Analysis of the Field Effectiveness of General Motors Model Year 2017-2021 Advanced Driver Assistance System Features

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16. Abstract

Over 11.2 million Model Year 2017–2021 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 49%, 40%, and 14%, respectively. When restricting to crashes with suspected minor or higher injury severities reported, reductions were elevated to 57%, 53%, and 25%, respectively, providing evidence of additional crash mitigation benefits. Similarly, the Lane Keep Assist with Lane Departure Warning system provided 17%, 8%, and 7% reductions in roadway departure, same direction sideswipe, and opposite direction sideswipe crashes, as well as a 22% reduction in injuries reported for roadway departure crashes. The Lane Change Alert with Side Blind Zone Alert system reduced lane change crashes by 15%. The backing crash findings indicated Rear Vision Camera, Rear Park Assist, Rear Cross Traffic Alert, and Reverse Automatic Braking (note more advanced backing features generally include all less advanced backing features) provided 34%, 49%, 62%, and 85% reductions in backing crashes, respectively. Front Pedestrian Braking reduced front pedestrian crashes by 23%. 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 fifth in a series of studies examining the field effectiveness of various General Motors (GM) Advanced Driver Assistance Systems (ADAS) features aimed at addressing a wide range of system-relevant crash types. The ADAS features examined break down into features that are intended help the driver avoid or mitigate forward (rear-end striking, front-to-rear), front pedestrian, lane departure, lane change, and backing crashes.

The current updated GM Model Year 2017-2021 study employed VIN-linked feature ADAS content data from over 11.2 million vehicles of various vehicle types across GM brands (i.e., Buick, Cadillac, Chevrolet, and GMC). These data were provided by GM to UMTRI, who then matched to police-report crash data available in 14 states (identifying 600,613 matched vehicle crashes) and conducted the ADAS field effectiveness analysis. Unlike the prior GM ADAS feature effectiveness analyses, Model Year 2013-2016 data were removed from the current analysis to modernize the fleet examined and make the vehicle type distribution of the crash sample more representative of the current GM fleet. More generally, it should be stressed that the safety benefits reported here incorporate important real-world factors such as the extent to which drivers leave these features on (which is not available in the police-report data), the demographics of drivers of ADAS-equipped vehicles, and the wide range of driving conditions experienced by drivers with these features.

ADAS feature effectiveness (i.e., percent reductions in system-relevant crashes) was estimated using quasi-induced exposure logistic regression. This method compares system-relevant and system-irrelevant (referred to as "control") crash counts for vehicles equipped and unequipped with ADAS feature(s). 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 vehicle 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 curvature, and road surface conditions), crash year, model year, and vehicle type/model.

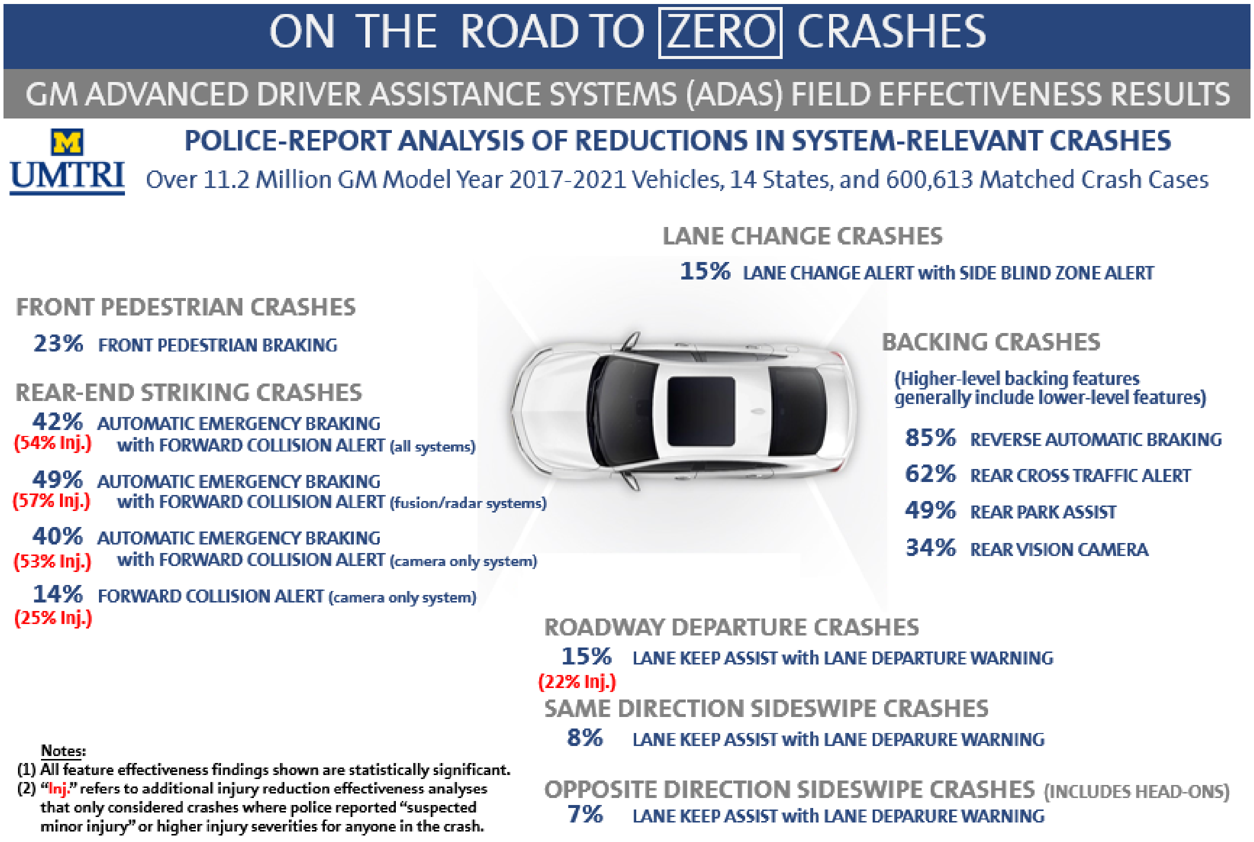
In addition, for the forward collision and lane departure features examined, sample sizes were large enough to support an additional "injury-focused" analysis using a more restricted set of crashes which were police-reported to be more severe crashes. In state police reports, crash injuries are coded 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)". In this injury-focused analysis, only system-relevant crashes with a "K", "A", or "B" on the KABCO rating were included. This injury-focused analysis can be contrasted with the more general analysis approach described above, which included "all crashes" irrespective of the police-reported injury levels.

High-Level Summary of GM ADAS Field Effectiveness

The high-level summary figure below (Figure-ES 1) provides ADAS feature effectiveness results found to be statistically significant for reducing system-relevant crashes, with the results for the injury-focused analyses shown parenthetically in red. Percent effectiveness is relative to the system-relevant crash types that the feature is designed to address. Non-significant results, some of which can be attributed to small sample sizes, are included in the results discussions below.

Overall, the results from this updated GM ADAS feature effectiveness analysis are generally similar to those observed in previous analyses, except for the Lane Departure Warning (LDW) feature, which is being phased out by GM and replaced by the Lane Keep Assist (LKA) with LDW feature. In the current effort, the LDW feature did not produce significant benefits, which is believed to be attributed to the changes in the LDW-equipped penetrations across vehicle types which have occurred across model years.

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).



ON THE ROAD TO ZERO CRASHES

GM ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) FIELD EFFECTIVENESS RESULTS

UMTRI

POLICE-REPORT ANALYSIS OF REDUCTIONS IN SYSTEM-RELEVANT CRASHES

Over 11.2 Million GM Model Year 2017-2021 Vehicles, 14 States, and 600,613 Matched Crash Cases

FRONT PEDESTRIAN CRASHES

23% FRONT PEDESTRIAN BRAKING

REAR-END STRIKING CRASHES

42% AUTOMATIC EMERGENCY BRAKING with FORWARD COLLISION ALERT (all systems) (54% Inj.)

49% AUTOMATIC EMERGENCY BRAKING with FORWARD COLLISION ALERT (fusion/radar systems) (57% Inj.)

40% AUTOMATIC EMERGENCY BRAKING with FORWARD COLLISION ALERT (camera only system) (53% Inj.)

14% FORWARD COLLISION ALERT (camera only system) (25% Inj.)

LANE CHANGE CRASHES

15% LANE CHANGE ALERT with SIDE BLIND ZONE ALERT

BACKING CRASHES

(Higher-level backing features generally include lower-level features)

85% REVERSE AUTOMATIC BRAKING

62% REAR CROSS TRAFFIC ALERT

49% REAR PARK ASSIST

34% REAR VISION CAMERA

ROADWAY DEPARTURE CRASHES

15% LANE KEEP ASSIST with LANE DEPARTURE WARNING (22% Inj.)

SAME DIRECTION SIDESWIPE CRASHES

8% LANE KEEP ASSIST with LANE DEPARURE WARNING

OPPOSITE DIRECTION SIDESWIPE CRASHES (INCLUDES HEAD-ONS)

7% LANE KEEP ASSIST with LANE DEPARURE WARNING

Notes:
(1) All feature effectiveness findings shown are statistically significant.
(2) "Inj." refers to additional injury reduction effectiveness analyses that only considered crashes where police reported "suspected minor injury" or higher injury severities for anyone in the crash.

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 three times as effective as FCA alone (14% effective) for reducing system-relevant, rear-end striking crashes. Overall, AEB was found to be 42% effective, with higher estimates observed for Radar/Fusion AEB (49% effective) than Camera AEB (40% effective), noting the latter feature only operates below 50 mph. In the corresponding injury-focused analysis, FCA effectiveness estimates increased to 25%, and overall, AEB estimated benefits increased to 54% (with 57% and 53% reductions associated with the Radar/Fusion and Camera AEB features, respectively). These increases provide evidence that the AEB and FCA 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, which can in turn reduce injury severities. This pattern of findings also suggests some rear-end striking crashes that would have otherwise likely involved reported injurie/s without FCA and AEB are potentially being shifted to property damage-only crashes.

Lane Departure-Related Crash Prevention and Crash Mitigation Findings

The Lane Keep Assist with Lane Departure Warning (LKA with LDW) was observed to reduce roadway departure, same-direction sideswipe, and opposite-direction sideswipe crashes (the latter of which includes head-on crashes) by 15%, 8%, and 7%, respectively. The former roadway departure benefit was found to be restricted to non-adverse conditions (i.e., “dry” and “clear/cloudy”). For the corresponding injury-focused analysis, only reductions for the roadway departure crash type were observed for the LKA with LDW feature, with an increased effectiveness estimate of 22% (compared to the 15% for the corresponding “all crashes” analysis). For the LDW feature alone, which is being phased out by GM, across all three system-relevant crash types, no effects were observed either in either the “all crashes” analysis or in the corresponding injury-focused analysis. These results follow the same pattern found for the AEB and FCA features, namely, that the greater degree of automation provided by the LKA with LDW feature (i.e., a brief steering wheel nudge) improves feature effectiveness.

This pattern of lane departure countermeasure results emphasizes the importance of measuring the effects of such 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 left its lane 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 Lane Change Alert with Side Blind Zone Alert (LCA with SBZA) feature reduced lane change crashes by an estimated 15%. The Side Blind Zone Alert (SBZA) feature alone, which has substantially lower detection ranges than LCA with SBZA, was not found to be significant (consistent with previous findings).

