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Analysis of the Field Effectiveness of General Motors Production Active Safety and Advanced Headlighting Systems

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16. Abstract

The safety system content of over 3.7 million vehicles across 20 different GM Model Year 2013-2017 vehicles were provided by GM to UMTRI to examine the field effectiveness of 15 Active Safety and Advanced Headlighting systems. These data were matched to police-report data from vehicles involved in crashes using 10 state crash databases. Using the quasi-induced exposure method, comparisons of system-relevant and control crash counts for equipped and unequipped vehicles were used to estimate field effectiveness using logistic regression. Results indicated Automatic Emergency Braking reduced rear-end striking crashes by 46%, Lane Keep Assist with Lane Departure Warning reduced lane departure-related crashes by 20%, Lane Change Alert with Side Blind Zone Alert reduced lane change crashes by 26%, Reverse Automatic Braking (offered with several backing systems) reduced backing crashes by 81%, and Intellibeam (automatic high beams) and High-Intensity Discharge (HID) headlight features provided 35% and 21% reductions, respectively, in nighttime pedestrian/bicyclist/animal crashes relative to halogen headlights (with a 49% reduction when offered together). These results provide further evidence of the substantial safety benefit opportunities afforded by the systems evaluated.

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Executive Summary

The current research provides an analysis of the field effectiveness of 15 General Motors (GM) active safety and advanced headlighting systems. The safety system content of over 3.7 million GM vehicles across 20 different Model Year 2013-2017 vehicles were provided by GM to the University of Michigan Transportation Research Institute (UMTRI) to conduct this analysis. These safety content data were then matched to police-report data from vehicles involved in crashes using 10 state crash databases. Using the method of "quasi-induced exposure," comparisons of "system-relevant" crash counts and "control" crash counts for equipped and unequipped vehicles were used to estimate safety system effectiveness. Control crashes served to control for vehicle exposure and were selected to be unaffected by the system examined. The statistical method of field effectiveness estimation was logistic regression, which can also adjust for other factors such as weather, road type, and driver age and gender. The results of this GM Model Year 2013-2017 safety system effectiveness analysis are summarized in the Table below.

Estimated percent reductions in system-relevant crashes for various GM active safety and advanced headlighting systems (Note shaded green cells denote statistically significant field effectiveness effects)

Crash Category and Safety System(s)	Percent Reduction in System-Relevent Crash
FRONTAL	
Camera-Based Forward Collision Alert (Camera FCA)	21%
Automatic Emergency Braking (AEB)	46%
FRONT PEDESTRIAN	
Front Pedestrian Braking (FPB)	13%
LANE DEPARTURE	
Lane Departure Warning (LDW)	10%
Lane Keep Assist (LKA) with LDW	20%
LANE CHANGE	
Side Blind Zone Alert (SBZA)	3%
Lane Change Alert (LCA) with SBZA	26%
Rear Camera Mirror (RCM) with LCA & SBZA	37%
BACKING	
Rear Vision Camera (RVC)	21%
Rear Park Assist (RPA, Front & Rear PA or Automatic Park Assist with Steering)	38%
Rear Cross Traffic Alert (RCTA) with RVC	52%
Reverse Automatic Braking (RAB) with RVC, RPA, & RCTA	81%
HEADLIGHTS (Nightime Vulnerable Road Users; versus Halogen)	
HID (High-Intensity Discharge)	21%
Articulating HID	17%
Intellibeam (can be offered with any of the above headlights)	35%

The Automatic Emergency Braking (AEB) and camera-based Forward Collision Alert (FCA) systems evaluated produced, respectively, an estimated 46% and 21% reduction in rear-end striking crashes. For addressing lane departure crashes, Lane Keep Assist (LKA) with Lane Departure Warning (LDW), GM's next generation of the earlier LDW only system, produced an estimated 20% reduction in lane departure crashes compared to a corresponding 10% reduction with LDW alone. It should be noted that large-scale telematics-based (OnStar) studies suggest that the relative low usage of LDW systems (compared to FCA and AEB) may be an important limiting factor in obtaining desired higher effectiveness estimates.

With respect to the lane change crash prevention analysis, Lane Change Alert (LCA) with Side Blind Zone Alert (SBZA) produced an estimated 26% reduction in lane change crashes, compared to a corresponding non-significant 3% reduction with SBZA. This difference is likely to be due to the substantially longer vehicle detection ranges for the LCA with SBZA system relative to GM's earlier generation SBZA system.

For the variety of backing systems evaluated, a "stack up" system effect was apparent under which the addition of more advanced backing features to less advanced backing features resulted in an increased reduction in backing crashes. Rear Vision Camera (RVC) alone, Rear Park Assist (RPA) functionality, Rear Cross Traffic Alert (or RCTA; which nearly always included both RVC and RPA functionality), and Reverse Automatic Braking (which includes all the aforementioned backing features) produced, respectively, an estimated 21%, 38%, 52%, and 81% reduction in backing crashes.

For safety systems examined that are aimed at reducing crashes involving Vulnerable Road Users (VRUs), both Intellibeam (auto high beam headlights) and HID headlights were estimated to provide 35% and 21% reductions in such VRU crashes (i.e., pedestrians, bicyclists, and animals), respectively. When Intellibeam and HID headlights were offered together, a 49% reduction in such VRU crashes were observed. The estimated 17% reduction in VRU crashes for articulating HID headlights did not reach statistical significance. Given the relatively small sample of articulating HIDs and the significant 21% benefit for HIDs headlights, we interpret these results to indicate articulating (steerable) HID headlights are likely to produce a benefit similar to HID (non-steerable) headlights.

It is important to acknowledge that while we group animal, bicyclist and pedestrian crashes collectively as VRU crashes in the headlighting analysis, these crashes are dominated by animal crashes, especially at night. This allows us to estimate the benefits of headlamps, but these benefits primarily apply to nighttime animal crashes. That said, we argue that the mechanisms for each of these three VRU crash types involve the driver's inability to see the VRU at night early enough to prevent a crash. Thus, a headlamp effect for animal crashes is likely to apply to pedestrian and bicyclist crashes as well, since the underlying causal mechanism for the crash should be similar. As with the Front Pedestrian Braking (FPB) system analysis, which showed a non-significant 13% reduction in front pedestrian crashes, the rarity of front pedestrian crashes means that a substantially larger dataset would be required for a pedestrian only analysis to have sufficient power to detect effects of this magnitude.

In general, the current pattern of results indicated that newer systems that can provide under certain driving situations either brief, limited, vehicle control (e.g., an LKA steering wheel "nudge"), and particularly more sustained, severe automatic vehicle control (e.g., AEB and RAB), resulted in substantially greater crash avoidance system field effectiveness benefits than "alert only" system counterparts (i.e., LDW, FCA, and RPA).   Although these systems still require the driver to always remain attentive to driving, they have the advantage of not strictly relying on drivers to respond to alerts in a timely and appropriate fashion and to respond to imminent crash situations that unfold quickly.

More generally, the wide variety of GM safety systems evaluated in the current effort provide further widespread evidence of the substantial safety benefit opportunities afforded by these systems. We recommend evaluating safety systems using the police report methodology employed in the current effort (as well as using telematics-based crash data), leveraging additional state crash databases that may be available to UMTRI (or other organizations) in the future, and using safety system effectiveness estimates for ongoing assessment of emerging safety features and for informing New Car Assessment Program (NCAP) and safety system decision making.

Introduction

A wide variety of new vehicle safety systems are coming on the market across a broad range of vehicle types. With this surge in safety benefit opportunity comes the challenge of measuring the safety impact of these systems in a timely and sensitive manner so that manufacturers and agencies can prioritize system development and/or inclusion in National Highway Traffic Safety Administration (NHTSA) and various Global New Car Assessment Programs (NCAPs). Although systems may be tested in analysis, in simulation, on test tracks, and on public roads prior to production release, crash data remain fundamental for understanding achieved safety benefits in the field. Indeed, this period of emerging active safety system roll-out, when both equipped and non-equipped vehicles coexist in the field and can be examined over the same time periods, is in many ways ideal for assessing system effectiveness prior to any NCAP, regulation, or system manufacturer standardization decisions. The active safety systems evaluated in this paper are sometimes referred to as advanced driver assistance systems (or ADAS) and can be contrasted with passive safety systems such as air bags and seat belts.

A recent insurance-loss based study by the Highway Loss Data Institute (HLDI, 2017) looked at a number of General Motors (GM) active safety and advanced headlighting systems across a wide range of vehicles. That study demonstrated significant reductions in overall collision and/or property damage liability claims for forward alerts, (forward) automatic emergency braking, lane change alerts, parking alerts (with and without rear-vision camera), reverse automatic braking, and High Intensity Discharge (HID) and steerable HID headlamps. Indeed, the Intellibeam headlamps feature was the only system examined associated with a significant increase in overall claims. However, in this HLDI (2017) analysis, as is true in most insurance-loss based studies, the approach taken was to look at the effectiveness on *overall* claims irrespective of crash circumstances (e.g., time of day was not available for the headlighting analysis).

