Analysis of the Field Effectiveness of General Motors Model Year 2013-2020 Advanced Driver Assistance System Features

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16. Abstract

Over 10.9 million Model Year 2013–2020 vehicles were matched to police-reported crashes from 14 states to examine the effectiveness of GM ADAS features. The quasi-induced exposure method was used, with logistic regression used to adjust for 13 covariates. Results indicated fusion/radar Automatic Emergency Braking (AEB), camera AEB, and Forward Collision Alert systems reduced rear-end striking crashes by 45%, 40%, and 20%, respectively. When restricting to crashes with suspected minor or higher injury severities reported, reductions were elevated to 58%, 55%, and 25%, respectively, providing evidence of additional crash mitigation benefits. Similarly, the Lane Keep Assist with Lane Departure Warning system provided 17% and 10% reductions in roadway departure and same direction sideswipe crashes, respectively, with corresponding injury reduction benefits elevating to 21% and 16%, respectively. The Lane Change Alert with Side Blind Zone Alert system reduced lane change crashes by 16%. Reverse Automatic Braking (which includes Rear Cross Traffic Alert, Rear Park Assist, and Rear Vision Camera) produced an 83% reduction in backing crashes. Front Pedestrian Braking reduced front pedestrian crashes by 23%. IntelliBeam (auto high beam headlighting) provided a 22% reduction in a combined set of (unlighted) nighttime animal, pedestrian, and bicyclist crashes. These results provide further evidence of widespread ADAS field benefits, as well as identify opportunities for moving closer toward a zero crashes vision.

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Executive Summary

Background and Methodological Approach

This effort is the fourth in a series of field effectiveness studies examining General Motors (GM) Advanced Driver Assistance Systems (ADAS) and headlighting features. The current GM Model Year 2013-2020 study employed VIN-linked feature ADAS and headlighting content data from over 10.9 million GM vehicles. These data were provided by GM to UMTRI, who then matched to police-report crash data available in 14 states and conducted the effectiveness analysis.

The feature effectiveness (i.e., percent reductions in system-relevant crashes) was estimated using quasi-induced exposure logistic regression. The "quasi-induced exposure" method compares system-relevant and system-irrelevant (referred to as "control") crash counts for equipped and unequipped vehicles. This controls for the lack of traditional exposure data (e.g., miles traveled) by selecting control crashes that should be unaffected by the feature examined (i.e., control crashes should occur at a similar rate in both equipped and unequipped populations). The logistic regression estimates were made adjusting for various covariates, including driver demographics (age and gender), speed limit, driver behavior (alcohol, fatigue, and distraction presence), driving context (weather, road, and road surface conditions), crash year, model year, and vehicle type/model. For forward collision and lane departure features, crash sample sizes were large enough to support additional analyses of feature effectiveness for a more restricted set of crashes coded by the police to have "suspected minor injury" or higher injury severity for anyone in the crash (i.e., "B" or higher on the KABCO injury scale), which will be referred to in the summary below simply as the "injury" analysis.

High-Level Summary of GM ADAS Field Effectiveness

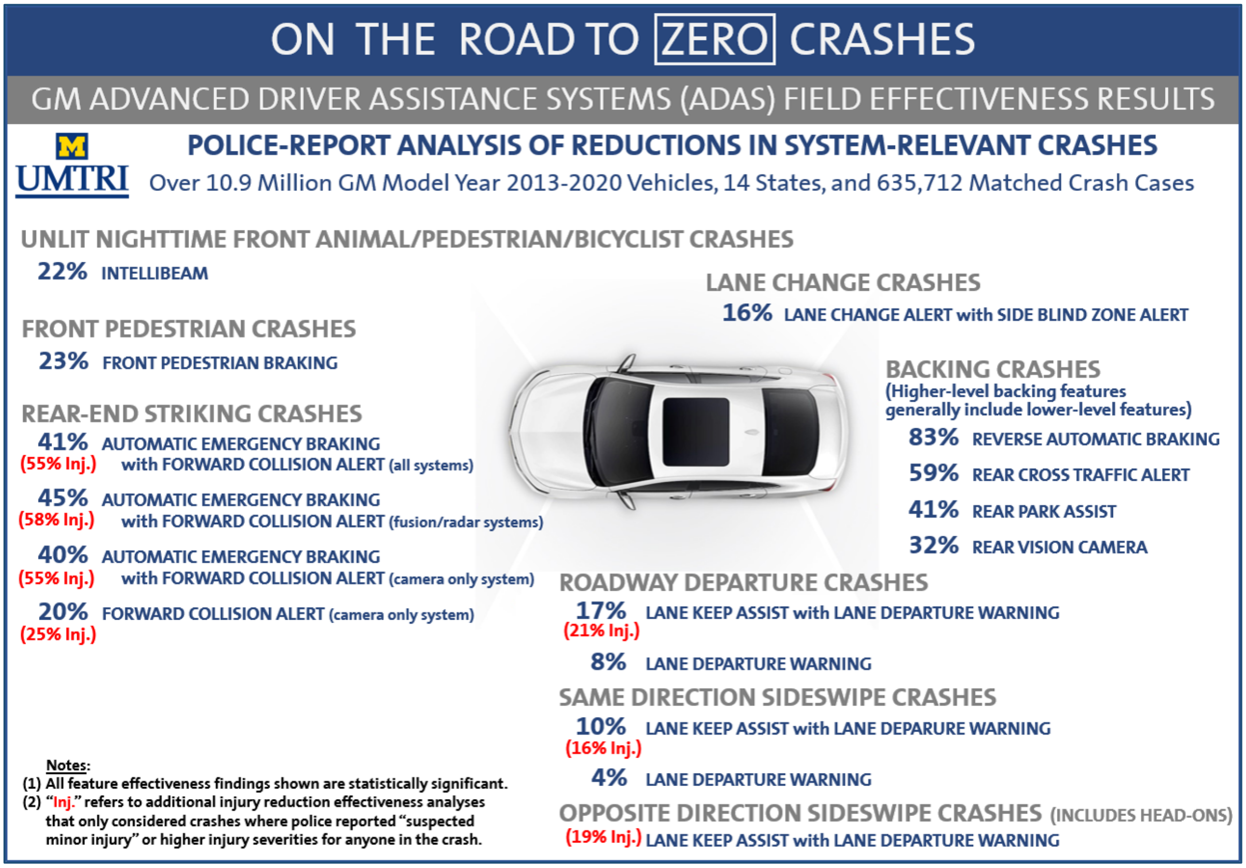
The high-level summary figure below (Figure-ES 1) provides effectiveness results found to be statistically significant for reducing system-relevant crashes. Results for injury crashes are shown in red and in parentheses. Non-significant results, many of which can be attributed to small sample size, are included in the results discussions below.

Forward Collision (Rear-end Striking Crash) Prevention and Crash Mitigation Findings

Automatic Emergency Braking (AEB) features, which includes Forward Collision Alert (FCA) functionality, were estimated to be approximately twice as effective as FCA (20% effective) for reducing system-relevant, rear-end striking crashes (AEB with FCA was 40% or 45% effective, depending on AEB technology type).

In the corresponding injury analysis, FCA effectiveness estimates increased to 25%, and overall AEB estimated benefits increased to 55%. These increases provide evidence these features are not only helping drivers completely avoid rear-end striking crashes, but also helping to reduce (or mitigate) the severity of some rear-end striking crashes which are not avoided. Furthermore, this pattern of findings suggests some rear-end striking crashes that would have otherwise likely involved reported injuries without FCA and AEB are potentially being shifted to property damage-only crashes.

Figure-ES 1 Estimated statistically significant percent reductions in system-relevant crashes for various GM Advanced Driver Assistance Systems (ADAS) when considering all system-relevant crashes, as well as when considering only system-relevant injury-related crashes (with injury analysis restricted to rear-end striking and lane departure crashes).



Lane Departure-Related Crash Prevention and Crash Mitigation Findings

Across analyses, Lane Keep Assist with Lane Departure Warning (LKA with LDW) provided higher crash reductions than LDW (only) across each of the three system-relevant crash types. Results for the crash prevention analysis indicated single-vehicle road departure crashes were reduced by Lane Keep Assist with Lane Departure Warning (LKA with LDW) and LDW (only) by an estimated 17% and 8%, respectively. In addition, same direction sideswipes, which could be due to the actions of non-equipped vehicles which lane departure systems are not designed to address, were also reduced, albeit at lower levels with LKA with LDW and LDW (only) by an estimated 10% and 4%, respectively. No effect was observed for opposite direction sideswipes (which include head on-crashes) likely due to insufficient sample size (note this is another system-relevant crash type involving multiple vehicles where the crash could have been due to the non-equipped vehicle).

For the corresponding injury analysis, the pattern for LKA is similar to that observed for forward crashes, under which elevated significant effectiveness estimates are observed. LKA (with LDW) effectiveness estimates when focused on injury-related crashes increased to 21% for roadway departures, 16%, for same direction sideswipes, and 19% for opposite direction sideswipes (note this latter effect was significant despite not being significant in the corresponding crash prevention analysis). For LDW, unlike in the crash prevention analysis, no effects were observed across crash types in this injury analysis. It should be noted that a telematics-based OnStar study suggests the relative low usage of the LDW feature, which may be an important limiting factor in obtaining desired higher effectiveness estimates (Flannagan et al., 2016, 2018). (Note the LKA feature, which includes LDW functionality, by design substantially reduces the frequency of LDW alerts which some drivers find annoying.).

More generally, the pattern of results emphasize the importance of measuring the effects of lane departure-related countermeasures using crash types that distinguish between single- versus multi-vehicle crashes. Since the role of the vehicle equipped with the countermeasure in multiple-vehicle lane departure crash cases is less clear (e.g., the other vehicle could very well have been unequipped and caused the crash), effectiveness estimates for single-vehicle road departures are generally felt to provide a more accurate assessment of lane departure countermeasure effectiveness.

Lane Change Crash Prevention Findings

Lane Change Alert with Side Blind Zone Alert (LCA with SBZA) reduced lane change crashes by an estimated 16%, and Side Blind Zone Alert (SBZA) alone was not found to be significant (with an estimated 7% reduction).

Backing Crash Prevention Findings

The backing crash findings indicated more advanced backing features (which generally include all less advanced backing features) provided increased backing crash reduction levels. That is, Rear Vision Camera (RVC), Rear Park Assist (RPA), Rear Cross Traffic Alert (RCTA), and Reverse Automatic Braking (RAB) were estimated to provide 32%, 41%, 59%, and 83% reductions in backing crashes, respectively. RVC mirror showed an estimated 33% reduction in backing crashes, comparable to standard RVC, which failed to reach significance (likely due to small sample size).

It should also be noted that relative to other crash types observed here, backing crashes are known to be under-represented in police-report databases as they often occur off public roads (e.g., on private property or in parking lots) or do not reach reporting thresholds (e.g., minor crashes not causing property damage or simply not reported to the police). Consequently, with respect to the number of backing crashes being reduced by backing features in the field, there are likely substantially more "property damage only" crashes that are not being captured in the current police-report analysis.

Vulnerable Road User (VRU) Crash Prevention Findings

Results indicated Front Pedestrian Braking (FPB) provided an estimated 23% reduction in frontal pedestrian crashes (regardless of time of day), and that independent of the specific headlight type, IntelliBeam (auto high beam headlights) provided an estimated 22% reduction in unlit nighttime VRU crashes. These nighttime VRU crashes included frontal animal, pedestrian, and bicyclist crashes. Since the vast majority of these crashes are animal-related, an additional analysis focused on pedestrians was performed and indicated a similar-sized, albeit non-significant 24% reduction in unlit nighttime pedestrian crashes. This suggests that the use of animal crashes is not particularly biasing these nighttime VRU results.

Concluding Remarks: Working Toward a Zero Crashes Vison

The current effort not only quantifies the substantial crash reduction and crash mitigation (injury reduction) benefits afforded by a wide variety of production GM ADAS features, but also identifies potential strategies for moving closer toward a zero crashes vision. These include offering ADAS features that provide some degree of automated control (in additional to alerts), since such features were found to consistently outperform their less advanced "alert only" counterparts (e.g., AEB versus FCA). The results also highlighted the need to address lane departure and lane change crashes more effectively, and increased our understanding of system-relevant crashes not prevented by ADAS-equipped vehicles. More generally, there remain significant opportunities for moving toward zero crashes beyond the ADAS features examined here, including addressing seat belt use, driver behavior choices (e.g., speeding and impairment due to alcohol or other drugs, drowsiness, or distraction), and different crash configurations (e.g., intersection crashes).

