HLDI
Highway Loss Data Institute

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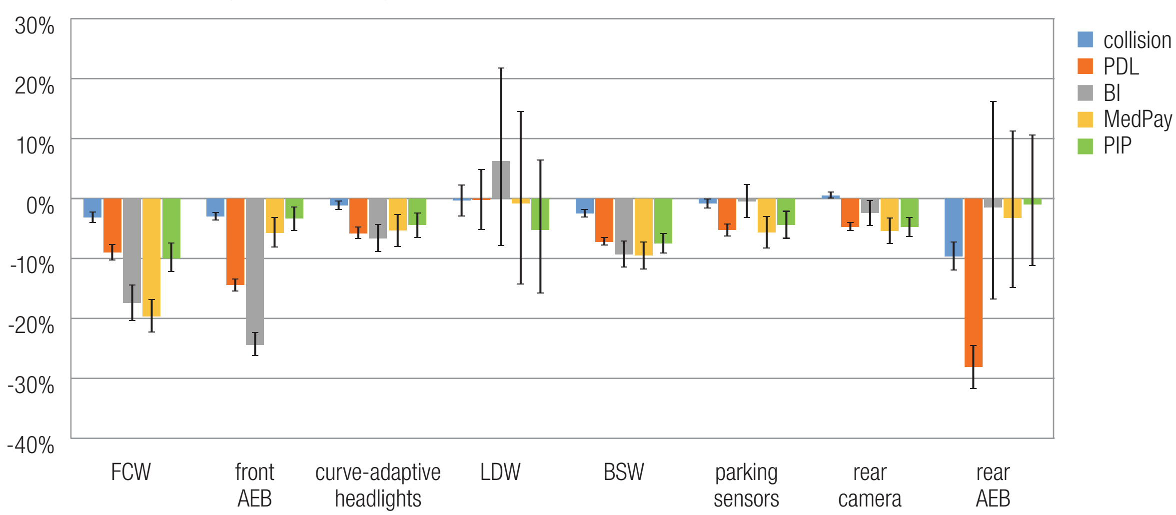
Compendium of HLDI collision avoidance research

Summary

The Highway Loss Data Institute (HLDI) has evaluated and reported on collision avoidance technologies since 2009. To date, HLDI has published more than 80 research reports evaluating collision avoidance technologies. This compendium synthesizes the most recent findings from these analyses and combines findings from individual manufacturers to estimate the combined 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. A weighted average was calculated to estimate the combined effect of each crash avoidance technology on claim frequencies under each coverage type across manufacturers. With the exception of lane departure warning, the combined effects for all of the technologies are associated with statistically significant reductions in claim frequencies. The only statistically significant increase in claim frequency was associated with rear cameras under collision coverage. That increase was 0.5 percent. Front automatic emergency braking (AEB) and rear AEB, technologies that automatically take action for the driver in a crash-imminent situation, have been associated with larger reductions in claim frequencies 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, have been associated with increases to claim severities. While the findings indicate that collision avoidance technologies are reducing claim frequencies, only a fraction of vehicles in the U.S. fleet are equipped with these technologies. Claim frequencies across the entire population of vehicles in the U.S. will 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 collision avoidance technologies by coverage type



Introduction

Collision avoidance technologies have 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 more than 80 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 (BSW), parking sensors, rear camera, and rear AEB (HLDI, 2017a; 2018a-i; 2019a-f). Results were combined to estimate the collective 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 12 manufacturers: Acura, Audi, BMW, Buick, General Motors, Honda, Kia, Mazda, Mercedes-Benz, Nissan, Subaru, and Volvo. Many collision avoidance technologies offered by these manufacturers are not available as standard equipment and are optional. Consequently, HLDI had to determine which vehicles were equipped with crash avoidance technologies to evaluate each technology's effect on claim frequencies, severities, and overall losses.

HLDI used the following three methods 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, BMW, Buick, General Motors, Mazda, Mercedes-Benz, Nissan, and Volvo vehicles.
- Some collision avoidance technologies are standard on certain vehicle trim levels. On some vehicles from certain manufacturers, the trim level can be identified in the first 10 positions of the VIN, 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, Honda Pilot, and Kia Sportage.
- 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) mitigates frontal crashes by using 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 uses the same kinds of sensors as forward collision warning to alert drivers of emergency situations 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 lamps or newer types of lights like light-emitting diode (LED) or high intensity discharge (HID) lamps.

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 an adjacent lane blind spot or when a vehicle is swiftly approaching the blind spot.

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. The system audibly indicates when objects are in close proximity at very low speeds.

Rear cameras enhance rear visibility by providing a view of the area directly behind the vehicle in an interior display. Rear cameras visually display surroundings directly to the rear of the vehicle at very low speeds when the vehicle is traveling in reverse.

Rear AEB automatically applies the brakes to keep the vehicle from reversing into an object detected by sensors.

Other technologies

Some collision avoidance features are only available with other collision avoidance or advanced driver assistance features.

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, 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 switches 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.

The insurance coverages that deal with injuries are more complicated. 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. 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, defined as the number of claims per 100 or 1,000 insured vehicle years, 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 2016; 2017b).

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 loss results

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 Obstruction Warning (or FCW). Each version of the technology was included in the weighted average. The marketing name was used to differentiate the versions.

Linked features

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, which 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, would result in larger reductions to insurance claim frequencies than 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 prevalence of safety features

Vehicle feature information from HLDI was combined with vehicle registration data from IHS Automotive (formerly R.L. Polk and Company) to estimate the prevalence of each collision avoidance technology in the registered vehicle fleet for calendar years 2019 and 2024. For calendar year 2019, each model year, make, and series 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 2020 calendar year and each subsequent calendar year in the conventional scenario. On average, new vehicle registrations would increase 1.2 percent each calendar year, and attrition rates would decline 0.21 percent each model year under the conventional scenario.

The global pandemic caused by COVID-19 is also likely to affect the availability of new vehicles, new vehicle sales and consequently future levels of ADAS penetration. While the full effect of COVID-19 on the economy and vehicle sales, remains to be seen, an alternative scenario (recession scenario) was included to demonstrate how a recession may impact the future prevalence of features. This scenario was based on the annual changes to new vehicle registrations from the 2007-09 recession, and the subsequent recovery from 2009-12. Results from this alternative scenario (recession scenario) are presented alongside the traditional scenario where future new vehicle registrations are based on a 30-year past trend. The future is uncertain, and future new vehicle registrations may behave completely differently from the prior recession. Availability of collision avoidance technology in the 2020 calendar year and each subsequent calendar year was estimated several different ways as described in HLDI 2020b.

Results

Figure 1 summarizes the effects of 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. There were only two technologies associated with increased claim frequencies. Increased claim frequencies were estimated for lane departure warning under BI liability coverage and for rear cameras under collision coverage. The increase associated with the rear cameras under collision coverage was the only statistically significant increase.

