

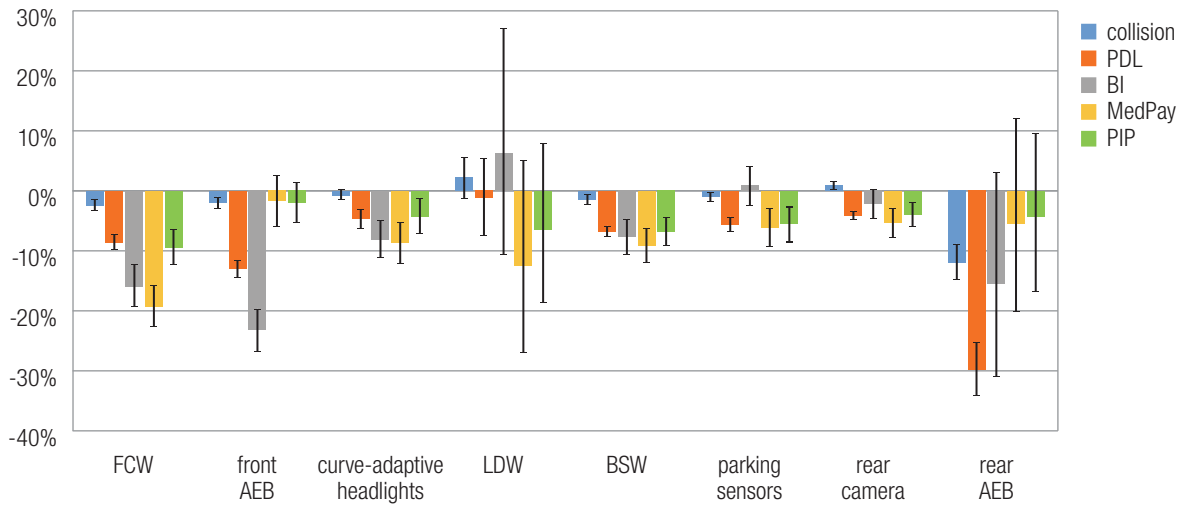


## Compendium of HLDI collision avoidance research

### ► Summary

The Highway Loss Data Institute (HLDI) has evaluated and reported on collision avoidance technologies since 2009. HLDI has published nearly 50 research reports to date evaluating collision avoidance technologies offered by individual manufacturers. This compendium synthesizes the most recent findings from these analyses and combines findings from individual manufacturers to estimate the overall effect of each technology on the frequency of claims and the effect of vulnerable, front-end-mounted technologies like curve-adaptive headlights on collision claim severity and overall losses. Overall, many collision avoidance technologies have reduced the frequency of claims under various coverage types and were seldom associated with increased claim frequency. Front automatic emergency braking (AEB) and rear AEB, technologies that automatically take action for the driver in a crash-imminent situation, were associated with larger reductions in the frequency of claims than technologies that rely on the driver to respond to warnings. Curve-adaptive headlights and forward collision warning, both of which are enabled by front-mounted equipment vulnerable to damage in a crash, were associated with increased claim severity. Although the findings indicate that collision avoidance technologies are reducing the frequency of claims under various coverage types, the benefits are only being experienced by a fraction of vehicles in the U.S. fleet. The number of claims filed by the entire population of vehicles in the U.S. fleet each year will continue to decrease as the proportion of the vehicle population equipped with collision avoidance technologies increases in the coming decades.

**Percent change in claim frequency associated with the presence of various collision avoidance technologies by coverage type**



## ► Introduction

Collision avoidance technology has the potential to reduce crashes and related injuries and deaths. An Insurance Institute for Highway Safety (IIHS) analysis of police-reported crashes between 2004 and 2008 indicated that, together, forward collision warning, lane departure warning, blind spot monitoring, and curve-adaptive headlights could prevent or mitigate nearly one-third of crashes reported to police each year (Jermakian, 2011). In 2009, HLDI was the first group to document the effects of a collision avoidance technology on motor vehicle crashes when it evaluated the Mercedes-Benz Distronic system (HLDI, 2009). Since then, HLDI has published nearly 50 manufacturer-specific research reports documenting the efficacy of various collision avoidance technologies for reducing claim frequencies and insurance losses. This report summarizes HLDI's most recent evaluations for the following collision avoidance technologies: forward collision warning (FCW), front automatic emergency braking (AEB), curve-adaptive headlights, lane departure warning (LDW), blind spot warning, parking sensors, rear camera, and rear AEB (HLDI, 2016a-d; 2017a; 2017b; 2017e-g; 2018a-e). Results were combined to estimate the overall effect of each technology on the frequency of claims across the manufacturers and vehicle models examined to date. Collision claim severity and overall loss results were combined across manufacturers and vehicle models only for those technologies mounted on the front of the vehicle and most susceptible to damage in a crash.

## ► Methods

### Vehicles

HLDI analyses of collision avoidance technologies have examined insurance claim frequencies, severities, and overall losses for 10 manufacturers: Acura, Audi, Buick, Dodge/Jeep, General Motors, Honda, Mazda, Mercedes-Benz, Subaru, and Volvo. Many collision avoidance technologies offered by these manufacturers are not available as standard equipment and are optional. Consequently, HLDI had to discern the vehicles equipped with crash avoidance technologies from the unequipped vehicles to evaluate each technology's effect on claim frequencies, severities, and overall losses. HLDI used three ways to determine the presence or absence of collision avoidance technologies for vehicles in a study population.

- A manufacturer supplied HLDI with vehicle identification numbers (VINs) and the presence or absence of collision avoidance technologies for each VIN. This approach was used to analyze the effects of collision avoidance technologies for Acura, Audi, Buick, Dodge/Jeep, General Motors, Mazda, Mercedes-Benz, and Volvo vehicles.
- Some collision avoidance technologies are equipped to certain vehicle trim levels. The trim level can be identified in the first 10 positions of the VIN for some manufacturers, allowing the presence of an associated collision avoidance technology to be determined. This approach was used to analyze collision avoidance technologies on the Acura TLX, Honda Accord, Honda Odyssey, and Honda Pilot.
- Some manufacturers explicitly code the presence of collision avoidance technologies in the first 10 positions of the VIN. This approach was used to analyze collision avoidance technologies for Subaru and some Honda vehicles.

### Collision avoidance technologies

This report summarizes the most recent HLDI results for the following collision avoidance technologies:

**Forward collision warning (FCW)** uses sensors like cameras or radar to detect when the vehicle is getting too close to the one in front of it and alerts the driver using an audible, visual, and/or haptic warning. Some systems also are capable of detecting pedestrians.

**Front AEB** use the same kinds of sensors as forward collision warning and automatically applies the vehicle brakes if the driver does not respond to the warning (if presented) or the crash-imminent situation.

**Curve-adaptive headlights** pivot in the direction of travel based on steering wheel movement and sometimes the vehicle's speed to better illuminate curved roads at night. Curve-adaptive headlights may use traditional incandescent or halogen light types or newer light types like light-emitting diode (LED) or high intensity discharge (HID).

**Lane departure warning (LDW)** uses cameras to track the vehicle's position in the lane and alerts the driver if the vehicle inadvertently strays across the lane markings when the turn signal is not activated. Some systems also support lane-keeping by directing the vehicle back into the lane using light braking or minor steering adjustments.

**Blind spot warning (BSW)** uses sensors to monitor areas beside the vehicle and alerts the driver when a vehicle is detected in a blind spot or when a vehicle is swiftly approaching the blind spot.

Honda offers a related technology called LaneWatch that uses a rear-facing camera to display a video of the blind spot on the passenger side of the vehicle to the driver. Although similar in purpose to other BSW systems, Honda Lane-Watch does not provide warnings and only operates on one side of the vehicle, so it was excluded from this report.

**Parking sensors** use radar or ultrasonic sensors to detect nearby objects or objects in the vehicle's path to help drivers park and back up.

**Rear cameras** enhance rear visibility by providing a view of the area directly behind the vehicle in an interior display.

**Rear AEB** automatically applies the brakes to keep the vehicle from reversing into an object detected by sensors like radar, ultrasonic sensors, or camera.

## Other technologies

Some collision avoidance features are only available with other collision avoidance or advanced driver assistance features. Other features associated with the collision avoidance technologies above include:

**Adaptive cruise control (ACC)** maintains a set speed and following distance from the vehicle ahead using information from a camera or radar sensor. Frequently, it is present on vehicles equipped with FCW or front AEB.

**Rear cross-traffic alert (RCTA)** issues a warning when the vehicle is reversing and another vehicle approaching from either side is detected that may cross its path. RCTA often is enabled by the same radar sensor that enables BSW.

**Distance alert** uses information from a camera or radar to inform the driver about the time interval to the vehicle in front and alerts the driver when the vehicle is closer than a set time interval. This function is sometimes combined with FCW or front AEB.

**Fatigue warning** alerts the driver if signs of drowsiness are detected based on steering input and other driver behaviors.

**Surround view cameras** integrate views from multiple cameras including a rear camera to provide the driver with a 360-degree, panorama top-down view of the vehicle and its surroundings to assist the driver with parking and other low-speed maneuvers.

**Automatic high beams** use a camera to detect headlights and taillights from other vehicles and automatically switch between low and high beams to better illuminate the road ahead without blinding other drivers.

Manufacturers have adopted different names for the technologies listed above. For simplicity, this report uses the terms above when discussing the results for each manufacturer. Some manufacturers offer multiple versions of the same collision avoidance technology. The marketing name of the collision avoidance technology is included in these instances.

## Insurance data

Automobile insurance covers damages to vehicles and property in crashes and injuries to people involved in crashes. Different insurance coverages pay for vehicle damage versus injuries, and different coverages may apply depending on who is at fault. This report discusses results for property damage liability (PDL), collision, bodily injury (BI) liability, personal injury protection (PIP), and medical payment (MedPay) coverages. Exposure was measured in insured vehicle years. An insured vehicle year is one vehicle insured for 1 year, two vehicles insured for 6 months, etc.

Collision avoidance technologies may affect different insurance coverage types differently, so it is important to understand how coverages vary among the states and how this affects inclusion in the analyses. Collision coverage insures against vehicle damage to an at-fault driver's vehicle sustained in a crash with an object or other vehicle. This coverage is common to all 50 states. PDL coverage insures against physical damage that at-fault drivers cause to other people's vehicles and property in crashes. This coverage exists in all states except Michigan, where vehicle damage is covered on a no-fault basis where each insured vehicle pays for its own damage in a crash, regardless of who is at fault.

Coverage of injuries is more complex. BI liability coverage insures against medical, hospital, and other expenses for injuries that at-fault drivers inflict on occupants of other vehicles or other road users. Although motorists in most states may have BI liability coverage, this information was only analyzed for the 33 states with traditional tort insurance systems where the at-fault driver has first obligation to pay for injuries. MedPay coverage also is sold in the 33 states with traditional tort insurance systems and covers injuries to insured drivers and the passengers in their vehicles, but not injuries to people in other vehicles involved in the crash. The 17 other states without traditional tort insurance systems employ no-fault injury systems where PIP coverage pays up to a specified amount for injuries to occupants of involved-insured vehicles, regardless of who is at fault in a collision. The District of Columbia has a hybrid insurance system for injuries and was excluded from each injury analysis.