In addition, a series of police-report based Insurance Institute for Highway Safety (IIHS) studies examining safety systems across multiple manufacturers (Cicchino, 2016, 2017a, 2017b, 2018, 2019a, 2019b) have similarly reported system benefits of forward collision warning, automatic emergency braking, lane departure warning, blind spot warning, rear cross traffic alert, and reverse automatic braking. In these IIHS studies, the effect of these systems on system-relevant crashes were evaluated using a Poisson rate model, where insured vehicle years was used in the denominator for estimating crash rates.

The goal of the project described in this report was to examine GM safety system effectiveness. In this study, police-reported crash data from 10 states were linked to over 3.8 million GM Model Year 2013-2017 vehicles with known crash avoidance and headlamp system content. Unlike the series of IIHS police-report based studies reported above, the current study used a method known as *quasi-induced exposure* (Keall & Newstead, 2009), where equipped and unequipped vehicles are compared using the rate of crashes that are specifically targeted by the safety system (i.e., referred to “system-relevant” crashes) relative to crashes unrelated to the function of a particular safety systems (referred to as the “control” crashes, which are used to control for crash exposure). Logically, the presence of a safety system should reduce its system-relevant (or targeted) crashes more than crashes that are not system-relevant (or non-targeted), whereas vehicles without the safety system should have a “baseline” ratio of the two crash types (with the “baseline” ratio depending on the crash types involved).

Methods

Data

For this analysis, two types of data were required. Data on crash configurations and circumstances came from police crash reports obtained from ten Unites States state agencies. These data were matched on Vehicle Identification Number (VIN) with a database of safety system content information provided by GM indicating, at the VIN-level, the presence or absence of the various safety systems examined.

Safety Content Data

The GM safety content dataset contained VIN-linked data on 3,785,419 vehicles across 22 models (across all GM brands, including Buick, Cadillac, Chevrolet, and GMC) and five Model Years (Model Year 2013-2017). GM provided data for a model/model-year pair only when a (forward) Automatic Emergency Braking (AEB) system was available on at least one trim level for that model/model-year pair. This was done to enable comparing the relative field effectiveness of active safety systems that range from camera systems (e.g., rear vision camera) to "alert only" systems (e.g., forward collision alert, lane change alert with side blind zone alert, rear cross traffic alert, and park assist) to automatic control-oriented systems (e.g., AEB, reverse automatic braking, and lane keep assist with lane departure). As seen in Table 1, during this period of emerging active safety roll-out (which as mentioned earlier is ideal for assessing system effectiveness), this meant that the majority of models were only included for a subset of the Model Years examined. It also means that the vehicles available for matching increased sharply for later Model Years (as seen in Table 2). Overall, this analysis included 3,785,419 Model Year 2013-2017 vehicles.

Table 1. Vehicle models and range of Model Years provided in safety content data provided by GM

Model Year Range	Models
2013-2016	Cadillac SRX (discontinued after 2016)
2013-2017	Cadillac ATS, Cadillac XTS
2014-2017	Cadillac CTS, Chevrolet Impala, Buick Lacrosse, Buick Regal
2015-2017	Cadillac Escalade, Chevrolet Suburban, Chevrolet Tahoe, GMC Yukon, GMC Yukon XL
2016-2017	Cadillac CT6, Chevrolet Malibu, Chevrolet Volt
2017	Buick Acadia, Chevrolet Bolt, Buick Envision, GMC Sierra, Chevrolet Silverado, Chevrolet Silverado HD, Cadillac XT5

Table 2. Vehicle count by Model Year

Model Year	Vehicles
2013	132,858
2014	405,108
2015	677,652
2016	824,621
2017	1,745,180

For each vehicle (or VIN) in the dataset, the presence or absence of the various safety systems examined was provided by GM. These systems break down into seven aimed at addressing rear-end striking (or front-to-rear) crashes, two aimed at addressing lane departure crashes, three aimed at addressing lane change crashes, six aimed at reducing backing crashes, and six headlighting systems specifically targeted at reducing low visibility nighttime crashes. The full list of the systems examined in this analysis is presented in Table 3, along with the corresponding abbreviations for these systems that will be used throughout this report. It is important to keep in mind that a number of these systems have important relationships and dependencies that are not entirely reflected in Table 3. For example, AEB includes FCA functionality, more advanced level backing/parking systems generally include the functionality of less advanced backing/parking systems, and certain systems addressing different crash types were offered together in production (e.g., LKA, LDW, and camera-based FCA are co-dependent, FPB is only offered with AEB, RAB implies the presence of forward AEB but not vice-versa, etc.). Where relevant to point out, these relationships will be mentioned in the corresponding analysis discussion.

Table 3. Analysis group, system evaluated, and system abbreviations used in report

Analysis Group	System(s) Evaluated	Corresponding System(s) Abbreviations
Forward Collisions	Camera Forward Collision Alert	Camera FCA
	Automatic Emergency Braking with FCA	AEB
Front Pedestrian	Front Pedestrian Braking	FPB
Lane Departure	Lane Departure Warning	LDW
	Lane Keep Assist with Lane Departure Warning	LKA w/LDW
Lane Change	Side Blind Zone Alert	SBZA
	Lane Change Alert with Side Blind Zone Alert	LCA w/SBZA
	Rear Camera Mirror with Lane Change Alert and Side Blind Zone Alert	RCM w/LCA & SBZA
Backing Collisions	Rear Vision Camera	RVC
	Rear Park Assist	RPA
	Rear Cross Traffic Alert with Rear Vision Camera	RCTA w/RVC
	Reverse Automatic Braking with Rear Vision Camera, Rear Park Assist, and Rear Cross Traffic Alert	RAB w/RVC, RPA, & RCTA
Headlights	Halogen Headlamps	HAL
	High-Intensity Discharge (HID) Headlamps	HID
	Intellibeam (Automatic High-Beams)	Intellibeam

Police Crash Report Data

UMTRI obtained data on police-reported crashes from ten states that were able to provide full 17-character VINs for the vehicles involved.

Table 4 shows a calendar year summary of the accident data provided to UMTRI from each of these states. Six states provided data on crashes through calendar year 2017, two states provided partial data from calendar year 2018, and two states provided complete calendar year 2018 data.

Table 4. States and calendar years of police crash report data available

State	Calendar Years
Florida	2012 – 2018
Idaho	2012 – 2017
Kansas	2012 – 2018
Louisiana	2012 – 2017
Maryland[1]	2012 – 2013, 2015 – Q2 2018
Michigan	2012 – 2017
Missouri	2012 – 2017
Nebraska	2012 – 2017
Tennessee	2012 – November 2018
Utah	2012 – 2017

Matched Subset Data

After alignment of the crash data across the ten states (see subsequent *Crash Definitions and Variable Creation* section), the resulting dataset was merged with the safety content dataset provided by GM to UMTRI to identify which vehicles were present in both the GM VIN and police report datasets. The result was 123,377 matches.

In addition, the matched data came predominantly from a small number of the states used in this analysis, which was likely due to a combination of the state population being larger and the GM fleet penetration being higher in those states. Figure 1 provides a visual representation of the matched crash contribution levels for each of the 10 states included in the analysis, with darker shading indicating increased match levels. Florida (FL) and Michigan (MI) contributed to 69% of the matched dataset (47% FL, 22% MI). For the remaining 8 of 10 states, only Louisiana and Tennessee contributed to more than 5% of the matched total, with each contributing about 9%.

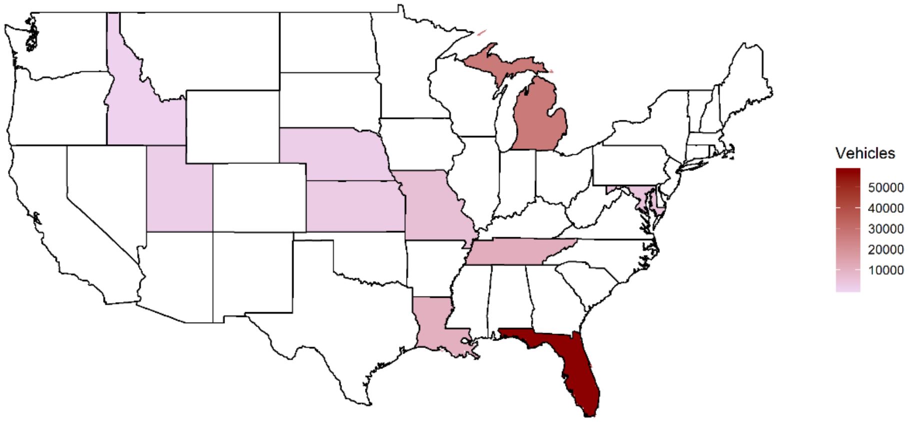

Figure 1. United States map showing the relative contribution levels of matched crashes from each of the 10 states used in this analysis

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[1] Over the course of 2014, Maryland changed the format of their police crash report. As a result, a number of fields, including initial contact point, have ambiguous coding and consequently the data collected in that period were deemed not suitable for use in this project.