Figure 1: Percent change in claim frequency associated with collision avoidance technologies by coverage type

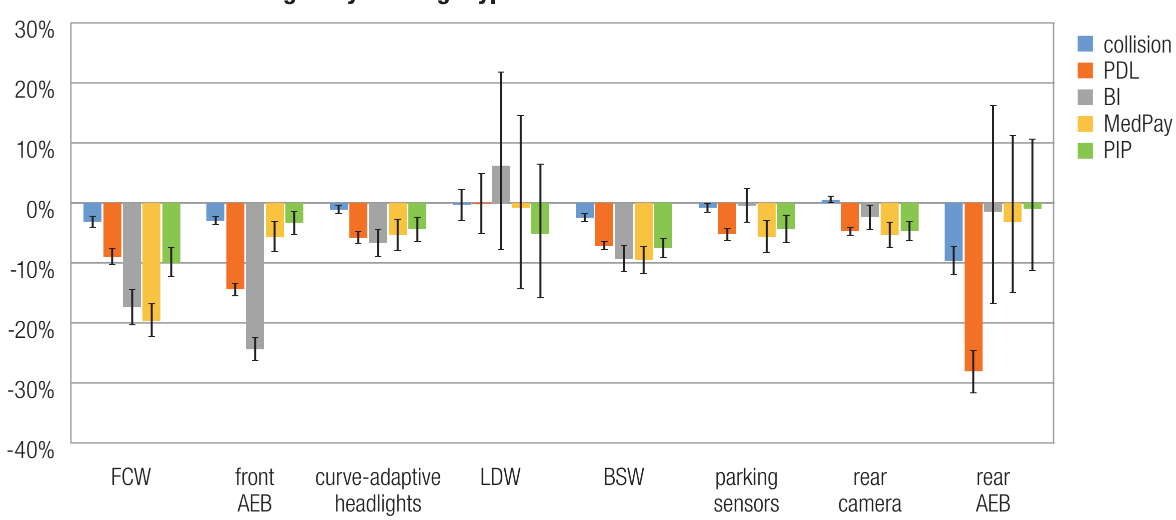
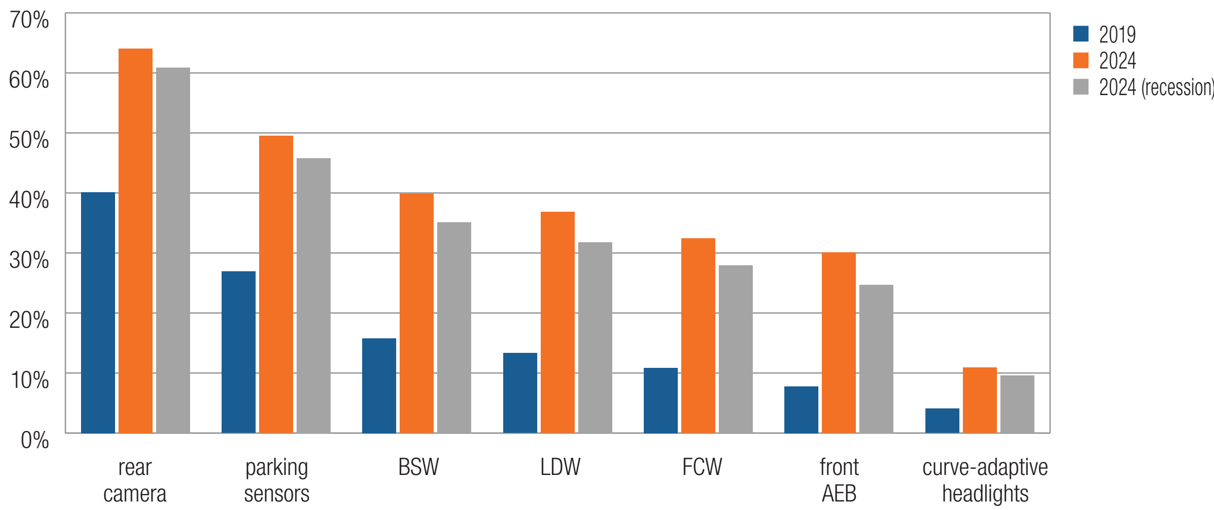


Figure 2 shows the proportion of registered vehicles in the U.S. with various collision avoidance technologies in 2019 and the estimated proportion of registered vehicles with the technologies in 2024 under the conventional and recession scenarios. Under the traditional scenario, most systems are estimated to see increases of over 20 percentage points by 2024. Adaptive headlights are an exception, with an estimated increase in fitment of only 7 percent by 2024. Fitment rates are expected to be between 1 percent (adaptive headlights) and 5 percent (front AEB) lower by 2024 under the recession scenario compared with the conventional scenario. More than 60 percent of the registered vehicle population is expected to be equipped with rear cameras by 2024 under both scenarios. Rear parking sensors would be estimated to approach 50 percent fleet penetration by 2024 under the conventional scenario. Front AEB is estimated to increase from 8 percent of the registered vehicle population in 2019 to between 25 and 30 percent in 2024. This increase is associated with a voluntary commitment by vehicle manufacturers, brokered by IIHS and the National Highway Traffic Safety Administration, to equip vehicles with the feature by 2022.

Figure 2: Percent of registered vehicles equipped with various collision avoidance technologies in 2019 and estimated for 2024

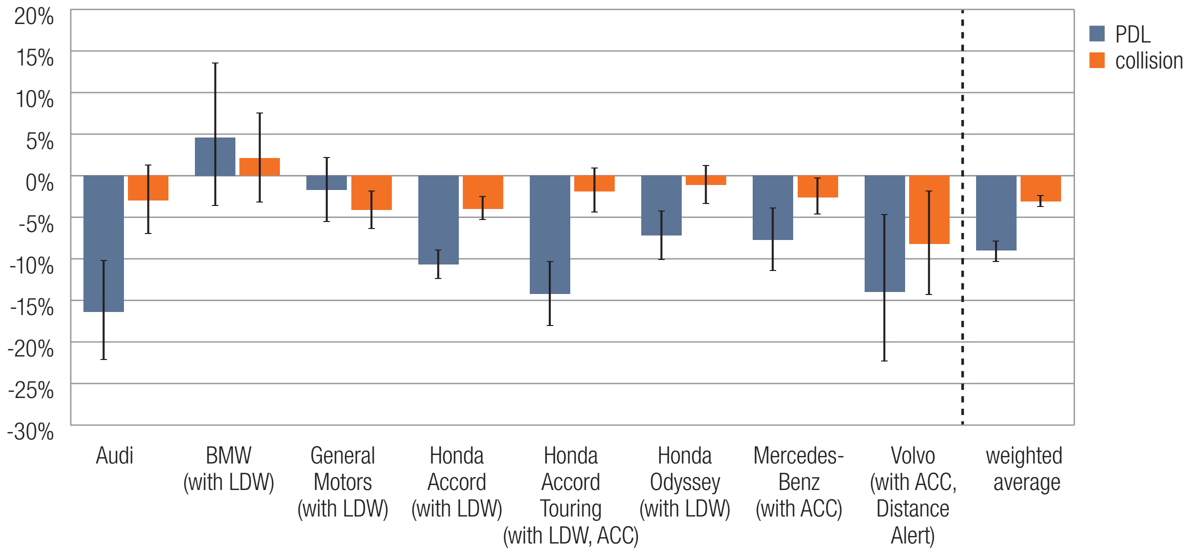


Forward collision warning (FCW)

Claim frequency

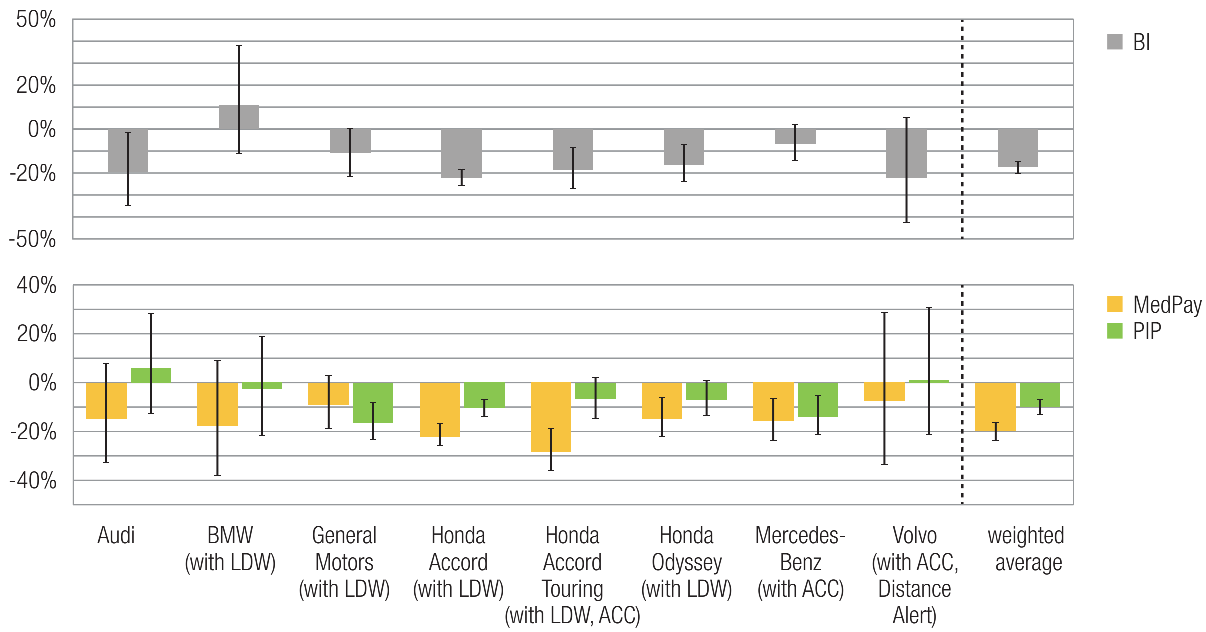
FCW alerts the driver when the system determines that the vehicle is rapidly approaching another vehicle ahead. HLDI examined FCW systems offered on Audi, BMW, General Motors, Honda Accord, Honda Odyssey, Mercedes-Benz, and Volvo vehicles. Some of the FCW systems were only available with LDW and/or ACC. FCW reduced the frequency of PDL and collision claims for every manufacturer except BMW (**Figure 3**). Combined across manufacturers, FCW was associated with a significant 9.0 percent reduction in the frequency of PDL claims and a significant 3.1 percent reduction in the frequency of collision claims.