When evaluating zero crashes vision progress, it should be remembered that *overall* crash reduction and crash mitigation benefits are determined by the prevalence of the system-relevant crash in the entire crash population, the feature effectiveness (which incorporates driver feature usage), and the penetration of the feature across the entire fleet (not just GM portion). For example, assuming rear-end crashes account for 31% of all crashes in the United States (Swanson et al., 2019), and that the entire US fleet is equipped with the GM fusion/radar AEB feature examined here (which reduced rear-end striking crashes by 45%), this feature alone would be estimated to reduce 14% of all police-reported crashes in the United States (i.e., 31% of all crashes multiplied by the assumed 45% effectiveness value).

In addition to continuing this series of ADAS effectiveness studies, we recommend leveraging additional state crash databases as they become available to UMTRI, as well as exploring the use of telematics-based data (such as GM's OnStar low-level EDR and AACN data). Finally, we also recommend using these large-scale field effectiveness estimates for informing New Car Assessment Program (NCAP) and feature content decision-making.

Introduction

This report describes the fourth in a series of field effectiveness studies examining a wide range of Advanced Driver Assistance Systems (ADAS) offered on General Motors (GM) production vehicles, as well as the automatic high beam headlighting feature, IntelliBeam. Across these studies, we have continued to increase the number of vehicles, models, vehicle types and features analyzed. Although safety features can be motivated by harm reduction opportunities apparent in the field (Najm, Smith, and Yanagisawa, 2007; Swanson et al., 2019), and tested in simulation, on test tracks, and on public roads, real-world crash data remains fundamental for understanding *achieved* ADAS safety benefits in the field. Achieved safety benefits incorporate important real-world factors such as the extent to which drivers leave these features on, the demographics of drivers of ADAS-equipped vehicles, and the wide range of driving conditions experienced by drivers with these features.

In collaboration with GM and sponsored by the National Highway Traffic Safety Administration (NHTSA), Flannagan and Leslie (2020) conducted the first of this series of ADAS field effectiveness analyses examining GM Model Year 2013-2015 (MY 13-15) vehicles. In that study, police-reported crash data from 13 states was linked to over 1.2 million vehicles with known ADAS content provided by GM to UMTRI. The study used a method known as *quasi-induced exposure* (Keall & Newstead, 2009), where equipped and unequipped vehicles are compared on the rate of crashes that are specifically targeted by the feature (i.e., referred to here as "system-relevant" crashes) relative to system-irrelevant crashes unrelated to the function of a particular feature (referred to here as "control" crashes), which are used to control for crash exposure. Logically, the presence of a feature should reduce its system-relevant crashes more than non-system relevant crashes, whereas vehicles without the feature should have a "baseline" ratio of the two crash types (with the "baseline" ratio depending on the crash types involved.) Results from this police-report study indicated system-relevant crashes were reduced for GM's Forward Collision Alert, (forward) Automatic Emergency Braking, Lane Keep Assist with Lane Departure, Rear Park Assist, Rear Cross Traffic Alert, and Reverse Automatic Braking features.

An updated analysis in 2019, using the same methods was sponsored by GM (Leslie, Kiefer, Meitzner, & Flannagan, 2019)[1], added GM MY 16-17 vehicles to the previous GM MY 13-15 database. That study included 3.7 million vehicles, examined 15 ADAS and headlighting systems, and used police-report crash data from 10 states. Following that, the study was updated again in 2020 to include GM MY 18-19 vehicles, increasing the count of vehicles to 8.3 million and the number of states to 12 (Leslie, Kiefer, Meitzner, & Flannagan, 2021). The magnitudes of the crash reduction effects for the various ADAS features examined in these expanded analyses continued to be largely consistent with the initial GM MY 13-15 findings.

The goal of the project described in this report was to update the previous GM effectiveness studies by adding GM MY 20 vehicles with VIN-linked ADAS and headlighting content, as well as incorporating more recent and newly available state crash police report data. As the sample size increases each year, both for vehicles and crashes, the ability to detect and accurately measure effectiveness improves.

[1] A public version of this report can be found here: https://deepblue.lib.umich.edu/handle/2027.42/150660

Methods

Data

For this analysis, data on crash configurations and circumstances came from police crash reports obtained by UMTRI from 14 Unites States state agencies. These data were matched to a database provided by GM, which included for each Vehicle Identification Number (VIN) information indicating the presence of various ADAS and headlighting feature content.

Advanced Driver Assistance Systems (ADAS) and Feature Data

The GM ADAS and headlighting content dataset (also referred to as "safety content") contained VIN-linked data on 10,947,669 vehicles across all GM brands (i.e., Buick, Cadillac, Chevrolet, and GMC) and covered MYs 13-20 as available (note that some MY 2021 Cadillac models were included to support a separate field analysis of the Super Cruise feature).

As seen in Table 1, the majority of models were only included for a subset of the MYs examined, and the vehicles available for matching to available police report databases increased sharply for later MYs. Overall, this updated analysis saw a 1.3-fold growth in the VIN dataset compared to the GM MY 13-19 analysis (8,311,707 VINs), a 2.9-fold increase over the GM MY 13-17 analysis (3,785,419 VINs), and a 9-fold increase on the initial GM MY 13-15 analysis (1,215,618 VINs, Flannagan & Leslie, 2018).

Table 1 Vehicle models and range of Model Years provided in Advanced Driver Assistance Systems (ADAS) content data provided by GM

Model Year Range	Models
2013-2016	Cadillac SRX (discontinued after 2016)
2013-2019	Cadillac ATS, Cadillac XTS
2014-2019	Buick Lacrosse, Buick Regal, Cadillac CTS, Chevrolet Impala
2015-2019	Cadillac Escalade, Chevrolet Suburban, Chevrolet Tahoe, GMC Yukon, GMC Yukon XL
2016-2019	Cadillac CT6, Chevrolet Malibu, Chevrolet Volt
2017-2019	Buick Acadia, Buick Envision, Cadillac XT5, Chevrolet Bolt, Chevrolet Silverado, Chevrolet Silverado HD, GMC Sierra, GMC Sierra HD
2018-2019	Buick Enclave, Chevrolet Cruze, Chevrolet Equinox, Chevrolet Traverse, GMC Terrain
2019	Cadillac XT4, Chevrolet Blazer, Chevrolet Spark
2020	Buick Encore, Cadillac CT4, Cadillac CT5, Cadillac XT6, Chevrolet Camaro, Chevrolet Colorado, Chevrolet Corvette, Chevrolet Express, Chevrolet Low Cab Forward, Chevrolet Silverado MD, Chevrolet Sonic, Chevrolet TRAX, GMC Canyon, GMC Savana

The ADAS features examined break down into features that are intended help the driver avoid or mitigate forward (rear-end, front-to-rear), front pedestrian, lane departure, lane change, backing, and crashes in darkness. The full list of features examined in this analysis is presented in Table 2 (note that a given crash type may be addressed by multiple features), along with corresponding feature abbreviations that will be used throughout this report. It is important to keep in mind that a number of these features have important relationships and dependencies that are reflected in Table 2. In addition, certain features addressing different crash types were offered (or bundled) together in production (e.g., LKA/LDW and camera FCA are co-dependent, FPB is only offered with AEB, RAB implies the presence of forward AEB but not vice-versa, etc.). Where relevant, these relationships will be mentioned in the corresponding analysis discussion.

Table 2 Analysis group, feature evaluated, and feature abbreviations used in report

Analysis Group	Feature(s) Evaluated	Corresponding Feature(s) Abbreviations
Forward Collision	Camera Forward Collision Alert	Camera FCA
	Radar/Fusion Automatic Emergency Braking	Radar/Fusion AEB
	Camera Automatic Emergency Braking	Camera 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
Backing[2]	Rear Vision Camera	RVC
	Rear Vision Camera Mirror	RVC Mirror
	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
Unlit Nighttime Vulnerable Road Users (VRUs)	IntelliBeam (Automatic High-Beams)	IntelliBeam

Police Crash Report Data

UMTRI obtained data on police reported crashes from 14 states[3] that were able to provide full 17-character VINs for the vehicles involved in these crashes. Table 3 shows a calendar year summary of the crash data provided to UMTRI from each of these states. Some states experienced delays in reporting more recent data due to the COVID-19 pandemic.

[2] It should be noted that more advanced level backing/parking features generally include the functionality of less advanced backing/parking features.

[3] Two states, Connecticut and South Dakota, were new to the GM MY 13-20 analysis. Three states (Alabama, Georgia, and New Mexico) used in the Phase 1 GM MY 13-15 analysis (Flannagan & Leslie, 2020) vehicles were not available for the non-NHTSA partnered analyses due to data agreements.

Table 3 States and calendar years of police crash report data available

State	Calendar Years
Connecticut[4]	2015 – 2020
Florida	2012 – March 2021
Idaho	2012 – June 2020
Kansas	2012 – June 2021
Louisiana	2012 – 2019
Maryland[5]	2012 – 2013, 2015 – June 2021
Michigan	2012 – 2020
Missouri	2012 – 2019
Ohio[6]	2014 – June 2021
Nebraska	2012 – 2020
South Dakota	2012 – 2020
Tennessee	2012 – June 2021
Texas	2012 – June 2021
Utah	2012 – 2020

Matched Subset Data

After alignment of the crash data across the 14 states (see subsequent *Crash Definitions and Variable Creation* section), the resulting dataset was merged with the GM-provided VIN-linked ADAS and headlighting technology content dataset to identify which vehicles were present in both the GM VIN and police report datasets. The result was 635,712 matches out of the approximately 10.9 million VINs in this GM content dataset (a 5.8% match rate). The dataset continues to grow substantially with each iteration of this series of GM feature effectiveness studies, and the current matched crashes count is nearly 50% greater than the preceding GM MY 13-19 study (and over a 5-fold increase compared to the earlier studies). However, despite being weighted towards newer MYs in the GM content data, due to the increasing volume of vehicles offering AEB over time, the matched dataset had an outsized volume of the older vehicles (see Table 4). This is because the earlier MY vehicles have been in the fleet longer, and thus have had a longer time window to experience crashes reflected in the state data.

Table 4 Percent of vehicles in VIN dataset and matched dataset by Model Year range

Model Years	Percent of Content Data	Percent of Matched Cases
2013-2015	11.1	25.4
2016-2017	23.5	33.6
2018-2019	41.3	34.0
2020-2021	24.1	6.9

[4] Connecticut public data is only provided for 2015 onward, so 2012-2014 were unavailable for this analysis.
[5] Over the course of 2014, Maryland changed their police crash report format. 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.
[6] Ohio only provided five years of historical data at the time it was first collected (2014-2019), so data from 2012-2013 were not available for analysis.

The matched data came predominantly from a small number of states used in this analysis, which was likely due to a combination of the range of data available, the state population, and GM vehicle sales in those states. Figure 1 provides the matched crash contribution levels for each of the 14 states included in the analysis, with darker shading indicating increased match levels. Florida, Michigan, and Texas contributed 68% of the matched crash dataset (25% FL, 17% MI, and 26% TX). The next highest volume state was Ohio with 8% of the dataset. These numbers are generally in line with the proportion of crashes with VIN available in each state, with only Michigan being noticeably overrepresented, likely due to high GM vehicle sales in the state.