Backing Crash Prevention Findings

The backing crash findings indicated more advanced backing features (which generally include all less advanced backing features) provided increasing backing crash reduction levels in a “stack-up effect.” More explicitly, Rear Vision Camera (RVC), Rear Park Assist (RPA), Rear Cross Traffic Alert (RCTA), and Reverse Automatic Braking (RAB) were estimated to provide 34%, 49%, 62%, and 85% reductions in backing crashes, respectively. The RVC mirror feature, which is only offered on vans and displays the standard RVC image in the inside rear-view mirror, showed an estimated 27% reduction in backing crashes, comparable to standard RVC, but failed to reach significance (likely due to small sample sizes).

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, there are likely substantially more “property damage only” crashes that are not being captured in police-report data collection that could be prevented by these systems. Finally, it should also be noted that although GM offers features that are relevant to low-speed forward parking crashes (e.g., Front and Rear Park Assist), the inconsistency of parking crash coding across state crash databases did not allow a reasonable evaluation of effectiveness levels for such features in reducing such forward parking crashes.

Vulnerable Road User (VRU) Crash Prevention Findings

Results indicated the Front Pedestrian Braking (FPB) feature provided an estimated 23% reduction in frontal pedestrian crashes. Despite the known limitations of this feature under nighttime conditions, no significant interactions with light condition were identified in this analysis, which could be related to the relatively low sample of pedestrian crashes.

Concluding Remarks: Working Toward a Zero Crashes Vision

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 addition to alerts), since such features were found to consistently outperform their less advanced "alert only" counterparts (e.g., AEB versus FCA, LKA with LDW versus LDW only). The results also highlighted the need to address lane departure and lane change crashes at higher levels of effectiveness, the former of which is likely related to lower customer use of the LKA with LDW and LDW features.

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 feature usage), and feature penetration across the entire fleet (not just the GM portion of the fleet). Table-ES 1, adapted from Swanson et al. (2019), shows estimated counts and percentages of crashes in the United States where a light vehicle performed the critical pre-crash action used here for defining system-relevant crashes. This simplified version of the Swanson et al. crash types, under which multiple crash types are combined (e.g., five separate rear-end crash types are mapped to a single collective rear-end striking crash type), identifies crashes plausibly addressable by the ADAS features examined in this analysis. If one assumes that all of the crash types shown in the rightmost column are addressable by one or more of the ADAS features examined in the current study, the current set of features examined have the maximum potential (i.e., if 100% effective) to address approximately 55.4% of all US crashes (and 60.3% of fatal crashes). If we further assume that that the entire US fleet were equipped with the GM Radar/Fusion AEB, LKA (with LDW), LCA (with SBZA) and RAB (with RPA and RCTA) features examined here at their estimated effectiveness rates shown in Figure-ES 1, approximately 37.7% of addressable crashes, and 20.9% of all crashes, could be prevented.

More generally, there remain significant opportunities for moving toward zero crashes beyond improving or expanding 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 additional crash configurations (e.g., intersection crashes). Going forward, we recommend continuing this series of ADAS feature effectiveness studies, leveraging additional state crash databases as they become available to researchers, and exploring the use of telematics-based data (such as GM's OnStar low-level EDR and AACN data). This telematics data could enhance understanding of feature usage surrounding the crash (including feature usage more generally) and potentially enable more timely access to crash data automatically generated by the vehicle. This telematics-based crash data collection approach can be contrasted with state agency police report data, which have approximately 1- to 2-year delays due to availability, but also provide more detailed data surrounding crash circumstances. Finally, we also recommend using these large-scale field effectiveness estimates for informing New Car Assessment Program (NCAP) decision-making and feature content decision-making and planning.

Table-ES 1 Estimated counts of crashes where the critical action was performed by a light vehicle (adapted from Swanson, et al. (2019) Table 12)

Crash Type	Fatal Crashes	Percentage of Fatal Crashes	All Crashes	Percentage of All Crashes	Mapped Swanson Crash Type
Rear-end	1,244	4.9%	1,709,716	31.2%	20-24
Pedestrian	3,731	14.7%	70,461	1.3%	9, 10
Lane Change	285	1.1%	320,052	5.8%	16
Backing	61	0.2%	166,550	3.0%	6, 13
Same Direction Drifting	196	0.8%	120,223	2.2%	17
Opposite Direction	3,258	12.9%	100,786	1.8%	18, 19
Road Departure	6,501	25.6%	547,098	10.0%	7, 8
Total Addressable	15,276	60.3%	3,034,886	55.4%	
Unaddressed	10,074	39.7%	2,446,000	44.6%	
Total	25,350	100.0%	5,480,886	100.0%	

Introduction

This report describes the fifth in a series of field effectiveness studies examining a wide range of Advanced Driver Assistance Systems (ADAS) offered on General Motors (GM) production vehicles. 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 evaluated 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). These latter control crashes 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 specific crash types involved.) Results from this initial police-report study (Flannagan and Leslie, 2020) indicated system-relevant crashes were reduced for GM's Forward Collision Alert, Automatic Emergency Braking, Lane Keep Assist with Lane Departure, Rear Park Assist, Rear Cross Traffic Alert, and Reverse Automatic Braking features.

This police report analysis was updated in 2019 (Leslie et al., 2019), 2020 (Leslie et al., 2021), and 2021 (Leslie et al., 2022). In each study, newer crash and safety content data were added, resulting in larger matched sample sizes and smaller confidence intervals around the observed effectiveness estimates. Also notably, the larger samples have enabled analysis of newer technologies (e.g., Front Pedestrian Braking; FPB) and more detailed crash types (e.g., three lane departure crash types). Broadly, the magnitudes of the crash reduction effects for the various ADAS features examined in this sequence of police report analyses have been found to be largely consistent year to year.

As in the previous GM feature effectiveness studies, the goal of the project described in this report was to continue to update GM feature effectiveness estimates by adding GM MY 21 vehicles with VIN-linked ADAS 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. In this report, a major change from previous effectiveness analyses is the elimination of MY 13-16 vehicle data. These older vehicles make up the bulk of the "no ADAS" control group, potentially resulting in overestimates of effectiveness (especially because of the potential for systematic driver differences) due to the greater exposure of these vehicles. Additional reasons supporting the removal of these vehicles include such vehicles may not have benefited from feature improvement or be in proper operating condition, and such vehicles are more likely to be driven now by completely different drivers.

Methods

Data

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

Advanced Driver Assistance Systems (ADAS) and Feature Data

The GM ADAS content dataset (also referred to as “safety content”) contained VIN-linked data on 11,266,320 vehicles across all GM brands (i.e., Buick, Cadillac, Chevrolet, and GMC) and covered MYs 17-21. Unlike the previous iterations of this project, these analyses did not make use of MY 13-16 VIN-linked content data that were previously provided by GM to UMTRI. As touched upon earlier, the older vehicles were excluded in an effort to increase the representativeness of the analysis set of vehicles to the current GM fleet. The available MY 13-16 vehicles were disproportionately sedans, and truck models were not added until MY 17, rendering the early portion of the data a poor representation of the vehicle type mix of the current GM fleet. Additionally, earlier model years included system-vehicle type combinations that are no longer offered or offered at a high volume. (Most notably, the Lane Departure Warning without Lane Keep Assist feature was largely retired on SUVs across MY 16-17.) By removing the older vehicles, the analysis set is kept more modern and applicable to the fleet at large. In total, 2,040,239 MY 13-16 vehicles from the previous projects were excluded from the current analysis for the reasons described above.

Overall, this analysis saw a slight increase in total vehicles in the safety content dataset compared to the MY 13-20 dataset from the previous effort, which had 10,947,669 vehicles. Note this increase occurred despite the aforementioned reduction in model years covered. Prior to MY 20, GM provided content data for a model/MY pair only when a (forward) Automatic Emergency Braking (AEB) feature was available on at least one trim level for that model/MY pair. Starting with the MY 20 dataset, this requirement was relaxed, allowing for the inclusion of a broader set of vehicles (including vans) in the current study. As a result, the raw volume of VIN data provided was higher than in the earlier model years.

Table 1 shows the model-year range for each of the make-models included in the safety content dataset provided by GM to UMTRI. Table 2 summarizes the number of vehicles included for each model year. There were approximately 2.4 million vehicles for most model years in the dataset (with somewhat lower counts for MY17 and MY19).

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

Model Year (MY) Range	Models
2017-2019	Buick Lacrosse, Buick Regal, Cadillac ATS, Cadillac CTS, Cadillac XT5, Cadillac XTS, Chevrolet Volt
2018-2019	Chevrolet Cruze
2017-2020	Cadillac CT6, Chevrolet Impala
2020	Chevrolet Sonic
2017-2021	Buick Acadia, Buick Envision, Cadillac Escalade, Chevrolet Bolt, Chevrolet Malibu, Chevrolet Silverado, Chevrolet Silverado HD, Chevrolet Suburban, Chevrolet Tahoe, GMC Sierra, GMC Sierra HD, GMC Yukon, GMC Yukon XL
2018-2021	Buick Enclave, Cadillac XT4, Chevrolet Equinox, Chevrolet Traverse, GMC Terrain
2019-2021	Chevrolet Blazer, Chevrolet Spark
2020-2021	Buick Encore, Cadillac CT4, Cadillac CT5, Cadillac XT6, Chevrolet Camaro, Chevrolet Corvette, Chevrolet Colorado, Chevrolet Express, Chevrolet Low Cab Forward, Chevrolet Silverado MD, Chevrolet TRAX, GMC Canyon, GMC Savana
2021	Chevrolet Trailblazer

Table 2 Vehicle count by Model Year

Model Year (MY)	Vehicle Count
2017	1,745,180
2018	2,438,205
2019	2,085,087
2020	2,595,168
2021	2,402,680

The ADAS features examined break down into features that are intended to help the driver avoid or mitigate forward (rear-end striking, front-to-rear), front pedestrian, lane departure, lane change, and backing crashes. Note that a given crash type may be addressed by multiple features. For example, forward rear-end striking crashes may be impacted by both the Automatic Emergency Braking and Forward Collision Alert features. The full list of features examined in this analysis is presented in Table 3, along with corresponding feature abbreviations used throughout this report. It is important to keep in mind that a number of these features have important relationships to each other, including dependencies, which are reflected in Table 3. In addition, certain features addressing different crash types were offered (or bundled) together in production (e.g., the Lane Keep Assist with Lane Departure feature and the Camera Forward Collision Alert features are co-dependent, Front Pedestrian Braking is only offered with the (forward) Automatic Emergency Braking (AEB) feature, Reverse Automatic Braking (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 3 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[1]	Rear Vision Camera	RVC
	Rear Vision Camera Mirror	RVC Mirror
	Rear Park Assist	RPA
	Rear Cross Traffic Alert with Rear Vision Camera or Surround Vision	RCTA w/RVC or SV
	Reverse Automatic Braking with Rear Vision Camera or Surround Vision, Rear Park Assist, and Rear Cross Traffic Alert	RAB w/RVC or SV, RPA, & RCTA

Police Crash Report Data

UMTRI obtained data on police-reported crashes from 14 states that were able to provide full 17-character VINs for crash-involved vehicles. Table 4 shows the calendar years of the crash data provided to UMTRI from each of these states.