### **Statistical methods**

The HLDI research discussed in this report used regression analysis to quantify the effect of each collision avoidance technology on claim frequencies by comparing vehicles equipped with a collision avoidance technology to vehicles without the technology. The same method was used to quantify the effect of curve-adaptive headlights, forward collision warning, and front AEB on collision claim severities and overall losses. All regression models included a variable that indicated the presence or absence of a collision avoidance technology for a specific model year, make, and series vehicle. Other covariates included were: calendar year; model year; garaging state; vehicle density, defined as the number of registered vehicles per square mile; rated driver age group; rated driver gender; rated driver marital status; deductible range for collision coverage; and rated risk. Additional variables indicating the presence of other collision avoidance technologies were included to better isolate the effect of the collision avoidance technology of interest. Finally, a variable that combined model year and vehicle series was included to control for vehicle design changes that occurred across model years.

Claim frequency was modeled using a Poisson distribution, and claim severity, defined as the average loss payment per claim, was modeled using a Gamma distribution. Both variables were modeled using a logarithmic link function. Estimates for overall losses were derived from the claim frequency and claim severity models. Estimates for claim frequency are presented for collision, PDL, BI liability, PIP, and MedPay coverage types. The frequency of BI liability, PIP, and MedPay claims is for all claims, including those that have been paid and those for which money has been set aside for possible payment in the future, known as claims with reserves. Collision claim severity and overall losses under collision coverage are only reported for forward collision warning, front AEB, and curve-adaptive headlights because these technologies are enabled by equipment mounted on the front of the vehicle and more vulnerable to damage in a crash (e.g., HLDI 2016e; 2017c).

The estimated effect of a crash avoidance technology is presented as a percent change. The percent change in an outcome measure was calculated by subtracting 1 from the exponent of the parameter estimate for the crash avoidance technology indicator variable and multiplying the resultant by 100. A percent change less than 0 indicated that the crash avoidance technology was associated with a reduction in the outcome measure, and a value above 0 indicated the technology was associated with an increase in the outcome measure. The percent change can be considered statistically significant when the 95 percent confidence interval does not include 0.

### **Combined analysis**

A weighted average was calculated to estimate the combined effect of each crash avoidance technology on claim frequencies under each coverage type across manufacturers and vehicle models, and the combined effect of curve-adaptive headlights, forward collision warning, and front AEB on collision claim severity and overall losses. The weights in the average were proportional to the inverse variance of the respective estimates. Estimates with high variance as indicated by large confidence intervals contributed less than estimates with low variance as indicated by small confidence intervals. Wider confidence intervals typically reflected cases with less exposure and/or fewer claims. The weighted average is presented as a percent change.

The weighted average only included estimates from manufacturers or vehicle models where HLDI was reasonably certain that the model estimates were due to the collision avoidance technology of interest. Some manufacturers offered multiple versions of the same collision avoidance technology. For example, two front AEB systems offered by Mazda were included: Smart City Brake and Smart City Brake and Forward Object Warning (or FCW). Each version of the technology was included in the weighted average. The marketing name was used to differentiate the versions.

## Feature dependencies

Some collision avoidance technologies are only available with other technologies, and the effects of each technology on insurance claim frequencies cannot be separated. However, in some circumstances it is reasonable to assume that one technology contributes more to a model estimate than another. FCW addresses front-to-rear crashes that make up a much larger proportion of the crash population than crashes addressed by LDW. Jermakian (2011) estimated that FCW was relevant to about 20 percent of crashes reported to police each year, and LDW was only relevant to 3 percent. Likewise, in separate analyses of FCW and LDW, the proportion of police-reported crashes relevant to FCW was twice the size of the proportion that was relevant to LDW (Cicchino, 2017a; 2018a). Note that these studies examined different but comparable passenger vehicle populations. Thus, estimates for FCW that include LDW are assumed to mostly reflect the effect of FCW.

FCW, front AEB, and ACC are often enabled by the same radar and available together, but, while FCW and front AEB are typically always on (Reagan, Cicchino, Kerfoot, & Weast, 2018), ACC is used at the driver's discretion. Hence, estimates of FCW or front AEB that also included ACC were assumed to mostly reflect the effect of FCW and/or front AEB.

BSW systems enabled by radar sensors are often only available with RCTA. Backing crashes like those that occur in parking lots make up a small proportion of police-reported crashes (Cicchino, 2017b), but these low severity events are estimated to contribute to around one-fifth of collision and PDL claims (Wells, Gouse, & Williams, 1991). Hence, it is likely that RCTA, when combined with BSW, moderates any effect BSW alone has on insurance claim frequencies. Despite this limitation, BSW systems with RCTA were included in the weighted average with estimates of BSW alone. Future analyses will reconsider whether the weighted estimate for BSW should include systems where BSW is paired with RCTA. Throughout this report the presence of additional technologies is noted when an estimate includes a technology other than the one of interest.

Some manufacturers only offered collision avoidance technologies in a large bundle of features. For example, the technology package for the 2015–17 model year Acura TLX bundled forward collision warning with pedestrian detection, blind spot warning, lane departure warning, lane-keeping assist, and rear cross-traffic alert. Manufacturers of vehicle models where multiple collision avoidance technologies relevant to many different crash types were bundled are discussed separately.

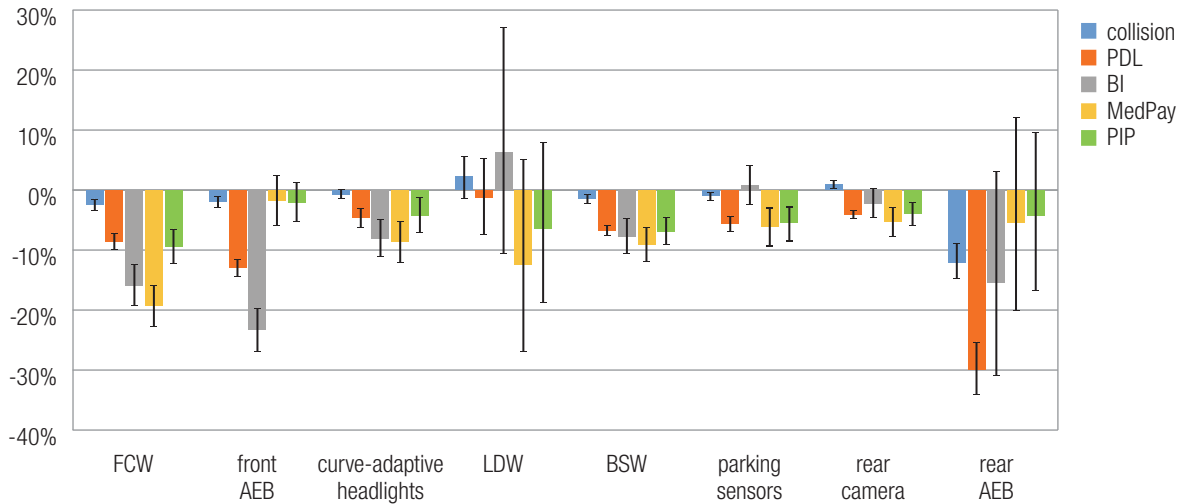
## Predicted fitment of safety features

Vehicle feature information from HLDI was combined with vehicle registration data from IHS Markit (2018) to estimate the prevalence of each collision avoidance technology in the registered vehicle fleet for calendar years 2016 and 2021. For calendar year 2016, each model year, make, and series vehicle with an available collision avoidance technology was weighted by the number of registered vehicles to compute the proportion of all registered vehicles with a collision avoidance technology. A technology was considered available if it was “standard” or “optional” equipment. Thirty-year trends in new vehicle registrations and attrition rates were used to estimate the number of vehicle registrations for the 2017 calendar year and each subsequent calendar year. On average, new vehicle registrations increased 0.9 percent each calendar year, and attrition rates declined 0.2 percent each calendar year. Availability of collision avoidance technology in the 2017 calendar year and each subsequent calendar year was estimated several different ways as described in HLDI (2017d).

## ► Results

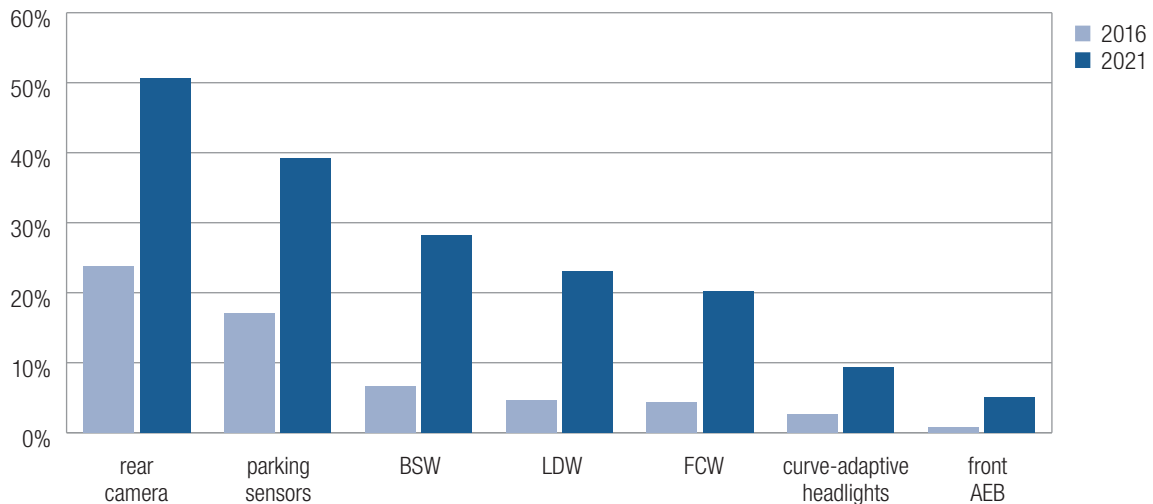
**Figure 1** summarizes the effects of different collision avoidance technologies on claim frequencies under five coverage types combined across manufacturers and vehicle models. The numerical values of the point estimates and the associated confidence intervals are shown in **Appendix A**. Many collision avoidance technologies were associated with reductions in the frequency of claims under each coverage type, and more than two-thirds of the reductions were statistically significant. Some technologies increased the frequency of claims, such as lane departure warning for collision and BI liability coverages, parking sensors for BI liability coverage, and rear cameras for collision coverage. Only the increase in the frequency of collision claims observed for rear cameras was statistically significant.

**Figure 1: Percent change in claim frequency associated with the presence of various collision avoidance technologies by coverage type**



**Figure 2** shows the proportion of registered vehicles in the U.S. with various collision avoidance technologies in 2016 and the estimated proportion of registered vehicles with the technologies in 2021. Among the collision avoidance technologies listed, rear cameras are the most prevalent feature in the vehicle fleet, and front AEB is the least prevalent. The prevalence of each collision avoidance technology among registered vehicles is projected to more than double between 2016 and 2021. Rear cameras are required on all new vehicles with a gross vehicle weight rating under 10,000 lbs. and are expected to be on more than half of the registered vehicle population in 2021. Less than half of the registered vehicle population will have one of the other technologies.

