P. & Leslie, A. (in press). *Crash avoidance technology evaluation using real-world crash data: Updated data sufficiency report*. Washington, DC: National Highway Traffic Safety Administration.

Highway Loss Data Institute. (2017, April). General Motors collision avoidance features, [HLDI] *Bulletin Vol. 34*, No. 6.

Insurance Institute for Highway Safety. (2012, July). Special issue: Crash avoidance, *Status Report*, Vol. 47, No. 5.

Keall, M., & Newstead, S. (2009). Selection of comparison crash types for quasi-induced exposure risk estimation. *Traffic injury prevention*, *10*(1), 23-29.

Mueller, A. S., Sangrar, R., & Vrkljan, B. (2017). Rearview camera system use among older drivers: A naturalistic observation study. *Transportation Research Part F: Traffic Psychology and Behaviour*. DOI: 10.1016/j.trf.2017.06.014.

6 Appendix A Safety System Descriptions

The following descriptions of the systems evaluated were provided by General Motors:

Forward Collision Avoidance Systems

Forward Collision Alert (FCA) uses either a camera, a radar sensor or both and can detect a preceding vehicle within distances of 60m (197 ft) and operates at speeds above 40 km/h (25 mph). If the vehicle has adaptive cruise control, it can detect vehicles to distances of approximately 110m (360 ft) and operates at all speeds. FCA timing can be set to a far, medium, or near alert timing, and FCA can be turned off. The chosen setting will remain until it is changed and the alert timing will effect the Collision Alert and the Tailgating Alert timing, as well as the Adaptive Cruise Control (ACC) gap setting. FCA provides a green indicator when a vehicle is detected ahead which turns to amber if following another detected vehicle much too closely. If the system detects that a front-end collision situation is imminent while following a detected vehicle, the system alerts the driver to a potential crash. A red indicator display appears (which on most vehicle flashes on the windshield), and either eight beeps will sound, or both sides of the Safety Alert Seat will pulse five times.

Front Automatic Braking (FAB) with FCA uses FCA sensors to automatically apply the brakes to help reduce the collision's severity if the system detects that a front-end collision situation is imminent while following a detected vehicle, and the driver has not already applied the brakes. The system may even help avoid the collision at very low speeds. FAB may slow the vehicle to a complete stop and the electric parking brake will engage to hold the vehicle at a stop. A firm press of the accelerator pedal will release the brake. Automatic Braking can be disabled or reduced through the vehicle personalization menu.

Adaptive Cruise Control (ACC) uses FCA sensors to enhance regular Cruise Control such that the cruise control speed is automatically adapted in order to maintain a driver-selected gap between the vehicle and vehicles detected ahead while the driver steers, reducing the need for the driver to frequently brake and accelerate. ACC is not available at speeds less than 25 km/h (16 mph). Changing the ACC gap automatically changes the FCA alert timing (Far, Medium, or Near). Some vehicles equipped with ACC are capable of operating in stop-and-go traffic.

Lateral Collision Avoidance Systems

Side Blind Zone Alert (SBZA) uses radar sensors to provide side mirror alerts to help the driver avoid crashing into a moving vehicle detected in their side blind spot (or zone) during a lane-change maneuver. If a vehicle has been detected in the blind spot, the SBZA icon will light up in the corresponding outside side mirror. The SBZA sensor covers a zone of approximately one lane over from both sides of the vehicle, or 3.5m (11 ft). This zone starts at each side mirror and goes back approximately 5m (16 ft). The height of the zone is between approximately 0.5 m (1.5 ft) and 2m (6 ft) off the ground. SBZA can be disabled through the vehicle personalization menu.

Lane Change Alert (LCA) with SBZA is an enhancement to SBZA, and uses radar sensors to provide side mirror alerts to help the driver avoid crashing into a moving vehicle detected in their side blind spot (or zone) or a vehicle that is rapidly approaching their side blind spot during a lane-change maneuver. The LCA icon will light up in the corresponding side mirror and will flash if the turn signal is on. The LCA sensor covers a zone of approximately one lane over from both sides of the vehicle, or 3.5m (11 ft). The height of the zone is between approximately 0.5m (1.5 ft) and 2m (6 ft) off the ground. Drivers are also warned of vehicles rapidly approaching from beyond the side blind zone areas behind the vehicle. This feature can be disabled through the vehicle personalization menu.