Figure 3: Percent change in PDL and collision claim frequency associated with the presence of FCW



FCW reduced the frequency of MedPay claims for each manufacturer and reduced the frequency of BI liability and PIP claims for most manufacturers and vehicle models (**Figure 4**). Across manufacturers the technology was associated with a significant 17.4 percent reduction in the frequency of BI liability claims, a significant 19.6 percent reduction in the frequency of MedPay claims, and a significant 10.0 percent reduction in the frequency of PIP claims.

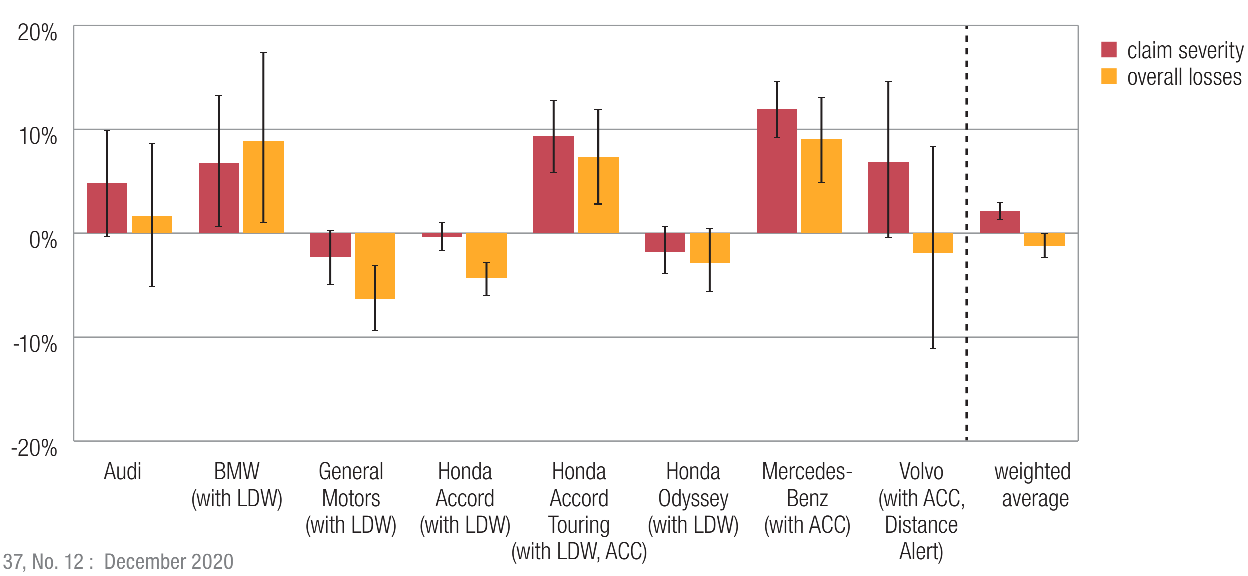
Figure 4: Percent change in BI liability, MedPay, and PIP claim frequency associated with FCW



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. The difference in claim severity changes for the two Honda Accords merits comment. The system described as “Honda Accord (with LDW)” is enabled by a camera-based sensor mounted behind the windshield, while the system described as “Honda Accord Touring (with LDW, ACC)” is enabled by a radar-based sensor mounted in the front grill. The camera-based sensor, due to its location, is much less likely to be damaged than the radar-based sensor, and, because the camera-based sensor is mounted to the windshield, it would likely be covered under comprehensive coverage and not collision. Forward Collision Warning was associated with a significant 2.1 percent increase in collision claim severity. Overall losses under collision coverage significantly decreased 1.2 percent for vehicles equipped with FCW.

Figure 5: Percent change in collision claim severity and overall losses associated with FCW

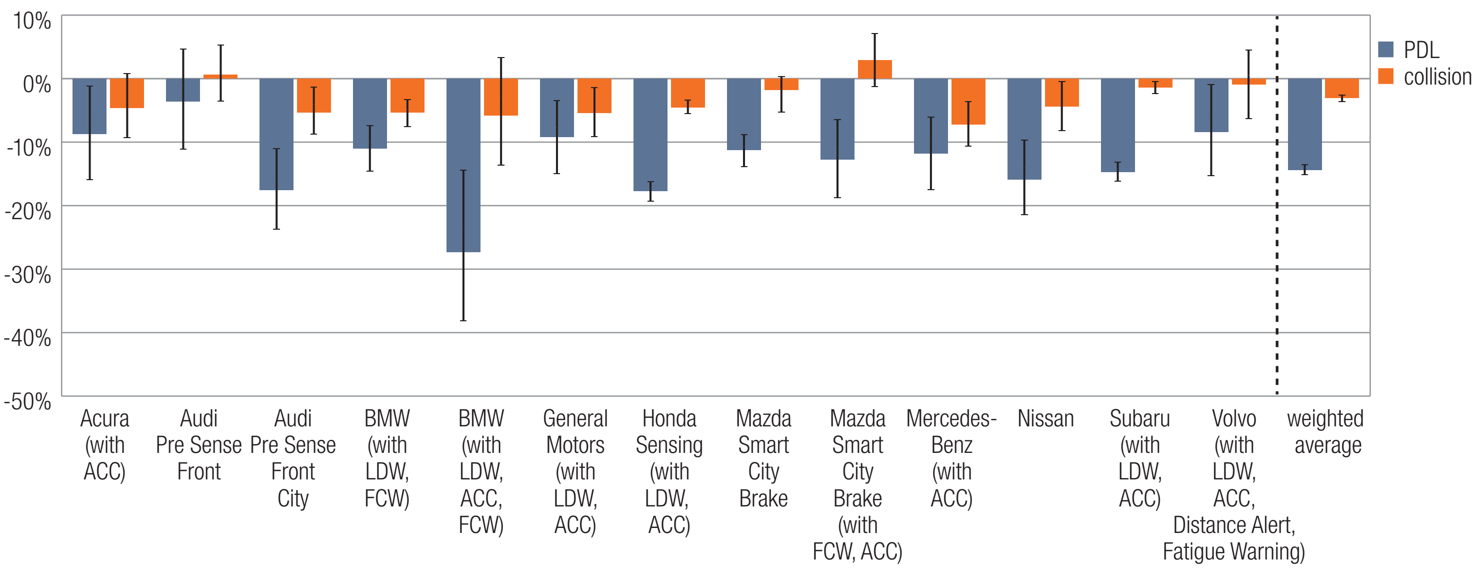


Front automatic emergency braking (AEB)