**Figure 2: Percent of registered vehicles equipped with various collision avoidance technologies in 2016 and estimated for 2021**

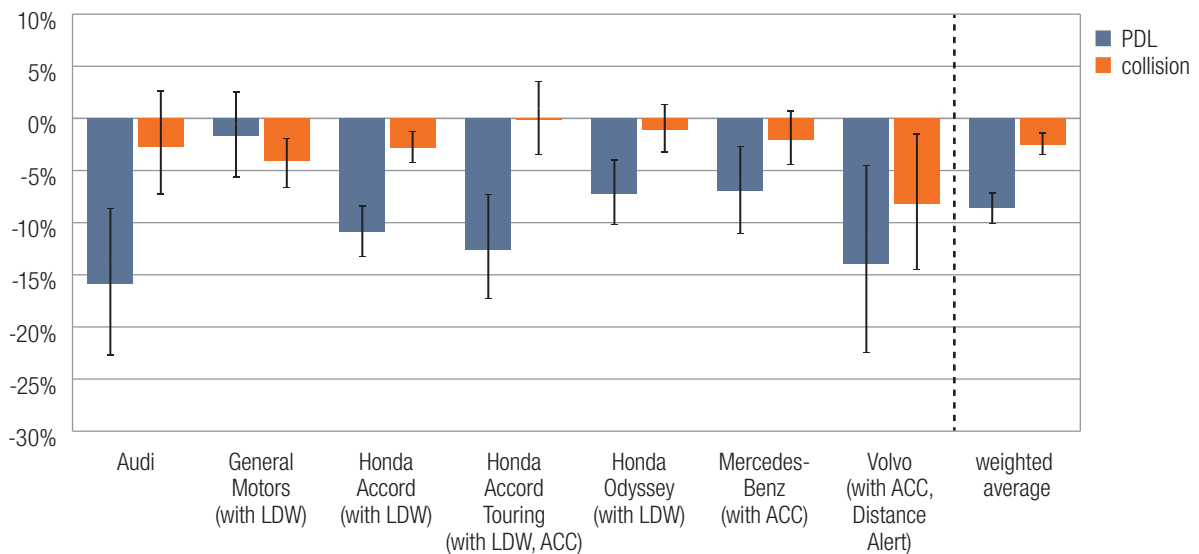


## ► Forward collision warning (FCW)

### Claim frequency by coverage type

FCW alerts the driver when sensors like radar and cameras detect the vehicle is rapidly approaching another vehicle ahead. HLDI examined FCW systems offered on Audi, General Motors, Honda Accord, Honda Odyssey, Mercedes-Benz, and Volvo vehicles. Some of the FCW systems were only available with LDW and/or ACC. FCW reduced the frequency of PDL claims between 1.7 and 15.9 percent and reduced the frequency of collision claims between 0.1 and 8.2 percent across manufacturers and vehicle models (**Figure 3**). Overall, the presence of FCW was associated with a significant 8.6 percent reduction in the frequency of PDL claims and a significant 2.5 percent reduction in the frequency of collision claims.

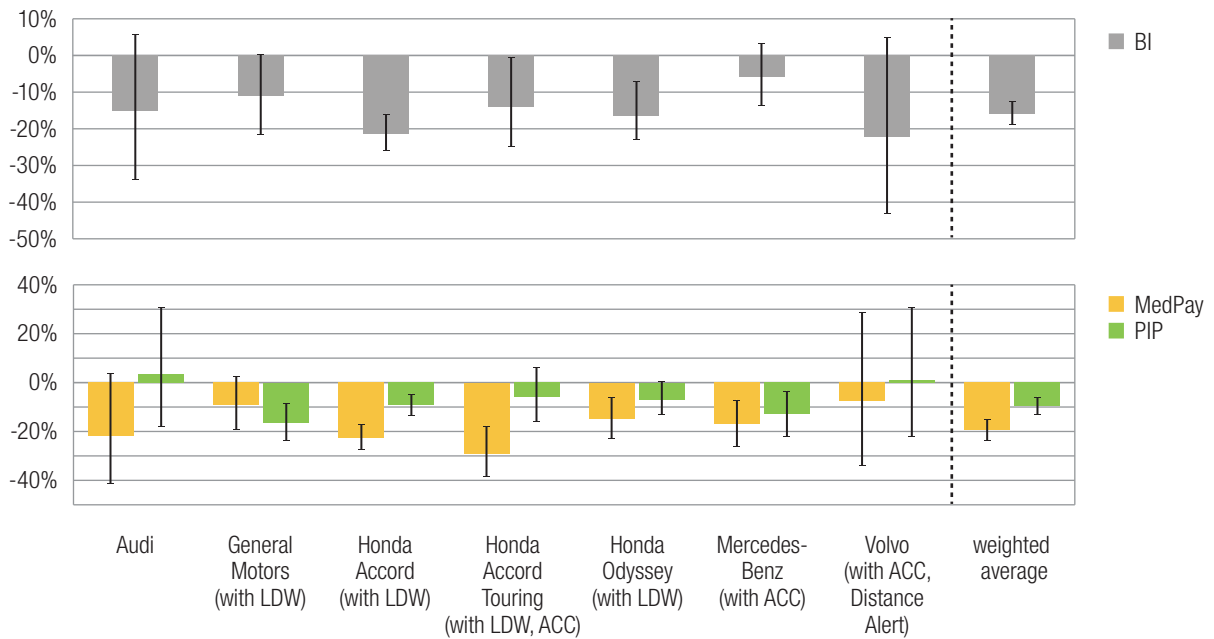
**Figure 3: Percent change in PDL and collision claim frequency associated with the presence of FCW by manufacturer, vehicle model, and combined**





FCW reduced the frequency of BI liability and MedPay claims for each manufacturer and reduced the frequency of PIP claims for most manufacturers and vehicle models (Figure 4). Overall, the technology was associated with a significant 15.9 percent reduction in the frequency of BI liability claims, a significant 19.3 percent reduction in the frequency of MedPay claims, and a significant 9.5 percent reduction in the frequency of PIP claims.

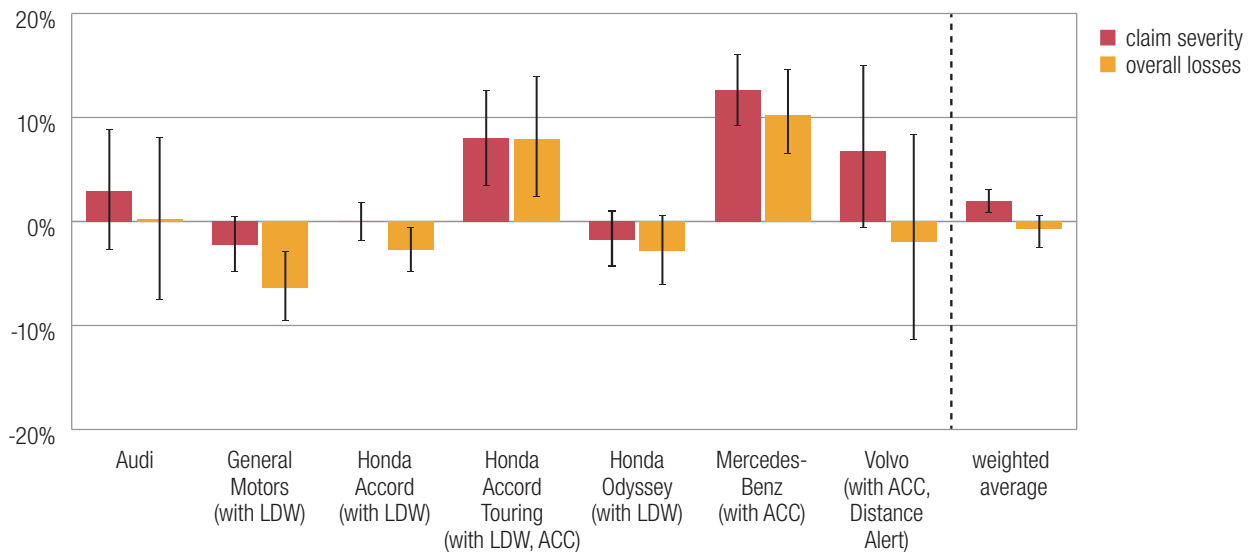
**Figure 4: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of FCW by manufacturer, vehicle model, and combined**



### Collision claim severity and overall losses

FCW was associated with a reduction in the frequency of vehicle damage claims but not always a reduction in claim severity. As illustrated in Figure 5, the severity of collision claims for vehicles with FCW increased for some manufacturers and vehicle models but not for others. A similar pattern was observed for overall losses under collision coverage. Overall, FCW was associated with a significant 2.0 percent increase in collision claim severity. Overall losses under collision coverage decreased 0.7 percent for vehicles equipped with FCW, but this reduction was not statistically significant.

**Figure 5: Percent change in collision claim severity and overall losses associated with the presence of FCW by manufacturer, vehicle model, and combined**