Analysis Structure

The analysis approach focused on identifying system-relevant (or "targeted") crashes and control crashes that could be compared to determine the effectiveness of the safety systems. This method, called quasi-induced exposure (Keall & Newstead, 2009), was intended to control for the lack of traditional exposure data (e.g., miles traveled). The control crash needs to be a crash type that should not be impacted by the safety system and would, therefore, occur at a similar rate in both equipped and unequipped populations since these control crashes are assumed to occur randomly as exposure (i.e., vehicle miles traveled) increases (rather than due to particular driver actions). Conversely, the system-relevant crash is expected to be less frequent in the equipped population relative to the control crash. The prevalence of these crash types was then evaluated using odds ratios.

For example, a test of any of the various backing systems evaluated uses backing crashes as the system-relevant crash type. Since the backing system should be irrelevant for rear-end struck crashes, such crashes are used as the control crash type. This scenario is shown in Table 5, where A, B, C, D represent observed crash counts. The odds of an equipped vehicle being involved in a backing crash relative to a control crash is A/C, while the odds ratio for the effect of the backing system is $\left(\frac{A}{C}\right) / \left(\frac{B}{D}\right)$. In the full analysis, we used a regression approach to adjust for ten covariates (described below), but the Table 5 serves to illustrate the concept underlying the quasi-induced exposure technique.

Table 5. The layout for quasi-induced exposure logistic regression

		Backing System Equipment	
		Equipped	Not Equipped
Crash Configuration	Backing	A	B
	Rear-end Struck	C	D

The final odds ratios were estimated using a mixed effects logistic regression model. For each model, the full set of 123,377 matched vehicles was limited to cases of the system-relevant and associated control crashes, and then a model predicting the probability of the system-relevant crash was constructed. The starting model included a random effect for the vehicle model, and fixed effects for the safety systems and covariates. (Model Year was not included since GM indicated any differences in system behavior over the range of model years examined was too minor to produce a significant impact on system performance.) Backward selection, using a likelihood ratio test, was then performed until all non-significant effects were removed, excepting driver demographic characteristics (i.e., age and gender). After the conclusion of the backward selection process, interactions between the safety system and any significant predictors were tested, again with likelihood ratio tests. The driver demographic characteristics were included in all models because they have been previously shown to be related to crash outcomes and they provide a means for attempting to control for demographic trends.

The inclusion of vehicle model in the modelling process attempted to capture differences between the driver demographics associated with various vehicles. Since demographic differences in the driver populations of equipped and unequipped vehicles can mask (or heighten) the safety system effect, including the vehicle model insulates the analysis from scenarios where unobserved factors (such as cost) restrict vehicle models (and their associated safety content) to certain demographics. Since the precise effect of various vehicle models is not of primary interest in this context, a random effect treatment of vehicle model is deemed appropriate.

The ten covariates listed below were employed in this analysis. The first eight listed were obtained from the police accident reports, and the last two listed below were associated with the VIN data provided by GM:

- Driver age: *<25, 25-64, 65+*
- Driver gender: *Male, Female*
- Speed Limit (miles per hour): *Continuous*
- Alcohol or Drug Presence (police reported): *Yes, No*
- Distracted Driver: *Yes, No*
- Fatigued Driver: *Yes, No*
- Weather: *Clear/Cloudy, Not Clear/ Cloudy (rain, snow, etc.)*
- Road Surface Condition: *Dry, Not Dry (wet, icy, etc.)*
- Vehicle Type: *Sedan, Small/Medium Utility, Large Utility, Truck (see* Table 6 *for definitions)*
- Vehicle Model: *see* Table 6

Table 6. Model to vehicle type mapping used for the logistic regression predictor variable

Vehicle Type	Models
Sedan	ATS, Bolt, CT6, CTS, Impala, LaCrosse, Malibu, Regal, Volt, XTS
Small/Medium Utility	Acadia, Envision, SRX, XT5
Large Utility	Escalade, Suburban, Tahoe, Yukon, Yukon XL
Truck	Sierra, Silverado, Silverado HD

Crash Definitions and Variable Creation

Although police accident reports have a core set of available fields present in most states, the coding of the variables associated with those fields is not uniform. For example, initial impact location is coded in various states with either an 8-, 12- or 16-point grid, with additional variability coming from the orientation of the reference grid around the vehicle. Consequently, before pooling the accident data across states, each state crash dataset was separately reduced to a standard set of crash definitions and potential covariates to ensure comparability across states. The difficulty in aligning state crash field levels also leads to binary coding for many covariates in order to maximize consistency of variable definitions across states, including definitions for alcohol/drug involvement, distraction, weather and road surface condition. Furthermore, although GM offers systems that are relevant to low-speed forward parking crashes (e.g., Front and Rear Park Assist, and Automatic Parking Assist with Steering), the inconsistency of parking crash coding across state crash databases does not allow a reasonable evaluation of effectiveness levels for these systems.

The assumed system-relevant and corresponding control crash definitions used in each analysis are shown in Table 7 and Table 8, respectively. The goal is to identify a group of crashes that best represents (with the available data elements) the system-relevant crashes that each system is designed to address. For all analysis groups except headlights, “rear-end struck” (i.e., being struck from behind in a rear-end crash) served as the control crash type. However, due to the potential ambiguity of crash configurations in police reports, and the subset of rear-end struck crashes included in the lane change crash analysis, it was possible for a rear-end struck crash to also qualify as a system-relevant crash (e.g., when the GM vehicle changed lanes in front of another vehicle and was subsequently impacted in the rear). In such circumstances, the crash was counted as system-relevant rather than a control crash. For the headlight analysis, nighttime and daylight crashes with Vulnerable Road Users (VRUs), defined here as pedestrians, bicyclists, and animals, were used for the system-relevant and control crash types, respectively.[2] Finally, in addition to the crash type definitions provided in Table 7 and Table 8, some states had special variables we used in the analysis, when available, that more directly indicated the crash types of particular interest for this analysis.

Table 7. System-relevant crash types and definitions by analysis group

Analysis Group	Crash Type	Definition
Frontal	Rear-end Striking	Manner of Crash = Rear-end AND Initial Contact Point on Vehicle = Front
Front Pedestrian	Front Pedestrian	Initial Contact Point on Vehicle = Front AND First Event = Pedestrian
Lane Departure	Lane Departure	Manner of Crash = Sideswipe OR Harmful Event = Run off road, Cross centerline, Cross median
Lane Change	Lane Change	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	Motor Vehicle Maneuver/Action = Backing AND Initial Contact Point on Vehicle = Rear
Headlight	Night VRU Crash	Light Condition = Dark – Unlighted AND Initial Contact Point on Vehicle = Front AND First Event = (Pedestrian, Bicyclist, Animal)

Table 8. Control crash types and definitions by analysis group

Analysis Group	Crash Type	Definition
Not Headlight	Rear-end Struck	Manner of Crash = Rear-end AND Initial Contact Point on Vehicle = Rear
Headlight	Daylight VRU Crash	Light Condition = Daylight AND Initial Contact Point on Vehicle = Front AND First Event = (Pedestrian, Bicyclist, Animal)

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[2] The inclusion of animals in VRU crashes was done to compensate for the rarity of pedestrian/bicyclist crashes, particularly at night. In the matched crash crashes, approximately 87% of the VRU crashes involve animals, with the rest being pedestrians or bicyclists. At night, this shifts to animals being 97% of the VRU crashes. During the day, animals are only about 60% of VRU events, and there are also fewer VRU events overall.

It should be noted that we could not determine based on the State Crash data whether or not the safety system was turned on or off at the time of the crash, or whether the driver used the safety system properly (i.e., as characterized in the Owner's Manual system descriptions). If actual system usage is less than 100%, or if the feature was turned on but not being used properly by the driver, this analysis will underestimate the *potential* effectiveness if the system were always turned on and used properly.

Results

The active safety and advanced headlighting systems evaluated were divided into six general analysis group categories: forward collision, front pedestrian, lane departure, lane change, backing, and headlights (nighttime vulnerable road users). Each category is discussed separately below with the corresponding model fits provided in *Appendix A: Logistic Regression Model Fits*. Only significant effects involving safety systems are discussed here, and none of the covariates examined interacted with the observed safety system effects. For an understanding of remaining effects examined, the interested reader is referred to *Appendix A: Logistic Regression Model Fits*.

Analysis Data Subsets

Table 9 shows the sample size of matched cases for both system-relevant and control crashes for each analysis group and system(s) evaluated, which are derived from the original set of 123,377 vehicle cases matched between GM VINs (with safety system content indicated) and the set of police accident report cases from the ten states used in this analysis. Note that some safety systems are listed as co-occurring with other safety systems due generally to the bundling of less advanced systems with their more advanced counterparts, which will be addressed in the relevant analysis discussions below.