Claim frequency

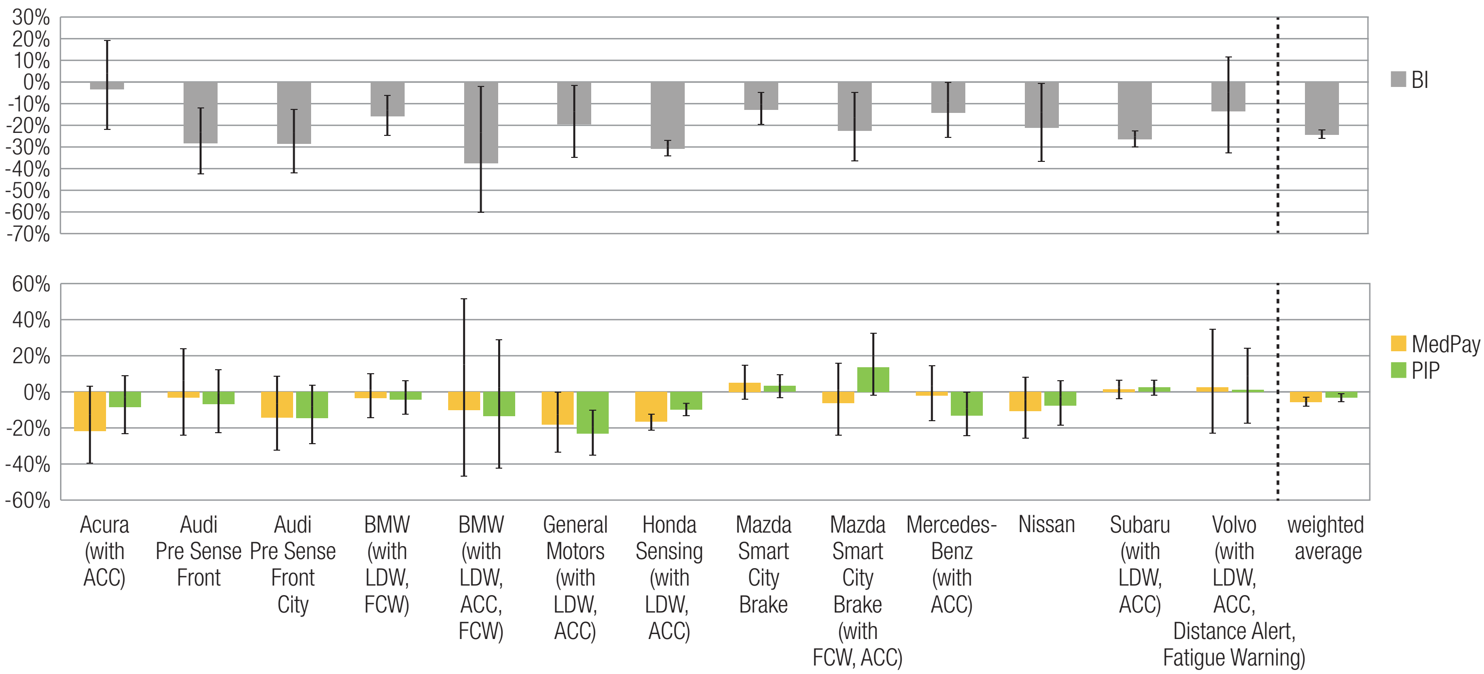
Front AEB applies the vehicle's brakes if the vehicle is rapidly approaching an object ahead and the driver does not respond. HLDI examined front AEB systems offered on Acura, Audi, BMW, General Motors, Honda (Sensing), Mazda, Mercedes-Benz, Nissan, Subaru, and Volvo vehicles. Some front AEB systems 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, BMW vehicles with LDW and FCW, General Motors vehicles, Honda Sensing vehicles, Mercedes-Benz vehicles, Nissan vehicles, and Subaru vehicles (**Figure 6**). Across manufacturers, front AEB was associated with a significant 3.0 percent reduction in collision claim frequency. Front AEB was also associated with a significant 14.4 percent reduction in PDL claim frequency. Across manufacturers, PDL frequency reductions ranged from 3.6 (Audi Pre Sense Front) to 27.3 (BMW with LDW, ACC, FCW).

Figure 6: Percent change in PDL and collision claim frequency associated with the presence of front AEB



The presence of front AEB was associated with reductions in the frequency of BI liability claims between 3.3 and 37.4 percent for each manufacturer or vehicle model (**Figure 7**). Reductions in the frequency of MedPay or PIP claims also were observed for most manufacturers. When manufacturers were combined front AEB was associated with a significant 24.4 percent reduction in BI liability claim frequency, a significant 5.7 percent reduction in MedPay claim frequency and a significant 3.3 percent reduction in PIP claim frequency.

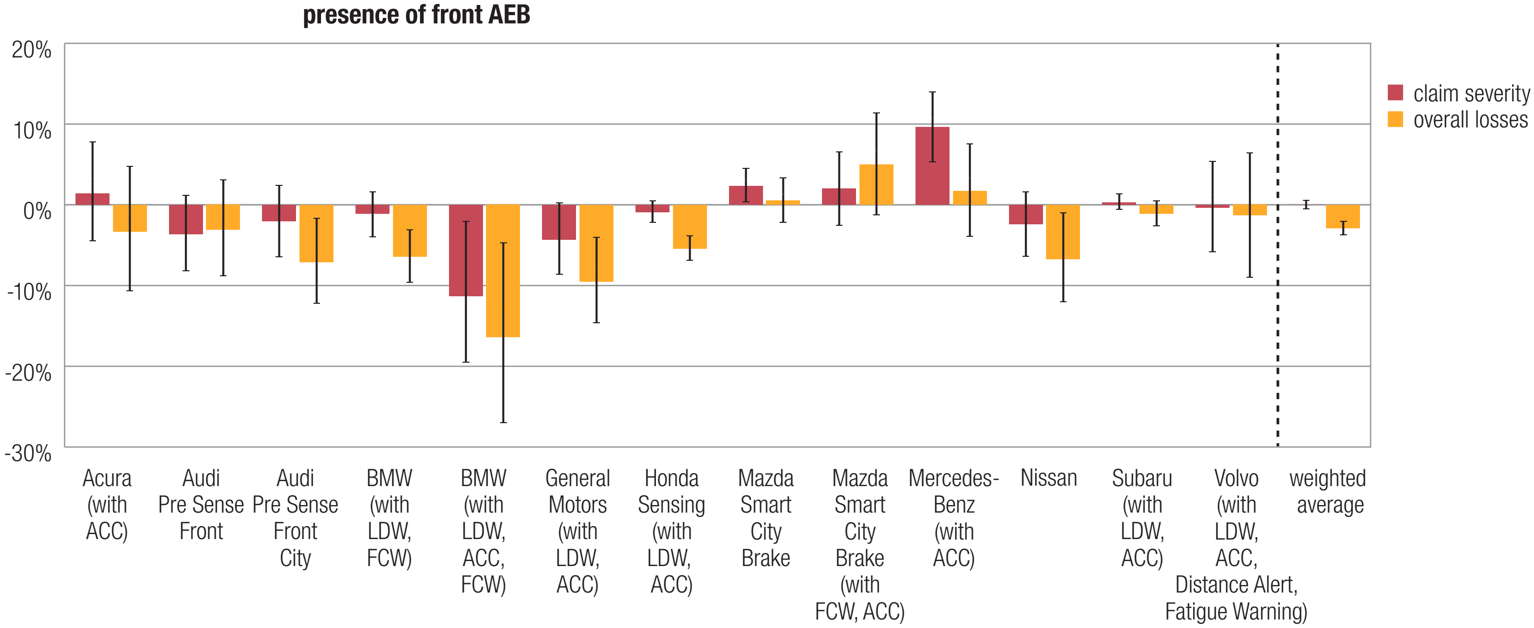
Figure 7: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of front AEB



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**). Front AEB did not significantly reduce collision claim severity. Front AEB significantly reduced overall losses under collision coverage by 2.9 percent.