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

State	Calendar Years
Connecticut	2016 – July 2022
Florida	2016 – March 2022
Idaho	2016 – June 2022
Kansas	2016 – June 2022
Louisiana	2016 – 2021
Maryland	2016 – March 2022
Michigan	2016 – 2021
Missouri	2016 – 2021
Ohio	2016 – June 2022
Nebraska[2]	2016 – 2020
South Dakota	2016 – 2021
Tennessee	2016 – June 2022
Texas	2016 – June 2022
Utah	2016 – 2021

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

[2] Due to a change to their data format in 2021, Nebraska was not able to provide an updated dataset for this project. We will monitor their status and attempt to incorporate their new data format into subsequent projects when it becomes available.

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 safety content dataset to identify which vehicles were present in both the GM VIN and police report datasets. The result was 600,613 matches out of the approximately 10.9 million VINs in this GM content dataset (a 5.3% match rate). Due to the removal of the MY 13-16 vehicles, the matched dataset for this analysis was slightly smaller than the 635,712 vehicles matched in the previous MY 13-20 analysis.[3] The matched number of crash cases remains substantially larger than any year prior to that, (e.g., nearly 40% greater than the MY 13-19 GM feature effectiveness study and over a 5-fold increase compared to earlier such effectiveness studies). As shown in Table 5, the matched dataset is weighted towards older vehicles despite the available safety content data being weighted towards newer vehicles. This is largely due to the greater exposure of older vehicles to crashes (i.e., a MY 17 vehicle could have crashed anytime from 2016 to 2022 whereas a MY 21 vehicle must have crashed between 2020 and 2022). This pattern emphasizes the importance of removing the MY 13-16 vehicles that had a great deal of exposure, increasing their influence on the matched crashes, but which are no longer representative of the fleet overall.

As in previous studies, the matched data came predominantly from a small number of the available states. This was likely due to a combination of the range of police report data available to UMTRI, 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 higher numbers of matched crashes. Florida, Michigan, and Texas contributed 69% of the matched crash dataset (25% FL, 17% MI, and 27% TX). The next highest volume state was Ohio with 9% of the dataset. These matching crash proportions across states correspond well to the proportions of available VINs across states, with only Michigan being noticeably overrepresented, likely due to high GM vehicle sales in the state.

Table 5 Percent of vehicles in VIN dataset and matched dataset by Model Year range

Model Year (MY)	Percent of Content Data	Percent of Matched Cases
2017	15.4	25.2
2018	21.6	31.2
2019	18.5	19.6
2020	23.0	16.4
2021	21.3	7.6

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[3] For brevity, in this report “previous” analyses or studies will refer to the series of GM ADAS feature effectiveness studies conducted by the authors of this report with the precise reference omitted (except for a Model Year range as appropriate. These reports are Flannagan & Leslie, 2020 and Leslie et al., 2019, 2020, and 2022.

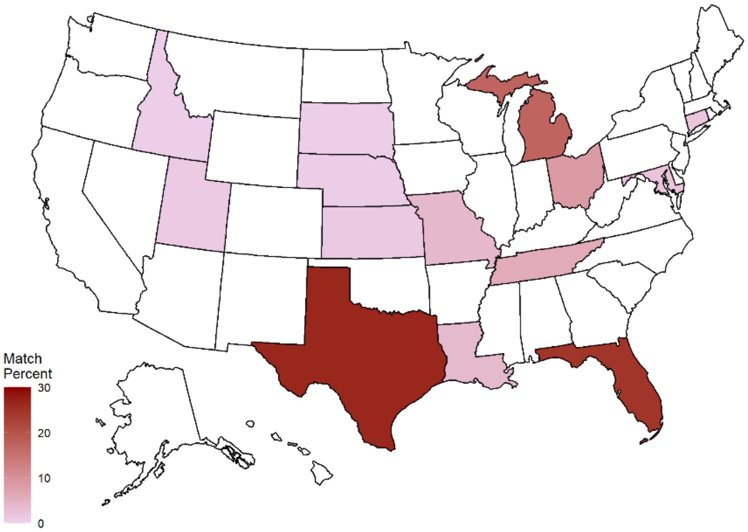

Figure 1 United States map showing the relative contribution levels of matched crashes from each of the 14 states used in this analysis

The matched crash dataset also highlights the effect that dropping the MY 13-16 vehicles has on the distribution of vehicle types. Table 6 shows the distribution of vehicle types for the safety content database and the matched database for the previous MY 13-20 analysis and the current MY17-21 analysis. For both MY 13-20 and MY 17-21, there is a noticeable shift in vehicle-type distribution in the matched dataset (compared to the safety-content dataset) such that sedans are overrepresented and small/medium SUVs, trucks, and vans are underrepresented. However, with the removal of MY 13-16 vehicles, which were mostly sedans, the current dataset is much closer to the fleet proportions across vehicle types. While sedans are still overrepresented in matched crashes, they are no longer the plurality of the matched data, and trucks and small/medium utilities are more accurately reflected in the crash data volumes. More generally, the overrepresentation of sedans continues to occur in the current analysis because sedans have been on the road longer, and thus, have had more time to crash. In summary, keeping the matched dataset model years more recent (i.e., MY17-21) enables the matched dataset to better reflect changes in the fleet over time.

Table 6 Percent of available and matched vehicles by vehicle type for the MY 13-20 and MY 17-21 studies

Vehicle Type	Available MY 13-20	Matched MY 13-20	Available MY 17-21	Matched MY 17-21
Sedan	24.3	40.5	15.1	24.4
Sm./Med. Utility	30.7	22.1	35.6	32.3
Large Utility	15.5	18.5	11.5	11.5
Truck	28.7	18.7	36.5	31.2
Van	0.7	0.2	1.3	0.6

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 feature-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 7, 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 (as described below), but Table 7 serves to illustrate the concept underlying the quasi-induced exposure technique.

Table 7 The layout for quasi-induced exposure logistic regression

Crash Configuration	Backing Feature Equipment	
	Equipped	Not Equipped
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 forced to be 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, two additional filters were used to avoid overfitting the models. First, 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 values being more desirable. In parallel, the potential interactions were provided to GM for review to determine if they seemed plausible. Of the proposed interactions, only two were identified as meriting further investigation, but ultimately neither was included in the core model estimates due to the unclear interpretations. These are discussed in detail in the *Vehicle Type Interactions with Features* section below.

The inclusion of vehicle model in the modelling process attempted to capture differences between the driver demographics associated with various vehicle models. 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 the vehicle model factor was used.

The 13 covariates listed below were employed in this analysis, all of which were obtained from the police accident reports, except for Vehicle Type and Vehicle Model, which 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*[4]
- 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: *2017 – 2021*
- Crash Year: *2016 – 2021*
- Vehicle Type: *Sedan, Small/Medium Utility, Large Utility, Truck, Van (see Table 8 for definitions)*
- *Vehicle model: (see Table 8)*

Table 8 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, Terrain, Trailblazer, 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 all states used in this analysis. The

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

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 for definitions associated with 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), the inconsistency of parking crash coding across state crash databases does not allow a reasonable evaluation of effectiveness levels for these features in reducing such 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 9 and Table 10, 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 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. Finally, in addition to the crash type definitions provided in Table 9 and Table 10, 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 MY 13-19 analysis, was changed again in the current effort. Rather than pooling three types of system-relevant crashes, these types were analyzed separately. These three types included same direction sideswipes, opposite direction sideswipes (which includes head-on crashes), and single vehicle run-off-road crashes. This change brings the analysis in line with recent ADAS effectiveness studies (e.g., MITRE PARTS, 2022) and leverages the increasing volume of matched crashes to better examine specific crash circumstances.

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

As with the MY 13-19 analysis, separate analyses were conducted to examine injury crashes for the two most populated matched crash groups (see Table 11): 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 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) when compared to a medical diagnosis. Nonetheless, KABCO is strongly correlated with injury level based on medical diagnosis. Thus, in this context, police-reported injury crashes are likely to be generally more severe than reported non-injury crashes. Therefore, an analysis restricted to injury-reported crashes should still provide insight into the performance of GM features for crashes that are capable of causing injury, even though the injury definition is not as precise as one using medical diagnosis. In general, NHTSA, state agencies, and traffic safety researchers routinely rely on KABCO information to characterize harm levels associated with crashes.

As in the MY 13-20 analysis, this analysis identified injury crashes based on 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 threshold for GM vehicle occupants used in the previous MY 13-19 study. The change was motivated by two factors: 1) the larger matched dataset supports the stricter injury 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 9 System-relevant crash types and definitions by analysis group

Analysis Group	Crash Type	Definition
Forward Collision	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

Table 10 Control crash type and definition by analysis group

Analysis Group	Crash Type	Definition
All Analyses	Rear-end Struck	Manner of Crash = Rear-end AND Initial Contact Point on Vehicle = Rear

Results

The features evaluated were divided into five general analysis categories: forward (i.e., rear-end striking) collision, front pedestrian, lane departure (which included three crash sub-type analyses), lane change, and backing. Each of these five categories were used in "prevention" (i.e., crash avoidance) analyses.

As discussed above, additional "injury-focused" analyses were conducted for the forward collision and lane departure analysis categories. These analyses attempt to account for crash mitigation effects, where although the feature may not have prevented the crash, it may reduce the crash severity and thereby importantly help mitigate or prevent crash-related injuries.

Each analysis category is discussed separately below. Note that only significant feature-related effects are discussed here.

Analysis Data Subsets

Table 11 shows the sample size of matched cases for both system-relevant and associated control crashes for each analysis group and feature(s) evaluated. These crashes are derived from the original set of 600,613 vehicle cases matched between GM VINs (with ADAS 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 GM practice of bundling less advanced features with their more advanced counterparts, which will be addressed in the relevant analysis discussions below.

Unlike in previous analyses, where sample sizes consistently grew for all equipment types, this updated analysis has seen a reduction in certain older ADAS equipment groups. Notably the volumes of FCA-, Radar AEB-, LDW- and SBZA-equipped vehicles in Table 11 have decreased from the corresponding MY 13-20 analysis. These systems are less frequent in the later MY17-21 equipment packages, being largely replaced by systems that include their functionality (e.g., LKA w/ LDW replacing LDW alone) or which are alternative versions of the system (e.g., Camera AEB or Fusion AEB rather than Radar AEB). While this reduction in volume decreases the precision of the estimated effect sizes, as reflected by the larger confidence intervals observed in the current analyses, it importantly allows for more accurate estimation of the benefit of the systems to the current GM fleet mix.