Table 9. Sample sizes by system(s) evaluated and crash type (system-relevant versus control) for each analysis category

Analysis Category	System(s) Evaluated	Crash Type Sample Size	
		System-Relevant	Control
Forward	None	8,645	14,695
	Camera-based Forward Collision Alert (FCA)	4,125	8,953
	Automatic Emergency Braking (AEB)	1,178	3,808
Front Pedestrian	None	142	14,380
	Front Pedestrian Braking (FPB)	6	657
Lane Departure	None	10,902	14,631
	Lane Departure Warning (LDW)	5,267	8,035
	Lane Keep Assist (LKA) with LDW	2,624	4,678
Lane Change	None	1,553	13,887
	Side Blind Zone Alert (SBZA)	522	4,537
	Lane Change Alert (LCA) with SBZA	561	7,034
	Rear Camera Mirror (RCM) with LCA & SBZA	19	267
Backing	None	708	4,145
	Rear Vision Camera (RVC)	389	2,746
	Rear Park Assist (RPA)	851	5,826
	Rear Cross Traffic Alert (RCTA) with RVC	1,070	8,772
	Reverse Automatic Braking (RAB) with RVC, RPA, & RCTA	40	679
Headlights	Halogen	1,184	624
	HID	415	251
	Articulating HID	94	86
	No Intellibeam	1,546	820
	Intellibeam	147	141

Forward Collision Prevention Analysis

Table 10 provides a summary of the systems and crash types (system-relevant and control) used in the forward collision prevention analysis. In this analysis, various Automatic Emergency Braking (AEB) system types (which all include the FCA system) were analyzed together, which included camera only AEB (which operates below 50 MPH), radar only AEB, and fusion-based AEB systems (the latter two systems of which are offered with either regular or full-speed range Adaptive Cruise Control). The two system levels shown in Table 10 were compared against the reference level of "Unequipped" with either FCA or any type of AEB system.

Table 10. Summary of the forward collision prevention analysis

Characteristic	Value
System Levels	Forward Collision Alert (FCA) Automatic Emergency Braking (AEB) w/ FCA
System-relevant Crash	Rear-end Striking
Control Crash	Rear-end Struck
Analysis Subset Sample Size	41,404

Figure 2, which will mirror how safety system effectiveness results are shown in the remainder of the paper, shows the estimated odds ratios (with values shown on the right vertical axis) for each of the forward collision safety systems evaluated, along with green bolded values corresponding to statistically significant reductions in the system-relevant crash type (in this case, rear-end striking). (Note blue values are used later in the paper to indicate cases where statistically significant results are not observed.) AEB systems were shown to reduce rear-end striking crashes by 46% (odds ratio=0.54), which substantially exceeds the 21% reduction observed with the camera-based FCA system (odds ratio=0.79) which only provides alerts.

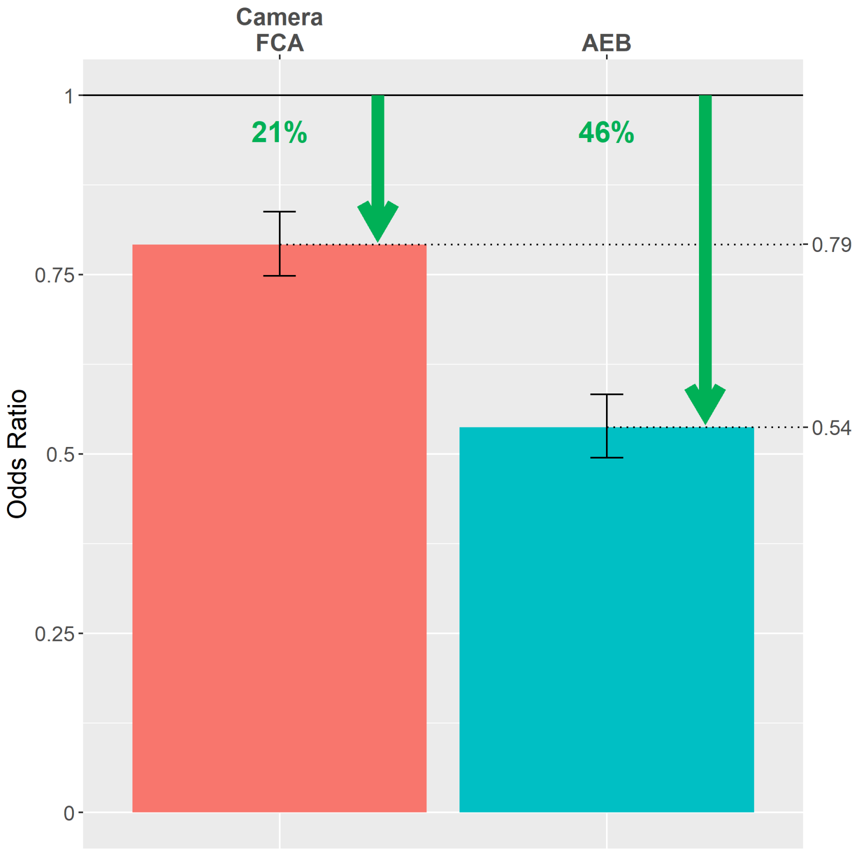

Figure 2. Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for forward collision crash prevention systems

Front Pedestrian Crash Prevention Analysis

Table 11 shows a summary of the front pedestrian crash prevention analysis. Note that Front Pedestrian Braking (FPB) is only offered on vehicles with AEB, and operates below 50 MPH. Furthermore, since FPB was not available on vehicle models that were either trucks or large utility vehicle types, these vehicles were excluded from the analysis. In this analysis, the ability to detect any existing FPB effects was limited by the rarity of system-relevant front pedestrian crashes (148 of the 15,185 cases in the analysis subset). In this analysis, FPB was compared against the reference level of "Unequipped" with FPB.

Table 11. Summary of the front pedestrian crash prevention analysis

Characteristic	Value
System Levels	Front Pedestrian Braking (FPB)
System-relevant Crash	Front Pedestrian Crash Daylight/Night VRU Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Size	15,185

Figure 3 shows the primary analysis findings, which indicate the FPB effect was non-significant (odds ratio=0.87), but indicates a positive trend (13% reduction in front pedestrian crashes). Front pedestrian crashes are rare enough such that it is estimated that to detect a true 25% decrease in the odds of pedestrian crashes with 80% power (i.e., a 25% reduction in pedestrian crashes), an overall sample size of over 450,000 matched vehicles would be required (approximately four times the size of the current matched crashes dataset).

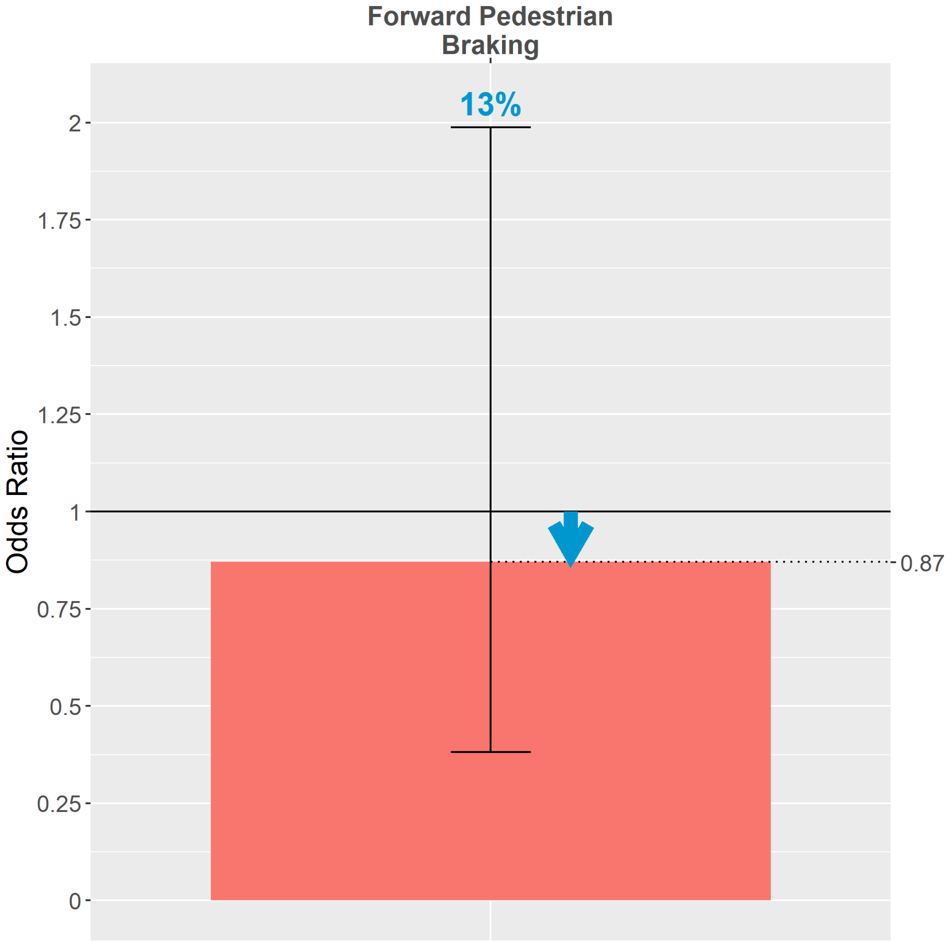

Figure 3. Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the front pedestrian braking crash prevention system

Lane Departure Crash Prevention Analysis

Table 12 shows a summary of the lane departure crash prevention analysis. Note the Lane Keep Assist (LKA) system analyzed includes a Lane Departure Warning (LDW) system, but the LDW functionality is somewhat modified by the existence of the LKA system (such that the frequency of LDW alerts are markedly reduced). The reference category for the system factor is “Unequipped” with either “LDW only” or LKA with LDW.