Figure 8: Percent change in collision claim severity and overall losses associated with the presence of front AEB

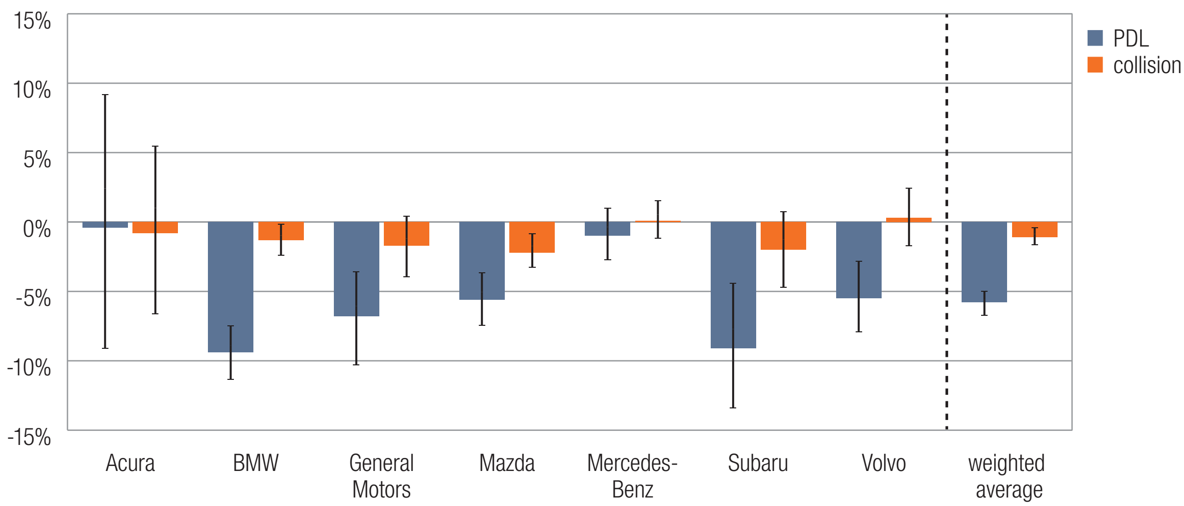


Curve-adaptive headlights

Claim frequency

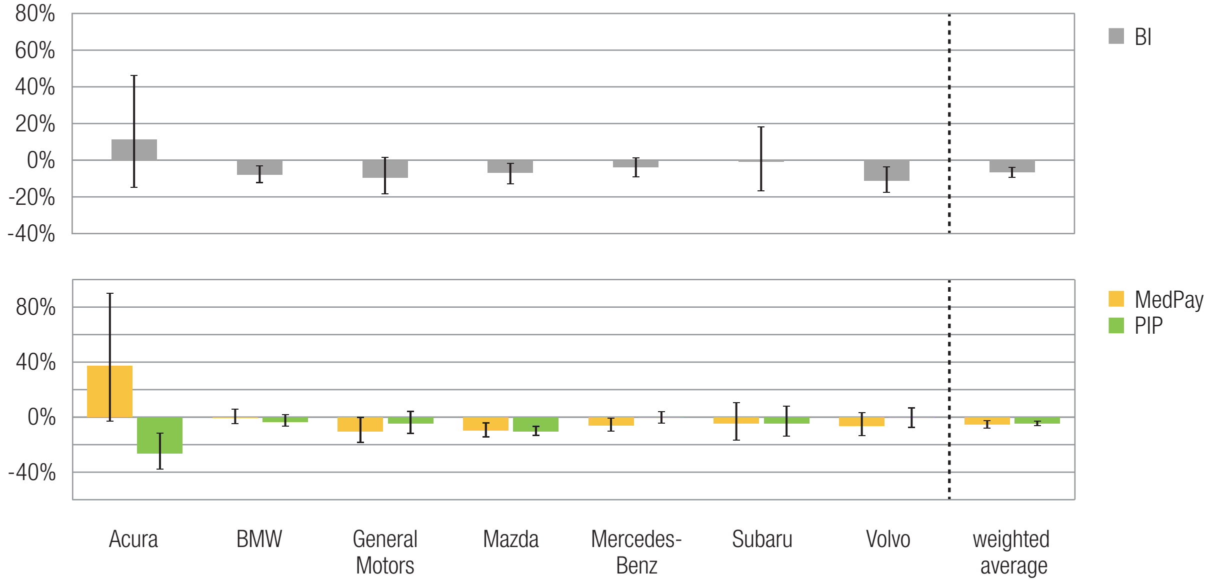
Curve-adaptive headlights are designed to help drivers see better at night on straight and curved roads than conventional headlights. **Figure 9** shows the changes in the frequency of PDL and collision claims associated with the presence of curve-adaptive headlights for Acura, BMW, General Motors, Mazda, Mercedes-Benz, Subaru, and Volvo vehicles. Curve-adaptive headlights were associated with significant reductions in PDL claim frequencies for BMW, General Motors, Mazda, Subaru, and Volvo vehicles and significant reductions in collision claim frequencies for BMW and Mazda vehicles. Across manufacturers, curve-adaptive headlights were associated with a significant 5.8 percent reduction in the frequency of PDL claims and a significant 1.1 percent reduction in the frequency of collision claims.

Figure 9: Percent change in PDL and collision claim frequency associated with the presence of curve-adaptive headlights



Curve-adaptive headlights were associated with reduced claim frequencies under BI liability and MedPay for every manufacturer except Acura. Curve-adaptive headlights also were associated with frequency reductions under PIP coverage for every manufacturer (**Figure 10**). Across manufacturers the presence of curve-adaptive headlights was associated with a significant 6.6 percent reduction in the frequency of BI liability claims, a significant 5.3 percent reduction in the frequency of MedPay claims, and a significant 4.4 percent reduction in the frequency of PIP claims.

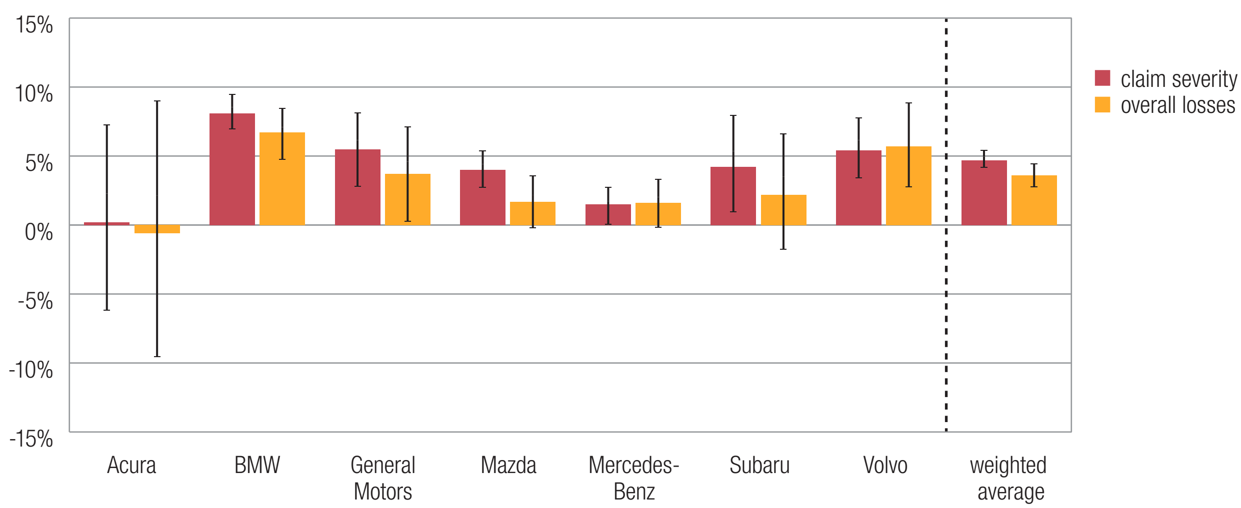
Figure 10: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of curve-adaptive headlights



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**). On average, curve-adaptive headlights were associated with a significant 4.7 percent increase in collision claim severity and a significant 3.6 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



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. When combined LDW was associated with a 0.2 percent reduction in PDL claim frequency and a 0.3 percent reduction 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