Lane Departure Warning (LDW) uses a camera located behind the windshield to identify traffic lane markings and provides alerts to help drivers avoid crashes due to unintentionally drifting out of their lane when their turn signal is not activated. The LDW indicator appears green if a lane marking is detected. When the vehicle crosses a detected lane marking, the LDW indicator will flash and either three beeps will sound from the left or right, or three Safety Alert Seat pulses will occur on the left or right side of the seat. LDW is functional at speeds of 56 km/h (35 mph) or greater. The system may be deactivated by the driver.

Lane Keep Assist (LKA) with LDW uses a camera located behind the windshield to identify traffic lane markings and provides gentle steering wheel turns (and Lane Departure Warning alerts if necessary) to help drivers avoid crashes due to unintentionally drifting out of their lane when they are not actively steering and their turn signal is not activated. It may also provide a LDW alert as the lane marking is crossed. The system will not assist or alert if it detects that the driver is actively steering. LKA is functional between 60 km/h (37 mph) and 180 km/h (112 mph).

Backing Collision Avoidance Systems

Rear Parking Assist (RPA) uses ultrasonic sensors on the rear bumper to provides distance-to-object alerts to help the driver park and avoid crashing into nearby detected objects directly behind the vehicle when driving in Reverse and at speeds less than 8 km/h (5 mph). The system detects objects up to 2.5m (8 ft) behind the vehicle that are within a zone 25 cm (10 in) high off the ground and below bumper level. A warning triangle, which changes from amber to red and increases in size the closer the object may appear on the rear vision camera screen, and the instrument cluster may provide object location information. In addition, beeps or Safety Alert Seat pulses may occur, for example, when an object is first detected and if very close to an object.

Front and Rear Parking Assist (FRPA) operates and works similarly to RPA; adding ultrasonic sensors on the front bumper that detect objects up to 1.2 m (4ft) to provides distance-to-object alerts to help the driver park and avoid crashing into nearby detected objects directly ahead or behind the vehicle during low-speed maneuvering.

Automatic Parking Assist (APA) uses front, rear, and side ultrasonic sensors to help the driver parallel and perpendicular park by automatically steering the vehicle into a detected parking space while the driver follows text commands, selects gear, and does all braking and acceleration. The searching function operates at speeds below 30 km/h (18 mph) and is enabled by pressing a button.

Rear Vision Camera (RVC) uses a camera to provide the driver of a view of the scene directly behind the vehicle on a center-stack (or inside rear-view mirror) display to help them park and avoid crashing into nearby objects during low-speed maneuvering when in Reverse gear.

Surround Vision (SV) uses a front, rear and two side cameras (mounted on bottom of side mirrors) to provide the driver an overhead "bird's eye" view of the scene around the vehicle on a center-stack display to help them park and avoid crashing into nearby objects during low-speed maneuvering.

Rear Cross Traffic Alert (RCTA) uses radar sensors to provide alerts to help driver avoid crashing into approaching detected left- or right-cross traffic (e.g., out of a crowded parking space or driveway with side obstructions) when in Reverse gear. The system detects objects coming from up to 20 m (65 ft) on either side. When an object is detected, a red triangle with a left or right pointing arrow appears on the RVC screen, and three beeps will sound from the left or right, or three Safety Alert Seat pulses will occur on the left or right side of the seat. RCTA can be disabled by the driver.

Rear (or Reverse) Automatic Braking (RAB), when in Reverse gear, uses radar technology to helps the driver avoid crashing (or mitigates impacts) into detected objects directly behind the vehicle by providing alerts and automatically applying hard emergency braking, under certain conditions, if necessary. When the system detects a potential imminent crash, beeps will be heard from the rear, or five pulses will occur both sides of the Safety Alert Seat. There may also be a brief, sharp application of the brakes. If the system detects the vehicle is backing too fast to avoid a crash with a detected object, it may automatically brake hard to a stop. The system operates at speeds greater than 0.8 km/h (0.5 mph).

Advanced Headlighting Systems

HID headlamps are high-intensity discharge headlamps.

LED headlamps are light-emitting diode headlamps.

Steerable HID headlamps pivot horizontally to provide greater road illumination while turning. The system is enabled by setting the exterior lamp control on the turn signal lever to the AUTO position and is disabled by moving the control out of the AUTO position. The lights will operate when the vehicle speed is greater than 3 km/h (2 mph), but the lights are not immediately operable after starting the vehicle; driving a short distance is required to calibrate the system. Headlamps do not operate when the transmission is in reverse.