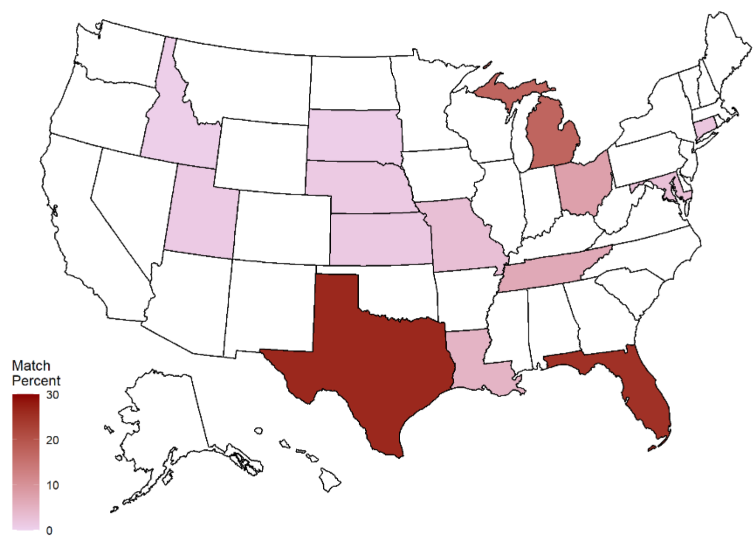


Figure 1 United States map showing the relative contribution levels of matched crashes from each of the 14 states used in this analysis

Analysis Structure

The analysis approach focused on identifying system-relevant crashes and associated control crashes that could be compared to determine the effectiveness of the feature evaluated. 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 feature 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 features evaluated uses backing crashes as the system-relevant crash type. Since the backing feature 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, whereas the odds ratio for the effect of the backing feature is $\left(\frac{A}{C}\right) / \left(\frac{B}{D}\right)$. Crashes are sufficiently rare such that this ratio represents an estimate of the risk ratio (i.e., the relative risk of experiencing such a crash in an equipped vehicle versus an unequipped (but similar) vehicle). Ratios less than 1 indicate safety benefits. In the full analysis, we used a regression approach to adjust for 13 covariates (described below), but Table 5 serves to illustrate the concept underlying the quasi-induced exposure technique.

Table 5 The layout for quasi-induced exposure logistic regression

		Backing Feature 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 635,712 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 features and covariates. Backward selection using a likelihood ratio test was then performed until all non-significant effects were removed, with the exception of driver demographic characteristics (namely, age and gender). The driver demographic characteristics were included in all models because they have been previously shown to impact crash outcomes and they provide a means for attempting to control for demographic patterns.

After the conclusion of the backward selection process, interactions between the feature and any significant predictors were tested, again with likelihood ratio tests. With the much larger sample size in this analysis, several interactions reached significance when evaluated by likelihood ratio tests, but did not appear to contribute any meaningful explanatory information. As such, to avoid overfitting the models, any models including interactions were compared to the main-effect-only models using the Bayes Information Criterion (BIC), which evaluates the amount of information added to the model with a penalty for the number of additional coefficients, with lower BIC being more desirable. Of the proposed interactions, only one was identified as meriting further investigation (see the Forward Collision Prevention analysis section) but was not included in the core model estimates due to the unclear interpretation.

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 feature effect, including the vehicle model insulates the analysis from scenarios where unobserved factors (such as cost) restrict vehicle models (and their associated ADAS 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 was used.

The 13 covariates listed below were employed in this analysis. The first 11 listed were obtained from the police accident reports, and the last 2 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*[7]
- Alcohol or Drug Presence (police reported): *Yes, No*
- Distracted Driver: *No, Cell phone distraction, Other distraction*
- Fatigued Driver: *Yes, No*
- Weather: *Clear/Cloudy, Not Clear/ Cloudy (rain, snow, etc.)*
- Road Surface Condition: *Dry, Not Dry (wet, icy, etc.)*
- Light Condition: *daylight, dawn/dusk, dark – lit, dark – unlit*
- Model Year: *2013 – 2021*
- Crash Year: *2012 – 2021*
- Vehicle Type: *Sedan, Small/Medium Utility, Large Utility, Truck, Van (see* Table 6 *for definitions)*
- Vehicle Model: *see* Table 6

This list includes four changes from the previous projects. First, light condition, MY and crash year were added to the analysis. The first reflected a previously uncontrolled factor that was expected to impact crash risk, while the MY and crash year variables controlled for change over time in the feature implementation (Model Year) and the environment (crash year). Finally, the distracted driver variable was changed to differentiate between cell phone-related distraction and other types of distraction.

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

Vehicle Type	Models
Sedan	ATS, Bolt, Cruze, Camaro, Corvette, CT4, CT5, CT6, CTS, Impala, LaCrosse, Malibu, Regal, Sonic, Spark, Volt, XTS
Small/Medium Utility	Acadia, Blazer, Enclave, Encore, Envision, Equinox, SRX, Terrain, Traverse, TRAX, XT4, XT5, XT6
Large Utility	Escalade, Suburban, Tahoe, Yukon, Yukon XL
Truck	Canyon, Colorado, Low Cab Forward, Sierra, Sierra HD, Silverado, Silverado HD, Silverado MD
Van	Express, Savana

Crash Definitions and Variable Creation

Although police crash 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 crash data across states, each state dataset was separately reduced to a standard set of crash definitions and potential covariates to ensure comparable, consistent data fields across states. The difficulty in aligning state crash field levels also leads to the need for 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 features that are relevant to low-speed forward parking crashes (e.g., Front and Rear Park Assist, and Automatic Parking

[7] Additional definition considered in forward collision, see Forward Collision Prevention Analysis for details.

Assist), the inconsistency of parking crash coding across state crash databases does not allow a reasonable evaluation of effectiveness levels for these features in reducing forward parking crashes.

The assumed system-relevant and corresponding control crash definitions used in each analysis, developed in consultation with GM, 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 feature is designed to address. For all analysis groups except unlit nighttime VRUs, 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 unlit nighttime VRU analysis, dark-unlit and daylight crashes with Vulnerable Road Users (VRU), defined here as animals, pedestrians, and bicyclists, were used for the system-relevant and control crash types, respectively. Finally, in addition to the crash type definitions provided in Table 7 and Table 8, some states had additional special variables we used that more directly indicated the crash types of particular interest for this analysis.

The lane departure crash, which was updated in the GM MY 13-19 analysis, was changed again in this iteration. Rather than pooling three types of system-relevant crashes, a set of three such crashes was created: same direction sideswipes, opposite direction sideswipes and head-on, and single vehicle run-off-road crashes. This change leverages the increasing volume of matched crashes to better examine specific crash circumstances.

For the IntelliBeam (automatic high beam) analysis, the inclusion of animals in Vulnerable Road User (VRU) crashes was done to compensate for the rarity of pedestrian/bicyclist crashes, particularly in dark-unlit conditions. In the matched crash set, approximately 88% of the VRU crashes involve animals, with the rest of the crashes involving pedestrians or bicyclists. In darkness, animals represented 97.6% of VRU crashes, whereas during daylight animals represented 74.5% of VRU events, and overall, there are substantially fewer pedestrian and bicyclist events. See Table 9 for a detailed breakdown.

It should be noted that we could not determine based on the State Crash data whether or not the features analyzed were turned on or off at the time of any of the examined crash types, or whether the driver used these features properly (i.e., as characterized in the Owner’s Manual feature descriptions). If actual feature usage is less than 100% (e.g., as has been observed with lane departure-related systems; e.g., Flannagan et al., 2016), or if the feature was turned on but not being used properly or not being paid attention to by the driver, this analysis will underestimate the *potential* effectiveness if the feature were always turned on and used properly.

As with the GM MY 13-19 analysis, this analysis included an examination of injury crashes for the two most populated matched crash groups (see Table 10): forward collision (rear-end striking with another vehicle) and lane departure.

In state police reports, crash injuries are coded using the KABCO scale, which ranks injury on a five-level scale of “Fatal Injury (K)”, “Suspected Serious Injury (A)”, “Suspected Minor Injury (B)”, “Possible Injury (C)”, and “No Apparent Injury (O)”. This scale, which is defined in the Model Minimum Uniform Crash Criteria (MMUCC) (USDOT, 2012) data standard.

Research has shown that police-reported injury level overestimates the incidence of serious injuries in crashes by as much as 2-3 times (Flannagan, Mann, & Rupp, 2013), as measured by a medical diagnosis-based definition. Nonetheless, KABCO is strongly correlated with injury level based on medical diagnosis. Thus, in this context, injury crashes are likely to be generally more severe than non-injury crashes, and analysis of this group of crashes should still enable understanding of the performance of GM features on more severe crashes that are capable of causing injury, even though the definition is not as precise as one using medical diagnosis. In general, NHTSA, states, and traffic safety researchers routinely rely on KABCO information to characterize harm levels associated with crashes.

In this iteration of the analysis, injury crashes were identified by the presence of B or higher injury on the KABCO scale for any crash participant (i.e., a "K", "A", or "B" injury). This is a substantially higher threshold than the C or higher injury in the GM vehicle used in the previous GM MY 13-19 study. The change was motivated by two factors: 1) the larger matched dataset supports the stricter requirement (better reflecting actual injury outcomes), and 2) there was an interest in including injured parties in the other vehicle to better reflect the severity of the crash overall.

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 AND Speed Limit < 50
Lane Departure – Same Direction	Lane Departure	[Manner of Crash = Same Direction Sideswipe] AND Speed Limit > 30
Lane Departure – Opposite Direction	Lane Departure	[Manner of Crash IN {Opposite Direction Sideswipe, Head-on}] AND Speed Limit > 30
Lane Departure – Road Departure	Lane Departure	[Single Vehicle AND Harmful Event IN {Run off road, Cross centerline, Cross median, Fixed object}] AND Speed Limit > 30
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
Unlit Nighttime Vulnerable Road Users (VRUs)	Night Vulnerable Road User (VRU) Crash	Light Condition = Dark – Unlighted AND Initial Contact Point on Vehicle = Front AND First Event IN {Animal, Pedestrian, Bicyclist}

Table 8 Control crash types and definitions by analysis group

Analysis Group	Crash Type	Definition
Analyses other than Unlit Nighttime Vulnerable Road Users (VRUs)	Rear-end Struck	Manner of Crash = Rear-end AND Initial Contact Point on Vehicle = Rear
Unlit Nighttime Vulnerable Road Users (VRUs)	Daylight Vulnerable Road User (VRU) Crash	Light Condition = Daylight AND Initial Contact Point on Vehicle = Front AND First Event IN {Animal, Pedestrian, Bicyclist}

Table 9 VRU crash breakdown by light and VRU type (for matched crashes)

	Animals		Pedestrians		Bicyclists	
	Count	Row Pct.	Count	Row Pct.	Count	Row Pct.
Day	4,985	74.9%	948	14.2%	722	10.8%
Night	11,324	97.6%	215	1.9%	62	0.5%

Results

The features evaluated were divided into six general analysis group categories: forward collision, front pedestrian, lane departure, lane change, backing, and unlit nighttime Vulnerable Road Users, or VRUs. Each category is discussed separately. Note that only significant feature-related effects are discussed here.

Analysis Data Subsets

Table 10 shows the sample size of matched cases for both system-relevant and associated control crashes for each analysis group and feature(s) evaluated, which are derived from the original set of 635,712 vehicle cases matched between GM VINs (with ADAS and headlighting feature content indicated) and the set of police report crash cases from the 14 states used in this analysis. Note that some features are listed as co-occurring with other features due generally to the practice of bundling less advanced features with their more advanced counterparts, which will be addressed in the relevant analysis discussions below.

Table 10 Sample sizes by feature(s) evaluated and crash type (system-relevant versus control) for each analysis category

Analysis Category	Feature(s) Evaluated	Crash Type: System-Relevant	Crash Type: Control
Forward	None	37,949	57,713
	Camera Forward Collision Alert (FCA)	9,408	18,635
	Radar/Fusion AEB	2,074	6,205
	Camera AEB	4,981	14,122
Front Pedestrian	None	1,219	73,670
	Front Pedestrian Braking (FPB)	79	7,627
Lane Departure – Same Direction	None	28,078	48,304
	Lane Departure Warning (LDW)	6,542	12,439
	Lane Keep Assist (LKA) with LDW	8,843	18,984
Lane Departure – Opposite Direction	None	4,183	36,885
	Lane Departure Warning (LDW)	995	10,590
	Lane Keep Assist (LKA) with LDW	1,161	14,568
Lane Departure – Road Departure	None	8,189	36,775
	Lane Departure Warning (LDW)	1,810	10,590
	Lane Keep Assist (LKA) with LDW	2,106	14,568
Lane Change	None	6,935	53,903
	Side Blind Zone Alert (SBZA)	964	7,855
	Lane Change Alert (LCA) with SBZA	2,775	30,261
Backing	None	1,622	10,475
	Rear Vision Camera (RVC)	3,481	29,863
	Rear Vision Camera Mirror (RVC Mirror)	34	122
	Rear Park Assist (RPA)	2,899	21,872
	Rear Cross Traffic Alert (RCTA) with RVC	3,631	40,938
	Reverse Automatic Braking (RAB) with RVC, RPA, & RCTA	119	2,393
Unlit Nighttime Vulnerable Road Users (VRUs)	No IntelliBeam	8,740	4,787
	IntelliBeam	1,249	855

Forward Collision Prevention Analysis

Table 11 provides a summary of the features and crash types (system-relevant and control) used in the forward collision prevention analysis. Note that the camera AEB (Automatic Emergency Braking) feature evaluated only operated below 50 mph, that all AEB features include the Forward Collision Alert (FCA) feature. In addition, camera FCA here corresponds to vehicles with the FCA feature, but without AEB. All three feature levels shown in Table 11 were compared against the reference level of "Unequipped" with FCA (which implies these "Unequipped" vehicles were also not equipped with any type of AEB feature).