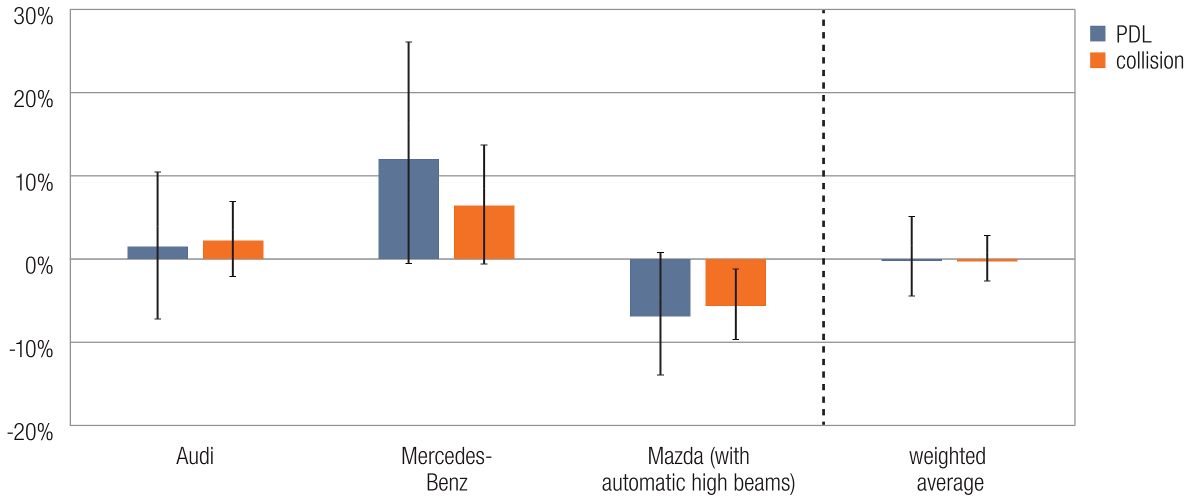
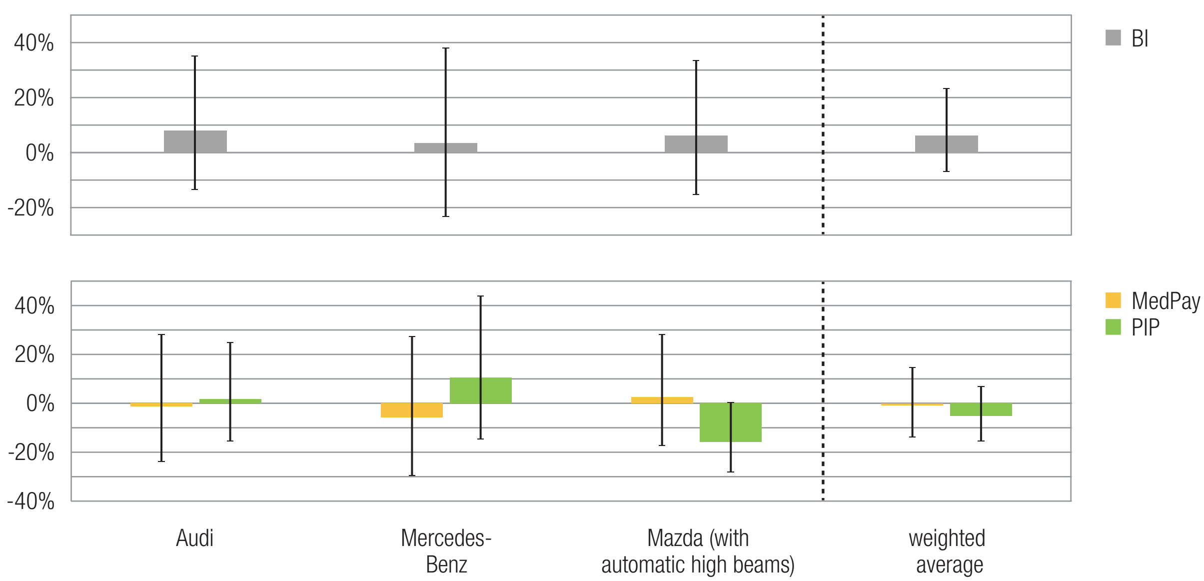


Figure 13 shows the percent change in the frequency of BI liability, MedPay, and PIP claims associated with LDW for Audi, Mercedes-Benz, and Mazda. The presence of LDW was associated with mixed effects for the frequency of MedPay and PIP claims across manufacturers. Combined the frequency of MedPay claims decreased 0.8 percent and the frequency of PIP claims decreased 5.2 percent for vehicles with LDW. In contrast, LDW was associated with BI liability claim frequency increases for each manufacturer and was associated with a 6.2 percent increase in the weighted average. The 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

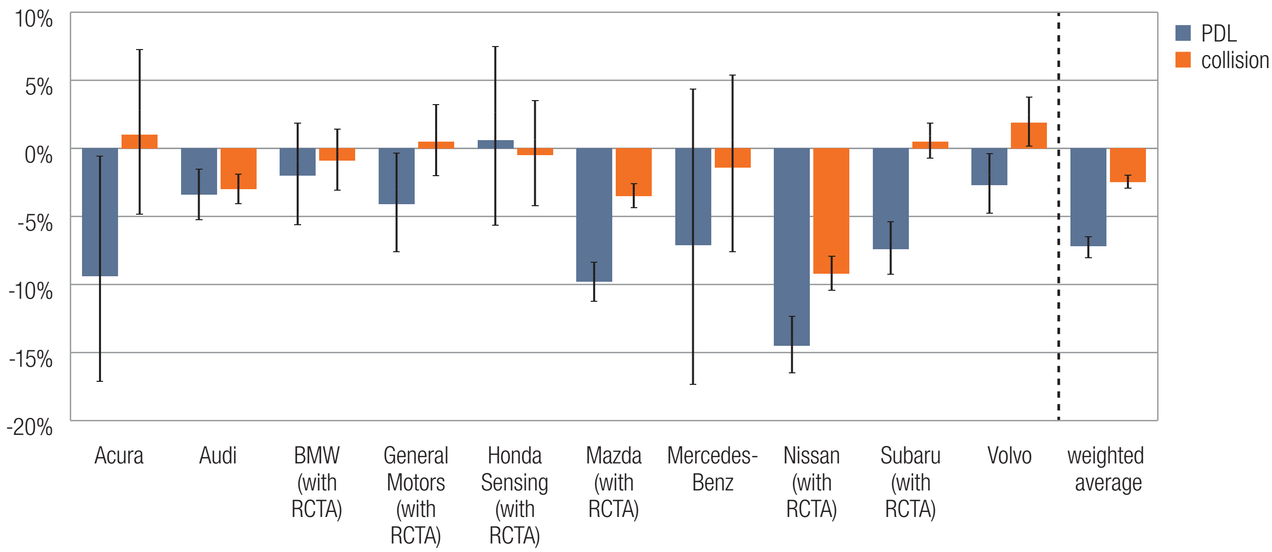


Blind spot warning (BSW)