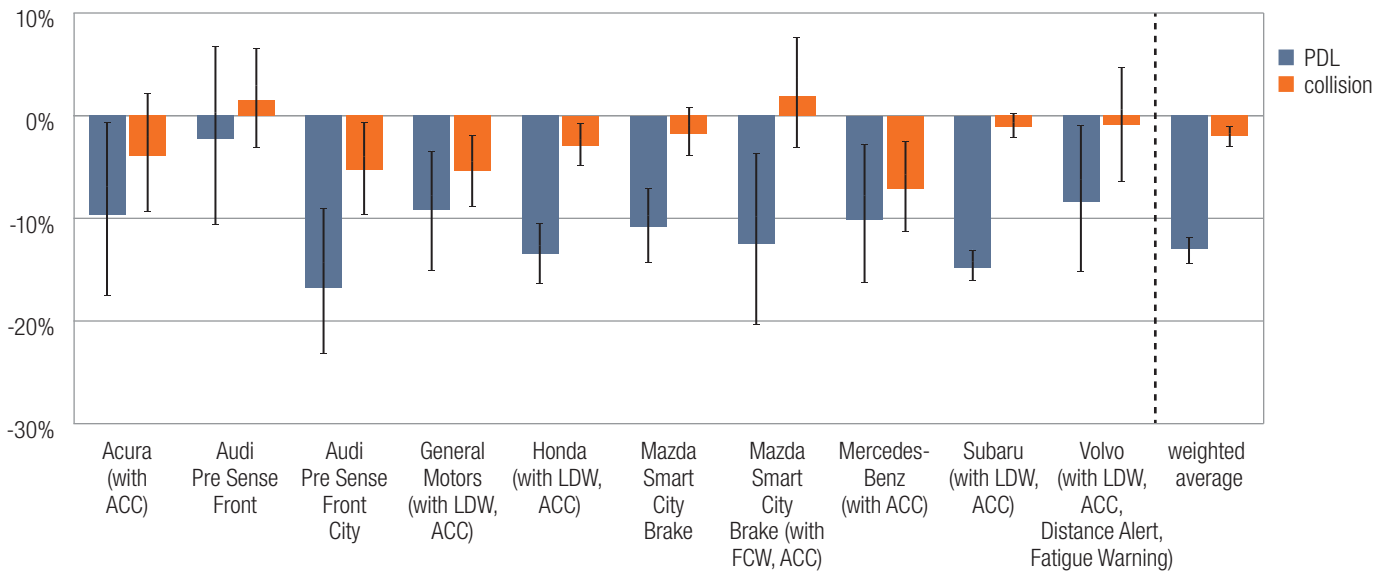


## ► Front automatic emergency braking (AEB)

### Claim frequency

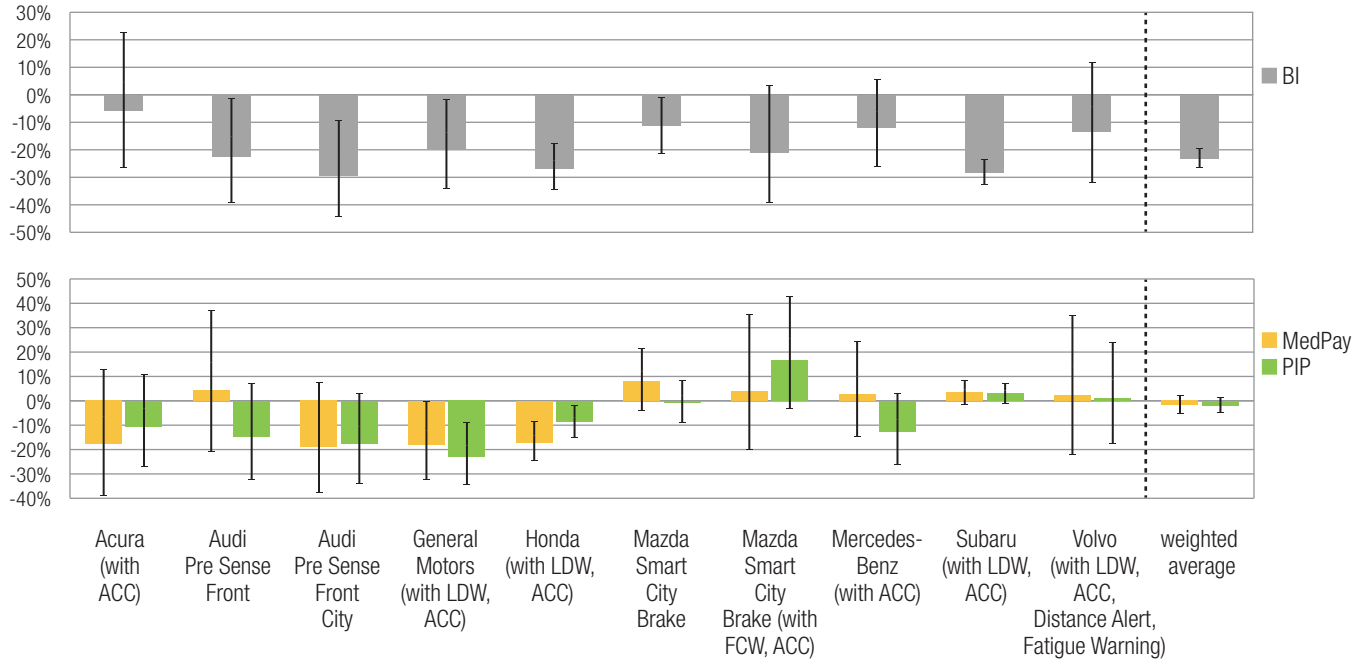
Front AEB applies the vehicle's brakes if the vehicle is rapidly approaching an object ahead and the driver does not respond. HLDI examined front AEB systems offered on Acura, Audi, General Motors, Honda, Mazda, Mercedes-Benz, Subaru, and Volvo vehicles. Some front AEB systems were only available with LDW, ACC, fatigue warning, and/or distance alert. Front AEB significantly reduced the frequency of collision claims for Audi vehicles with Pre Sense Front City, General Motors vehicles, Honda vehicles, and Mercedes-Benz vehicles (**Figure 6**). Overall, front AEB was associated with a significant 2.0 percent reduction in collision claim frequency. PDL claim frequency decreased between 2.3 and 16.8 percent across each manufacturer and vehicle model. Overall, front AEB was associated with a significant 13.0 percent reduction in PDL claim frequency.

**Figure 6: Percent change in PDL and collision claim frequency associated with the presence of front AEB by manufacturer, vehicle model, and combined**



The presence of front AEB was associated with reductions in the frequency of BI liability claims between 5.7 and 29.4 percent for each manufacturer or vehicle model (Figure 7). Reductions in the frequency of MedPay or PIP claims also were observed for most manufacturers. Overall, front AEB reduced the frequency of BI liability claims 23.2 percent, the frequency of MedPay claims 1.7 percent, and the frequency of PIP claims 2.0 percent. The reduction in the frequency of BI liability claims was statistically significant, but the reductions in the frequency of MedPay and PIP claims were not.

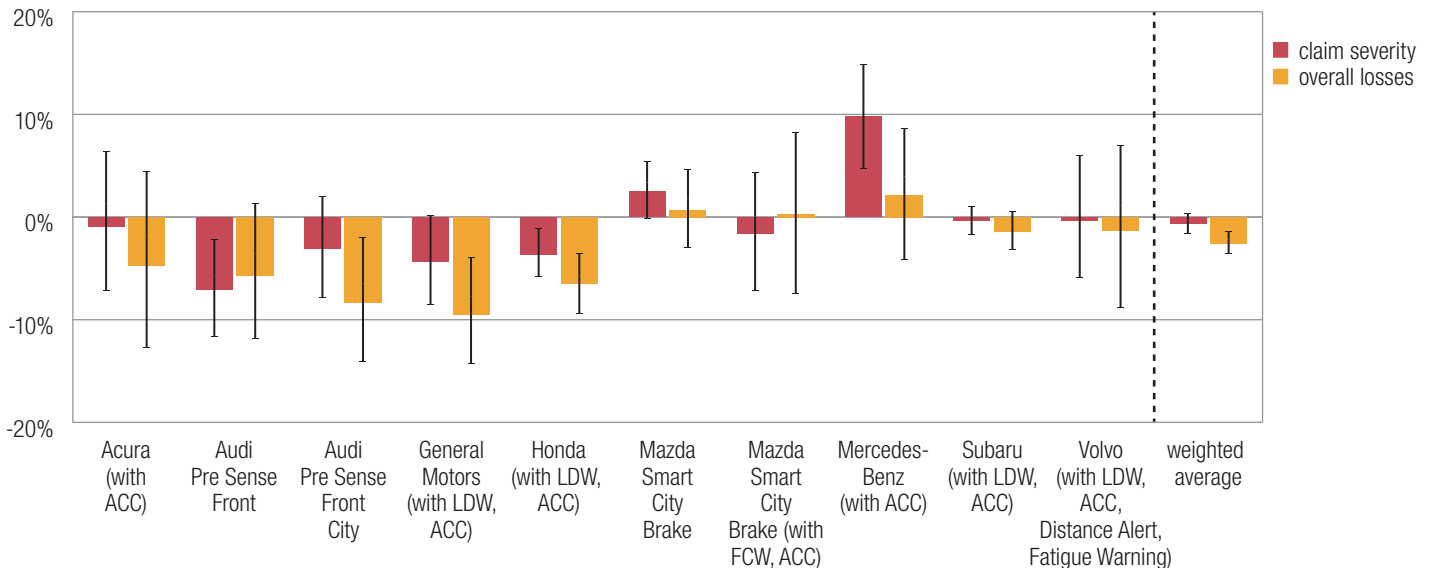
**Figure 7: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of front AEB by manufacturer, vehicle model, and combined**



### Collision claim severity and overall losses

Front AEB had inconsistent effects on collision claim severity and overall losses across each manufacturer and vehicle model (Figure 8). Overall, front AEB was associated with a 0.6 percent reduction in collision claim severity, but this effect was not statistically significant. Front AEB significantly reduced overall losses under collision coverage by 2.6 percent.

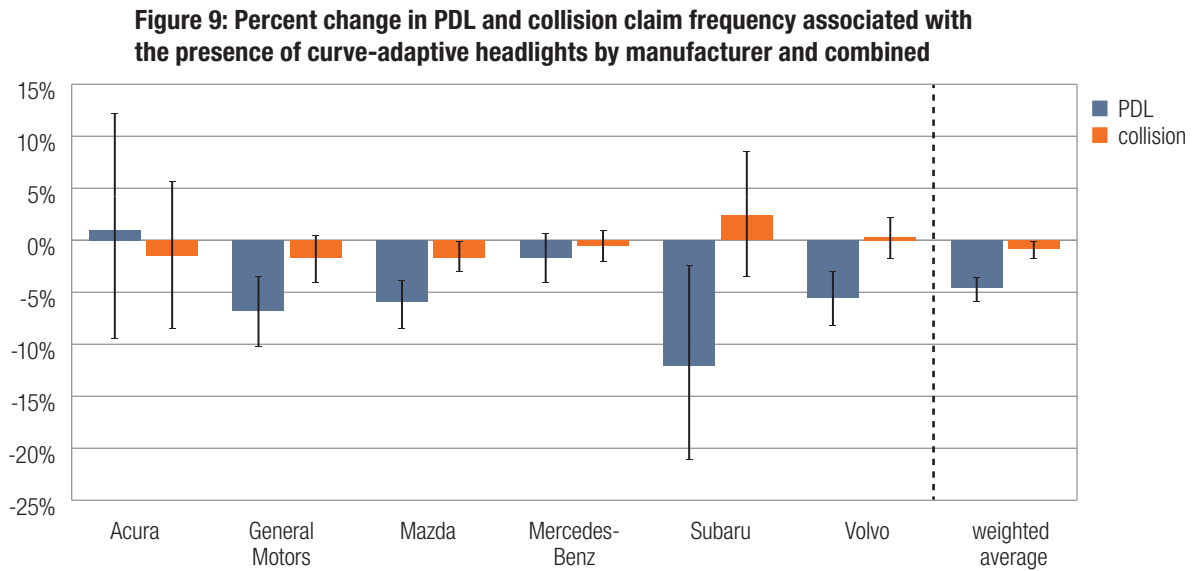
**Figure 8: Percent change in collision claim severity and overall losses associated with the presence of front AEB by manufacturer, vehicle model, and combined**



## ► Curve-adaptive headlights

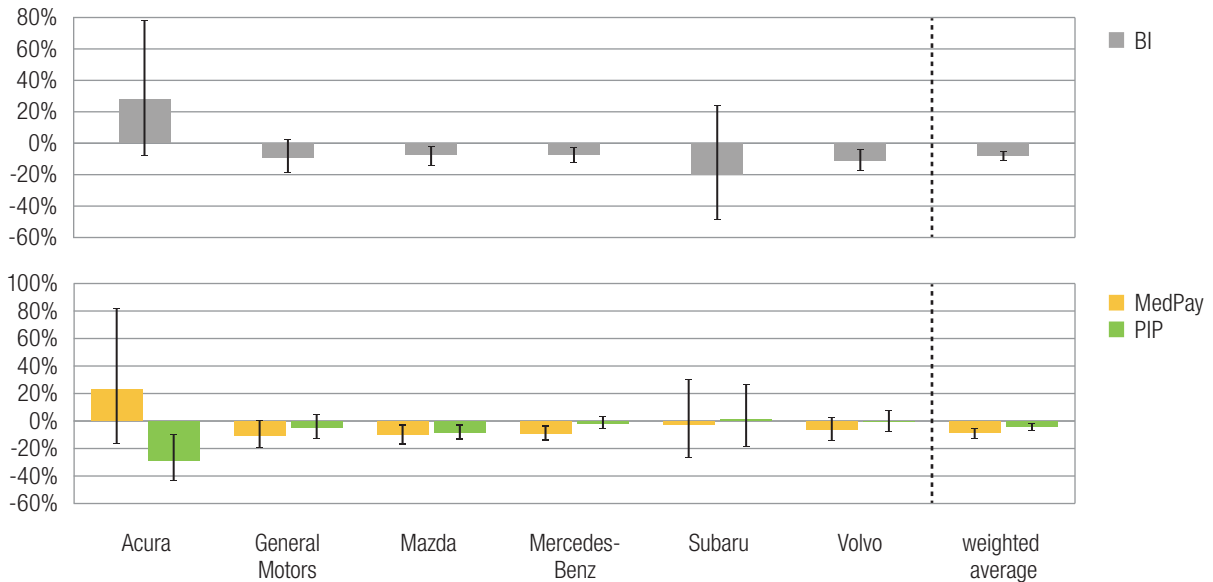
### Claim frequency

Curve-adaptive headlights are designed to help drivers see better at night on straight and curved roads than conventional incandescent or halogen headlights. **Figure 9** shows the changes in the frequency of PDL and collision claims associated with the presence of curve-adaptive headlights for Acura, General Motors, Mazda, Mercedes-Benz, Subaru, and Volvo vehicles. Curve-adaptive headlights significantly reduced the frequency of PDL claims for General Motors, Mazda, Subaru, and Volvo vehicles, and significantly reduced the frequency of collision claims for Mazda vehicles. Across manufacturers, curve-adaptive headlights were associated with a significant 4.6 percent reduction in the frequency of PDL claims and a 0.8 percent reduction in the frequency of collision claims that was not statistically significant.