Table 11 Summary of the forward collision prevention and injury/possible injury mitigation analysis

Characteristic	Value
Feature Levels	Forward Collision Alert (FCA) Radar/Fusion AEB Camera AEB
System-relevant Crash	Rear-end Striking Injury Rear-end Striking
Control Crash	Rear-end Struck
Analysis Subset Sample Sizes - all crashes - injury crashes	 54,412 (system-relevant) ; 96,675 (control) 5,885 (system-relevant) ; 120,416 (control[8])

Figure 2, which will mirror how features effectiveness results are shown in the remainder of the paper, shows the estimated odds ratios (with point values shown on right vertical axis) for each of the forward collision features evaluated, along with green bolded values corresponding to statistically significant reductions in the system-relevant crash type ($p<0.05$; 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.)

As shown in Figure 2, all of the examined forward crash prevention features significantly reduced the risk of rear-end striking crashes. FCA produced a 20% reduction (odds ratio=0.80), while all of the AEB features produced reductions approximately doubling the size of this reduction. The estimate of radar/fusion AEB features estimated a 45% benefit (odds ratio=0.55), while the estimate for camera AEB produced an estimated benefit of 40% (odds ratio=0.60). While the camera AEB feature does not function above 50 MPH, an interaction between the type of AEB feature and the speed limit was not significant. This may be because rear-end striking crashes are more common on lower speed roads (Najm, Smith, and Yanagisawa, 2007). In all, these results correspond closely to those observed in the GM MY 13-19 analysis (see Table 18).

[8] Note that the higher number of control crashes in the injury analysis is due to differences in significant effects reducing the number of cases lost due to missing values in the police report crash data.

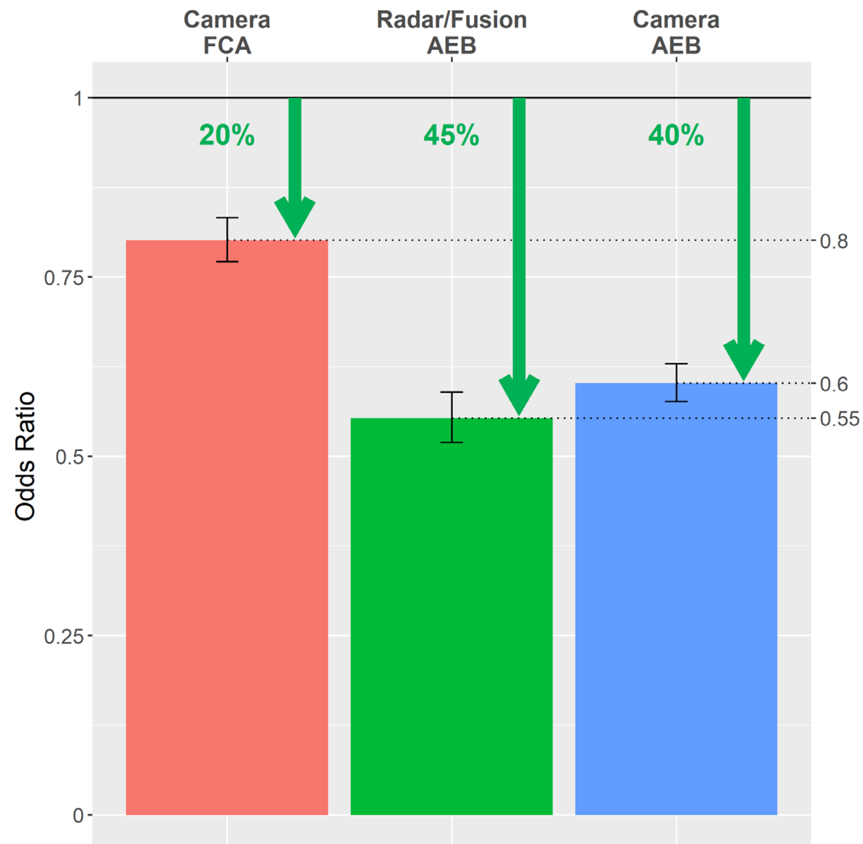


Figure 2 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for forward collision crash prevention systems

Before presenting the injury analysis, the reader is reminded that this analysis attempts to account for crash mitigation effects, where although the feature may not have prevented the crash, it may reduce the crash severity and thereby help mitigate or prevent crash-related injuries. The forward collision injury analysis is presented in Figure 3, generally indicates that the magnitude of the reductions in system-relevant crashes increased for this injury analysis relative to the previous corresponding ("all-crash") crash prevention analysis. For injury crashes, FCA showed an increased benefit, with the reduction increasing from 20% to 25% (odds ratio 0.75).   For radar/fusion AEB, the estimated injury crash benefit increased from 45% to 58% reduction (odds ration=0.42), while camera AEB increased from a 40% to 55% reduction (odds ratio=0.45).

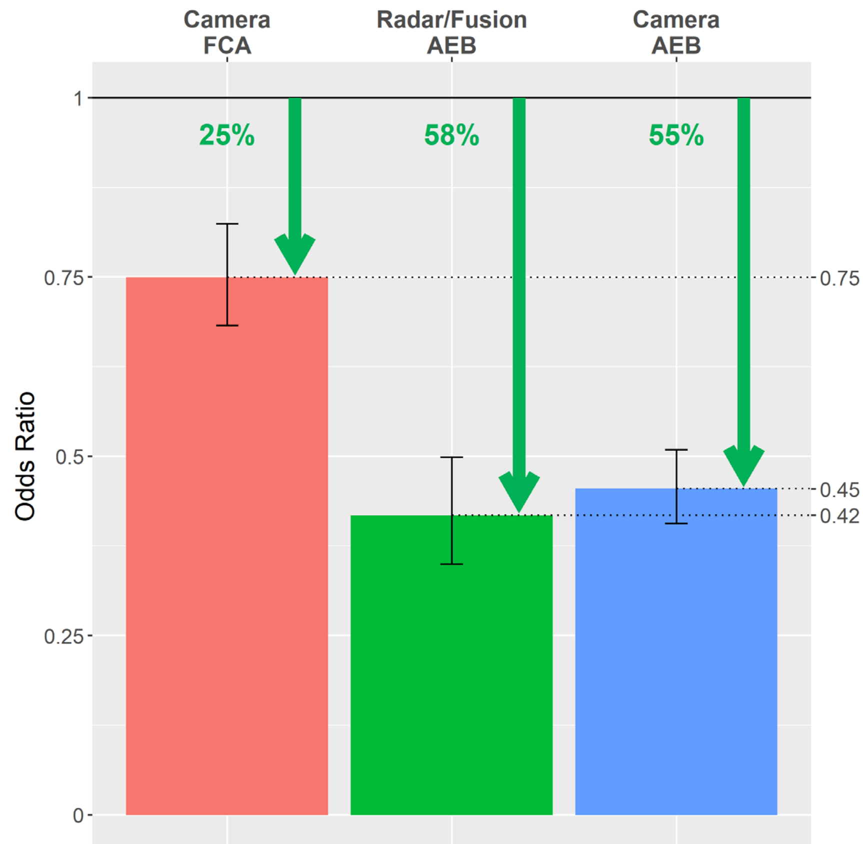


Figure 3 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) in injury ("B" or higher on KABCO scale) crashes for forward collision crash prevention systems

Vehicle Type Interaction Discussion

The forward crash prevention effect estimates produced a significant interaction between the feature type and vehicle type, as shown in Figure 4. Although this interaction was preferred by BIC (ΔBIC=35), meaning that additional variability explained is believed to be worth the additional complexity in the model, this interaction has an unclear explanation. Under this interaction, small/medium SUVs, trucks, and vans showed no effect of FCA, whereas sedans and large utilities had effectiveness estimates of 27% and 17%, respectively (bracketing the overall estimate of 20% from the no interaction model). Here, it is particularly puzzling that larger vehicles, the large SUVs and trucks, do not cluster together on camera FCA effectiveness. However, it should be noted that "FCA only" features are being largely replaced by the AEB (with FCA) feature. In contrast, under this interaction, the Camera AEB effect is clearer, with reduced effectiveness associated with larger vehicles. Interestingly, the sedan value for Camera AEB is close to the matching estimate for fusion AEB (a 47% reduction), with fusion AEB estimates more consistent than camera AEB across vehicle types. Taken together, this could indicate that there is an interaction between Camera AEB and larger vehicles that reduces the effectiveness, however given the complexity of this result and the unclear explanation, the preceding results without the interaction are used in the discussions.

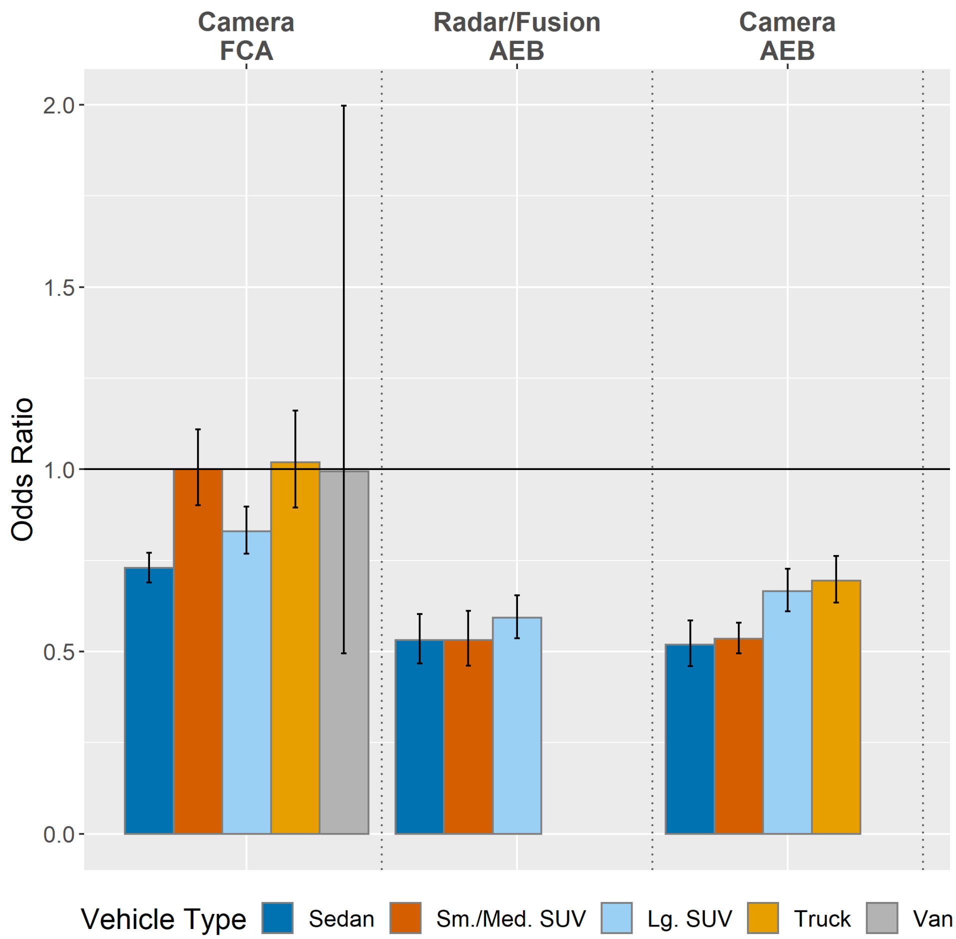


Figure 4 Estimated adjusted odds ratios for the prevalence of system-relevant crashes including an interaction between forward crash prevention feature and vehicle type

Lane Departure Crash Prevention Analysis

Table 12 shows a summary of the lane departure crash prevention analysis. It is important to note that the LKA with LDW feature provides a limited form of automatic control via a brief steering wheel nudge, along with LDW alerts only if necessary. Hence, relative to an "LDW only" feature that only provides alerts, since the LKA with LDW feature by design effectively reduces the number of LDW alerts. The reference category for the feature factor is "Unequipped" with either "LDW only" or LKA with LDW.