Table 11 Count of vehicles analyzed by feature(s) evaluated and crash type (system-relevant versus control) for each analysis category

Analysis Category	Feature(s) Evaluated	Crash Type	
		System-Relevant	Control
Forward Collision	None	51,743	78,620
	Camera Forward Collision Alert (FCA)	2,176	3,320
	Radar/Fusion AEB	1,857	6,190
	Camera AEB	11,345	32,816
Front Pedestrian	None	996	63,316
	Front Pedestrian Braking (FPB)	150	15,281
Lane Departure – Same Direction	None	31,771	51,703
	Lane Departure Warning (LDW)	1,876	2,129
	Lane Keep Assist (LKA) with LDW	12,103	25,234
Lane Departure – Opposite Direction	None	5,574	50,291
	Lane Departure Warning (LDW)	364	2,058
	Lane Keep Assist (LKA) with LDW	1,855	24,451
Lane Departure – Road Departure	None	11,482	50,291
	Lane Departure Warning (LDW)	588	2,058
	Lane Keep Assist (LKA) with LDW	3,599	24,451
Lane Change	None	8,561	63,876
	Side Blind Zone Alert (SBZA)	113	889
	Lane Change Alert (LCA) with SBZA	4,526	46,188
Backing	None	690	3,403
	Rear Vision Camera (RVC)	5,613	47,127
	Rear Vision Camera Mirror (RVC Mirror)	108	440
	Rear Park Assist (RPA)	2,209	16,491
	Rear Cross Traffic Alert (RCTA) with RVC or Surround Vision (SV)	3,646	47,042
	Reverse Automatic Braking (RAB) with RVC or SV, RPA, & RCTA	66	1,567

Forward Collision Prevention Analysis

Table 12 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 feature evaluated only operated below 50 mph, and all AEB features include the FCA feature. In addition, the Radar/Fusion AEB system always includes an Adaptive Cruise Control (ACC) feature, whereas Camera AEB only sometimes include the ACC feature. Finally, Camera FCA here corresponds to vehicles equipped with the FCA feature, but not equipped with AEB. All five feature levels shown in Table 12 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 12 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	67,121 (system-relevant); 120,946 (control)
- injury crashes	5,982 (system-relevant); 120, 946 (control)

Figure 2, which demonstrates how features effectiveness results will be presented 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 ($p<0.05$). 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 system-relevant rear-end striking crashes. FCA produced a 14% reduction (odds ratio=0.86), while Radar and Fusion AEB features estimated a 49% benefit (odds ratio=0.51) and Camera AEB produced an estimated benefit of 40% (odds ratio=0.60). The 14% reduction represents a decrease from the MY 13-20 analysis, where it was estimated at 20%. This is likely due to the change in the "FCA only" (without AEB) equipped vehicles in this analysis (see interaction effect discussed further below), as SUV vehicles are much less frequently equipped with this system after MY 17.

The AEB results correspond closely to those observed in the MY 13-19 analysis (see *Discussion* section). There was a small increase in the effectiveness of Radar/Fusion AEB (increasing from 45% to 49%), which is again likely due to the change in vehicle type mix which resulted from the exclusion of older MY13-16 vehicles in this MY17-21 analysis. The Camera AEB feature, introduced after MY 16, remained unchanged at 40% effectiveness.

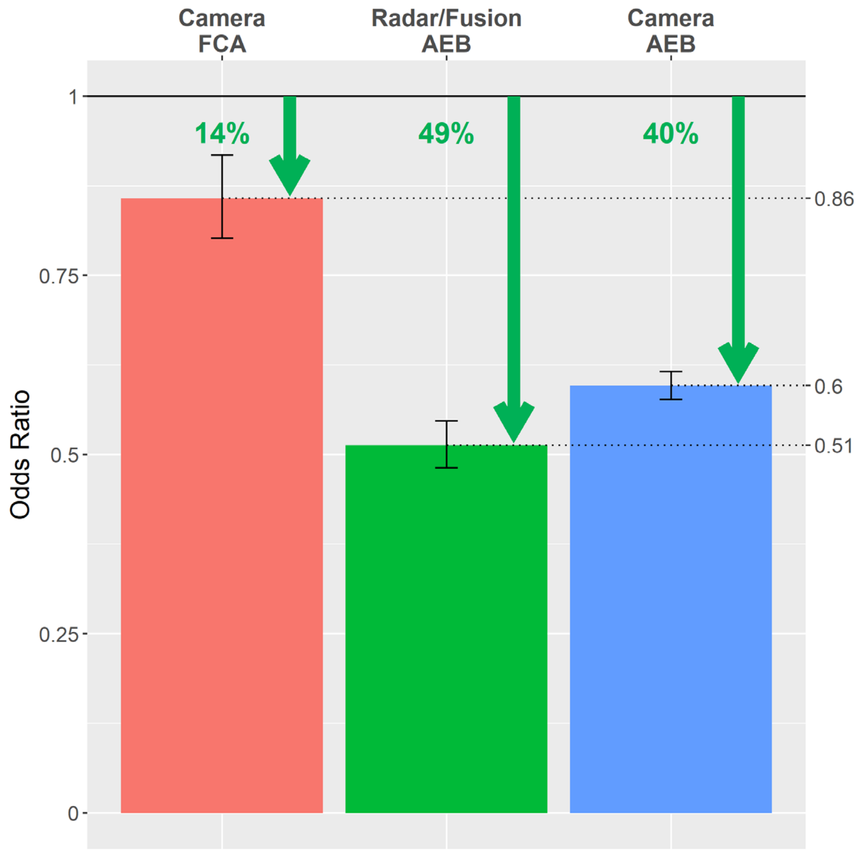

Figure 2 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for forward collision crash prevention systems

Injury Crash Analysis

The forward collision injury analysis is presented in Figure 3. Recall this injury-focused analysis is focused on more severe crashes where an injury level of K, A, or B on the police-reported KABCO scale was reported for any of the crash-involved persons. This analysis generally indicates that the magnitude of the reductions in system-relevant crashes increased for this injury-focused analysis relative to the previous crash prevention analysis, which included crashes with all levels of injury across the KABCO scale (i.e., K, A, B, or C). In the corresponding injury-focused analysis, FCA effectiveness estimates increased to 25%, and overall, AEB estimated benefits increased to 54% (with 57% and 53% reductions associated with the Radar/Fusion and Camera AEB features, respectively).

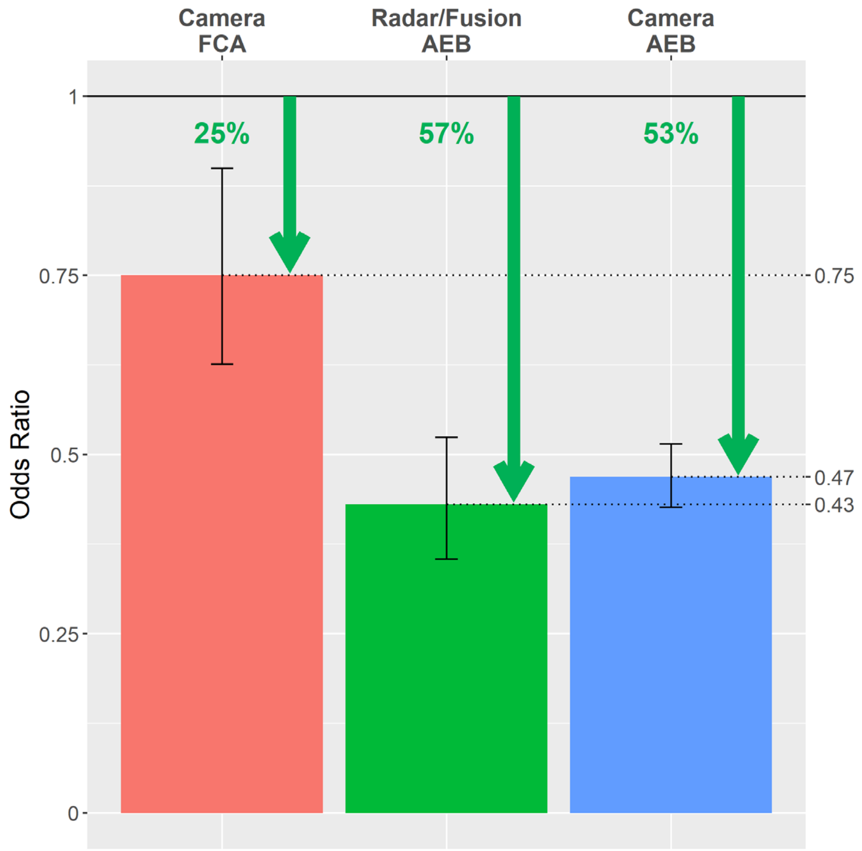

Figure 3 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) in injury ("B" or higher on KABCO scale) crashes for forward collision crash prevention systems in the injury-focused analysis.

System Interactions

As in previous analyses conducted to examine GM AEB and FCA features, there appears to be a significant interaction between the type of forward collision prevention system and vehicle type, which is depicted in Figure 4. Under this interaction, there appears to be a general pattern towards lower AEB effectiveness on larger vehicles (large utilities and trucks). On sedans and small/medium SUVs, camera and Radar/Fusion AEB have similar effectiveness levels, suggesting that the lower levels of Camera AEB effectiveness reported above are due to the prevalence of Camera AEB on larger vehicles.

In addition to the Camera AEB effect, there is a slight interaction for the "Camera FCA only" feature. In that case, it appears that trucks in particular have slightly worse performance than sedans (small/medium utilities and vans are also present, but not in high volumes). This may explain the reduced effectiveness estimate for FCA in this analysis, as trucks have increased weight in the MY 17-21 dataset examined in the current effort (see Table 6).

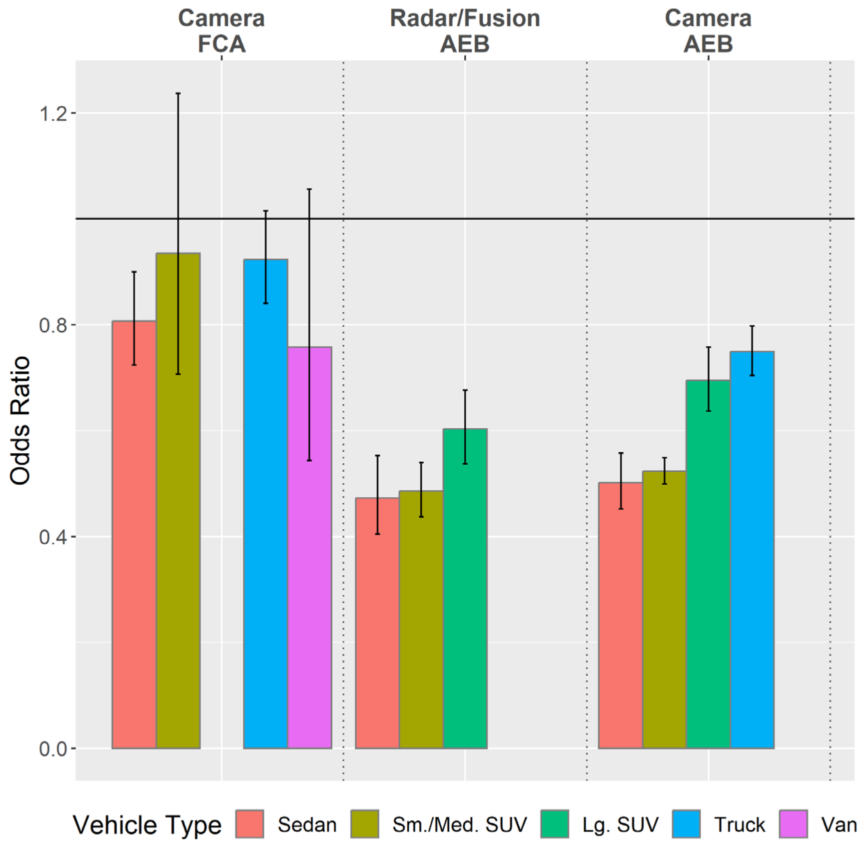

Figure 4 Estimated adjusted odds ratios for forward collision preventions systems when including an interaction between ADAS system and vehicle type

Lane Departure Crash Prevention Analysis

Table 13 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 which only provides alerts, the LKA with LDW feature by design effectively reduces the number of LDW alerts. The reference category for the feature factor is “Unequipped” for both the LDW (i.e., “LDW only”) and LKA with LDW features.