Curve-adaptive headlights reduced the frequency of BI liability and MedPay claims for every manufacturer except Acura and reduced the frequency of PIP claims for every manufacturer but Subaru (Figure 10). Overall, the presence of curve-adaptive headlights was associated with a significant 8.1 percent reduction in the frequency of BI liability claims, a significant 8.6 percent reduction in the frequency of MedPay claims, and a significant 4.3 percent reduction in the frequency of PIP claims.

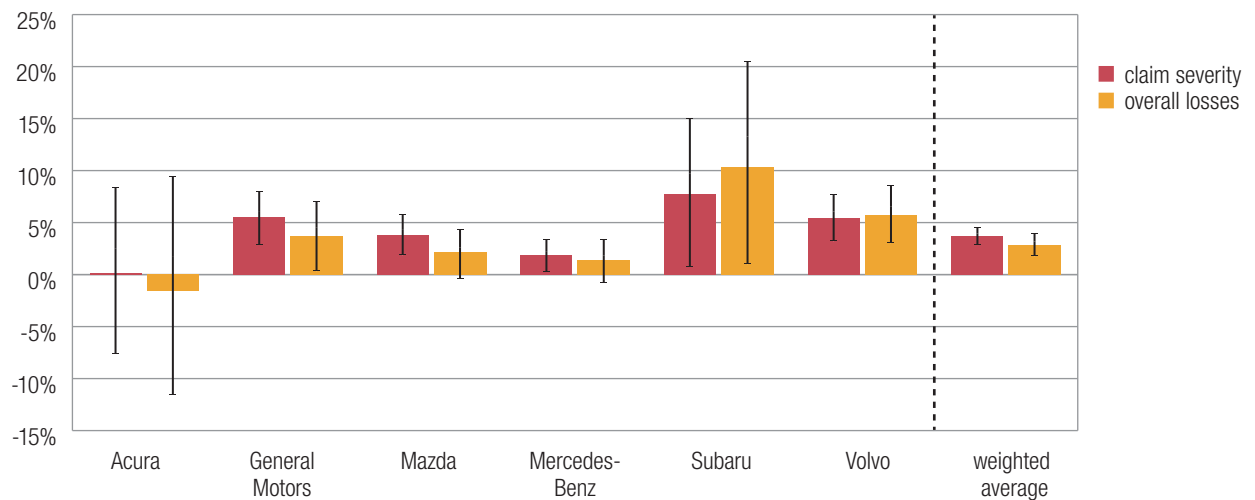
**Figure 10: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of curve-adaptive headlights by manufacturer and combined**



### Collision claim severity and overall losses

Collision claim severity for vehicles equipped with curve-adaptive headlights increased for each manufacturer, and overall losses for collision coverage increased for every manufacturer except Acura (Figure 11). Overall, curve-adaptive headlights were associated with a significant 3.7 percent increase in collision claim severity and a significant 2.8 percent increase in overall losses under collision coverage.

**Figure 11: Percent change in collision claim severity and overall losses associated with the presence of curve-adaptive headlights by manufacturer and combined**

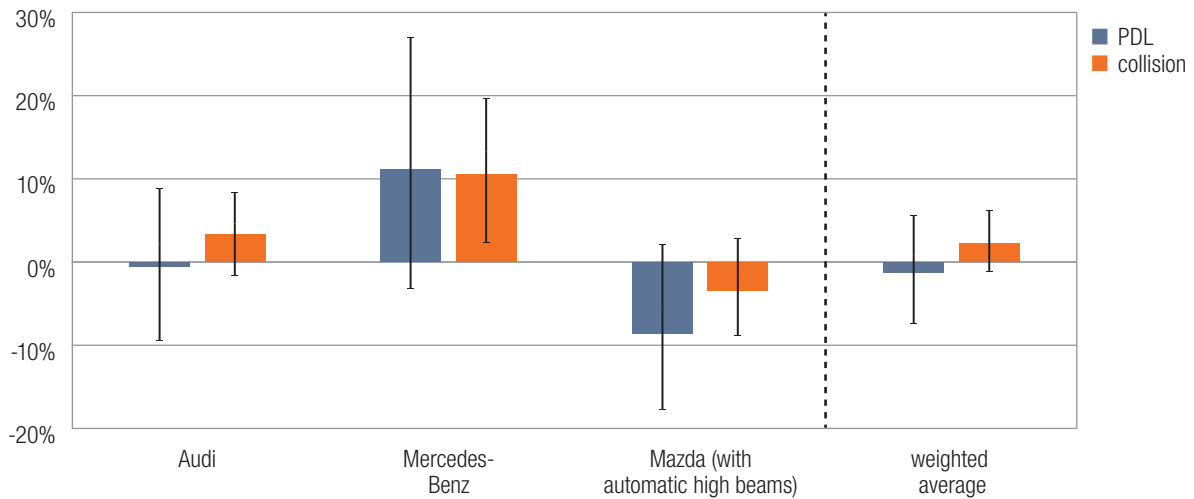


## ► Lane departure warning (LDW)

### Claim frequency

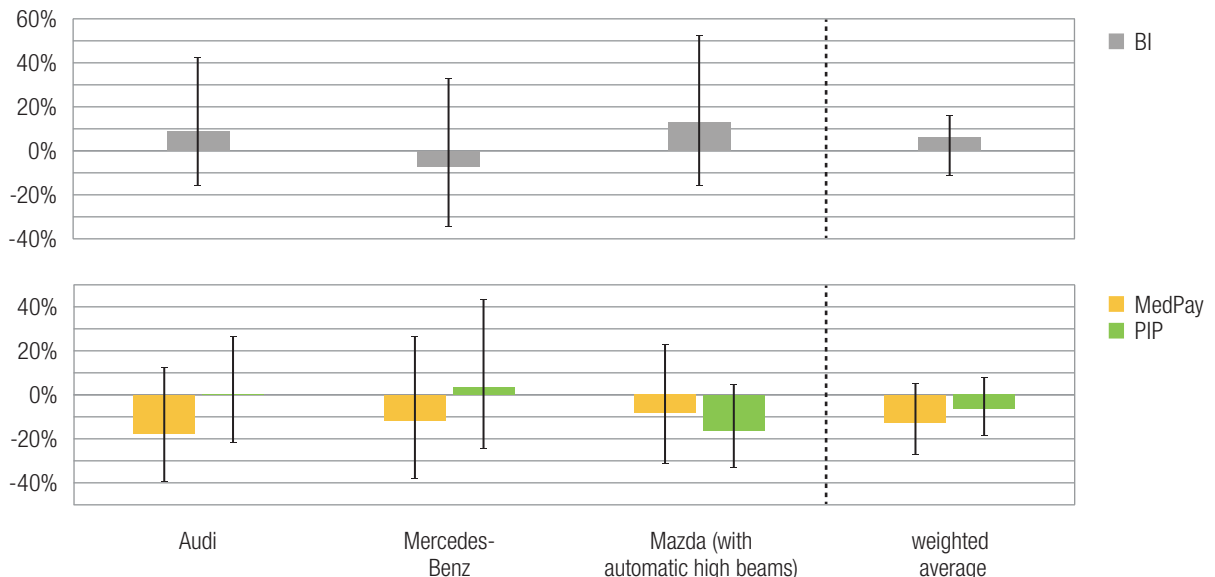
LDW alerts the driver if the vehicle is straying across a lane marking when the turn signal is not activated. **Figure 12** shows the change in PDL and collision claim frequency associated with LDW for Audi, Mercedes-Benz, and Mazda vehicles. Mazda vehicles with LDW also were equipped with automatic high beams. The changes in PDL claim frequency and collision claim frequency associated with LDW were inconsistent across manufacturers. Overall, LDW was associated with a 1.2 percent reduction in PDL claim frequency and a 2.2 percent increase in collision claim frequency; neither change was statistically significant.

**Figure 12: Percent change in PDL and collision claim frequency associated with the presence of LDW by manufacturer, vehicle model, and combined**



**Figure 13** shows the percent change in the frequency of BI liability, MedPay, and PIP claims associated with LDW for Audi, Mercedes-Benz, and Mazda. The presence of LDW was associated with mixed effects for the frequency of BI liability and PIP claims across manufacturers. Overall, the frequency of BI liability claims increased 6.3 percent and the frequency of PIP claims decreased 6.5 percent for vehicles with LDW. In contrast, LDW reduced the frequency of MedPay claims for each manufacturer and was associated with a 12.4 percent reduction overall. The overall percent changes in the frequency of BI liability, MedPay, and PIP claims were not statistically significant.