This analysis used three system-relevant crash definitions that identify the three main subsets of the crash type used in earlier GM lane departure crash prevention analyses. These are same direction sideswipes, opposite direction sideswipes and head-on, and single vehicle road departure crashes. As seen in Table 10 and Table 12, the majority of the system-relevant crashes were of the same direction sideswipes variety. As such, when comparing to previous analyses, it is most appropriate to compare those numbers to the same direction category due to it having the greatest degree of overlap with previous lane departure crash prevention analyses.

Table 12 Summary of the lane departure crash prevention and injury/possible injury mitigation analysis

Characteristic	Value
Feature Levels	Lane Departure Warning (LDW) Lane Keep Assist with LDW
System-relevant Crash	Lane Departure Crash Injury Lane Departure Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Sizes All Crashes - Same Direction - Opposite Direction - Road Departure Injury Crashes - Same Direction - Opposite Direction - Road Departure	 43,463 (system-relevant) ; 79,727 (control) 6,339 (system-relevant) ; 62,043 (control) 12,105 (system-relevant) ; 61,933 (control) 1,860 (system-relevant) ; 80,048 (control[7]) 1,771 (system-relevant) ; 61,978 (control[7]) 2,070 (system-relevant) ; 61,933 (control)

Figure 5 indicates that for the same direction sideswipes system-relevant crash type, LDW produced a 4% reduction (odds ratio=0.96), while LKA (with LDW) produced a larger 10% reduction (odds ratio=0.90). This beneficial effect increased for single vehicle road departures, with reductions of 8% (odds ratio=0.92) for LDW and 17% (odds ratio=0.83) for LKA (with LDW). Although the much smaller set of opposite direction sideswipe and head-on crashes did not show significance, effect sizes were comparable to same direction sideswipes (5% reduction for LDW and 8% for LKA (with LDW)). The estimated LKA (with LDW) effectiveness is broadly consistent with the overall 12% reduction observed in the GM MY 13-19 analysis, in which these three component lane crash prevention crash types were collapsed into a single crash type. Given that the single vehicle road departures are approximately a quarter the volume of the same direction sideswipes, a simple weighted average of the two significant LKA (with LDW) effectiveness results observed here would suggest that the 12% number remains consistent (10%*0.8 + 17%*0.2 = 11.4%). Conversely, the LDW effect continues to decrease, dropping by about half from the 10% estimate observed in both the GM MY 13-17 and GM MY 13-19 analyses. It is, however, consistent with the 3% estimate from the original GM MY 13-15 analysis, and appears to be influenced by the addition of the crash year effect. This pattern is discussed further in the *Crash Year Effect on System-Relevant to Control Crash Ratio* section below.

When viewing these results across system-relevant crash types, it is particularly important to consider that in the single vehicle roadway departure case, the GM host vehicle is always responsible for the lane departure. In contrast, for the 2-vehicle same direction sideswipe, as well as the opposite direction sideswipe/head-on crash cases, the crash can occur if either the GM host vehicle and/or the "other" crash-involved vehicle departs its lane. So, if we assume that the "other" crash-involved vehicle was responsible for approximately 50% of these 2-vehicle system-relevant crash cases, the effectiveness of LDW and LKA (with LDW) estimated for these 2-vehicle cases using this analysis method would be consequently reduced by half.

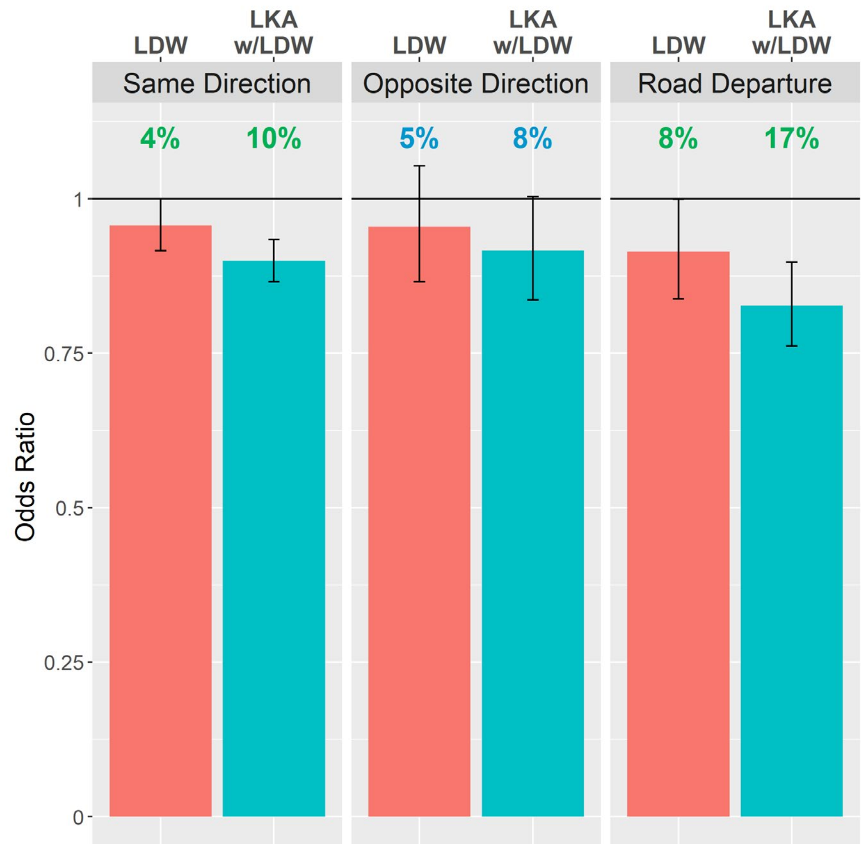


Figure 5 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the lane departure crash prevention systems

The corresponding analysis of injury crashes, shown in Figure *6*, shows an increased level of effectiveness for LKA (with LDW) across all three system-relevant crash types relative to the previous "all-crashes" analysis. These reductions were 16% (odds ratio=0.84) for the same direction sideswipes case, 19% (odds ratio=0.81) for opposite direction sideswipes and head-ons, and 21% for the single vehicle road departures (odds ratio=0.79). Unlike in the preceding "all-crashes" analysis, this reduction is also significant for the opposite direction case. The corresponding LDW injury analyses were non-significant (with effects close to 0 and including large confidence intervals), and reduced relative to the "all crashes" analyses for all three crash types. Again, the LKA (with LDW) effect here remains consistent with GM MY 13-19 results (17% reduction), while the LDW effect is substantially smaller (also 17% in the previous analysis). As mentioned in the "all crashes" case, this is likely influenced by the crash year effect.

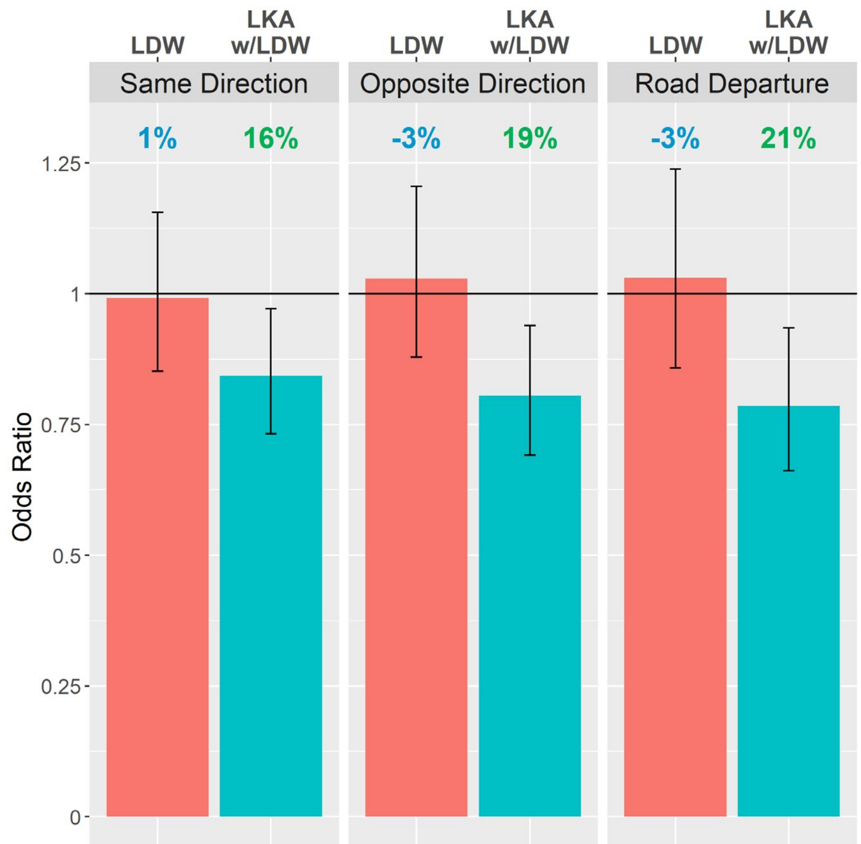


Figure 6 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) in injury ("B" or higher on KABCO scale) crashes for the lane departure crash prevention systems

Lane Change Crash Prevention Analysis

Table 13 provides a summary of the lane change crash prevention analysis. Note that the LCA (with SBZA) feature providing substantially increased vehicle detection ranges for detecting approaching vehicles compared to SBZA, which is of particular importance for alerting drivers to vehicles rapidly approaching from outside the side blind zone area. For the feature effect, the reference level was "Unequipped" with either LCA (with SBZA) or SBZA.

Table 13 Summary of lane change crash prevention analysis

Characteristic	Value
Feature Levels	Side Blind Zone Alert (SBZA) Lane Change Alert with SBZA
System-relevant Crash	Lane Change Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Sizes	10,674 (system-relevant) ; 92,019 (control)

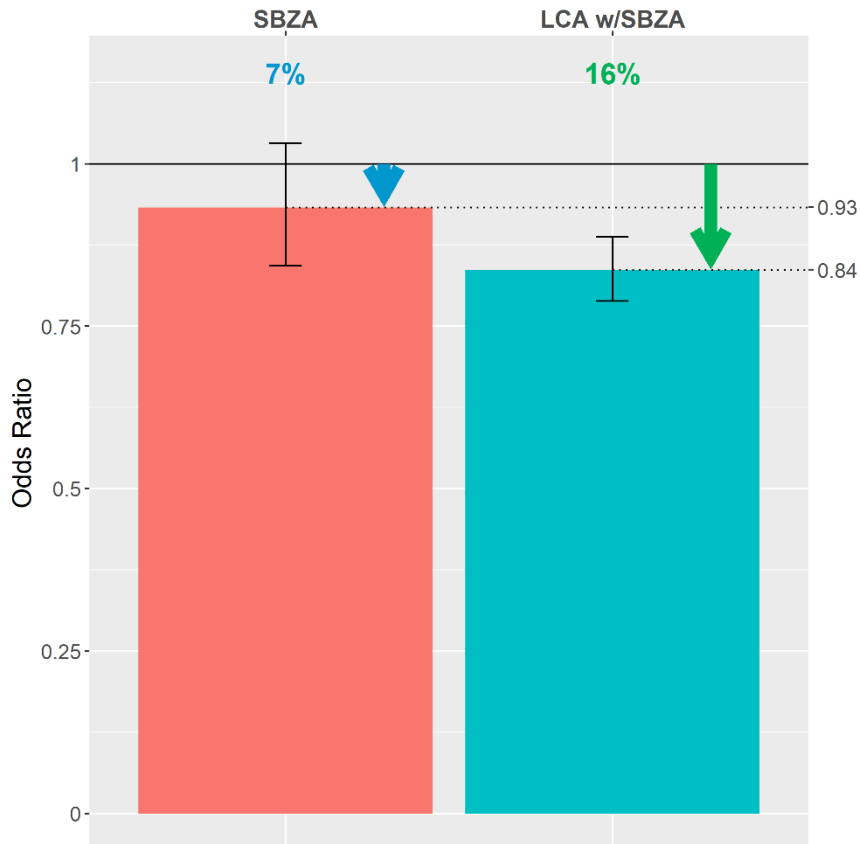


Figure 7 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the lane change crash prevention systems

Figure 7 indicates significant effects for LCA (with SBZA). The LCA (with SBZA) effect, a 16% reduction (odds ratio=0.84) in system-relevant lane change crashes, is consistent with the previous GM 13-19 analysis (also estimated at 16%). Although the SBZA effect was non-significant, the 7% point estimate reduction (odds ratio=0.93) is consistent with the GM MY 13-19 analysis (which was 9%). This indicates that the lane change prevention results may be stabilizing after a period of change (having been substantially reduced between the GM MY 13-17 and GM MY 13-19 analyses). Notably, unlike with the lane departure crash prevention work, the addition of the crash year and MY effects did not have as substantial an impact on this analysis.