This analysis used three system-relevant crash definitions that identify the three main subsets of the general “lane departure” crash type. These subsets are same direction sideswipes crashes, opposite direction sideswipes (which include head-on crashes), and single vehicle road departure crashes. As seen in Table 11 and Table 13, the majority of the system-relevant crashes were same direction sideswipes, though the volume of injury-related crashes as defined in the current analysis were roughly comparable across the three crash subsets (due to the difference in severity of the crash types).

Figure 5 indicates that across lane departure system-relevant crash types LDW did not provide any significant benefit, whereas the LKA with LDW system provided benefits in all three types. For the same-direction sideswipe crash type, LKA with LDW produced a significant 8% reduction (odds ratio=0.92). This LKA beneficial effect increased for single vehicle road departures to 15% (odds ratio=0.85). Unlike in the previous MY 13-20 analysis, the effect of LKA with LDW for the opposite direction crash type was significant with a reduction of 7% (odds ratio=0.93).

Table 13 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	45,750 (system-relevant); 79,066 (control)
- Opposite Direction	7,793 (system-relevant); 76,800 (control)
- Road Departure	15,669 (system-relevant); 76,800 (control)
Injury Crashes	
- Same Direction	1,912 (system-relevant); 79,506 (control[5])
- Opposite Direction	2,065 (system-relevant); 76,852 (control[4])
- Road Departure	2,512 (system-relevant); 76,800 (control)

More generally, the magnitude of these estimated LKA with LDW effectiveness estimates are quite consistent with those observed in the MY 13-20 analysis. The LDW results were less consistent, with the same direction and single vehicle road departure estimates now showing non-significant disbenefits. A change of this magnitude can likely be attributed to the change in vehicle equipage across model years. The MY 17-21 analysis has relatively few SUVs equipped with LDW, meaning that the effect is more driven by equipped trucks, which means that the observed pattern can be readily explained by the interaction effect discussed 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 same direction sideswipes and opposite direction sideswipes (which includes head-on crashes), which necessarily involve two vehicles, the crash can occur if either the GM host vehicle and/or the “other” crash-involved vehicle departs its lane. As such, if we assume that the “other” vehicle was responsible for approximately 50% of the system-relevant crash cases, then the estimated effectiveness of LDW and LKA with LDW for these cases would be half of the true estimate for crashes in which the GM vehicle initiates the crash. Considering the distinction between single- versus two-vehicle lane departure crash types, the results across crash types are strikingly consistent, such that if the same-direction and opposite-direction results were doubled, they would fall within 1% of the road departure effectiveness estimate of 15%.

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[5] The number of control crashes in the injury crash models differs from the “all crashes” models due to missingness combined with different significance of the main effects.

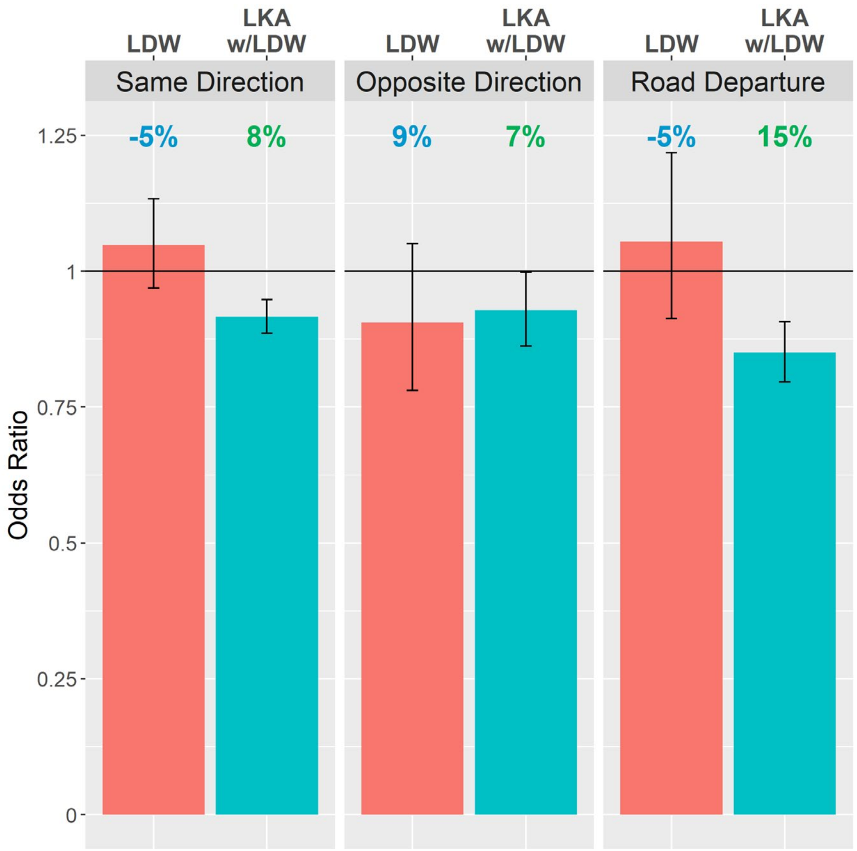

Figure 5 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the lane departure crash prevention systems

Injury Crash Analysis

The corresponding injury-focused analysis of lane departure crashes, shown in Figure 6, is less consistent with previous analyses. While the single vehicle road departure case results closely mirror MY 13-20 results, with a significant LKA with LDW benefit of 22% and no significant LDW effect (the LKA with LDW effect in previous analysis was 21% and the LDW effect was similarly non-significant), the same and opposite direction cases no longer show a significant benefit of LKA with LDW in injury crashes. There is some overall increase in the confidence interval widths for these latter two crash type cases, but the observed 9% and 2% estimates for same and opposite direction crashes are much lower than the 16% and 19% effects, respectively, seen in the MY 13-20 analyses. These patterns seem to be due to the decreased sample size and the change in the vehicle type mix of equipped vehicles in the MY 17-21 analysis, and hence, should continue to be monitored in follow-on efforts. Since the effectiveness of lane departure systems is clearest in the single vehicle road departure case, it is encouraging that the injury-focused results from the road departure analysis have remained stable, and the pattern of results for road departure crashes continues to indicate there is an enhanced benefit of the LKA with LDW system for injury crashes.

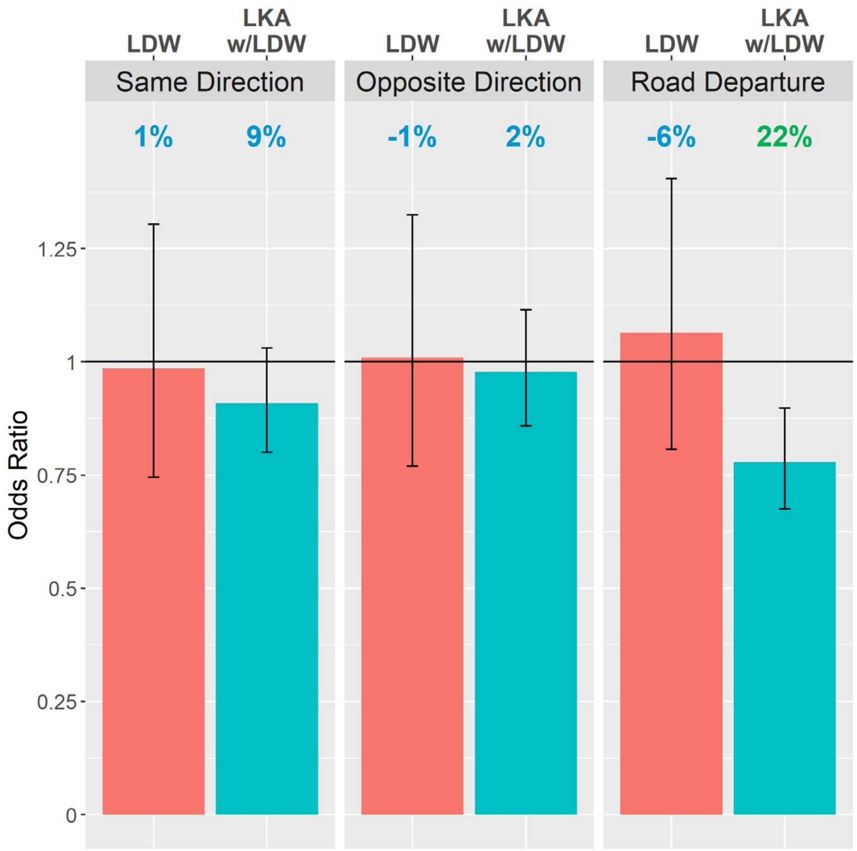

Figure 6 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) in injury ("B" or higher on KABCO scale) crashes for the lane departure crash prevention systems in the injury-focused analysis.

System Interactions

For lane departure crashes, three interactions were observed to be notable with the system type (i.e., LDW only versus LKA with LDW). Under the first interaction involving vehicle type (consistent with MY 13-20 results), decreased performance of LKA with LDW for trucks was observed compared to sedans and small/medium and large utility vehicles, with no benefit observed for trucks. Since GM has indicated that the decreased performance for trucks could be due to differences in system calibrations, which have been changed in newer vehicles, no further exploration of this interaction was performed in the current analysis. (For further details on this interaction the reader is referred to Leslie et al. (2022)).

The other two notable interactions observed were restricted to the single vehicle road departure crash type, where the system type was shown to interact with road surface (see Figure 7) and weather condition (see Figure 8). In both cases, while the interaction did not produce a significant change in LDW effectiveness, the LKA benefit is restricted to non-adverse conditions (i.e., "dry" and "clear/cloudy"). This pattern may be related to a number of factors, including reduced traction, reduced system availability, or selective customer use under adverse conditions (the user manual directs drivers not to use the system under inclement weather conditions).