**Figure 13: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of LDW by manufacturer, vehicle model, and combined**

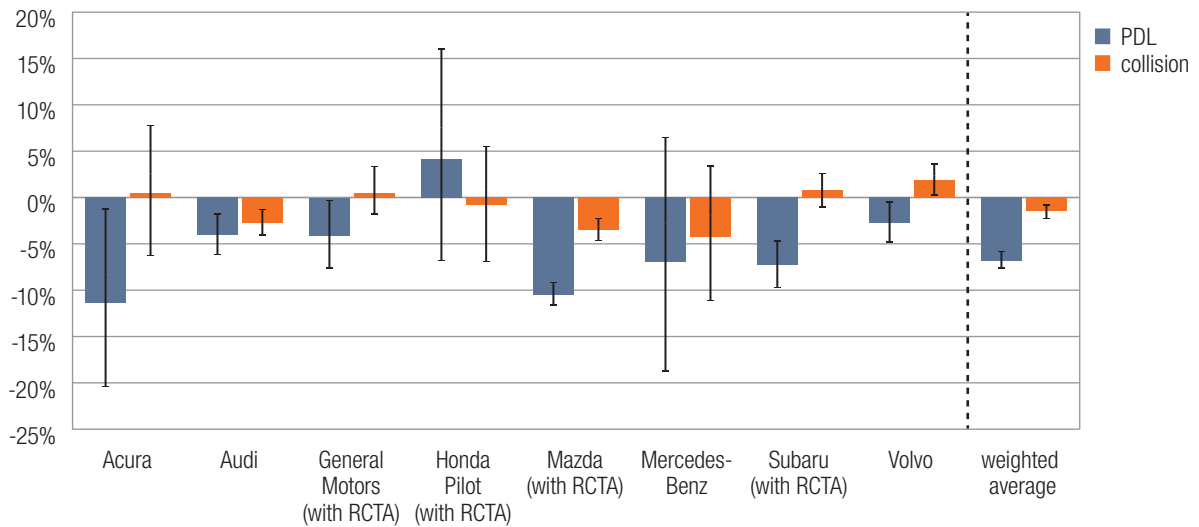


## ► Blind spot warning (BSW)

### Claim frequency

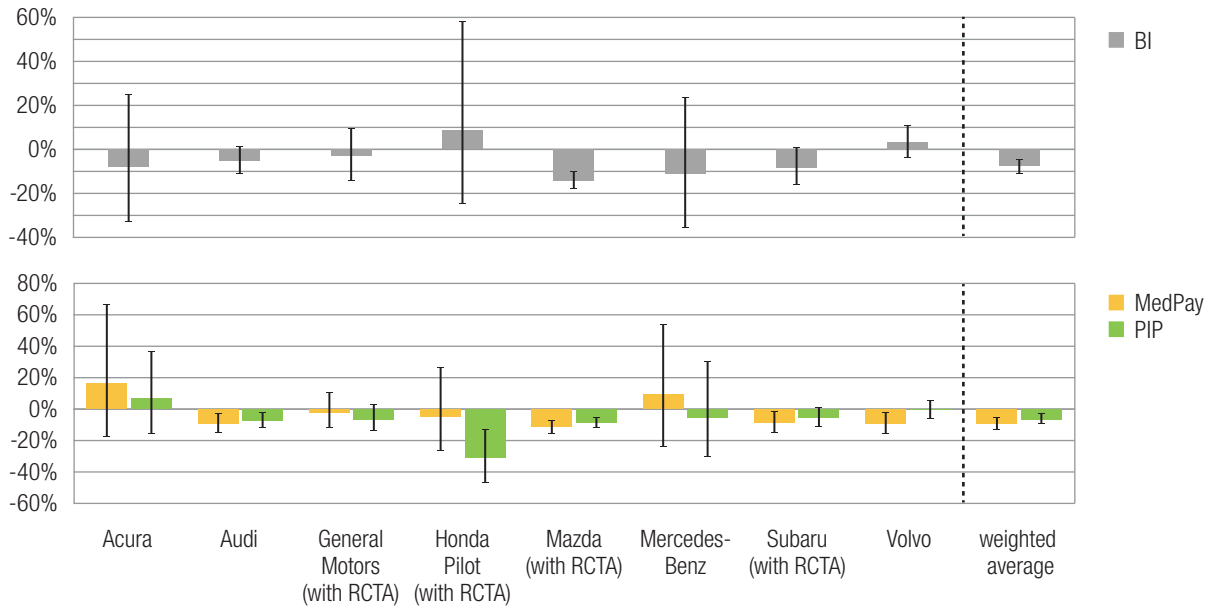
BSW informs the driver when another vehicle is in the blind spot or rapidly approaching it. **Figure 14** shows the changes in the frequency of PDL and collision claims associated with BSW for Acura, Audi, General Motors, Mazda, Mercedes-Benz, Subaru, and Volvo vehicles and the Honda Pilot. Estimates for General Motors, the Honda Pilot, Mazda, and Subaru are for BSW and RCTA combined. BSW reduced the frequency of PDL claims for every manufacturer but not the Honda Pilot, and, overall, the technology was associated with a significant 6.8 percent reduction in the frequency of PDL claims. BSW reduced the frequency of collision claims for some manufacturers but not for others. Overall, BSW was associated with a significant 1.5 percent reduction in the frequency of collision claims.

**Figure 14: Percent change in PDL and collision claim frequency associated with the presence of BSW by manufacturer, vehicle model, and combined**



The presence of BSW was associated with significant reductions in the frequency of claims for injury coverage types (**Figure 15**). Overall, BSW significantly decreased the frequency of BI liability, MedPay, and PIP claims by 7.7, 9.1, and 6.8 percent, respectively. At the manufacturer and vehicle model level, BSW reduced the frequency of BI liability claims for every manufacturer or vehicle model but Volvo and the Honda Pilot. The effects of BSW on the frequency of MedPay and PIP claims were mostly beneficial across manufacturers and vehicle models.

**Figure 15: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of BSW by manufacturer, vehicle model, and combined**



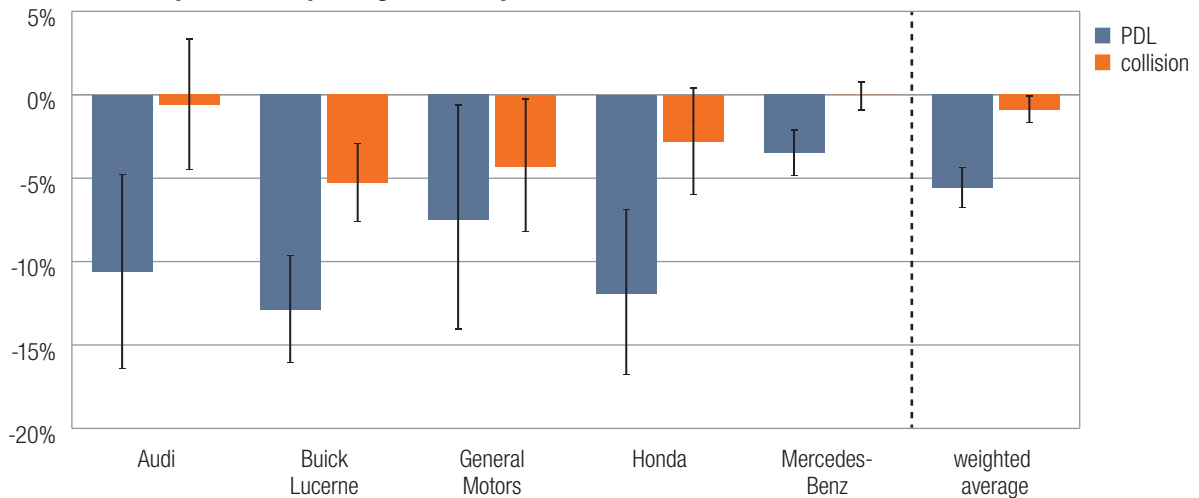


## ► Parking sensors

### Claim frequency

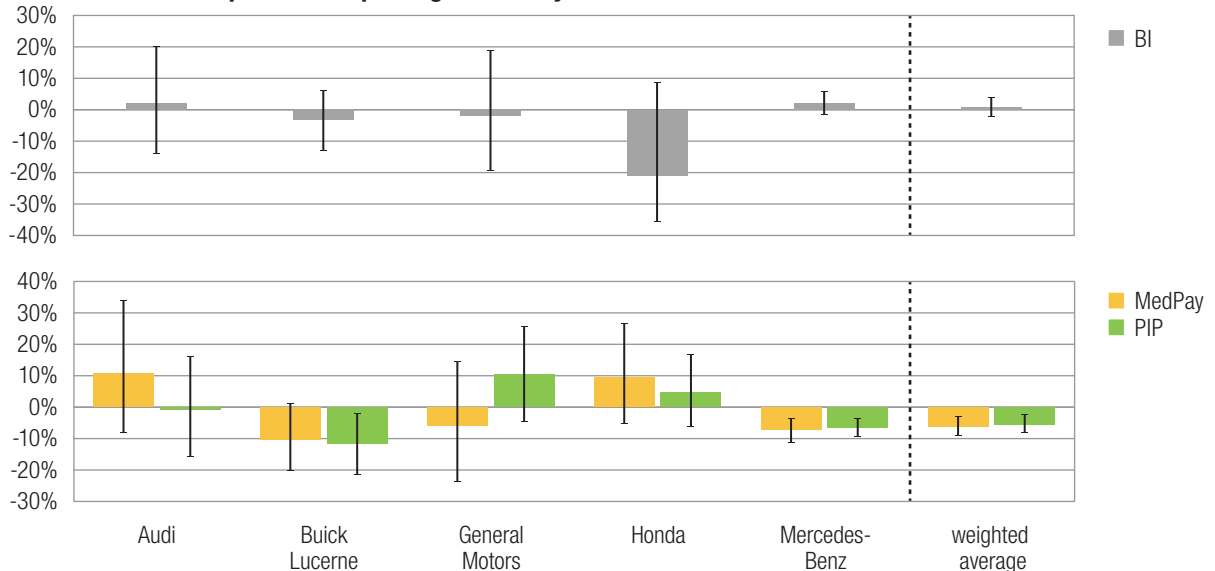
Parking sensors provide information about the distance between the vehicle and surrounding objects during low-speed maneuvers. **Figure 16** shows changes in the frequency of PDL and collision claims associated with the presence of parking sensors for Audi, Buick, General Motors, Honda, and Mercedes-Benz vehicles. Parking sensors reduced the frequency of PDL claims between 3.5 and 12.9 percent across manufacturers, and, overall, were associated with a significant 5.6 percent reduction in the frequency of PDL claims. Parking sensors reduced the frequency of collision claims for every manufacturer except Mercedes-Benz. Overall, parking sensors were associated with a significant 0.9 percent reduction in the frequency of collision claims.

**Figure 16: Percent change in PDL and collision claim frequency associated with the presence of parking sensors by manufacturer and combined**



Parking sensors had an inconsistent effect on the frequency of claims for injury coverage types across manufacturers (**Figure 17**). The effect of parking sensors on the frequency of BI liability claims ranged between -21.0 and 2.2 percent across each manufacturer. Overall, the presence of parking sensors was associated with a 0.9 percent increase in BI liability claim frequency; this effect was not statistically significant. The effect of parking sensors on the frequency of MedPay and PIP claims also was inconsistent across manufacturers; however, overall, the presence of parking sensors was associated with a significant 6.1 percent reduction in the frequency of MedPay claims and a significant 5.5 percent reduction in the frequency of PIP claims.