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, the three lower-speed park assist-related features (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 feature. Also note that since Surround Vision includes RVC functionality, failing to differentiate between features when examining RPA effectiveness was deemed a reasonable approach. This analysis adds a third variety of rear camera feature, the Rear Vision Camera Mirror (RVC mirror) feature, which was only available on vans. This feature displays the standard RVC image in the interior rear view mirror. It was not offered with other backing features, but is differentiated in this analysis from standard RVC.

Due to the complicated hierarchies of backing/parking features, as shown in Table 14, the feature levels as listed were treated as hierarchical with the more advanced feature taking priority as available (e.g., a car with RCTA automatically falls into that group regardless of the park assist feature equipment status). In most cases, this means that vehicles coded as having a particular backing feature also had all features listed above shown in Table 14 (when ignoring the RVC versus SV distinction). There were two exceptions involving a relatively small number of cases: (1) RCTA did not include an RPA feature in approximately 0.8% of cases; (2) RPA did not include RVC or SV in approximately 1.5% of cases. For the effect sizes, the features were compared to a reference level of "Unequipped" with any of the backing features shown in Table 14.

Table 14 Summary of the backing crash prevention analysis

Characteristic	Value
Feature Levels	Rear Vision Camera (RVC) Rear Vision Camera Mirror (RVC Mirror) Rear Park Assist (RPA)[9] Rear Cross Traffic Alert w/RVC Reverse Automatic Braking w/RVC, RPA, & RCTA
System-relevant Crash	Backing Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Sizes	11,786 (system-relevant) ; 105,663 (control)

Figure 8 indicates that all of the previously examined features continue to significantly reduce the incidence of system-relevant backing crashes in a stack-up fashion, where more advanced backing features (which generally include all less advanced backing features) shown increasing backing crash reduction levels. RVC produces a significant 32% reduction (odds ratio=0.68) and, while non-significant, the RVC Mirror feature point estimate result is consistent at an estimated 33% reduction (odds ratio=0.67) in backing crashes. Furthermore, the RPA effect is estimated at 41% (odds ratio=0.59), improving RVC effectiveness by 9%. The estimate of the RCTA effect puts it at a 59% reduction (odds ratio=0.41), improving RPA effectiveness by 18%. The RAB effect is estimated at an 83% reduction (odds ratio=0.17), improving RCTA effectiveness by 24%.

While largely consistent with the GM MY 13-19 backing feature analysis, these new effectiveness estimates show a slightly greater benefit for several features (see Table 19), particularly for RVC (increasing from 24% to 32%) and RPA (increasing from 36% to 41%). These improvements seem to be driven by a combination of the broader set of control variables, including crash year and MY, and the influx of new vehicle models (vans and a larger variety of trucks), though a vehicle type interaction is still not supported.

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

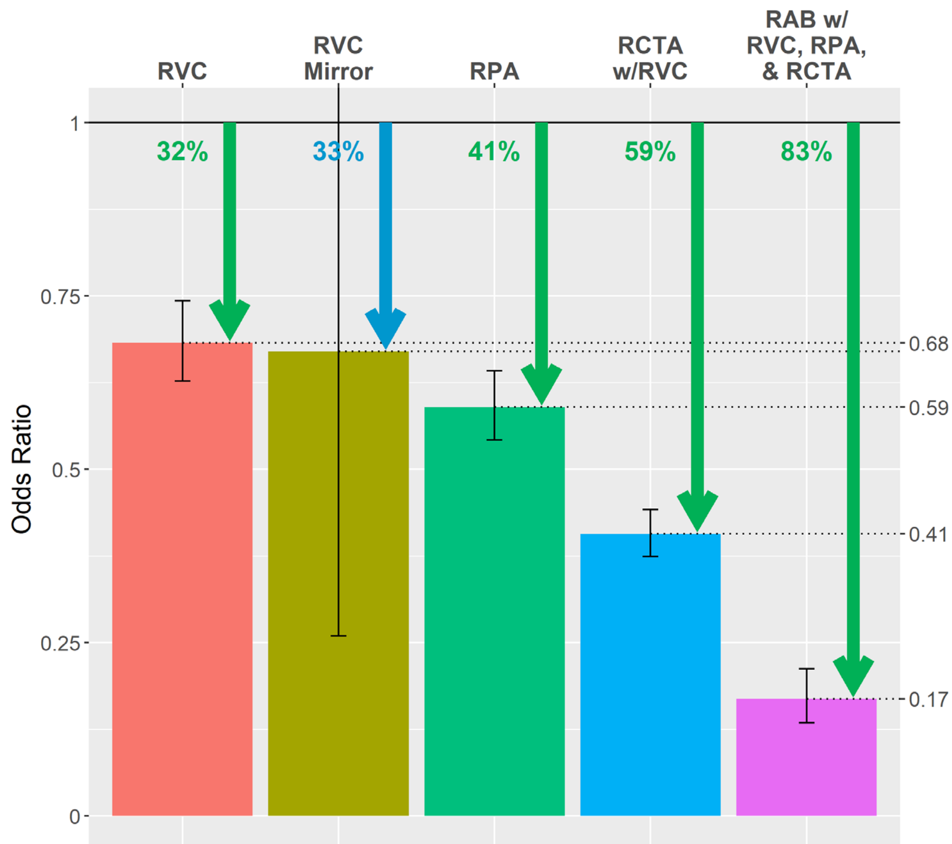


Figure 8 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the parking/backing crash prevention systems. (The Rear Park Assist, Front and Rear Park Assist, and Automatic Parking Assist features were all treated as Rear Park Assist for this analysis)

Vulnerable Road User (VRU) Crash Prevention Analyses

The following two sections cover systems related to VRU, and particularly pedestrian crashes. The first examines the effect of FPB on front pedestrian crashes and the second examines the effect of IntelliBeam on general VRU in unlit nighttime conditions.

Front Pedestrian Crash Prevention Analysis

Table 15 shows a summary of the front pedestrian crash prevention analysis. Note that Front Pedestrian Braking (FPB) is only offered on vehicles equipped with AEB, operates below 50 MPH, and has limited nighttime performance. Furthermore, since FPB was not available on vans, these vehicles were excluded from the analysis. The ability to detect FPB effects that might exist, particularly interactions with covariates, was limited by the rarity of system-relevant front pedestrian crashes (1,298 of the 82,595 cases in the analysis subset, or 1.6%). FPB was compared against the reference level of “Unequipped” with FPB.

Table 15 Summary of the front pedestrian crash prevention analysis

Characteristic	Value
Feature Levels	Front Pedestrian Braking (FPB)
System-relevant Crash	Front Pedestrian Crash Daylight/Night VRU Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Sizes	1,298 (system-relevant) ; 81,297 (control)

Figure 9 shows the analysis results, which indicate that FPB provided a significant 23% reduction (odds ratio=0.77) in system-relevant front pedestrian crashes. The magnitude of this effect is larger than the non-significant point estimates from the previous GM FPB analyses (14% for MY 13-19 and 13% for MY 13-17), however it falls within the confidence bounds of those estimates. Two notable factors influenced the newfound significance of this effect: the increased sample size and the expanding feature rollout across new vehicles. Given that this remains one of the more limited analysis sets and the current effect barely reached significance, it is possible that this significant result may shrink or become non-significant in future analyses as more data becomes available.

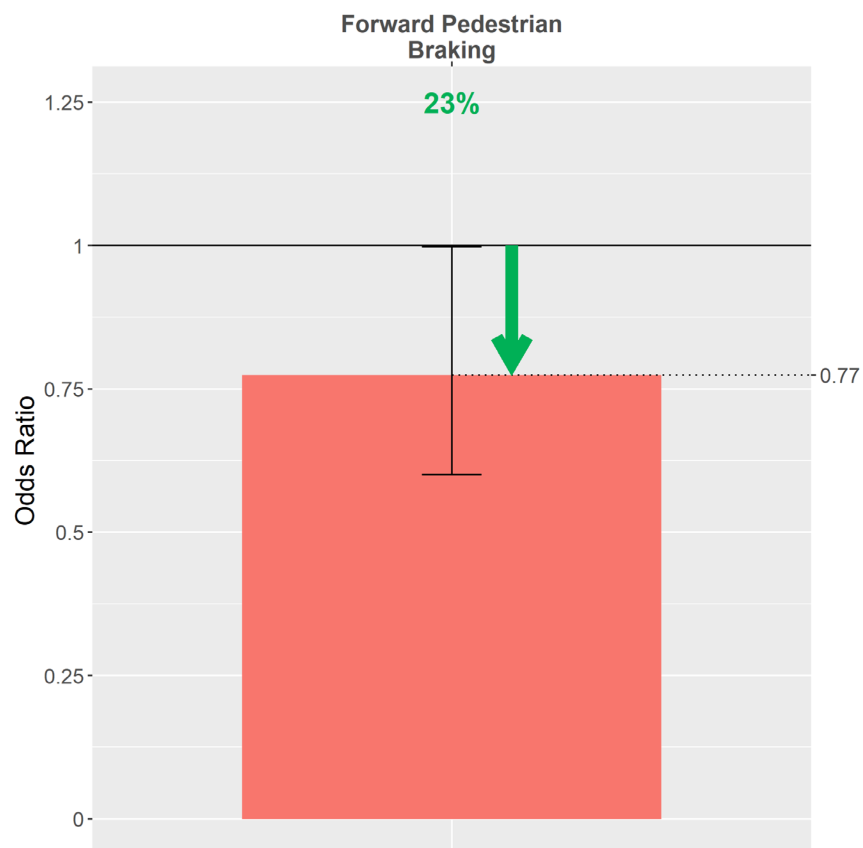


Figure 9 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the front pedestrian braking crash prevention system

Unlit Nighttime Vulnerable Road User (VRU) Crash Prevention Analysis

This analysis focused on the effect of the automatic high beam "IntelliBeam" feature on unlit nighttime Vulnerable Road Users (VRUs) crashes, which is summarized in *Table 16*. As illustrated in Table 8, 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 (animal, pedestrian, and bicyclist) crashes. Consequently, as with the Front Pedestrian Braking (FPB) analysis reported earlier, the power of the analysis is reduced due to the rarity of the relevant VRU crash types. Vehicles with FPB were excluded from this analysis to avoid confounding of the headlight and braking features.

As with the GM MY 13-19 analysis, IntelliBeam was modeled in conjunction with the type of headlight on the vehicle (as categorized by GM), so that a potential interaction between IntelliBeam and various headlight types could be examined.

Table 16 Summary of the dark-unlit nighttime crash prevention analysis

Characteristic	Value
Feature Levels	IntelliBeam
System-relevant Crash	Unlit Nighttime VRU Crash
Control Crash	Daylight VRU Crash
Analysis Subset Sample Sizes	9,989 (system-relevant) ; 5,642 (control)

Figure 10 shows IntelliBeam provided a significant 22% reduction (odds ratio=0.78) in the system-relevant unlit VRU crash set, which corresponds closely to the 24% reduction observed in the GM MY 13-19 analysis. The interaction between IntelliBeam and headlight type reached borderline significance ($p=0.06$). However, since this interaction did not provide significant added predictive value (dispreferred by BIC with $\Delta BIC = -7$), the interaction term was excluded from the Model.

Since animals dominate the set of unlit VRU crashes, as shown in Table 9, a second model was created to focus on unlit pedestrian crashes only. Although there was lack of a significant effect for IntelliBeam (quite possibly due to small sample size), the 24% point estimate observed suggests that the use of animal crashes in this analysis is not biasing the results in either direction.