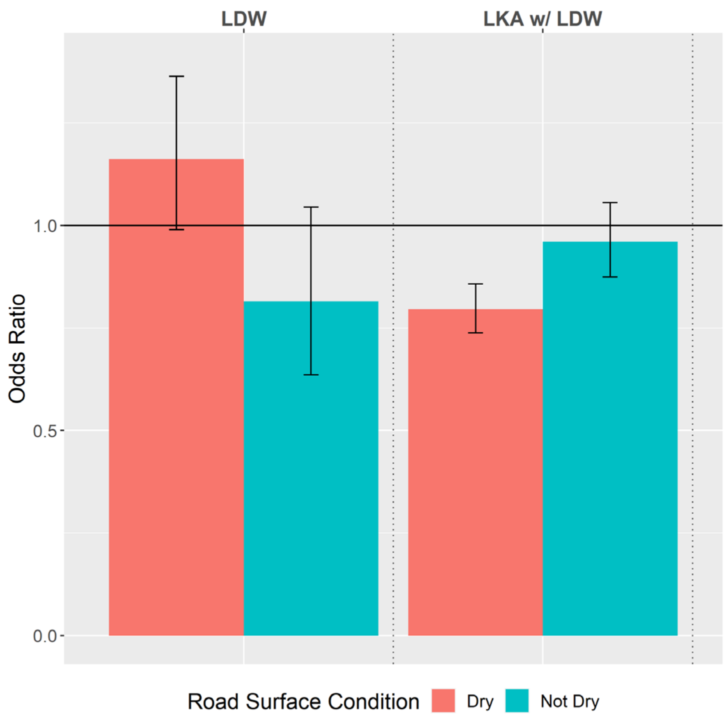

Figure 7 Estimated odds ratios for lane departure prevention systems when including an interaction between ADAS system type and road surface condition

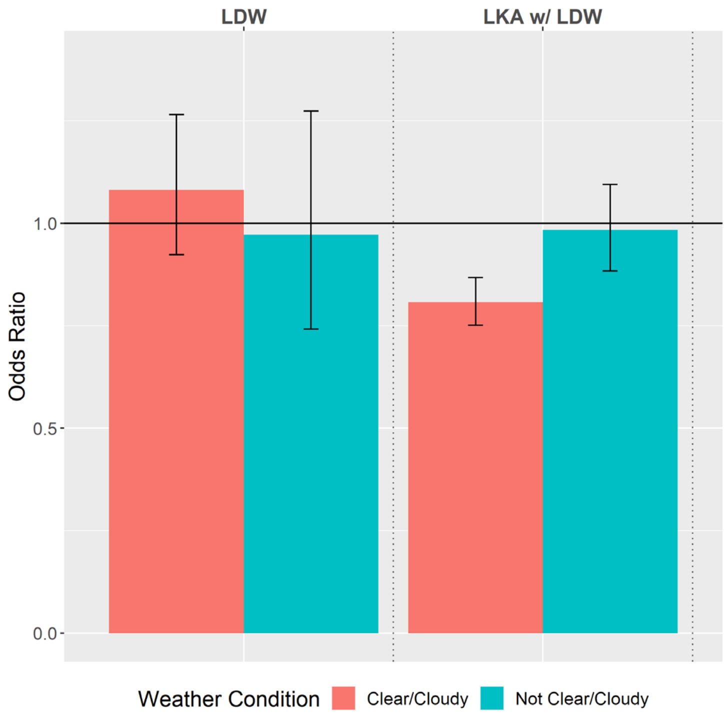

Figure 8 Estimated odds ratios for lane departure prevention systems when including an interaction between ADAS system type and weather condition

Lane Change Crash Prevention Analysis

Table 14 provides a summary of the lane change crash prevention analysis. Note that the LCA (with SBZA) feature provides substantially greater ranges for detecting approaching vehicles compared to the SBZA feature, which is of particular importance for alerting drivers to vehicles rapidly approaching from outside the side blind zone area. To assess the lane change feature effect, the reference level was "Unequipped" for LCA (with SBZA), SBZA, RCM (with LCA and SBZA), and Trailer SBZA.

Table 14 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	13,194 (system-relevant); 110,953 (control)

Figure 9 indicates the LCA with SBZA feature significant reduced system-relevant lane change crashes. The observed LCA with SBZA 15% reduction (odds ratio=0.85) mirrors the effect observed in the MY 13-20 analysis (16%). The SBZA alone effect was not significant, consistent with previous analyses, and the confidence bound increased substantially due to the smaller volume of equipped vehicles after the exclusion of the MY 13-16 vehicles in this analysis for reasons discussed above.

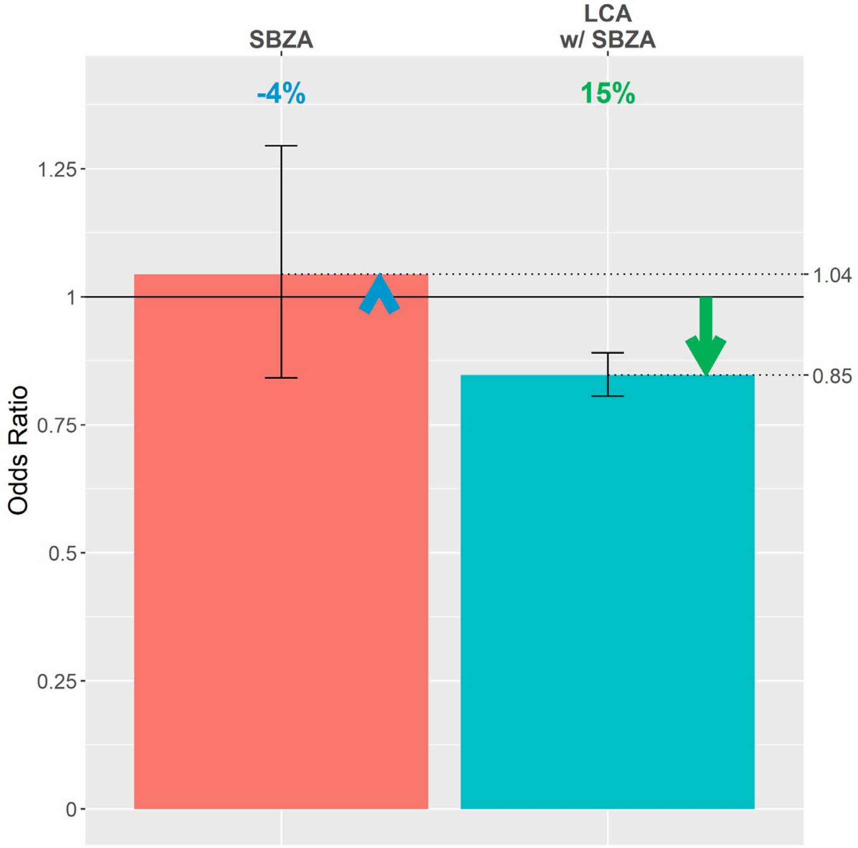

Figure 9 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the lane change crash prevention systems

Backing Crash Prevention Analysis

Table 15 provides a summary of the backing crash prevention analysis. Since there was not a reliable way to identify different backing crash types (e.g., parking, higher-speed backing, cross traffic) via available police reports, the four lower-speed park assist-related features (i.e., Rear Park Assist (RPA), Front and Rear Park Assist (FRPA), Automatic Park Assist with Steering (or APA2), and Enhanced Automatic Park Assist) were collapsed and treated as a single collective RPA feature. Furthermore, while Surround Vision (SV) was technically available without Rear Cross Traffic Alert (RCTA) or Reverse Automatic Braking (RAB), it was not at a production volume that allowed us to analyze Surround Vision (SV) as an independent effect for the single collective RPA feature in the current analysis. Also note that since SV includes RVC functionality, failing to differentiate between features was deemed a reasonable approach. This analysis also considers a third type of rear camera feature, Rear Vision Camera Mirror (RVC mirror), which is only available on vans. This feature, not to be confused with Rear Camera Mirror (discussed above in the *Lane Change Crash Prevention Analysis*), displays the standard RVC image in the interior rear-view mirror. This feature was not offered with other backing features but is differentiated in this analysis from (standard) the RVC feature. Starting for MY 21 vehicles, two additional, low-volume variants of RVC, Front Curb View and Rear Trailer View, were collapsed and treated as part of a collective RVC feature.

Due to GM's tendency to stack up backing/parking features, as shown in Table 15, the feature levels were treated as hierarchical with the more advanced feature taking priority (e.g., a car with RCTA but not offering AEB automatically falls into the RCTA 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 in Table 15 (when ignoring the RVC versus SV distinction noted above). There were two exceptions to this hierarchical backing feature assumption which involved a relatively small number of cases in the available vehicle dataset: (1) RCTA did not include an RPA feature in approximately 0.9% of cases, (2) RPA did not include RVC or SV in approximately 0.4% of cases. For the effect sizes, the features were compared to a reference level of "Unequipped" for each of the backing features shown in Table 15.

Table 15 Summary of the backing crash prevention analysis

Characteristic	Value
Feature Levels	Rear Vision Camera (RVC)[6] Rear Vision Camera Mirror (RVC Mirror) Rear Park Assist (RPA)[7] Rear Cross Traffic Alert w/RVC or Surround Vision (SV) Reverse Automatic Braking w/RCTA, RPA & RVC or SV
System-relevant Crash	Backing Crash
Control Crash	Rear-end Struck
Analysis Subset Sample Sizes	12,332 (system-relevant); 116,070 (control)

Figure 10 indicates that all the backing features examined, with the exception of RVC Mirror, significantly reduced the incidence of system-relevant backing crashes. These crash reduction benefits

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[6] Rear Vision Camera includes the Front Curb View and Rear Trailer View systems.

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

occur with a stack-up effect, such that more advanced backing features (which generally include all less advanced backing features) show increasing backing crash reduction levels. RVC produces a significant 34% reduction (odds ratio=0.66) and, while non-significant, the RVC Mirror feature point estimate result is consistent with an estimated 27% reduction (odds ratio=0.73) in backing crashes. Furthermore, the RPA effect is estimated at 49% (odds ratio=0.51), a 15% improvement beyond observed RVC effectiveness levels. The RCTA effect is estimated at a 62% reduction (odds ratio=0.38), which provides a 13% improvement beyond RPA effectiveness levels. RAB effectiveness is estimated at an 85% reduction (odds ratio=0.15), which provided a 23% improvement beyond observed RCTA effectiveness levels.

Overall, these results are consistent with those seen in the MY 13-20 analysis, aside from some relatively small increases in effectiveness that appear well within the previous confidence bounds for corresponding effectiveness estimates. The largest shifts in effectiveness were for RPA, which increased from 41% to 49% in this analysis. The increase in RPA effectiveness is likely due to the change in the equipped vehicle type mixture. While there has never been a significant vehicle type interaction in previous GM backing crash prevention analyses, comparisons across analyses performed at different times suggest that larger vehicles may get slightly greater benefits, which could explain the increase in effectiveness levels observed here.

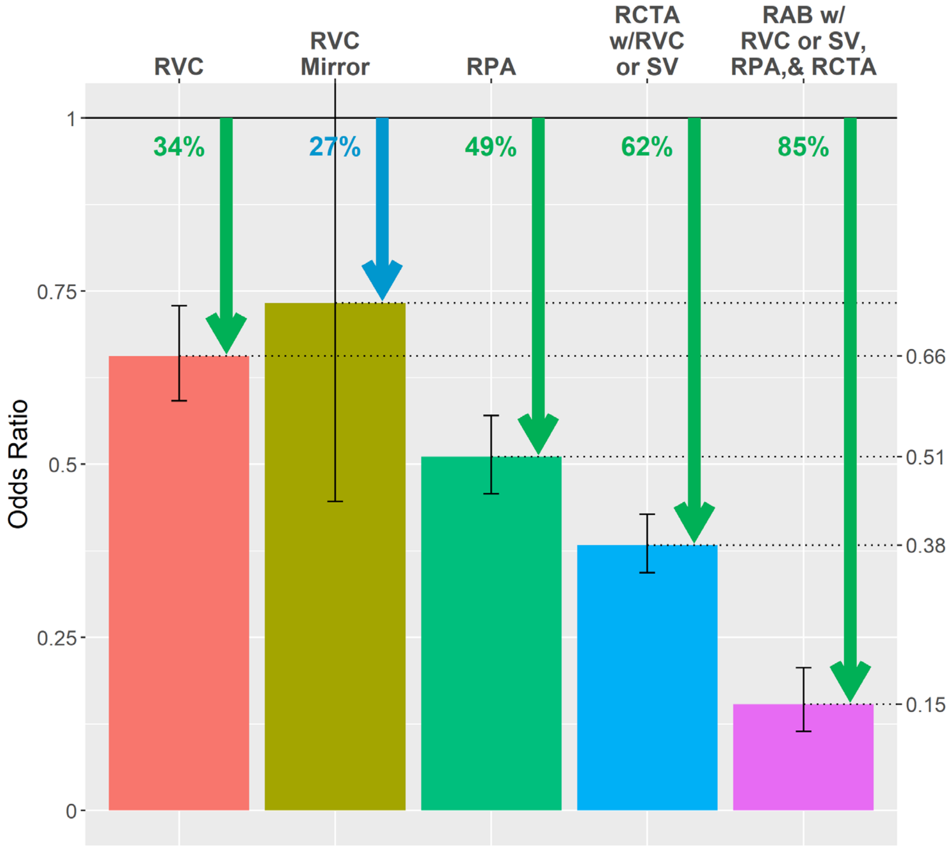

Figure 10 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the parking/backing crash prevention systems. (The Rear Park Assist, Front and Rear Park Assist, and Automatic Parking Assist features were all treated as Rear Park Assist for this analysis).