Table 12. Summary of the lane departure crash prevention analysis.

Characteristic	Value
System Levels	Lane Departure Warning (LDW) Lane Keep Assist w/LDW
System-relevant Crash	Lane Departure Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Size	46,137

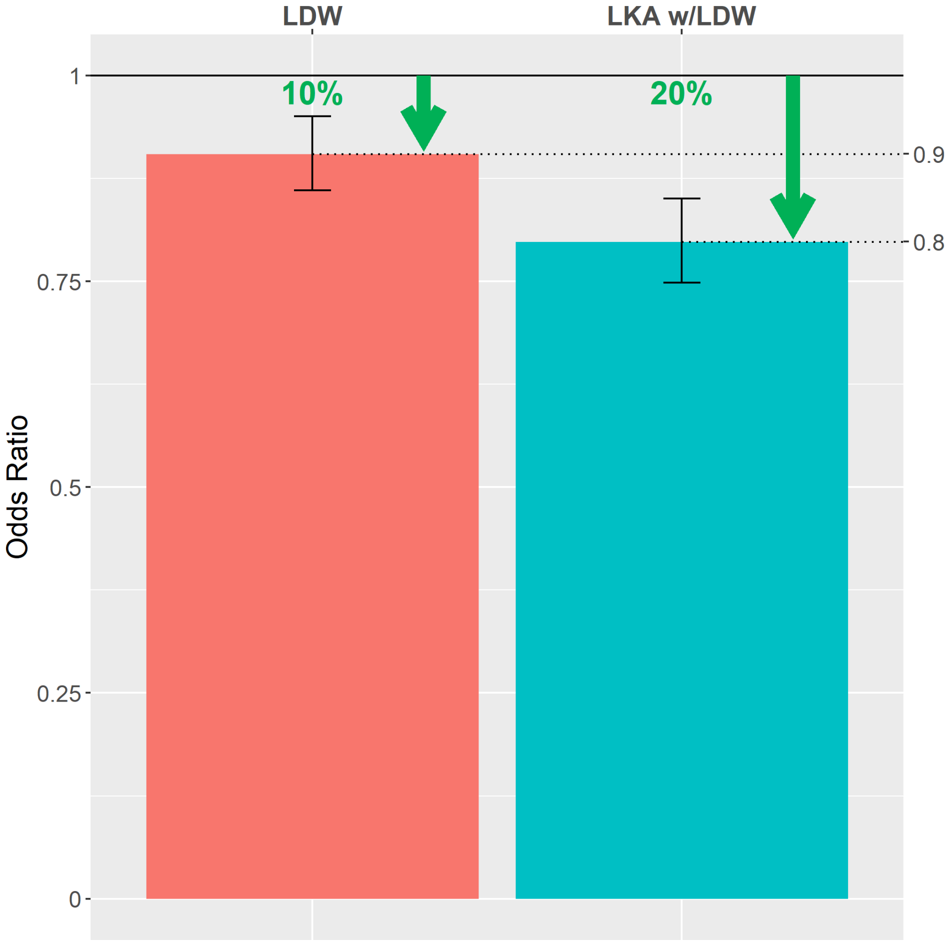

Figure 4. Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the lane departure crash prevention systems

Figure 4 indicates that both lane departure systems evaluated reduced lane departure crashes. The observed 20% reduction (odds ratio=0.80) for LKA with LDW (which provides a limited form of automatic control via a brief steering wheel nudge, along with lane departure warning alerts if necessary) exceeded the 10% reduction (odds ratio=0.90) observed with LDW only (which only provides alerts).

The lane departure system effect needs to be interpreted in the context of system usage, which may play an important factor in limiting larger system benefits. First, unlike the LDW system, the LKA with LDW system is set to “off” by factory default (to address potential confusion and complaints by customers first encountering LKA steering nudge inputs), and therefore must be enabled by the driver. Second, previous work (Flannagan et al., 2016) that used a large-scale, telematics-based approach system to examine GM LDW, FCA, and AEB usage has shown that drivers frequently turn off the GM LDW system, whereas both GM FCA and AEB systems have shown high customer usage (Flannagan et al., 2016, 2018). Note the type of non- visual LDW and FCA alert has shown to be an important factor in usage of these systems, with beeping alerts lead to more frequent disabling than Safety Alert Seat vibration alerts (particularly for LDW).

Lane Change Crash Prevention Analysis

Table 13 provides a summary of the lane change crash prevention analysis. Note that vehicles with Lane Change Alert (LCA) include Side Blind Zone Alert (SBZA) functionality, with the LCA system providing substantially increased vehicle detection ranges compared to SBZA, which is of particular importance for alerting drivers to vehicles rapidly approaching the side blind zone area. Also, the Rear Camera Mirror (RCM) system examined in this analysis was always offered with the LCA with SBZA system. Since none of the lane change systems investigated were available on trucks, trucks were excluded from the analysis. For similar reasons, large utility vehicles were not included in the SBZA analysis. For the system effect, the reference level was “Unequipped” with either LCA with SBZA, SBZA only, or RCM with LCA and SBZA.

Table 13. Summary of lane change crash prevention analysis

Characteristic	Value
System Levels	Side Blind Zone Alert (SBZA) Lane Change Alert w/SBZA Rear Camera Mirror w/LCA & SBZA
System-relevant Crash	Lane Change Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Size	28,380

Figure 5 indicates that only the LCA with SBZA system showed a statistically significant effect in reducing lane change crashes, with an observed 26% reduction (odds ratio=0.74). Rear Camera Mirror, always offered with both the LCA and SBZA systems, indicated a substantial positive trend (37% reduction in lane change crashes) which was limited in statistical power by a small sample size (286 vehicles, as shown in Table 9). The pattern of these findings, coupled with the observation that SBZA (odds ratio=0.97) did not approach significance, provides compelling evidence that the added vehicle detection range offered by the LCA system is of fundamental importance for lane change systems reducing lane change crashes.

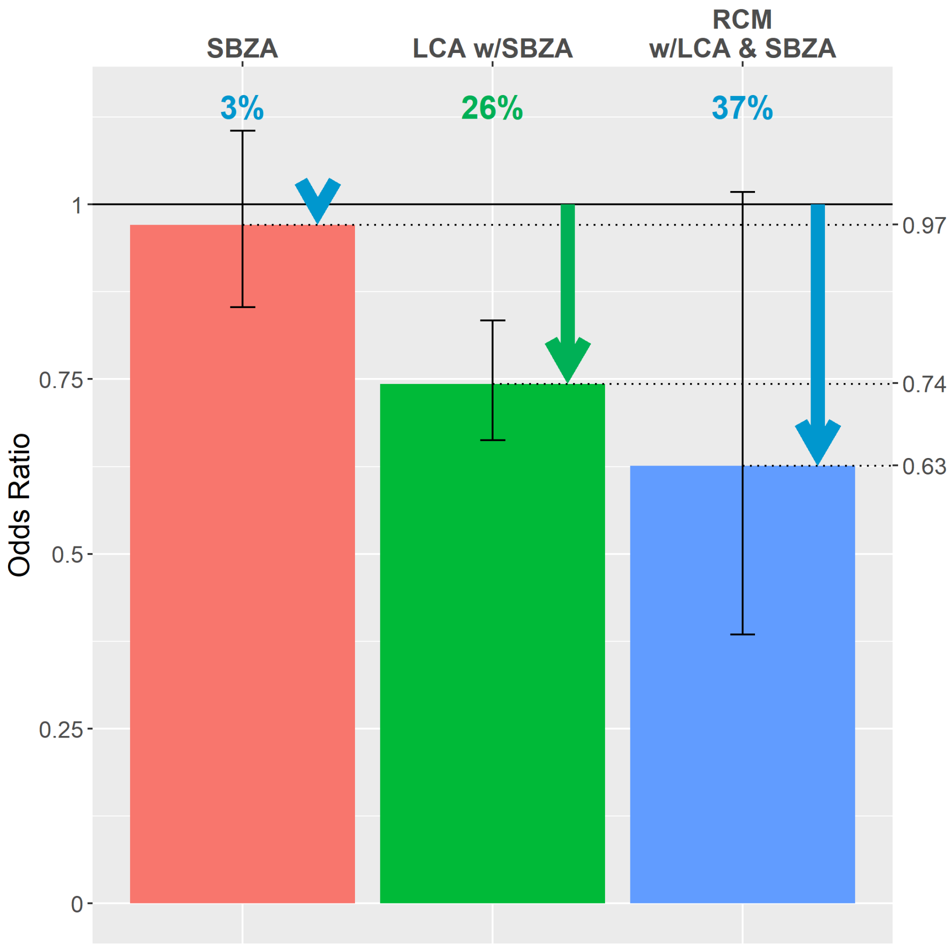

Figure 5. Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the lane change crash prevention systems