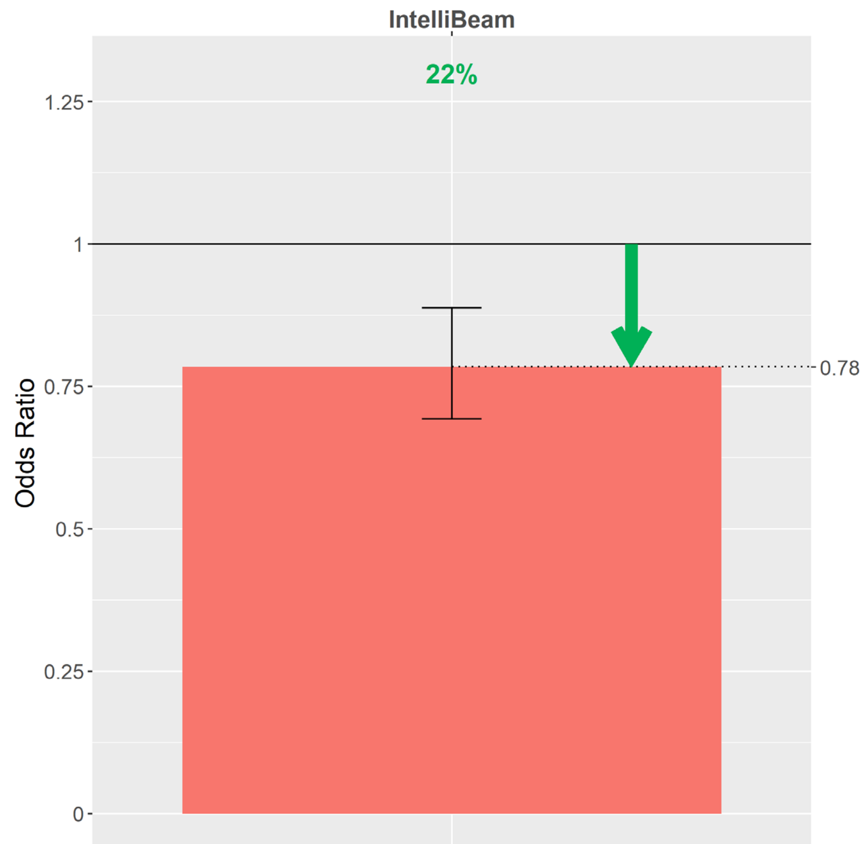


Figure 10 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the automatic high beam IntelliBeam feature

Crash Year Effect on System-Relevant to Control Crash Ratio

As part of the update to the previous GM MY 13-19 analysis, the MY of the crashing vehicle, as well as the crash year, were added to examine differences in crash behavior over time. These new additions improved the model fits. In general, these effects indicate that the ratio of system-relevant crashes to control crashes is increasing over time. For example, Table 17 shows the estimated odds ratios for the forward crash prevention model, which show an increasing trend. This suggests that these vehicles are experiencing more rear-end striking crashes per rear-end struck crash as the years advance (i.e., over time). Note that this does not refer to a particular crash, which must have both a striking and struck vehicle, but to the full set of crashes encountered by these vehicles. The accuracy of this pattern can be seen in Figure 11, using vehicles without a forward crash prevention feature (to avoid any potential side-effects of the AEB feature), which shows the decreasing proportion of rear-end struck crashes over time.

Table 17 Odds ratios for the crash year effect in the forward crash prevention model (rear-end striking crashes versus rear-end struck)

Crash Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Odds Ratio (vs. 2012)	0.97	1.06	1.11	1.14	1.21	1.35	1.46	1.59	1.63

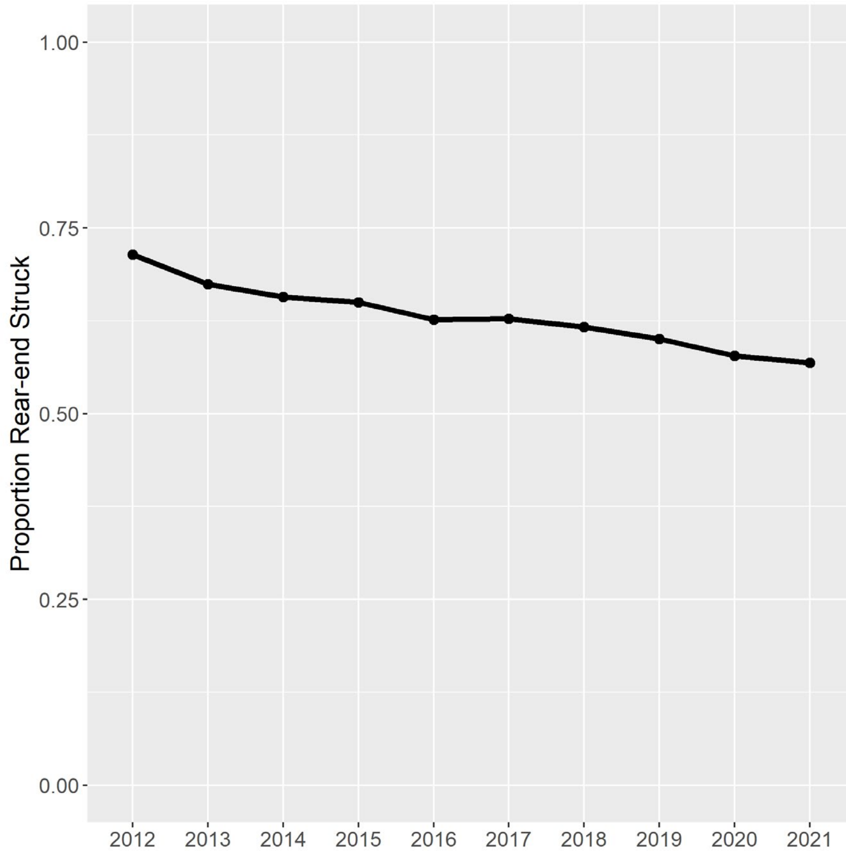


Figure 11 Proportion of rear-end crashes that are struck (as opposed to striking) by crash year for GM vehicles without a forward crash prevention feature

While the exact reason for this pattern is unclear, one reasonable explanation is the greater prevalence of AEB features in the population at large. If, as suggested by the results of this analysis, AEB is around 41% effective at preventing rear-end striking crashes (using a pooled estimate combining Radar/Fusion and Camera), then the proportion of time that GM vehicles experience rear-end struck crashes should be decreasing as the proportion of AEB-equipped vehicles increases in the rest of the fleet. This would not pose a problem for the induced exposure methodology provided that the decrease in rear-end struck crashes is proportionate for the equipped and unequipped vehicles. Given the consistency of the estimated effects for most features, between this analysis including the time-based MY and crash years effects, and the previous, GM MY 13-19 analysis, excluding these effects, it seems likely that this is the case. For example, the AEB effects across various analyses conducted at different points in time shown in Table 18 are quite similar.

The analysis most impacted by this "over time" effect appears to be lane departure crash prevention, which may fail to satisfy this proportionality requirement. This is because LDW was predominantly available on vehicles up to MY 15 or MY 16, depending on vehicle type, while LKA was available on the later portion of the dataset. Given this pattern, it would not be possible for LKA (with LDW) to be collected in early crash years while LDW would be overrepresented during these years. Referring to the simple odds ratio layout shown in Table 5, this creates a situation in which the equipped and unequipped cells have an a priori inequality due to the unaccounted time effect. This would produce, all other effects being equal, an elevated estimate for LDW and depressed estimate for LKA. This is consistent with the patterns observed between this study and the GM MY 13-19 analysis: this study estimates the LDW effect as only 5%, controlling for the time effect, while the preceding analysis estimated it at 10% when not controlling for the crash year. Based on these results, it seems appropriate to continue to control for the time effect in future ADAS and headlighting effectiveness analyses.

Discussion

Background and Methodological Approach

This effort is the fourth in a series of field effectiveness studies examining General Motors (GM) Advanced Driver Assistance Systems (ADAS) and headlighting features. The current GM Model Year 2013-2020 study employed VIN-linked feature ADAS and headlighting content data from over 10.9 million GM vehicles. These data were matched to police-report crash data available to UMTRI in 14 states, which resulted in identifying 635,712 matched crash cases. Relative to the previous GM Model Year 2013-2019 analysis, the number of vehicles included the analysis were 1.3 times higher, and the matched crash rate was 1.5 times higher.

The feature effectiveness (i.e., percent reductions in system-relevant crashes) was estimated using quasi-induced exposure logistic regression. The "quasi-induced exposure" method compares system-relevant and system-irrelevant (referred to as "control") crash counts for equipped and unequipped vehicles. This controls for the lack of traditional exposure data (e.g., miles traveled) by selecting control crashes that should be unaffected by the feature examined (i.e., control crashes should occur at a similar rate in both equipped and unequipped populations). The logistic regression estimates were made adjusting for various covariates, including driver demographics (age and gender), speed limit, driver behavior (alcohol, fatigue, and distraction presence), driving context (weather, road, and road surface conditions), crash year, model year, and vehicle type/model. For forward collision and lane departure features, crash sample sizes were large enough to support additional analyses of feature effectiveness for a more restricted set of crashes coded by the police to have "suspected minor injury" or higher injury severity for anyone in the crash (i.e., "B" or higher on the KABCO injury scale), which will be referred to in the summary below simply as the "injury" analysis.

High-Level Summary of GM Advanced Driver Assistance System (ADAS) Feature Effectiveness

Table 18, Table 19, and Table 20 below summarize the current results with comparison to previous GM and IIHS police-report analyses, including green-shaded statistically significant results which are discussed further below. The first four columns summarize results from the current and previous UMTRI studies conducted with GM, each of which employed the analysis approach described above. The rightmost column provides GM Model Year 2013-2015 results reported by the Insurance Institute for Highway Safety (IIHS) using a Poisson Rate statistical approach, under which insured vehicle years are used to control for exposure for estimating crash rates (Cicchino, 2018a, 2018b, 2019a, 2019b).

Furthermore, Tables 20 and 21 address analyses across all features, in which all police-reported crashes are considered (irrespective of reported injury levels). Table 20 focuses on injury crash reductions (or crash mitigation) for both forward collision and lane departure prevention features, with "all crashes" results provided for comparison purposes. Injury crashes were defined in the current analysis as crashes coded by the police to have “suspected minor injury” or higher injury severity (i.e., “B” or higher on the KABCO injury scale) for anyone in the crash. In contrast, in the previous Model Year 2013-2019 analysis, a lower injury severity criterion of “possible injury” or higher was adopted (i.e., effectively only excluding “property damage only” crashes), and in addition, only reported injuries for occupants of the GM vehicles identified in the crash matching process were included. These injury crash analysis changes were implemented in the current analysis to focus on higher injury severity crashes and include a larger injury-reported sample.

Table 18 Estimated percent reductions in system-relevant (target) crashes for various GM Advanced Driver Assistance System (ADAS) features. (Note shaded green cells denote statistically significant field effectiveness effects.)

	UMTRI				IIHS
GM ADVANCED DRIVER ASSISTANCE (ADAS) FEATURE	**Model Year 2013-2020 (Current)**	**Model Year 2013-2019**	**Model Year 2013-2017**	**Model Year 2013-2015**	**Model Year 2013-2015**
FRONTAL (Note AEB feature include Forward Collision Alert)					
Camera Forward Collision Alert	20%	20%	20%	16%	17%
Radar/Fusion AEB	45%	45%	46%	45%	
Camera AEB	40%	38%			
LANE DEPARTURE – ALL TYPES					
Lane Departure Warning (LDW)		10%	10%	3%	13%
Lane Keep Assist with LDW		12%	20%	30%	
LANE DEPARTURE – SAME DIRECTION					
Lane Departure Warning (LDW)	4%				
Lane Keep Assist with LDW	10%				
LANE DEPARTURE – OPPOSITE DIRECTION					
Lane Departure Warning (LDW)	5%				
Lane Keep Assist with LDW	8%				
LANE DEPARTURE – ROAD DEPARTURE					
Lane Departure Warning (LDW)	8%				
Lane Keep Assist with LDW	17%				
LANE CHANGE					
Side Blind Zone Alert (SBZA)	7%	9%	2%	8%	16%
Lane Change Alert (LCA) with SBZA	16%	16%	26%	32%	21%

Table 19 Estimated percent reductions in system-relevant (target) crashes for various GM Advanced Driver Assistance System (ADAS) features (Note shaded green cells denote statistically significant field effectiveness effects.)