IntelliBeam headlamps turn the vehicle's high-beam headlamps on and off based on surrounding traffic conditions and are active over 40 km/h (25 mph). The system is controlled by a sensor near the top center of the windshield. When IntelliBeam is enabled, a blue high beam indicator with an "A" over it will light up on the dash. Intellibeam highbeams remain on under automatic control until one of the following situations occurs: the system detects an approaching vehicle's headlamps; the system detects a preceding vehicle's taillamps, the outside light is bright enough that high-beam headlamps are not required, the vehicle's speed drops below 20 km/h (12 mph), the turn-signal lever is moved forward to the high-beam position or the Flash-to-Pass feature is used. If the IntelliBeam system is disabled by the High/Low-Beam Changer or the Flash-to-Pass feature, the High/Low-Beam Changer must be activated two times within two seconds to reactivate the system.

7 Appendix B Statistic Model Details

7.1 Forward Collision Avoidance

Fit Statistics	AIC	BIC	Deviance		Chi-sq	df	p-value
Intercept Model	16118.4	16125.8	16116.4	Likelihood Ratio Test	548.6	11	0
Fitted Model	15593.8	15690.9	15567.8				

Fixed Effects	Estimate	Std. Error	z value	Pr(>|z|)	Odds Ratio
(Intercept)	-0.4399	0.0779	-5.65	0.000000	
System - FCA	-0.1702	0.0447	-3.80	0.000142	0.84
System - FAB + ACC	-0.5939	0.1482	-4.01	0.000061	0.55
System - FAB + Full ACC	-0.5978	0.1275	-4.69	0.000003	0.55
Driver Age - < 25	0.8794	0.0749	11.75	< 2e-16	2.41
Driver Age - 65+	0.0143	0.0533	0.27	0.788013	1.01
Driver Gender - Female	-0.1092	0.0394	-2.77	0.005646	0.90
Speed Limit (mph/10)	-0.0716	0.0135	-5.32	0.000000	0.93
Driver Distracted	0.5179	0.0516	10.03	< 2e-16	1.68
Driver Fatigued	3.4368	0.7309	4.70	0.000003	31.09
Road Surface - Wet	-0.2862	0.0520	-5.50	0.000000	0.75
Driver Alcohol or Drugs	2.7947	0.3403	8.21	< 2e-16	16.36

Random Effects	Variance	Std. Dev
Vehicle Model - Intercept	0.0116	0.1075

	Sample Sizes		
System	Relevant	Control	
None	2,316	4,520	6,836
System - FCA	1,591	3,774	5,365
System - FAB + ACC	70	242	312
System - FAB + Full ACC	93	336	429
			12,942

7.2 Lane-Departure Collision Avoidance

Fit Statistics	AIC	BIC	Deviance		Chi-sq	df	p-value
Intercept Model	19878.1	19885.7	19876.1	LRT	486.9	8	0
Fitted Model	19409.2	19485.2	19389.2				

Fixed Effects	Estimate	Std. Error	z value	Pr(>|z|)	Odds Ratio
(Intercept)	-0.2677	0.0652	-4.11	0.000040	NA
System - LDW	-0.0293	0.0381	-0.77	0.441800	0.97
System - LKA with LDW	-0.3565	0.1623	-2.20	0.028100	0.70
Driver Age - < 25	0.6181	0.0727	8.50	< 2e-16	1.86
Driver Age - 65+	0.3805	0.0436	8.73	< 2e-16	1.46
Driver Gender - Female	-0.0893	0.0347	-2.57	0.010000	0.91
Speed Limit (mph/10)	-0.0590	0.0113	-5.22	0.000000	0.94
Driver Fatigued	3.4464	0.7364	4.68	0.000003	31.39
Driver Alcohol or Drugs	3.1981	0.3286	9.73	< 2e-16	24.49

Random Effects	Variance	Std. Dev
Vehicle Model - Intercept	0.0076	0.0871

	Sample Sizes		
System	Relevant	Control	
None	3,134	4,530	7,664
System - LDW	2,695	4,224	6,919
System - LKA with LDW	62	134	196
			14,779

7.3 Lane-Change Collision Avoidance

7.3.1 Separate SBZA and LCA Effects

Fit Statistics	AIC	BIC	Deviance		Chi-sq	df	p-value
Intercept Model	6016.6	6023.8	6014.6	LRT	173.6	9	0
Fitted Model	5863	5942	5841				