As with several other ADAS systems, RVC (or a variant) is rapidly becoming standard across the fleet. As a result, unequipped crashes are becoming rare (as seen in Table 11) making “unequipped” a less useful reference category for comparisons. The hierarchical behavior of backing systems means that RVC could potentially serve as a newer, more useful reference level for assessing backing feature effectiveness. The results of such a model using RVC as the reference level for the MY 17-21 dataset is shown in Figure 11. In addition to providing an estimate of the benefit compared to a (standard) RVC, these estimates can be used to construct an estimated benefit compared to unequipped by using the last known estimate of RVC effectiveness. For the MY 17-21 data, this would be the estimated 31% from the previous MY 13-20 study. The true" MY 17-21 estimates, as well as corrected RVC reference estimates, are shown in Table 16. The correspondence between the previously used approach and the potential new approach using RVC as the reference level is quite good, except for the RVC Mirror feature, which is confounded with the van effect in this model (due to the exclusion of unequipped vans). Hence, this latter effect would require special handling or would need to be rolled (or collapsed) into the general RVC category. In total, these results suggest that an approach like this is suitable for most systems with a hierarchical structure, though other alternative approaches will be required for crash types where a "top-level" system becomes standard (such as AEB).

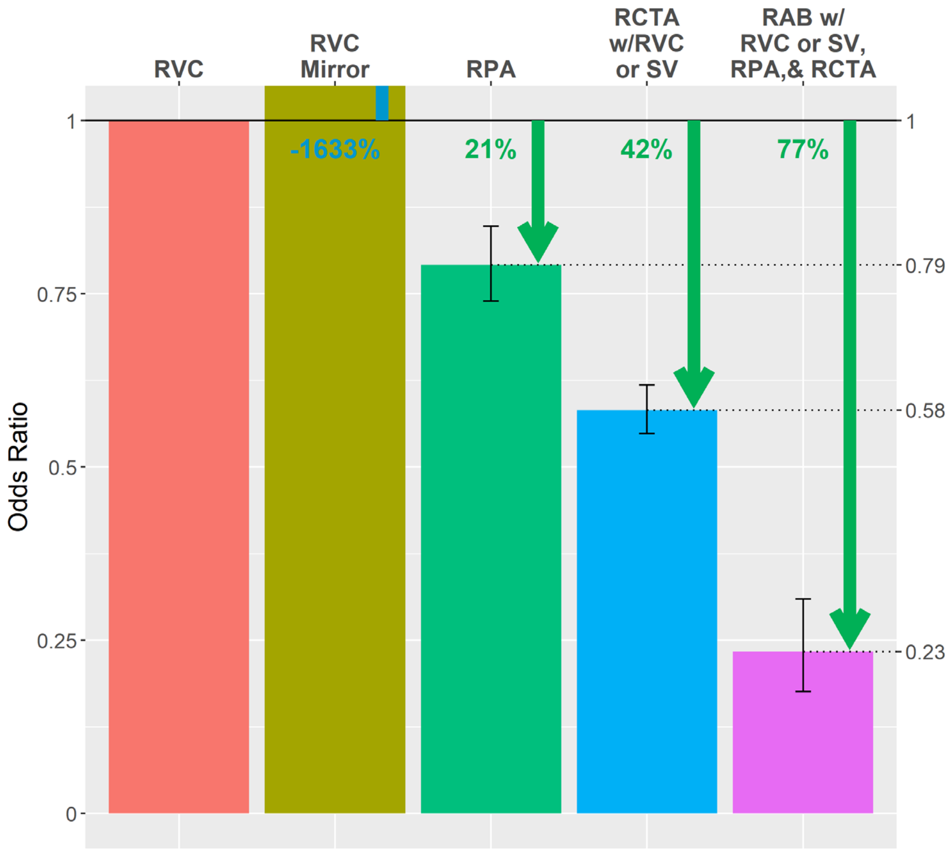

Figure 11 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the parking/backing crash prevention systems using RVC as a reference rather than unequipped.

Table 16 Estimated effectiveness estimates for backing systems using "unequipped" reverence and corrected estimates using an "RVC" reference

System	True MY 17-21 Estimate	Corrected “RVC Reference” Estimate
Rear Vision Camera	34%	31%
Rear Vision Camera Mirror	27%	-1096%
Rear Park Assist	49%	45%
Rear Cross Traffic Alert w/ RVC or SV	63%	60%
Rear Automatic Braking w/ RVC or SV	85%	84%

Front Pedestrian Crash Prevention Analysis

Table 17 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 known limited nighttime performance. Furthermore, since FPB was not available on vans, vans were excluded from this 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 (1,146 (1.4%) of the 79,743 cases in the analysis subset). FPB was compared against the reference level of “Unequipped” with FPB.

Table 17 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	1,146 (system-relevant); 78,597 (control)

Figure 12 shows the analysis results, which indicate that FPB provided a significant 23% reduction (odds ratio=0.77) in system-relevant front pedestrian crashes, which matches that observed in the MY 13-20 analysis (though the confidence interval has reduced yielding greater confidence in the current estimate). Though we continue to monitor for interactions between the FPB feature and various confounding factors (including light condition), no significant interactions were identified in this analysis, which could be related to the lower sample size of pedestrian crashes.

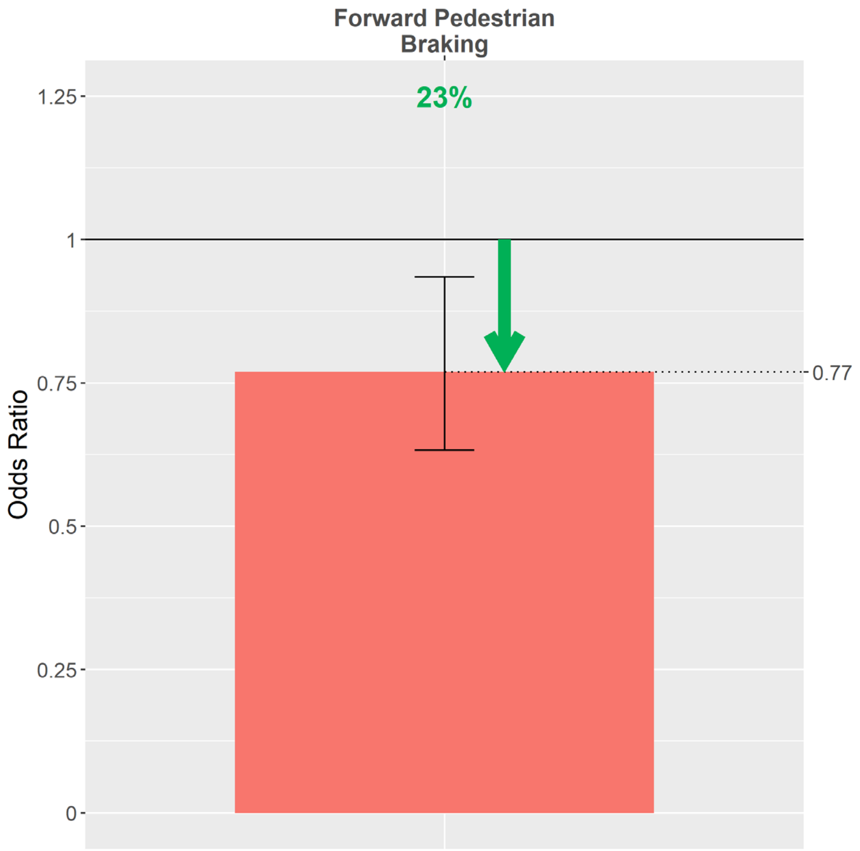

Figure 12 Estimated adjusted odds ratios and percent reductions in odds (i.e., system-relevant crashes) for the front pedestrian braking crash prevention system

Discussion

Background and Methodological Approach

This effort is the fifth in a series of studies examining the field effectiveness of various GM ADAS features aimed at addressing a wide range of system-relevant crash types. The current updated GM MY 17-21 ADAS effectiveness study employed VIN-linked feature ADAS content data from over 11.2 million vehicles of various vehicle types across GM brands (i.e., Buick, Cadillac, Chevrolet, and GMC). These data were matched to police report crash data available to UMTRI in 14 states, which resulted in identifying 600,613 matched crash cases. More generally, it should be stressed that the safety benefits reported here incorporate important real-world factors such as the extent to which drivers leave these features on (which is not available in the police-report data), the demographics of drivers of ADAS-equipped vehicles, and the wide range of driving conditions experienced by drivers with these features.

Unlike prior GM ADAS feature effectiveness analyses, MY 13-16 data were removed from the current analysis. This was done to address the issue that older vehicles tended to dominate the matched MY13-21 crash sample, but over time, the GM ADAS-equipped fleet has shifted from being sedan-focused at relatively low ADAS-equipped volumes to now including substantially higher ADAS feature penetrations that also include other vehicle types, notably larger SUVs and trucks. Hence, by dropping the older and less ADAS-equipped vehicles, the new sample examined here is proportionally more similar to the overall GM fleet with respect to the distribution of the various vehicle types. A consequence of dropping MY13-16 data was that relative to the previous GM MY 13-20 analysis, the number of matched vehicles included in the analysis was 6% lower the previous analysis, since the older vehicles have more crash exposure (i.e., years in which to experience a crash).

ADAS feature effectiveness (i.e., percent reductions in system-relevant crashes) was estimated using "quasi-induced exposure" logistic regression. This 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 ADAS equipped and unequipped vehicle 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 the forward collision and lane departure features examined, 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 injury" or higher injury severity for anyone involved in the crash (defined as "K", "A" or "B" on the KABCO injury scale), which will be referred to in the summary below simply as the "injury" analysis. This injury-focused analysis can be contrasted with the "all crashes" analysis, which did not consider the police-reported injury level.