**Figure 17: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of parking sensors by manufacturer and combined**

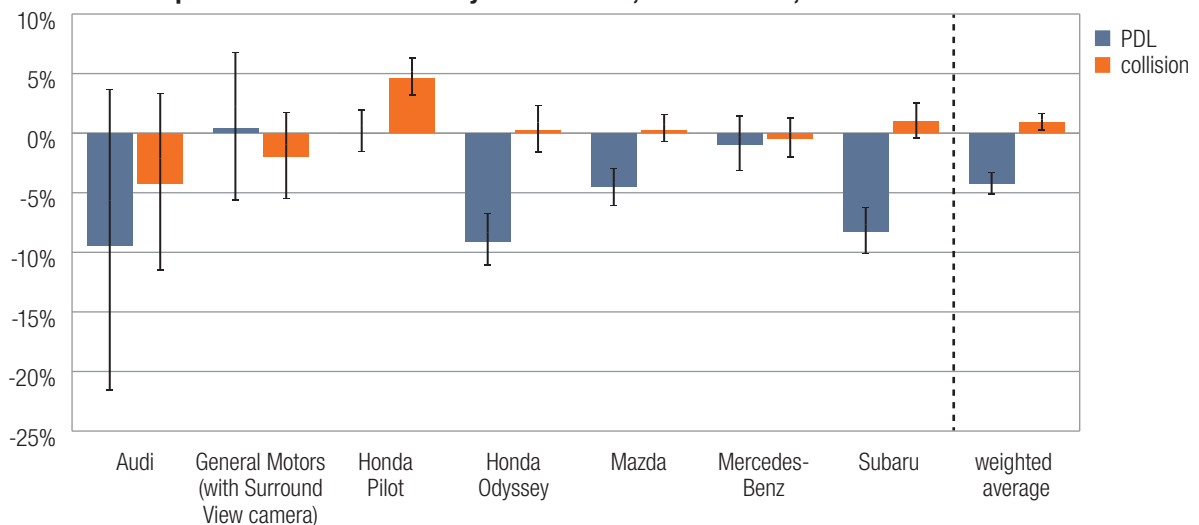


## ► Rear camera

### Claim frequency

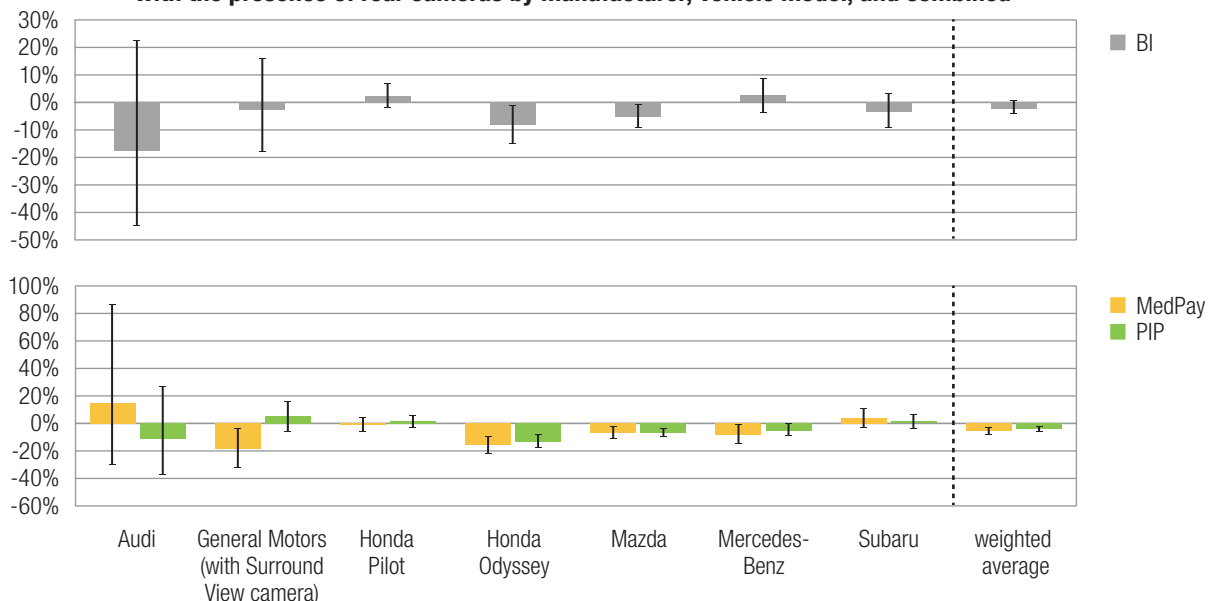
A rear camera displays an image of the area immediately behind the vehicle to enhance rear visibility when the vehicle is reversing. A rear camera was sometimes available with a surround view camera for General Motors vehicles. **Figure 18** shows the association between a rear camera and PDL and collision claim frequencies for Audi, General Motors, Honda (Pilot and Odyssey), Mazda, Mercedes-Benz, and Subaru vehicles. The presence of a rear camera was associated with a reduction in the frequency of PDL claims for 5 of the 7 manufacturers and vehicle models. Overall, the presence of a rear camera was associated with a significant 4.2 percent reduction in the frequency of PDL claims. Rear cameras had an inconsistent effect on the frequency of collision claims across manufacturers and vehicle models, but, overall, the presence of a rear camera was associated with a significant 0.9 percent increase in the frequency of collision claims.

**Figure 18: Percent change in PDL and collision claim frequency associated with the presence of rear cameras by manufacturer, vehicle model, and combined**



A rear camera had an inconsistent effect on the frequency of claims made for different injury coverage types across manufacturers and vehicle models (**Figure 19**), but, overall, the presence of a rear camera was associated with a significant 5.3 reduction in MedPay claim frequency and a significant 4.0 percent reduction in PIP claim frequency. The presence of a rear camera reduced the frequency of BI liability claims by 2.2 percent, but this effect was not statistically significant.

**Figure 19: Percent change in BI liability, MedPay and PIP claim frequency associated with the presence of rear cameras by manufacturer, vehicle model, and combined**

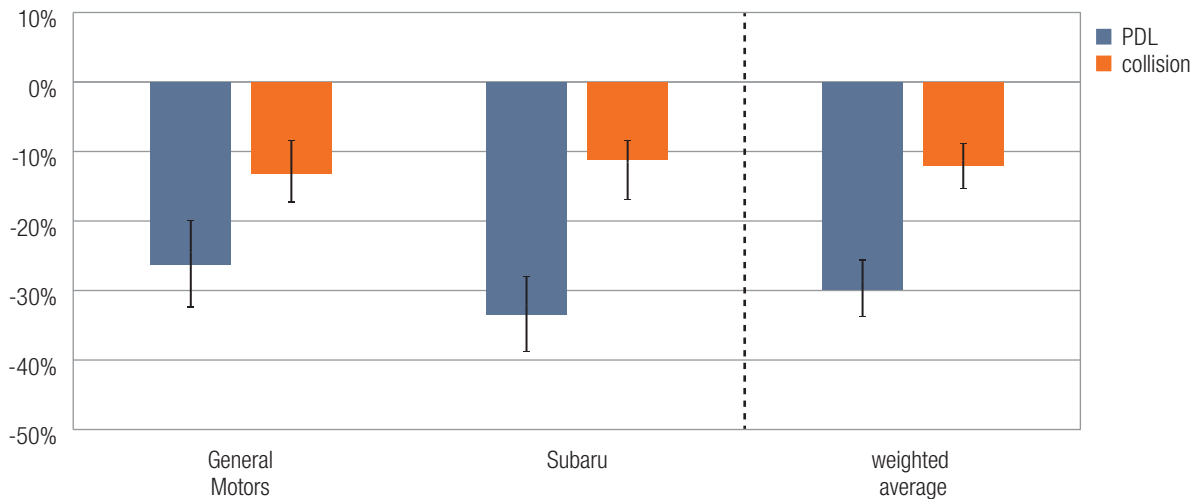


## ► Rear AEB

### Claim frequency

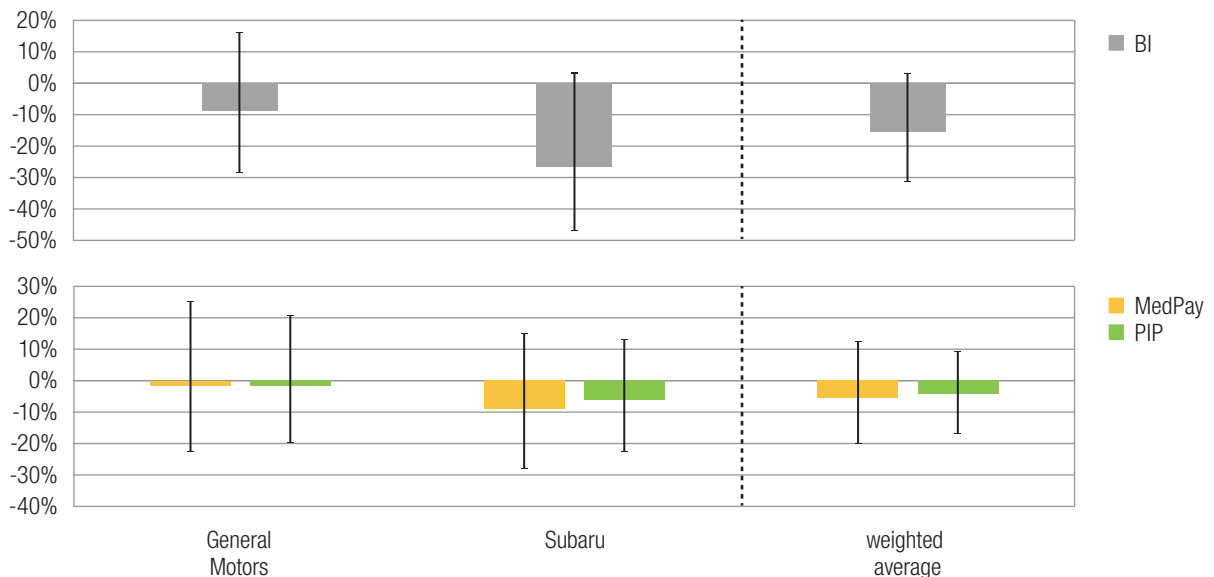
Rear AEB automatically applies the vehicle brakes if the driver does not respond to an object detected behind the vehicle while backing up. **Figure 20** shows the effects of rear AEB on the frequency of PDL and collision claims for General Motors and Subaru vehicles. Rear AEB was associated with significant 26.3 and 33.4 percent reductions in the frequency of PDL claims and significant 13.1 and 11.1 percent reductions in the frequency of collision claims for General Motors and Subaru vehicles, respectively. Overall, the presence of rear AEB was associated with a significant 29.9 percent reduction in the frequency of PDL claims and a significant 12.0 percent reduction in the frequency of collision claims.

**Figure 20: Percent change in PDL and collision claim frequency associated with the presence of rear AEB by manufacturer and combined**



Rear AEB also was associated with reductions in the frequency of BI liability, MedPay, and PIP claims for Subaru and General Motors vehicles (**Figure 21**). Overall, rear AEB reduced the frequency of BI liability claims by 15.5 percent, reduced the frequency of MedPay claims by 5.4 percent, and reduced the frequency of PIP claims by 4.2 percent. None of these changes were statistically significant.

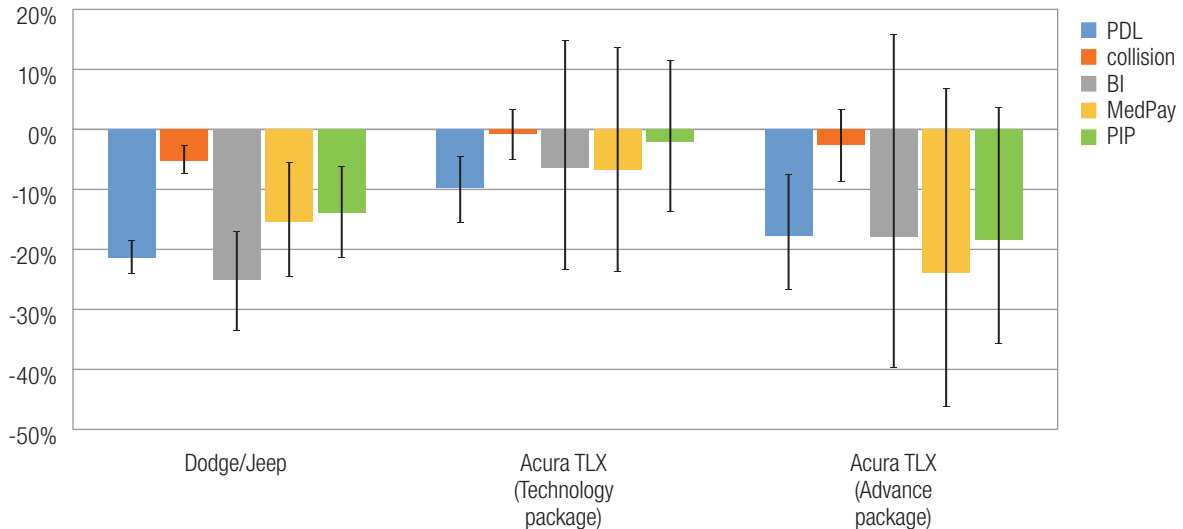
**Figure 21: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of rear AEB by manufacturer and combined**



## ► Collision avoidance technology bundles

Dodge and Jeep included FCW, ACC, BSW, and RCTA together in a single, optional collision avoidance technology bundle. Acura offered two optional collision avoidance technology bundles on the 2015–17 model year TLX: the Technology package and the Advance package. The Technology package included FCW with pedestrian detection, BSW, LDW, lane-keeping assist, and RCTA. The Advance package included the features in the Technology package and added front AEB, ACC, and parking sensors. The effects of these three collision avoidance technology bundles on claim frequencies for vehicle damage and injury coverage types are shown in **Figure 22**.

**Figure 22: Percent change in PDL, collision, BI liability, MedPay, and PIP claim frequencies associated with collision avoidance technology bundles from Dodge, Jeep, and Acura**



Each collision avoidance technology bundle was associated with reductions in the frequency of claims for every coverage type (**Figure 22**). Dodge and Jeep’s bundle significantly reduced the frequency of PDL claims by 21.5 percent, collision claims by 5.2 percent, BI liability claims by 25.1 percent, MedPay claims by 15.4 percent, and PIP claims by 14.0 percent. The frequency of PDL claims was significantly reduced by 9.8 percent for Acura TLX vehicles with the Technology package, but the reductions observed for collision, BI liability, MedPay, and PIP claim frequencies were not statistically significant. Similarly, the frequency of PDL claims was significantly reduced by 17.7 percent for Acura TLX vehicles with the Advance package, and while the package was associated with a reduced frequency of claims for every other coverage type, the reductions were not statistically significant.