Claim frequency

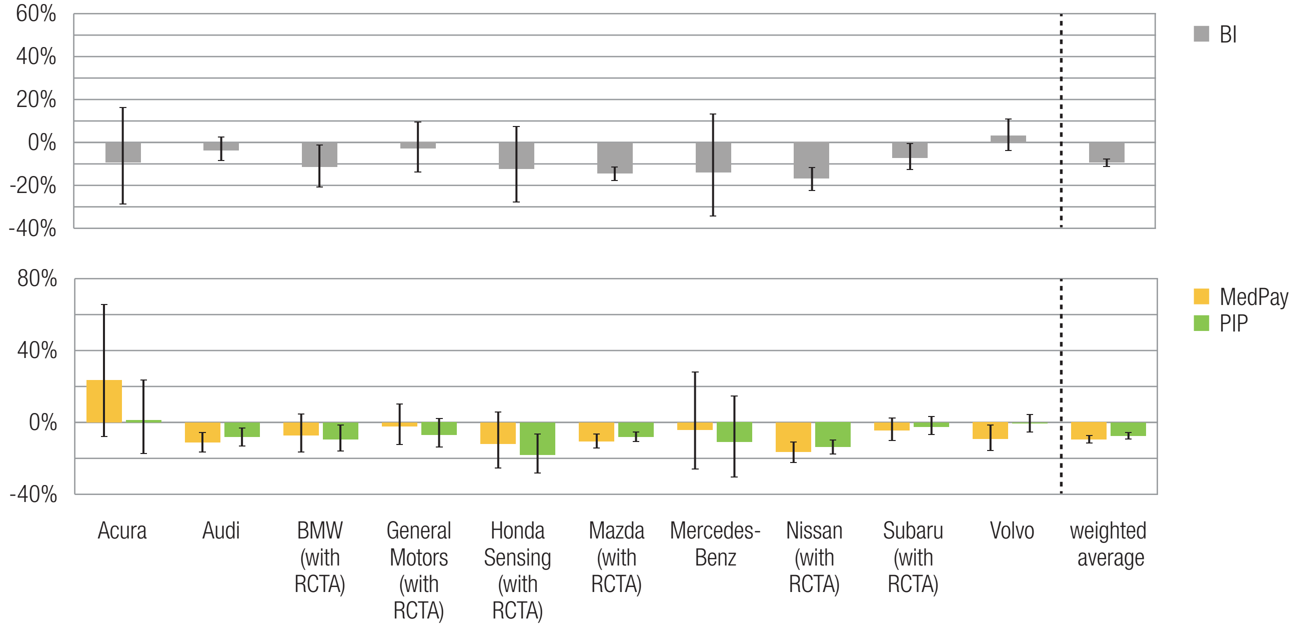
BSW informs the driver when another vehicle is in the blind spot or rapidly approaching it. **Figure 14** shows the changes in the frequency of PDL and collision claims associated with BSW for Acura, Audi, BMW, General Motors, Honda (Sensing), Mazda, Mercedes-Benz, Nissan, Subaru, and Volvo vehicles. Estimates for BMW, General Motors, Honda (Sensing), Mazda, Nissan, and Subaru are for BSW and RCTA combined. BSW was associated with PDL claim frequency reductions for every manufacturer except for Honda, and, across manufacturers the technology was associated with a significant 7.2 percent reduction in the frequency of PDL claims. BSW was associated with frequency reductions under collision coverage for some manufacturers but not for others. Across manufacturers BSW was associated with a significant 2.5 percent reduction in the frequency of collision claims.

Figure 14: Percent change in PDL and collision claim frequency associated with the presence of BSW



The presence of BSW was associated with significant reductions in the frequency of claims for injuries (**Figure 15**). Collectively BSW significantly decreased the frequency of BI liability, MedPay, and PIP claims by 9.3, 9.5, and 7.5 percent, respectively. At the manufacturer level, BSW reduced the frequency of BI liability claims for every manufacturer but Volvo. 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

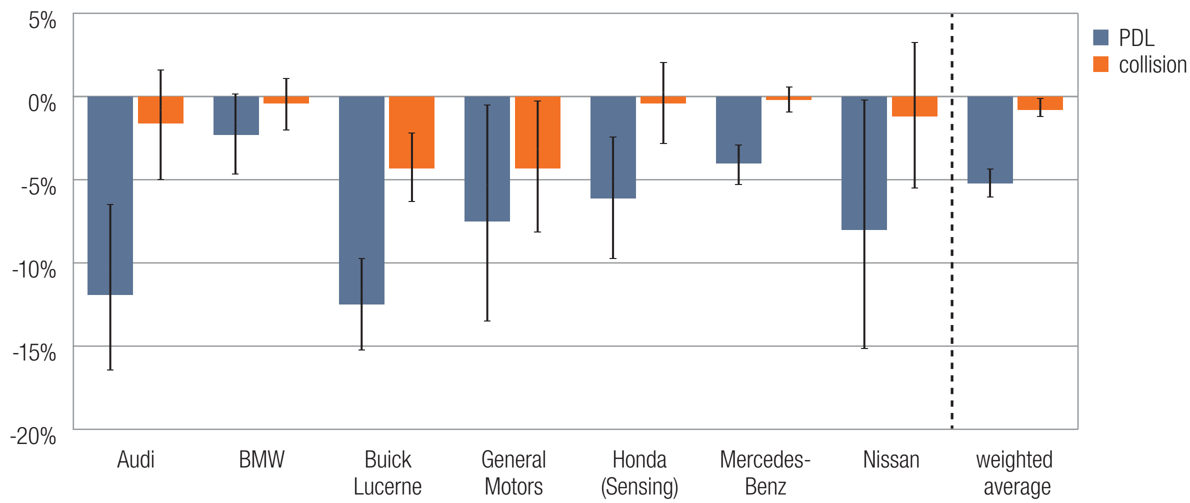


Parking sensors

Claim frequency

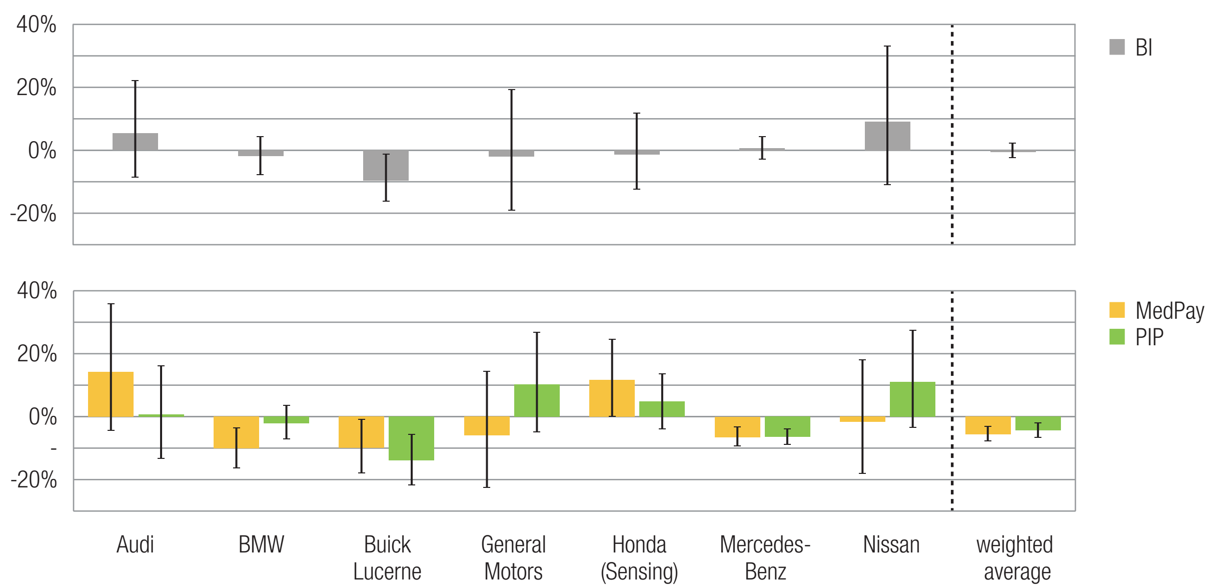
Parking sensors provide information about the distance between the vehicle and surrounding objects during low-speed maneuvers. **Figure 16** shows changes in the frequency of PDL and collision claims associated with the presence of parking sensors for Audi, BMW, Buick, General Motors, Honda (Sensing), Mercedes-Benz, and Nissan vehicles. Parking sensors reduced the frequency of PDL claims between 2.3 (BMW) and 12.5 percent (Buick Lucerne) across manufacturers, and were associated with a significant 5.2 percent reduction in the frequency of PDL claims. Parking sensors were associated with reduced collision claim frequencies for every manufacturer. Parking sensors were associated with a significant 0.8 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



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 from -9.6 (Buick Lucerne) to +9.1 percent (Nissan) for each manufacturer. When manufacturers were combined, the presence of parking sensors was associated with a 0.5 percent reduction 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, when combined, the presence of parking sensors was associated with a significant 5.6 percent reduction in the frequency of MedPay claims and a significant 4.4 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