Backing Crash Prevention Analysis

Table 14 provides a summary of the backing crash prevention analysis. Since there was not a reliable way to identify various backing crash types (e.g., parking, higher-speed backing, cross traffic) via available police reports, three lower-speed park assist related systems (i.e., Rear Park Assist (RPA), Front and Rear Park Assist (FRPA), and Automatic Park Assist with Steering (or APA2)) were treated as a single system, labeled Rear Park Assist (RPA). Due to the complicated hierarchies of backing/parking systems, the system levels as listed in Table 14 were treated as hierarchical with the more advanced system taking priority as available (e.g., a car with Rear Cross Traffic Alert (RCTA) automatically falls into that group regardless of the parking assist system equipment status). In most cases, this means that vehicles coded as having a particular backing system also had all systems listed above that in Table 14. There were two exceptions involving a relatively small number of cases: (1) RCTA did not include a RPA system in approximately 0.5% of cases; (2) RPA did not include Rear Vision Camera (RVC) in approximately 3% of cases. For the effect sizes, the systems were compared to a reference level of “Unequipped” with any of the backing systems shown in Table 14.

Table 14. Summary of the backing crash prevention analysis

Characteristic	Value
System Levels	Rear Vision Camera (RVC) Rear Park Assist (RPA)[3] Rear Cross Traffic Alert (RCTA) Reverse Automatic Braking w/RVC, RPA, & RCTA
System-relevant Crash	Backing Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Size	25,226

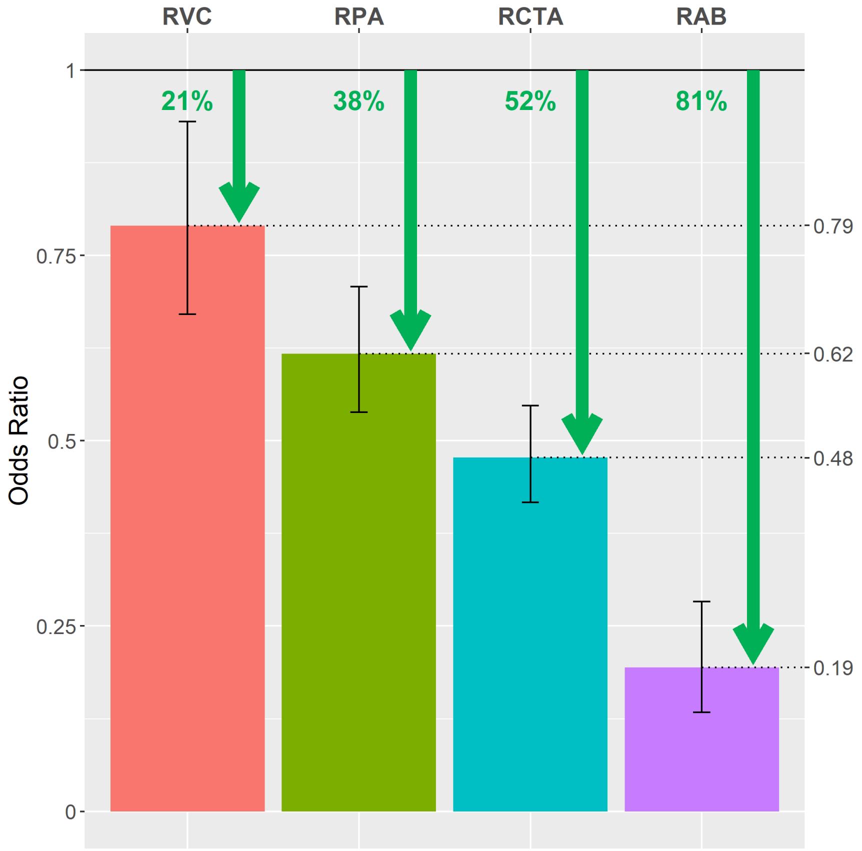

Figure 6. Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the parking/backing crash prevention systems. (The Rear Park Assist, Front and Rear Park Assist, and Automatic Parking Assist were all treated as Rear Park Assist for this analysis).

Figure 6 indicates that all backing systems evaluated reduced backing crashes, with a readily apparent "stack-up" effect indicating system benefits generally increased as more advanced backing systems were added. RVC alone provided approximately a 21% benefit (odds ratio=0.79), and RPA (which is nearly always offered with RVC) increased this backing crash reduction benefit to 38% (odds ratio=0.62).

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[3] Rear Park Assist includes the Rear Park Assist, Front & Rear Park Assist and Automatic Park Assist with Steering systems.

Furthermore, RCTA, which is always offered with RVC and is virtually always offered with RPA, increased the backing crash reduction benefit to 52% (odds ratio=0.48). Finally, Reverse Automatic Braking (RAB), which is always offered with RCTA, RPA, and RVC, further increased the backing crash reduction benefit to 81% (odds ratio=0.19).

Headlights (Nighttime Vulnerable Road User) Crash Prevention Analysis

The headlighting analysis (for nighttime Vulnerable Road Users, or VRUs) is summarized in Table 15. As illustrated in Table 9, the analysis subset was generally smaller in comparison to other analysis categories due to the control crash changing from rear-end struck to daylight VRU (pedestrian, bicyclist, and animal) crashes. Consequently, as discussed with the Front Pedestrian Braking (FPB) system analysis earlier, a larger dataset would be needed to reliably identify any significant safety effects for systems with lower fleet penetration, such as articulating High-Intensity Discharge (HID) headlights. Also, since Intellibeam (auto high beam headlighting) could be present or absent with all headlamp systems evaluated, it was treated as a separate variable independent of the headlamp type. An interaction term was considered during variable selection to check for different impacts of Intellibeam across headlamp types. For system comparisons, each of the advanced (i.e., non-halogen) headlight systems shown in Table 15 were compared to the reference level of “Halogen Headlamps” and “No Intellibeam”. Since Intellibeam could be offered with the FPB (also targeted to address nighttime VRU crashes), vehicles equipped with FPB were not included in this headlighting analysis to focus on headlamp-specific effects.

Table 15. Summary of the night crash prevention analysis

Characteristic	Value
System Levels	Halogen headlamps (baseline comparison) HID Headlamps Articulating HID Headlamps Intellibeam (present vs. absent)
System-relevant Crash	Night VRU Crash
Control Crash	Daylight VRU Crash
Analysis Subset Sample Size	2,654

Figure 7 indicates that Intellibeam and HID showed 35% (odds ratio=0.65) and 21% (odds ratio=0.79) reductions, respectively, in nighttime VRU (predominantly animal) crashes. In addition, the interaction between headlamp type and Intellibeam was found to be non-significant, indicating that the effect of Intellibeam in this dataset is generally additive. In addition, a separate analysis indicated that when Intellibeam and HID headlights were offered together, a significant 49% reduction (odds ratio=0.51) in VRU crashes were observed. Articulating HID produced a non-significant 17% reduction (odds ratio=0.83) in VRU crashes, which is generally consistent with the observed significant HID effect (i.e., 21%), though the smaller sample size results in a larger confidence interval.