## ► Discussion

HLDI has conducted nearly 50 studies analyzing the association between collision avoidance technologies and changes in claim frequencies, severities, and overall losses for different manufacturers. Most collision avoidance technologies are associated with reductions in the frequency of vehicle damage and injury claims made under different coverage types. FCW, front AEB, curve-adaptive headlights, BSW, and rear AEB reduced the frequency of collision, PDL, BI liability, MedPay, and PIP claims; many of these reductions were statistically significant. Parking sensors and rear cameras reduced the frequency of claims under most coverage types. Results for LDW were mixed. Collision claim severity and overall losses only were examined for curve-adaptive headlights, FCW, and front AEB because these technologies are mounted or are enabled by equipment mounted on the front of the vehicle, which is more susceptible to damage in a crash than other locations. Curve-adaptive headlights increased both collision claim severity and overall losses, and FCW-only increased claim severity.

## Claim frequencies

Most collision avoidance technologies influenced claim frequencies in an expected way. FCW, front AEB, and BSW are designed to mitigate or prevent collisions with other vehicles, and the findings from HLDI research suggest that the technologies have been successful in this regard. FCW, front AEB, and BSW significantly reduced the frequencies of PDL and BI liability claims that cover third-party property damage and injury. These technologies also significantly reduced collision claim frequency. Parking sensors, rear cameras, and rear AEB also appear to help drivers avoid objects and other vehicles when reversing or parking as intended. Each of these technologies significantly reduced the frequency of PDL claims, and parking sensors and rear AEB significantly reduced the frequency of collision claims.

Collision avoidance technologies that automatically respond in a crash-imminent situation were more effective for reducing third-party vehicle damage and third-party injury claim frequencies than technologies that only inform or warn drivers. FCW reduced the frequency of PDL claims by 8.6 percent and BI liability claims by 15.9 percent, but front AEB reduced the frequency of PDL claims by 13.0 percent and BI liability claims by 23.2 percent. Likewise, rear AEB reduced the frequency of PDL claims by 29.9 percent and BI liability claims by 15.5 percent, which was more than 5 times the reductions in the frequency of claims associated with parking sensors and rear cameras for these coverage types.

Some collision avoidance technologies influenced claim frequencies in an unexpected way. Curve-adaptive headlights can help prevent single-vehicle crashes that occur at night by providing more light on curved roads; however, this technology did not significantly reduce the frequency of collision claims. Curve-adaptive headlights were associated with significant reductions in the frequency of PDL and BI claims, which suggests the technology prevented multivehicle crashes or possibly crashes with pedestrians or other vulnerable road users. It is possible that the additional light from curve-adaptive headlights helps oncoming drivers detect equipped vehicles earlier on curved roads.

LDW can help prevent single-vehicle run-off-road crashes that result in collision claims, but, unexpectedly, this technology increased the frequency of collision claims, although the estimate was not statistically significant. Additionally, unlike the other collision avoidance technologies examined, the changes in claim frequency associated with LDW were inconsistent across coverage types. It is possible that any benefit of LDW is not detectable in the topline frequency of collision claims. Lane departure warning is estimated to be relevant to only 3 percent of crashes reported to police each year (Jermakian, 2011) and likely an even smaller proportion of collision claims, which are dominated by low-severity events. Lane departure prevention or lane-centering systems that provide steering or braking input to automatically adjust the vehicle's trajectory to keep it in the lane may prove more effective for reducing the frequency of claims than LDW systems that only inform the driver that the vehicle is leaving or has left the lane.

## Collision claim severities and overall losses

Curve-adaptive headlights tend to be more expensive than conventional halogen headlights. For instance, the 2017 Subaru Outback's steering-responsive xenon headlamp assembly (\$657) costs nearly twice as much as the regular halogen headlight assembly (\$355) (Audatex Estimating, 2018). Unfortunately, the front of the vehicle where headlights are located is a common point of impact in collision claims (e.g., HLDI, 2017c). Consequently, curve-adaptive headlights elevate repair costs for many collision claims as evidenced by an associated 7.7 percent increase in collision claim severity for Subaru and a 3.7 percent increase overall.

Locating forward-looking sensors that support FCW and front AEB in the front bumper may make vehicles with this technology more susceptible to increased repair costs, as well. HLDI analyses of FCW found that collision claim severity increased 8.0 percent for Honda Accord vehicles equipped with a radar unit mounted in the front bumper, but severity was unchanged for Honda Accord vehicles with a camera mounted in a more-protected location behind the windshield. This finding suggests the radar unit may have been responsible for the increase in claim severity, but Honda Accord vehicles equipped with a radar unit also had LED headlights. A HLDI (2016e) analysis of vehicle parts data from front impact collision damage estimates for the 2013–14 Honda Accord indicated that the LED headlights contributed to a larger percentage increase in repair estimate dollars (8 percent for LED vs. 3 percent for halogen) than the percentage of repair estimate dollars attributable to the radar unit (2 percent). Reductions in the frequency of collision claims also may offset some of the additional expense of radar or other forward-looking sensors that enable FCW and front AEB. For example, FCW significantly increased collision claim severity by 2.0 percent overall but significantly reduced the frequency of collision claims by 2.5 percent and was not associated with a significant change in overall losses under collision coverage.

## Converging evidence

HLDI analyses of insurance claims provided the first estimates of the real-world effect of different collision avoidance technologies on crash outcomes. Subsequent research by IIHS has used police-reported crash data to examine the effectiveness of different collision avoidance technologies for preventing crashes that the technologies were designed to address. Most of the IIHS findings are consistent with the HLDI findings. For example, IIHS found that FCW and front AEB reduced rear-end crash involvement rates (Cicchino, 2017a), BSW reduced lane-change crash involvement rates (Cicchino, 2017c), and rear cameras, rear parking sensors, and General Motors rear AEB system each reduced backing-crash involvement rates (Cicchino, 2017b; 2018b). Inconsistent with HLDI findings, IIHS found that LDW reduced the involvement rates for relevant police-reported crash types – single-vehicle run-off road, side-swipe and head on collisions (Cicchino, 2018a). As discussed above, these types of crashes are relatively rare, so even large reductions may be hard to detect among insurance claims, which are dominated by claims for lower severity crashes (e.g., HLDI, 2017h). The reductions in the frequency of MedPay and PIP claims, while not significant, were consistent with Cicchino’s findings.

Claim severity is typically interpreted as a measure of damageability and repair costs, but changes in claim severity also may provide valuable insights into the types of crashes a collision avoidance technology is preventing or mitigating. A HLDI (2017a) study of General Motors vehicles found that parking sensors with a rearview camera together or when combined with rear AEB significantly reduced the frequency of lower severity collision claims indicative of a parking lot crash, but not the frequency of higher severity claims that result from higher speed collisions. Other HLDI studies have noted shifts in average claim severity for other collision avoidance technologies that may reflect the absence of the crashes (e.g., low-speed crashes) the technology is designed to mitigate or prevent (HLDI 2017b).

More nuanced analyses of claim frequencies, severities, and overall losses can provide converging evidence that a technology is having the anticipated effects on crash outcomes in the real world. The frequency of PDL and collision claims are higher for drivers 24 years and younger than drivers 25-64 years old (HLDI, 2014). A HLDI (2017i) study found that the presence of FCW and LDW decreased the frequency of PDL claims by 16 percent for rated drivers 24 and younger, 12 percent for rated drivers 25-64 years old, and 6 percent for rated drivers 65 and older. The differences in PDL claim frequency between age groups were not statistically significant, but the pattern of results for drivers younger than 65 was consistent with variations in claim frequency by driver age.

Increasingly, manufacturers are bundling collision avoidance technologies, making it difficult to isolate the effects of each technology on claim frequencies. Traditional HLDI analyses of claim frequencies can be supplemented with analyses of other information sources (e.g., repair estimates, point of impact) to better understand the effect that each collision avoidance technology in a bundle is having on crash outcomes in the real world. For example, many collision and PDL claims result from front-to-rear crashes that FCW and front AEB are designed to mitigate or prevent. A HLDI (2017c) analysis of the point of impact distribution for matched pairs of collision and PDL claims found that 49 percent were front-impact collision claims and rear-impact PDL claims. Each bundle of collision avoidance technologies equipped to Dodge and Jeep vehicles and 2015–17 Acura TLX vehicles was associated with significant reductions in the frequency of both PDL and collision claims, but it is unclear whether these reductions were largely due to FCW, front AEB or other equipped technologies. Future research can match claims from different coverage types based on point of impact to isolate the crash configurations most relevant to a collision avoidance technology and more precisely evaluate the technology’s effect on claim frequency.

## Looking ahead

While collision avoidance technologies are offered on many new vehicles, these features are far less prevalent among all passenger vehicles in the U.S. fleet. For instance, a rear camera was either standard or optional equipment on 95 percent of new 2016 model year vehicles, but only 35 percent of registered vehicles in the 2016 calendar year. FCW was standard or optional on 64 percent of 2016 model year vehicles but only 12 percent of registered vehicles. Consequently, reductions in claim frequencies observed for many collision avoidance technologies, although sizeable, only have minimally impacted the population of passenger vehicle crashes that occur annually. Crashes and the associated insurance claims and losses experienced by the entire population of passenger vehicles will decrease over time as collision avoidance technologies become more common among registered vehicles in the U.S. fleet.

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► **Appendix A**

Appendix A				
Collision avoidance technology	Coverage type	Percent change	Lower 95% confidence limit	Upper 95% confidence limit
<b>FCW</b>	Collision	-2.5	-3.4	-1.6
	PDL	-8.6	-10.0	-7.3
	BI liability	-15.9	-19.3	-12.4
	MedPay	-19.3	-22.5	-15.9
	PIP	-9.5	-12.4	-6.5
<b>Front AEB</b>	Collision	-2.0	-2.8	-1.1
	PDL	-13.0	-14.2	-11.8
	BI liability	-23.2	-26.5	-19.8
	MedPay	-1.7	-5.5	2.2
	PIP	-2.0	-5.0	1.1
<b>Curve-adaptive headlights</b>	Collision	-0.8	-1.7	0.0
	PDL	-4.6	-5.8	-3.3
	BI liability	-8.1	-11.3	-4.8
	MedPay	-8.6	-12.0	-5.0
	PIP	-4.3	-7.1	-1.4
<b>LDW</b>	Collision	2.2	-1.2	5.8
	PDL	-1.2	-7.2	5.2
	BI liability	6.3	-10.5	26.3
	MedPay	-12.4	-27.0	5.0
	PIP	-6.5	-19.1	8.2
<b>BSW</b>	Collision	-1.5	-2.1	-0.8
	PDL	-6.8	-7.7	-5.8
	BI liability	-7.7	-10.4	-5.0
	MedPay	-9.1	-12.0	-6.1
	PIP	-6.8	-9.0	-4.6
<b>Parking sensors</b>	Collision	-0.9	-1.7	-0.1
	PDL	-5.6	-6.8	-4.3
	BI liability	0.9	-2.3	4.1
	MedPay	-6.1	-9.4	-2.7
	PIP	-5.5	-8.2	-2.6
<b>Rear camera</b>	Collision	0.9	0.3	1.5
	PDL	-4.1	-4.9	-3.3
	BI liability	-2.2	-4.6	0.2
	MedPay	-5.3	-7.7	-2.7
	PIP	-4.0	-5.9	-2.1
<b>Rear AEB</b>	Collision	-12.0	-14.9	-9.0
	PDL	-29.9	-33.8	-25.7
	BI liability	-15.5	-30.8	3.2
	MedPay	-5.4	-20.1	11.9
	PIP	-4.2	-16.5	9.8



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