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

Table 18 summarizes the estimated effectiveness of ADAS features designed to address forward or lateral crashes. Percent effectiveness is relative to the system-relevant crash types that the feature is designed to address. Results for the current MY17-21 analysis are shown in the second column of Table 18, whereas results from the two most recent GM ADAS feature effectiveness analyses (MY13-20 and MY13-19) are shown in the two rightmost columns. The results from this updated GM ADAS feature effectiveness analysis are generally similar to those observed across previous analyses, except for the LDW feature, which is being phased out by GM and is being replaced by the LKA with LDW feature. In the current effort, the LDW feature did not produce significant benefits, which is felt to be attributed to the changes which have occurred across model years in the LDW-equipped penetrations across vehicle types. The remainder of this discussion will primarily focus on results from the current analysis.

Table 18 Estimated percent reductions in system-relevant crashes for GM Advanced Driver Assistance System (ADAS) features related to forward and lateral crashes. (Note AEB includes FCA and shaded green cells denote statistically significant effects. Also, the MY13-19 lane departure results, marked by an asterisk, did not differentiate between the component crash types.)

GM ACTIVE SAFETY FEATURE	**GM MY17-21 Crashes (CURRENT ANALYSIS)**	**GM MY13-20 Crashes**	**GM MY13-19 Crashes**
FORWARD COLLSISION			
Camera Forward Collision Alert (FCA)	14%	20%	20%
Radar/Fusion AEB	49%	45%	45%
Camera AEB	40%	40%	38%
Front Pedestrian Braking (FPB)	23%	23%	14%
LANE DEPARTURE - SAME DIRECTION SIDESWIPE			
Lane Departure Warning (LDW)	-5%	4%	10%*
Lane Keep Assist (LKA) with LDW	8%	10%	12%*
LANE DEPARTURE - OPPOSITE DIRECTION SIDESWIPE (INCLUDES HEAD-ON CRASHES)			
Lane Departure Warning (LDW)	9%	5%	
Lane Keep Assist (LKA) with LDW	7%	8%	
LANE DEPARTURE - SINGLE VEHICLE ROAD DEPARTURE			
Lane Departure Warning (LDW)	-5%	8%	
Lane Keep Assist (LKA) with LDW	15%	17%	
LANE CHANGE			
Side Blind Zone Alert (SBZA)	-4%	7%	9%
Lane Change Alert (LCA) with SBZA	15%	16%	16%

With respect to the current analysis, the forward collision systems were found to be quite effective at reducing rear-end striking crashes and, to a lesser extent, front pedestrian crashes, with the more automated AEB feature producing greater benefit than the Camera FCA feature (which only provides alerts to the driver). AEB systems were estimated to be 40% effective for camera-based systems and 49% effective for Radar/Fusion-based AEB. In contrast, the Camera FCA feature was found to be 14% effective on rear-end striking crashes.

The FPB feature was observed to reduce pedestrian crashes by 23%. Despite the known limitations of this feature under nighttime conditions, no significant interactions with light condition were identified in this analysis, which could be related to the relatively low sample of pedestrian crashes.

Lateral systems were generally less effective than forward collision systems, but the more automated LKA with LDW feature produced significant reductions in roadway departure, same-direction sideswipe, and opposite-direction sideswipe crashes (the latter of which includes head-on crashes) by 15%, 8%, and 7%, respectively. The former roadway departure benefit was found to be restricted to non-adverse conditions (i.e., “dry” and “clear/cloudy”). This latter road departure benefit was found to be restricted to non-adverse conditions (i.e., “dry” and “clear/cloudy”). The crash estimate for opposite-direction sideswipes (which include head-on crashes) trended in a positive direction at 9% effectiveness (p=0.19).

More generally, this pattern of lane departure countermeasure results emphasizes the importance of measuring the effects of such 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 left its lane 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.

In addition, The Lane Change Alert with Side Blind Zone Alert (LCA with SBZA) feature reduced lane change crashes by an estimated 15%. The Side Blind Zone Alert (SBZA) feature alone was not found to be significant (consistent with previous findings).

Table 19 shows the results for the ADAS features aimed at addressing backing crashes. Backing features are generally hierarchical, such that more advanced features also include the less advanced features. For example, RAB, the most automated backing feature examined, is bundled with RCTA, RPA, and either RVC or SV. Overall, a distinct stack-up effect is observed under which RVC, RPA, RCTA, and RAB significantly reduced backing crashes by 34%, 49%, 62%, and 85%, respectively. In addition, the RVC mirror feature (only offered in vans) showed an estimated 27% reduction in backing crashes, comparable to standard RVC, but failed to reach significance (likely due to small sample sizes).

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 police report data collection. Furthermore, it should also be noted that although GM offers features that are relevant to low-speed forward parking crashes (e.g., Front and Rear Park Assist), the inconsistency of parking crash coding across state crash databases did not allow a reasonable evaluation of effectiveness levels for such features in reducing such forward parking crashes.

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

GM ACTIVE SAFETY FEATURE	GM MY17-21 Crashes (CURRENT ANALYSIS)	GM MY13-20 Crashes	GM MY13-19 Crashes
BACKING (note more advanced backing features generally include less advanced backing features)			
Rear Vision Camera (RVC)	34%	31%	24%
Rear Vision Camera Mirror (RVC Mirror)	27%	33%	
Rear Park Assist (RPA, Front & Rear PA or Automatic PA 2)	49%	41%	36%
Rear Cross Traffic Alert (RCTA) with RVC or Surround Vision (SV)	62%	59%	55%
Reverse Automatic Braking (RAB) with RVC or SV & RPA & RCTA	85%	83%	82%

In addition, for the forward collision and lane departure features examined, sample sizes were large enough to support an additional "injury-focused" analysis using a more restricted set of crashes which were police-reported to be more severe crashes. 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)". In this injury-focused analysis, only crashes with a "K", "A", or "B" on the KABCO rating were included. This analysis can be contrasted with the more general analysis approach described above, which included "all crashes" irrespective of the police-reported injury levels.

The third column of Table 20 shows effectiveness estimates for the injury-focused analyses. For comparison purposes, the second column of Table 20 provides the current "all crashes" results, as well as corresponding injury-focused results from the MY 13-20 analysis. Across all front collision systems examined in these injury-focused analyses, effectiveness for injury crashes is higher than for all crashes, consistent with the previous analysis. This improved effectiveness, when restricting the analysis to crashes that police report as more severe, provides compelling and important evidence that even when the crashes are not prevented the reduction in impact speed due to alerting the driver or automatic braking can reduce injury risk. This mitigation is potentially responsible for the higher effectiveness levels for injury crashes. That is, it is likely that avoided crashes are typically those that would have been less severe (i.e., involved lower relative speeds). Conversely, this pattern of findings suggests some rear-end striking crashes that would have otherwise likely involved reported K-, A-, or B-injuries without FCA and AEB are potentially being shifted to C-injury or property damage-only crashes.

In the lateral collision injury-focused analysis, the only significant effect observed was for LKA with LDW on single vehicle road departure crashes, which as discussed above, can be more straightforward to interpret than two-vehicle same and opposite direction sideswipe crashes (where the role of the equipped vehicle in these crashes is less clear).

Table 20 Summary of effectiveness of forward collision and lane departure-related GM Advanced Driver Assistance System (ADAS) features for the injury-focused analysis. (Note AEB includes FCA and shaded green cells denote statistically significant effects.)

GM ACTIVE SAFETY FEATURE	GM MY17-21 (CURRENT ANALYSIS)	GM MY17-21 Injury-Focused (CURRENT ANALYSIS)	GM MY13-20	GM MY13-20 Injury-Focused
FORWARD COLLISION				
Camera Forward Collision Alert (FCA)	14%	25%	20%	25%
Radar/Fusion AEB (FSACC)	49%	57%	45%	58%
Camera AEB	40%	53%	40%	55%
LANE DEPARTURE - SAME DIRECTION SIDESWIPE				
Lane Departure Warning (LDW)	-5%	1%	4%	1%
Lane Keep Assist (LKA) with LDW	8%	9%	10%	16%
LANE DEPARTURE - OPPOSITE DIRECTION SIDESWIPE (INCLUDES HEAD-ON CRASHES)				
Lane Departure Warning (LDW)	9%	-1%	5%	-3%
Lane Keep Assist (LKA) with LDW	7%	2%	8%	19%
LANE DEPARTURE - SINGLE VEHICLE ROAD DEPARTURE				
Lane Departure Warning (LDW)	-5%	-6%	8%	-3%
Lane Keep Assist (LKA) with LDW	15%	22%	17%	21%

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 addition to alerts), since such features were found to consistently outperform their less advanced “alert only” counterparts (e.g., AEB versus FCA, LKA with LDW versus LDW only). The results also highlighted the need to address lane departure and lane change crashes at higher levels of effectiveness, the former of which is likely related to lower customer use of the LKA with LDW and LDW features.

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 feature usage), and feature penetration across the entire fleet (not just the GM portion of the fleet). Table 21, adapted from Swanson et al. (2019), shows estimated counts and percentages of crashes in the United States where a light vehicle performed the critical pre-crash action used here for defining system-relevant crashes. This simplified version of the Swanson et al. crash types, under which multiple crash types are combined (e.g., five separate rear-end crash types are mapped to a single collective rear-end striking crash type), identifies crashes plausibly addressable by the ADAS features examined in this analysis. If one assumes that all of the crash types shown in the rightmost column are addressable by one or more of the ADAS features examined in the current study, the current set of features examined have the maximum potential (i.e., if 100% effective) to address approximately 55.4% of all US crashes and 60.3% of fatal crashes. If we further assume that that the entire US fleet were equipped with the GM Radar/Fusion AEB, LKA (with LDW), LCA (with SBZA) and RAB (with RPA and RCTA) features examined here at their estimated effectiveness rates shown in Figure-ES 1, approximately 37.7% of addressable crashes, and 20.9% of all crashes, are estimated to be prevented.

Table 21 Estimated counts of crashes where the critical action was performed by a light vehicle (adapted from Swanson, et al. (2019) Table 12)

Crash Type	Fatal Crashes	Percentage of Fatal Crashes	All Crashes	Percentage of All Crashes	Mapped Swanson Crash Type
Rear-end	1,244	4.9%	1,709,716	31.2%	20-24
Pedestrian	3,731	14.7%	70,461	1.3%	9, 10
Lane Change	285	1.1%	320,052	5.8%	16
Backing	61	0.2%	166,550	3.0%	6, 13
Same Direction Drifting	196	0.8%	120,223	2.2%	17
Opposite Direction	3,258	12.9%	100,786	1.8%	18, 19
Road Departure	6,501	25.6%	547,098	10.0%	7, 8
Total Addressable	15,276	60.3%	3,034,886	55.4%	
Unaddressed	10,074	39.7%	2,446,000	44.6%	
Total	25,350	100.0%	5,480,886	100.0%	

More generally, there remain significant opportunities for moving toward zero crashes beyond improving or expanding 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 additional crash configurations (e.g., intersection crashes). Going forward, we recommend continuing this series of ADAS feature effectiveness studies, leveraging additional state crash databases as they become available to researchers, and exploring the use of telematics-based data (such as GM's OnStar low-level EDR and AACN data). This telematics data could enhance understanding of feature usage surrounding the crash (including feature usage more generally) and potentially enable more timely access to crash data automatically generated by the vehicle. This telematics-based crash data collection approach can be contrasted with state agency police report data, which have approximately 1- to 2-year delays due to availability, but also provide more detailed data surrounding crash circumstances. Finally, we also recommend using these large-scale field effectiveness estimates for informing New Car Assessment Program (NCAP) decision-making and feature content decision-making and planning.

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