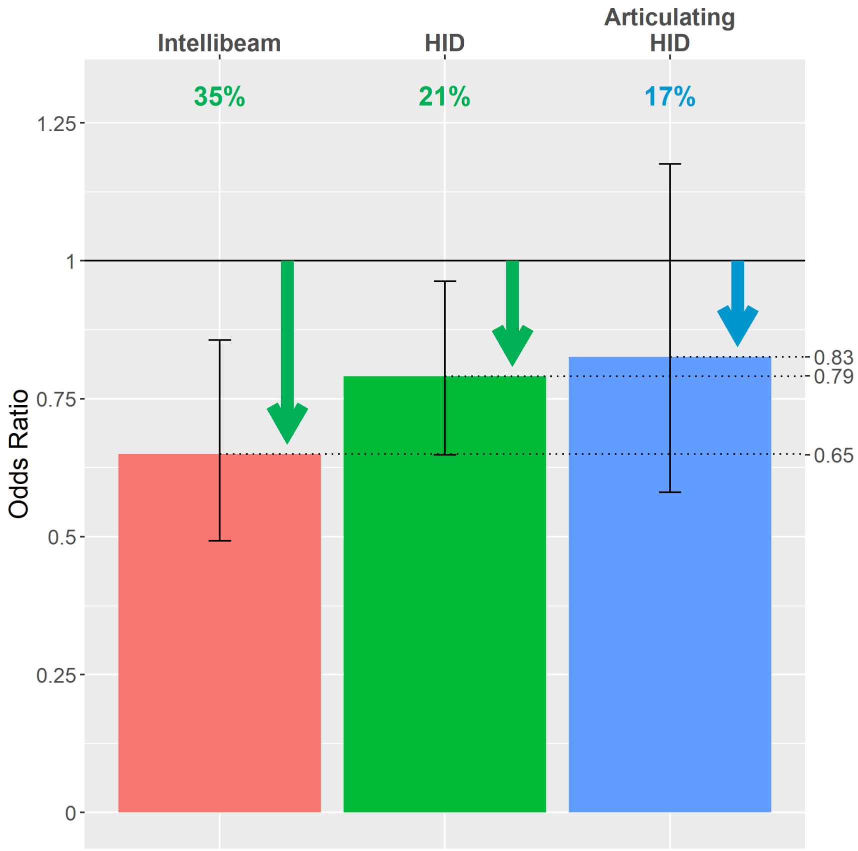

Figure 7. Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the advanced headlight systems

Discussion

The current research provides an analysis of the field effectiveness of 15 General Motors (GM) active safety and advanced headlighting systems. The safety system content of over 3.7 million GM Model Year 2013-2017 vehicles were provided by GM to the University of Michigan Transportation Research Institute (UMTRI) to conduct this analysis. These safety content data were then matched to police-report data from vehicles involved in crashes using 10 state crash police report databases. Using the method of “quasi-induced exposure”. comparisons of “system-relevant” crash counts and “control” crash counts for equipped and unequipped vehicles were used to estimate safety system effectiveness. Control crashes served to control for vehicle exposure and were selected to be unaffected by the system examined. The statistical method of field effectiveness estimation was logistic regression, which can also adjust for other factors such as weather, road type, and driver age and gender. The results of this GM Model Year 2013-2017 safety system field effectiveness analysis are summarized in Table 16.

Table 16. Safety system field effectiveness (estimated percent reductions in system-relevant crashes) across GM Model Year 2013-2017 Vehicles (Note shaded green cells denote statistically significant field effectiveness effects)

Crash Category and Safety System(s)	Percent Reduction in System-Relevent Crash
FRONTAL	
Camera-Based Forward Collision Alert (Camera FCA)	21%
Automatic Emergency Braking (AEB)	46%
FRONT PEDESTRIAN	
Front Pedestrian Braking (FPB)	13%
LANE DEPARTURE	
Lane Departure Warning (LDW)	10%
Lane Keep Assist (LKA) with LDW	20%
LANE CHANGE	
Side Blind Zone Alert (SBZA)	3%
Lane Change Alert (LCA) with SBZA	26%
Rear Camera Mirror (RCM) with LCA & SBZA	37%
BACKING	
Rear Vision Camera (RVC)	21%
Rear Park Assist (RPA, Front & Rear PA or Automatic Park Assist with Steering)	38%
Rear Cross Traffic Alert (RCTA) with RVC	52%
Reverse Automatic Braking (RAB) with RVC, RPA, & RCTA	81%
HEADLIGHTS (Nightime Vulnerable Road Users; versus Halogen)	
HID (High-Intensity Discharge)	21%
Articulating HID	17%
Intellibeam (can be offered with any of the above headlights)	35%

The Automatic Emergency Braking (AEB) and camera-based Forward Collision Alert (FCA) systems evaluated produced, respectively, an estimated 46% and 21% reduction in rear-end striking crashes. For addressing lane departure crashes, Lane Keep Assist (LKA) with Lane Departure Warning (LDW), GM's next generation of the earlier "LDW only" system, produced an estimated 20% reduction in lane departure crashes compared to a corresponding 10% reduction with LDW alone. Keeping in mind that we could not determine based on the State Crash data whether or not the safety system was turned on or off at the time of the crash, it should be noted that large-scale telematics-based studies suggest that the relative low usage of LDW systems (compared to FCA and AEB) may be an important limiting factor in obtaining desired higher effectiveness estimates (Flannagan et al., 2016, 2018).

The lane change crash prevention analysis indicated Lane Change Alert (LCA) with Side Blind Zone Alert (SBZA) produced an estimated 26% reduction in lane change crashes, compared to a corresponding non-significant estimated 3% reduction with SBZA. This difference is likely to be due to the substantially longer vehicle detection ranges for the LCA with SBZA system relative to GM's earlier generation SBZA system, which is of particular importance for alerting drivers to vehicles rapidly approaching the side blind zone area. Rear Camera Mirror (RCM), which is always offered with both LCA and SBZA, was also estimated to produce a 37% benefit, but the effect was not statistically significant due to small sample sizes. This feature should be re-evaluated when RCM fleet penetration has increased.

For the variety of backing systems evaluated, a "stack up" system effect was apparent under which the addition of more advanced backing features to less advanced backing features resulted in an increased reduction in backing crashes. Rear Vision Camera (RVC) alone, Rear Park Assist (RPA) functionality, Rear Cross Traffic Alert (or RCTA; which is always included both RVC and nearly always is included with RPA functionality), and Reverse Automatic Braking (which includes all the aforementioned backing features) produced, respectively, an estimated 21%, 38%, 52%, and 81% reduction in backing crashes.

For safety systems examined that are aimed at reducing crashes involving Vulnerable Road Users (VRUs), both Intellibeam (auto high beam headlights) and HID headlights were estimated to provide 35% and 21% reductions in such VRU crashes (i.e., pedestrians, bicyclists, and animals), respectively. When Intellibeam and HID headlights were offered together, an estimated 49% reduction in such VRU crashes were observed. The estimated 17% reduction in VRU crashes for articulating HID headlights did not reach statistical significance. Given the relatively small sample of articulating HIDs and the significant 21% benefit for HID headlights, we interpret these results to indicate articulating (steerable) HID headlights are likely to produce a benefit similar to HID (non-steerable) headlights.

It is important to acknowledge that while we group animal, bicyclist and pedestrian crashes collectively as VRU crashes in the headlighting analysis, these crashes are dominated by animal crashes, especially at night. This allows us to estimate the benefits of headlamps, but these benefits primarily apply to nighttime animal crashes. That said, we argue that the mechanisms for each of these three VRU crash types involve the driver's inability to see the VRU at night early enough to prevent a crash. Thus, a headlamp effect for animal crashes is likely to apply to pedestrian and bicyclist crashes as well, since the underlying causal mechanism for the crash should be similar. As with the Front Pedestrian Braking (FPB) system analysis, which showed a non-significant 13% reduction in front pedestrian crashes, the rarity of front pedestrian crashes means that a substantially larger dataset would be required for a pedestrian only analysis to have sufficient power to detect effects of this magnitude.

In the context of the current research which provides a safety system effectiveness analysis at a given point (or snapshot) in time, it is worth noting that a pattern has been observed for reduced safety system effectiveness as these systems move from early system introduction (perhaps purchase by more safety conscious drivers) to becoming widespread across the broader driving population. For example, Electronic Stability Control (ESC) was estimated in 2007 (Dang, 2007) to reduce fatal rollovers by decreased by 70 % in passenger cars and 88% in light duty vehicles. In 2011, an updated report (Siviski, 2011) estimated corresponding reductions of 56% and 74%. In addition, in comparison to an estimated 52% reduction in backing crashes for GM Model Year 2008-2010 vehicles equipped with both RVC and RPA (Flannagan et al., 2014), a corresponding 38% effectiveness was observed in the current study.

However, this increased penetration effect could very well be mitigated by the increasing number and variety of newer production Active Safety systems that can provide various levels of automatic vehicle control under certain driving situations. In general, the current pattern of results indicated that either brief, limited, vehicle control (e.g., an LKA steering wheel "nudge"), and particularly more sustained, severe automatic vehicle control (e.g., AEB and RAB), resulted in substantially greater crash avoidance system field effectiveness benefits than the "alert only" system counterparts (i.e., LDW, FCA, and RPA). Although these systems still require the driver to always remain attentive to driving, they have the advantage of not strictly relying on drivers to respond to alerts in a timely and appropriate fashion and to respond to imminent crash situations that unfold quickly. While it remains possible that these newer systems offering some level of automatic vehicle control may be driven by more safety conscious drivers who are willing to pay for additional safety technology, these safety systems have the potential to mitigate potential drops in system effectiveness in reducing crashes.