	UMTRI				IIHS
GM ADVANCED DRIVER ASSISTANCE (ADAS) FEATURE	**Model Year 2013-2020 (Current)**	**Model Year 2013-2019**	**Model Year 2013-2017**	**Model Year 2013-2015**	**Model Year 2013-2015**
BACKING (note more advanced backing features generally include less advanced backing features)					
Rear Vision Camera (RVC)	32%	24%	21%	19%	5%
Rear Vision Camera Mirror (RVC Mirror)	33%				
Rear Park Assist (RPA, Front & Rear Park Assist or Automatic Park Assist 2)	41%	36%	38%	36%	28%
Rear Cross Traffic Alert (RCTA) with RVC	59%	55%	52%	55%	18%
Reverse Automatic Braking (RAB) with RVC & RPA & RCTA	83%	82%	81%	82%	78%
VULNERABLE ROAD USERS					
Front Pedestrian Braking	23%	14%	13%		
IntelliBeam (Automatic High-Beams)	22%	26%	32%		

Table 20 Summary of effectiveness of frontal and lane departure-related GM Advanced Driver Assistance System (ADAS) features, including injury-only (including possible injuries) analysis and comparison to IIHS results addressing GM vehicles

	UMTRI				IIHS	
GM ADVANCED DRIVER ASSISTANCE (ADAS) FEATURE	**Model Year 2013-2020 All Crashes**	**Model Year 2013-2020 Injury[10]**	**Model Year 2013-2019 All Crashes**	**Model Year 2013-2019 Injury[11]**	**Model Year 2013-2015 All Crashes**	**Model Year 2013-2015 Injury**
FRONTAL (Note AEB feature include Forward Collision Alert)						
Camera Forward Collision Alert	20%	25%	20%	31%	17%	30%
Radar/Fusion AEB	45%	58%	45%	58%	43%	64%
Camera AEB	40%	55%	38%	53%		
LANE DEPARTURE – ALL TYPES						
Lane Departure Warning (LDW)			10%	17%	13%	21%
Lane Keep Assist with LDW			12%	17%		
LANE DEPARTURE – SAME DIRECTION						
Lane Departure Warning (LDW)	4%	1%				
Lane Keep Assist with LDW	10%	16%				
LANE DEPARTURE – OPPOSITE DIRECTION						
Lane Departure Warning (LDW)	5%	-3%				
Lane Keep Assist with LDW	8%	19%				
LANE DEPARTURE – ROAD DEPARTURE						
Lane Departure Warning (LDW)	8%	-3%				
Lane Keep Assist with LDW	17%	21%				

[10] Crash-level, injury defined as B+ on the KABCO injury scale (i.e., "Suspected Minor Injury" or higher in the crash)
[11] Vehicle-level, injury defined as C+ on the KABCO injury scale (i.e., "Possible Injury" or higher in the host vehicle)

Forward Collision (Rear-end Striking Crash) Prevention and Crash Mitigation Findings

As shown in Table 18, the current estimates of forward collision prevention effectiveness are generally consistent with previously reported results. The current analyses indicated Automatic Emergency Braking (AEB) features, which includes Forward Collision Alert (FCA) functionality, were estimated to be approximately twice as effective as FCA (20% effective) for reducing system-relevant, rear-end striking crashes (overall, 40% or 45% effective, depending on AEB technology type). In the corresponding injury crashes analysis shown in Table 22, FCA (camera-based) effectiveness estimates increased from 20% for all crashes to 25% for injury crashes, camera AEB effectiveness estimates increased from 40% for all crashes to 55% for injury crashes, and fusion/radar AEB effectiveness estimates increased from 45% for all crashes to 58% for injury crashes. The increases provide evidence indicating that these features are not only helping drivers completely avoid some rear-end striking crashes, but also helping to reduce (or mitigate) the severity of some rear-end striking crashes which are not avoided. This pattern of findings suggests some rear-end striking crashes that would have otherwise likely involved reported injuries without these features are potentially being shifted to property damage-only crashes.

Lane Departure-Related Crash Prevention and Crash Mitigation Findings

The crash sample size in the current effort was sufficient to enable analysis of three distinct lane departure-related crash types. In both the crash prevention and corresponding injury analysis, Lane Keep Assist with Lane Departure Warning (LKA with LDW) provided higher crash reductions across each of these crash types relative to LDW (only). Results for the crash prevention analysis, as shown in Table 20, indicated single-vehicle road departure crashes were reduced by Lane Keep Assist with Lane Departure Warning (LKA with LDW) and LDW (only) by an estimated 17% and 8%, respectively. In addition, same direction sideswipes, which could also be due to the actions of non-equipped vehicles which lane departure features are not designed to address, were also reduced, albeit at lower levels with LKA with LDW and LDW (only) showing estimated 10% and 4% reductions, respectively. No significant effect was observed in the all-crashes analysis for opposite direction sideswipes (which include head on-crashes), again a crash type involving multiple vehicles, likely due to insufficient sample size.

For the corresponding injury analysis shown in Table 22, the pattern for LKA with LDW is similar to that observed for forward crashes, under which elevated significant effectiveness estimates are observed. LKA (with LDW) effectiveness estimates increased from 17% to 21% for roadway departures, from 10% to 16% for opposite direction sideswipes, and from 8% (non-significant) to 19% for opposite direction sideswipes (which includes head-on crashes). For LDW, no effects were observed across crash types in this injury analysis.

It should be noted that large-scale telematics-based (OnStar) studies (Flannagan et al., 2016, 2018) suggest that the relative low usage of the LDW feature (compared to FCA and AEB) may be an important limiting factor in obtaining desired higher effectiveness estimates. (Note the LKA feature, which includes LDW functionality, by design substantially reduces the frequency of LDW alerts which some drivers find annoying.) For example, the observed effectiveness estimates could potentially be doubled for a feature with only 50% usage.

More generally, the pattern of results emphasizes the importance of measuring the effects of lane departure-related countermeasures using crash types that distinguish between single- versus multi-vehicle crashes. Since the role of the vehicle equipped with the countermeasure in multiple-vehicle lane departure crash cases is less clear (e.g., the other vehicle could very well have been unequipped and caused the crash), effectiveness estimates for single-vehicle road departures are generally felt to provide a more accurate assessment of lane departure countermeasure effectiveness.

Lane Change Crash Prevention Findings

The results of the lane change crash prevention analysis, as shown in Table 20, were nearly identical to the previous Model Year 2013-2019 analysis. In the current analysis, Lane Change Alert with Side Blind Zone Alert (LCA with SBZA) reduced lane change crashes by an estimated 16%. In addition, Side Blind Zone Alert (SBZA) alone was not significant (with an estimated 7% reduction).

Backing Crash Prevention Findings

As shown in Table 21, the current results indicated a stack-up pattern with more advanced backing features (which generally include all less advanced backing features) providing increased backing crash reduction levels. That is, Rear Vision Camera (RVC), Rear Park Assist (RPA), Rear Cross Traffic Alert (RCTA), and Reverse Automatic Braking (RAB) were estimated to provide 32%, 41%, 59%, and 83% reductions in backing crashes, respectively. RVC mirror, a feature not previously analyzed that is only offered on vans, showed an estimated 33% reduction which failed to reach significance (likely due to small sample size).

More generally, while these backing feature results are largely consistent with the previous Model Year 2013-2019 analysis, the current effectiveness estimates appear to show a slightly greater benefit for RVC (increasing from 24% to 31%) and RPA estimate (increasing from 36% to 41%). These improvements may be due to factors such as the inclusion of a broader set of control variables (i.e., crash year and Model Year) and the influx of new vehicle models (vans and a larger variety of trucks), though a vehicle type interaction was not observed.

It should also be noted that backing crashes, in particular, are known to be under-represented in police-report databases as they often occur off public roads (e.g., on private property or in parking lots) or do not reach reporting thresholds (e.g., minor crashes not causing property damage or simply not reported to the police). Consequently, with respect to the number of backing crashes being reduced by backing features in the field, there are likely substantially more “property damage only” crashes that are not being captured in the current police-report analysis.

Vulnerable Road User (VRU) Crash Prevention Findings

The Front Pedestrian Braking (FPB) and IntelliBeam (automatic high beam) features examined were aimed at reducing crashes involving Vulnerable Road Users (VRUs), with results shown in Table 21. For FPB results indicated an estimated 23% reduction in frontal pedestrian crashes, based on 1,298 system-relevant crash cases available. The previous GM Model Year 2013-2019 analysis, which had only 594 such crash cases available, found an estimated 14% non-significant reduction. Part of the sample size increase was due to the new inclusion of large utility vehicles, which were not equipped with FPB prior to MY 2020. These results are generally consistent with the overall 27% reductions recently reported by Cicchino (2022) in an examination of FPB systems offered by a variety of manufacturers.

Results also indicated that IntelliBeam (auto high beam headlights) provided an estimated 22% reduction in unlit nighttime VRU crashes (the GM Model Year 2013-2019 analysis showing a 24% effect), which was independent of the specific headlight type. Although these unlit VRU crashes include a set of animal, pedestrian, and bicyclist crashes, the vast majority are animal crashes. Consequently, an additional analysis focused only on pedestrians was conducted and indicated a similarly sized, non-significant 24% reduction when only looking at unlit pedestrian crashes. This suggests that the use of animal crashes is not biasing the results particularly, and that the processes behind unlit animal and pedestrian crashes are similar (i.e., driver unable to see the hazard in time).

Induced Exposure Methodology (Control Crash Considerations)

The rear-end struck crash has been commonly used as the control crash in induced exposure analyses (e.g., Keall & Newstead, 2009), which has been the approach taken in this series of GM feature effectiveness studies. However, as ADAS fleet penetration increases in general, there are potential concerns about how such features might impact rear-end struck crashes, possibly affecting feature benefits estimates in unintended ways. For example, if AEB stops more quickly than following vehicles expect, this could potentially lead to more rear-end struck crashes for AEB-equipped vehicles. However, it can be argued this is unlikely to make an appreciable difference in crashes, since AEB events have been found to be rare occurring at a rate of approximately 1 per 100,000 miles of driving (Flannagan et al., 2018).

An alternative is that as AEB enters the fleet in larger numbers on previously unequipped vehicles, those vehicles will be in rear-end *striking* crashes less often, resulting in an overall reduction in rear-end crashes (and rear-end struck events) over time. Indeed, this pattern was seen in the current effort project. Because ADAS are more common on newer vehicles, which can only be in crashes in more recent years, the reduction in the control (rear-end struck) crashes tends to be greater for the newer equipped vehicles compared to older unequipped vehicles. This has the effect of, in a sense, raising the bar for equipped vehicles, and therefore underestimating effectiveness. To address this issue, in the current effort we included Crash Year as a predictor in the logistic regressions. Its role in the analyses is to adjust for the general reduction in rear-end struck crashes over time and, in essence, “level the playing field” for vehicles that crash in recent years compared to earlier years. In general, we think that this approach is effective, and that rear-end struck crashes remain the best option for control crashes in these induced exposure analyses.

Concluding Remarks: Working Toward a Zero Crashes Vison

The current effort not only quantifies the substantial crash reduction and crash mitigation (injury reduction) benefits afforded by a wide variety of production GM ADAS features, but also identifies potential strategies for moving closer toward a zero crashes vision. These include offering ADAS features that provide some degree of automated control (in additional to alerts), since such features were found to consistently outperform their less advanced “alert only” counterparts (e.g., AEB versus FCA). The results also highlighted the need to address lane departure and lane change crashes more effectively. More generally, there remain significant opportunities for moving toward zero crashes beyond the ADAS features examined here, including addressing seat belt use, driver behavior choices (e.g., speeding and impairment due to alcohol or other drugs, drowsiness, or distraction), and different crash configurations (e.g., intersection crashes).

When evaluating zero crashes vision progress, it should be remembered that *overall* crash reduction and crash mitigation benefits are determined by the prevalence of the system-relevant crash in the entire crash population, the feature effectiveness (which incorporates driver feature usage), and the penetration of the feature across the entire fleet (not just GM portion). For example, assuming rear-end crashes account for 31% of all crashes in the United States (Swanson et al., 2019), and that the entire US fleet is equipped with the GM fusion/radar AEB feature examined here (which reduced rear-end striking crashes by 45%), this feature alone would be estimated to reduce 14% of all police-reported crashes in the United States (i.e., 31% of all crashes multiplied by the assumed 45% effectiveness value).

In addition to continuing this series of ADAS effectiveness studies, we recommend leveraging additional state crash databases as they become available to UMTRI, as well as exploring the use of telematics-based data (such as GM's OnStar low-level EDR and AACN data). Finally, we also recommend using these large-scale field effectiveness estimates for informing New Car Assessment Program (NCAP) and feature content decision-making.

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