Fixed Effects	Estimate	Std. Error	z value	Pr(>|z|)	Odds Ratio
(Intercept)	-2.6274	0.1374	-19.12	< 2e-16	NA
System - Side Blind Zone Alert	-0.0852	0.1022	-0.83	0.404489	0.92
System - Lane Change Alert w/ SBZA	-0.3832	0.1178	-3.25	0.001138	0.68
Driver Age - < 25	0.5530	0.1470	3.76	0.000168	1.74
Driver Age - 65+	0.7102	0.0815	8.71	< 2e-16	2.03
Driver Gender - Female	-0.2051	0.0726	-2.83	0.004732	0.81
Speed Limit (mph/10)	0.0801	0.0254	3.15	0.001638	1.08
Driver Distracted	0.1857	0.1000	1.86	0.063317	1.20
Road Surface - Wet	-0.4817	0.1027	-4.69	0.000003	0.62
Driver Alcohol or Drugs	2.2933	0.4484	5.12	0.000000	9.91

Random Effects	Variance	Std. Dev
Vehicle Model - Intercept	0.0070	0.0839

Sample Sizes

System	Relevant	Control	
None	515	4,682	5,197
System - LDW	275	2,506	2,781
System - LKA with LDW	114	1,624	1,738
			9,716

7.3.2 Pooled SBZA and LCA Model

Fit Statistics	AIC	BIC	Deviance		Chi-sq	df	p-value
Intercept Model	6016.6	6023.8	6014.6	LRT	179	10	0
Fitted Model	5859.6	5945.8	5835.6				

Fixed Effects	Estimate	Std. Error	z value	Pr(>|z|)	Odds Ratio
(Intercept)	-2.5813	0.1342	-19.24	< 2e-16	NA
System - Any Side Blind Zone Alert	-0.2048	0.0805	-2.55	0.010906	0.81
Driver Age - < 25	0.5474	0.1470	3.72	0.000196	1.73
Driver Age - 65+	0.6857	0.0815	8.41	< 2e-16	1.99
Driver Sex - Female	-0.2292	0.0725	-3.16	0.001574	0.80
Speed Limit (mph/10)	0.0801	0.0254	3.15	0.001615	1.08
Driver Distracted	0.2084	0.1002	2.08	0.037475	1.23
Road Surface - Wet	-0.4794	0.1027	-4.67	0.000003	0.62
Driver Alcohol or Drugs	2.2953	0.4474	5.13	0.000000	9.93
Vehicle Type - SRX (Sm. Utility)	0.2583	0.1080	2.39	0.016758	1.29
Vehicle Type - Utility	-0.2355	0.1002	-2.35	0.018733	0.79

Random Effects	Variance	Std. Dev
Vehicle Model - Intercept	0.0000	0.0000

Sample Sizes

System	Relevant	Control	
None	515	4,682	5,197
System - Blind Zone Alert	389	4,130	4,519
			9,716

7.4 Backing Collision Avoidance

7.4.1 Model without interaction

Fit Statistics	AIC	BIC	Deviance		Chi-sq	df	p-value
Intercept Model	5522.6	5529.8	5520.6	LRT	263.1	11	0
Fitted Model	5283.5	5376.8	5257.5				

Fixed Effects	Estimate	Std. Error	z value	Pr(>|z|)	Odds Ratio
(Intercept)	-2.0954	0.1422	-14.74	< 2e-16	
System - Rear Vision Camera	-0.1589	0.2353	-0.68	0.499600	0.85
System - (Front) Rear Park Assist	-0.6845	0.1279	-5.35	0.000000	0.50
System - Rear Cross Traffic Alert	-0.8230	0.1188	-6.93	0.000000	0.44
System - Rear Automatic Braking	-1.7685	0.3800	-4.65	0.000003	0.17
Driver Age - < 25	-0.0256	0.1915	-0.13	0.893900	0.97

Driver Age - 65+	0.7070	0.0912	7.75	0.000000	2.03
Driver Gender - Female	-0.2447	0.0775	-3.16	0.001600	0.78
Road Surface - Wet	-0.8964	0.1265	-7.08	0.000000	0.41
Driver Alcohol or Drugs	2.8597	0.5220	5.48	0.000000	17.46
Vehicle Type - SRX (Sm. Utility)	0.2844	0.2412	1.18	0.238400	1.33
Vehicle Type - Utility	0.9710	0.1603	6.06	0.000000	2.64