More generally, the wide variety of GM safety systems evaluated in the current effort provide further widespread evidence of the substantial safety benefit opportunities afforded by these systems. It should be noted the current analysis does not address potential crash mitigation benefits that may also be associated with these safety systems. We recommend evaluating safety systems using the police report methodology employed in the current effort (as well as telematics-based crash data), leveraging additional state crash databases that may be available to UMTRI (or other organizations) in the future, and using safety system effectiveness estimates for ongoing assessment of emerging safety features and for informing New Car Assessment Program (NCAP) and safety system decision making. Simply put, safety systems that have been on the market longer and have higher fleet penetration result in smaller confidence intervals surrounding effectiveness estimates.

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Appendix A: Logistic Regression Model Fits

Forward Collision Systems

Fit Statistics	AIC	BIC	Deviance
Intercept Model	52677	52695	52673
Full Model	50217	20320	50193
[redacted]	X^2	df	p-Value
Likelihood Ratio Test	2481	10	<0.0001

Fixed Effects:	Estimate	Std. Error	Z Value	p-Value	Odds Ratio
(Intercept)	-0.4550	0.0544	-8.37	<0.0001	
System - FCA	-0.2334	0.0288	-8.12	<0.0001	0.79
System - AEB	-0.6218	0.0419	-14.85	<0.0001	0.54
Driver Age - <25	0.7827	0.0359	21.80	<0.0001	2.19
Driver Age - 65+	0.0084	0.0333	0.25	0.8020	1.01
Driver Sex - Female	-0.1460	0.0223	-6.54	<0.0001	0.86
Speed Limit (mph/10)	-0.0603	0.0071	-8.49	<0.0001	0.94
Distraction - Present	0.9504	0.0295	32.25	<0.0001	2.59
Fatigue - Present	2.8812	0.3210	8.97	<0.0001	17.84
Road Surface Cond. - Not Dry	-0.2032	0.0303	-6.71	<0.0001	0.82
Alcohol/Drugs - Involved	2.7706	0.1874	14.78	<0.0001	15.97

Random Effects	Variance	Std. Dev.
Vehicle Model	0.0288	0.1696

Front Pedestrian Braking (Pedestrian Only)

Fit Statistics	AIC	BIC	Deviance		
Intercept Model	1667	1675	1665		
Full Model	1591	1652	1575		
	X^2	df	p-Value		
Likelihood Ratio Test	90.4	7	<0.0001		
Fixed Effects:	Estimate	Std. Error	Z Value	p-Value	Odds Ratio
(Intercept)	-3.1754	0.1968	-16.14	<0.0001	
System - FPB	-0.1386	0.4212	-0.33	0.7421	0.87
Driver Age - <25	0.1735	0.3093	0.56	0.5748	1.19
Driver Age - 65+	0.5172	0.1883	2.75	0.0060	1.68
Driver Sex - Female	-0.1937	0.1676	-1.16	0.2476	0.82
Speed Limit (mph/10)	-0.3977	0.0449	-8.86	<0.0001	0.67
Road Surface Cond. - Not Dry	-1.0395	0.4433	-2.35	0.0190	0.35
Weather - Not Clear/Cloudy	1.0533	0.4446	2.37	0.0178	2.87
Random Effects	Variance	Std. Dev.			
Vehicle Model	NA	NA			

Lane Departure Systems

Fit Statistics	AIC	BIC	Deviance
Intercept Model	62243	62260	62239
Full Model	60780	60911	60750
	X^2	df	p-Value
Likelihood Ratio Test	1489	13	<0.0001

Fixed Effects:	Estimate	Std. Error	Z Value	p-Value	Odds Ratio
(Intercept)	-0.2308	0.0429	-5.38	<0.0001	
System - LDW	-0.1004	0.0253	-3.97	<0.0001	0.90
System - LKA w/ LDW	-0.2258	0.0326	-6.92	<0.0001	0.80
Driver Age - <25	0.4400	0.0354	12.44	<0.0001	1.55
Driver Age - 65+	0.4202	0.0271	15.48	<0.0001	1.52
Driver Sex - Female	-0.1354	0.0200	-6.77	<0.0001	0.87
Speed Limit (mph/10)	-0.0531	0.0061	-8.65	<0.0001	0.95
Distraction - Present	0.3279	0.0302	10.86	<0.0001	1.39
Fatigue - Present	3.0044	0.3120	9.63	<0.0001	20.17
Road Surface Cond. - Not Dry	0.0740	0.0255	2.90	0.0037	1.08
Alcohol/Drugs - Involved	3.0731	0.1841	16.69	<0.0001	21.61
Vehicle Type: Sm./Med. Utility	-0.1541	0.0588	-2.62	0.0088	0.86
Vehicle Type: Lg. Utility	0.0264	0.0507	0.52	0.6032	1.03
Vehicle Type: Truck	0.1420	0.0725	1.96	0.0500	1.15

Random Effects	Variance	Std. Dev.
Vehicle Model	0.0050	0.0705

Lane Change Systems

Fit Statistics	AIC	BIC	Deviance		
Intercept Model	17590	17606	17586		
Full Model	17065	17164	17041		
	X^2	df	p-Value		
Likelihood Ratio Test	545	10	<0.0001		
Fixed Effects:	Estimate	Std. Error	Z Value	p-Value	Odds Ratio
(Intercept)	-2.7214	0.0805	-33.82	<0.0001	
System - SBZA	-0.0297	0.0661	-0.45	0.6538	0.97
System - LCA w/ SBZA	-0.2965	0.0587	-5.06	<0.0001	0.74
System - RCM w/ LCA & SBZA	-0.4685	0.2479	-1.89	0.0587	0.63
Driver Age - <25	0.5875	0.0710	8.27	<0.0001	1.80
Driver Age - 65+	0.7757	0.0511	15.19	<0.0001	2.17
Driver Sex - Female	-0.1742	0.0422	-4.13	<0.0001	0.84
Speed Limit (mph/10)	0.0816	0.0142	5.75	<0.0001	1.09
Distraction - Present	0.7297	0.0565	12.91	<0.0001	2.07
Road Surface Cond. - Not Dry	-0.4356	0.0636	-6.85	<0.0001	0.65
Alcohol/Drugs - Involved	1.5308	0.3184	4.81	<0.0001	4.62
Random Effects	Variance	Std. Dev.			
Vehicle Model	0.0099	0.0994			

Backing/Parking Systems

Fit Statistics	AIC	BIC	Deviance
Intercept Model	18598	18615	18594
Full Model	17997	18127	17965
	X^2	df	p-Value
Likelihood Ratio Test	630	14	<0.0001

Fixed Effects:	Estimate	Std. Error	Z Value	p-Value	Odds Ratio
(Intercept)	-1.7328	0.0868	-19.96	<0.0001	
System - RVC	-0.2360	0.0835	-2.83	0.0047	0.79
System - RPA	-0.4823	0.0700	-6.89	<0.0001	0.62
System - RCTA	-0.7389	0.0693	-10.66	<0.0001	0.48
System - RAB	-1.6378	0.1912	-8.57	<0.0001	0.19
Driver Age - <25	0.2827	0.0764	3.70	0.0002	1.33
Driver Age - 65+	0.7370	0.0515	14.31	<0.0001	2.09
Driver Sex - Female	-0.1282	0.0410	-3.12	0.0018	0.88
Distraction - Present	0.1282	0.0578	2.22	0.0266	1.14
Road Surface Cond. - Not Dry	-0.6306	0.0988	-6.38	<0.0001	0.53
Weather - Not Clear/Cloudy	-0.4478	0.1272	-3.52	0.0004	0.64
Alcohol/Drugs - Involved	2.4876	0.2966	8.39	<0.0001	12.03
Vehicle Type: Sm./Med. Utility	0.2387	0.1328	1.80	0.0722	1.27
Vehicle Type: Lg. Utility	0.5575	0.1127	4.95	<0.0001	1.75
Vehicle Type: Truck	0.3230	0.1595	2.03	0.0429	1.38

Random Effects	Variance	Std. Dev.
Vehicle Model	0.0268	0.1637

Headlight Systems

Fit Statistics	AIC	BIC	Deviance		
Intercept Model	3477	3483	3475		
Full Model	3141	3194	3123		
	X^2	df	p-Value		
Likelihood Ratio Test	387	8	<0.0001		
Fixed Effects:	Estimate	Std. Error	Z Value	p-Value	Odds Ratio
(Intercept)	-2.1087	0.2131	-9.90	<0.0001	
System - HID	-0.2352	0.1009	-2.33	0.0181	0.79
System - HID Art	-0.1913	0.1801	-1.06	0.2480	0.83
System - Intellibeam	-0.4316	0.1412	-3.06	0.0056	0.65
Driver Age - <25	0.4770	0.1830	2.61	0.0087	1.61
Driver Age - 65+	-0.5022	0.1103	-4.55	<0.0001	0.61
Driver Sex - Female	-0.3590	0.0883	-4.07	<0.0001	0.70
Speed Limit (mph/10)	0.5658	0.0383	14.76	<0.0001	1.76
Road Surface Cond. - Not Dry	0.2951	0.1211	2.44	0.0123	1.34
Random Effects	Variance	Std.Dev.			
Vehicle Model	NA	NA			