Random Effects	Variance	Std. Dev
Vehicle Model - Intercept	0.0337	0.1836

Sample Sizes

System	Relevant	Control	Total
None	219	1,689	1,908
System - Rear Vision Camera	35	403	438
System - (Front) Rear Park Assist	217	2,638	2,855
System - Rear Cross Traffic Alert	319	3,902	4,221
System - Rear Automatic Braking	10	245	255
			9,677

7.4.2 Model with interaction

Fit Statistics	AIC	BIC	Deviance		Chi-sq	df	p-value
Intercept Model	5522.6	5529.8	5520.6	LRT	274.888	14	0
Fitted Model	5275.7	5383.4	5245.7				

Fixed Effects	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**	**Odds Ratio**
(Intercept)	-1.9348	0.0888	-21.79	< 2e-16	NA
System - Rear Vision Camera	-0.8070	0.2643	-3.05	0.002264	0.45
System - (Front) Rear Park Assist	-0.7718	0.1249	-6.18	0.000000	0.46
System - Rear Cross Traffic Alert	-0.8986	0.1236	-7.27	0.000000	0.41
System - Rear Automatic Braking	-2.4749	0.5922	-4.18	0.000029	0.08
Driver Age - 65+	0.5509	0.1794	3.07	0.002134	1.73
Driver Gender - Female	-0.2614	0.0774	-3.38	0.000737	0.77
Road Surface - Wet	-0.8980	0.1267	-7.09	0.000000	0.41
Driver Alcohol or Drugs	2.8783	0.5205	5.53	0.000000	17.78
Vehicle Type - SRX (Sm. Utility)	0.2088	0.1278	1.63	0.102358	1.23
Vehicle Type - Utility	0.8871	0.1004	8.84	< 2e-16	2.43
System - RVC * Age - 65+	1.1272	0.4076	2.77	0.005683	3.09
System - (F)RPA * Age - 65+	-0.0529	0.2564	-0.21	0.836668	0.95
System - RCTA * Age - 65+	0.1272	0.2236	0.57	0.569274	1.14
System - RAB * Age - 65+	1.7419	0.7341	2.37	0.017647	5.71

Random Effects	Variance	Std. Dev
Vehicle Model - Intercept	NA	NA

Sample Sizes

System	Relevant	Control	Total
None	219	1,689	1,908
System - Rear Vision Camera	35	403	438
System - (Front) Rear Park Assist	217	2,638	2,855
System - Rear Cross Traffic Alert	319	3,902	4,221
System - Rear Automatic Braking	10	245	255
			9,677

7.4.3 RVC and RPA Only (Sedan Subset)

Fit Statistics	AIC	BIC	Deviance		Chi-sq	df	p-value
Intercept Model	2311.7	2318.1	2309.7	LRT	108	8	0
Fitted Model	2221.7	2285	2201.7				

Fixed Effects	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**	**Odds Ratio**
(Intercept)	-2.2312	0.1927	-11.58	< 2e-16	NA
System - Rear Vision Camera	-0.1111	0.2556	-0.43	0.663973	0.89
System - (Front) Rear Park Assist	-0.4526	0.2704	-1.67	0.094088	0.64
System - RVC + (F)RPA	-0.7095	0.1866	-3.80	0.000143	0.49
Driver Age - < 25	0.0895	0.2417	0.37	0.711009	1.09
Driver Age - 65+	0.7707	0.1356	5.68	0.000000	2.16

Driver Gender - Female	-0.2475	0.1191	-2.08	0.037623	0.78
Road Surface - Wet	-0.8316	0.1944	-4.28	0.000019	0.44
Driver Alcohol or Drugs	2.2210	0.7906	2.81	0.004965	9.22

Random Effects	Variance	Std. Dev
Vehicle Model - Intercept	0.0411	0.2027

Sample Sizes - Sedan Only

System	Relevant	Control	Total
None	191	1547	1,738
System - Rear Vision Camera	35	403	438
System - (Front) Rear Park Assist	20	255	275
System - RVC + (F)RPA	85	1619	1,704
			4,155

Why Sedans Only?

System	Sedan	SRX	Utility
None	1738	170	0
System - Rear Vision Camera	438	0	0
System - (Front) Rear Park Assist	275	0	3
System - RVC + (F)RPA	1704	0	873

DOT HS 812 841
March 2020

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

14470-021920-v4