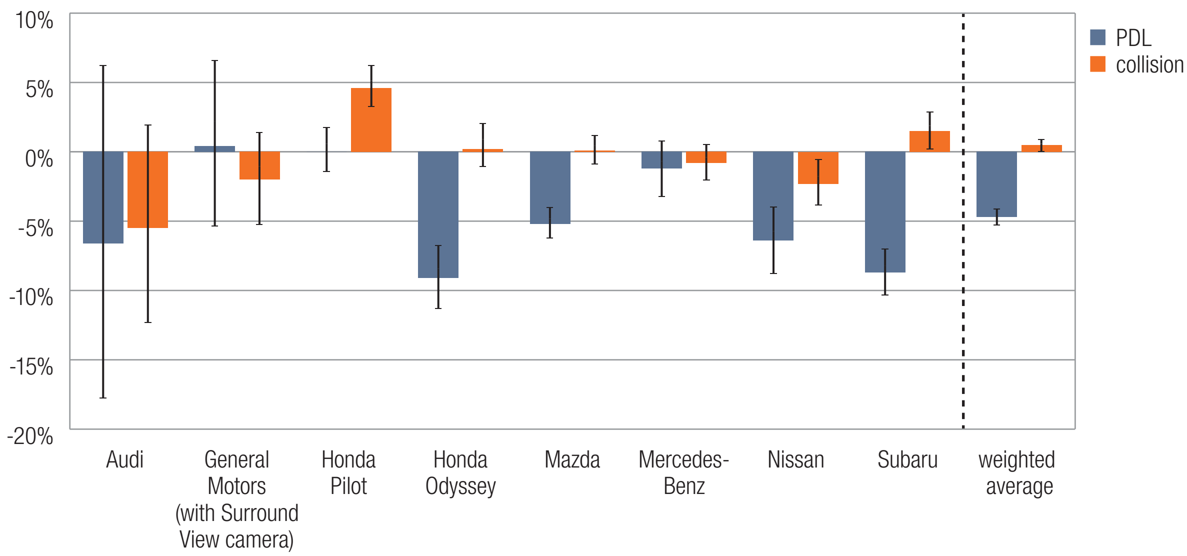


Rear camera

Claim frequency

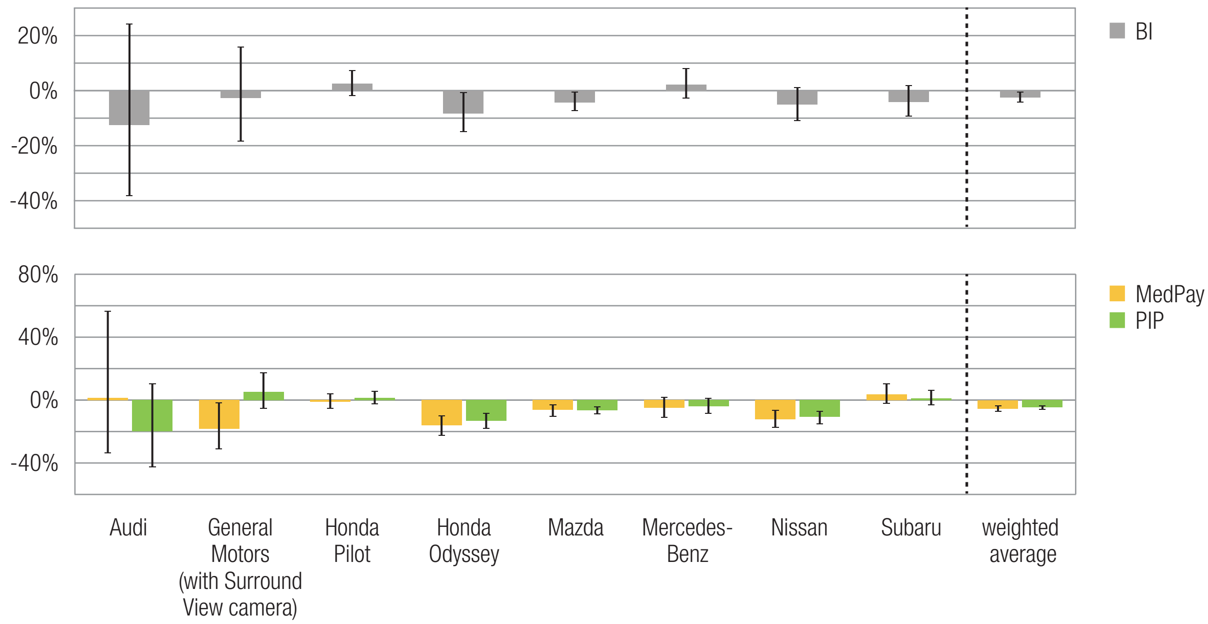
A rear camera displays an image of the area immediately behind the vehicle to enhance rear visibility when the vehicle is reversing. A rear camera was sometimes available with a surround-view camera for General Motors vehicles. **Figure 18** shows the association between a rear camera and PDL and collision claim frequencies for Audi, General Motors, Honda (Pilot and Odyssey), Mazda, Mercedes-Benz, Nissan, and Subaru vehicles. The presence of a rear camera was associated with a reduction in the frequency of PDL claims for 6 of the 8 manufacturers and vehicle models. When combined, the presence of a rear camera was associated with a significant 4.7 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. When combined, the presence of a rear camera was associated with a 0.5 percent increase in the frequency of collision claims, but this effect was not statistically significant.

Figure 18: Percent change in PDL and collision claim frequency associated with the presence of rear cameras



The changes in claim frequencies associated with rear cameras were not consistent for the injury coverage types across manufacturers and vehicle models (Figure 19). When combined, the presence of a rear camera was associated with a significant 5.4 reduction in MedPay claim frequency, a significant 4.7 percent reduction in PIP claim frequency and a significant 2.4 percent reduction in BI liability claims.

Figure 19: Percent change in BI liability, MedPay and PIP claim frequency associated with the presence of rear cameras

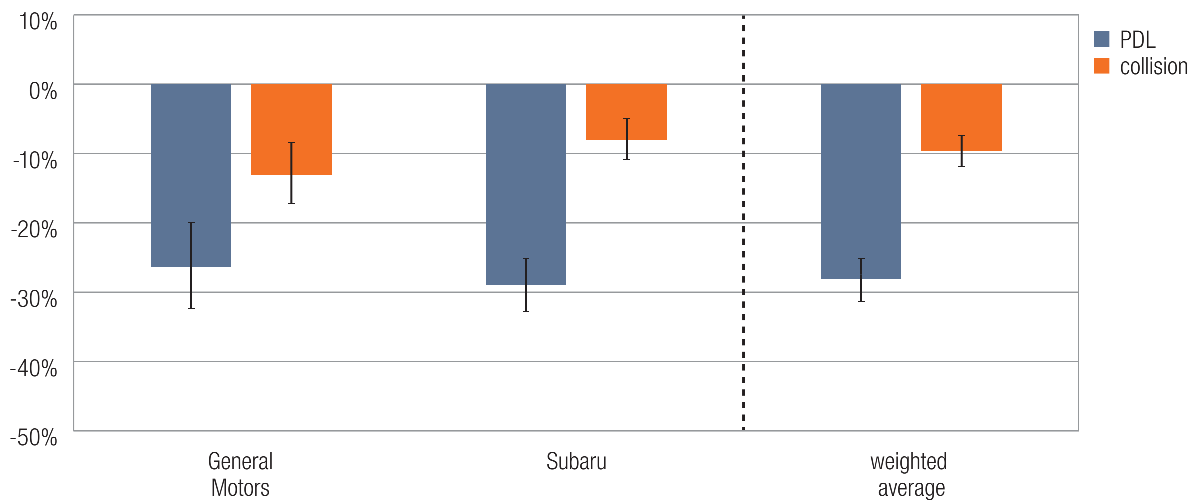


Rear AEB

Claim frequency

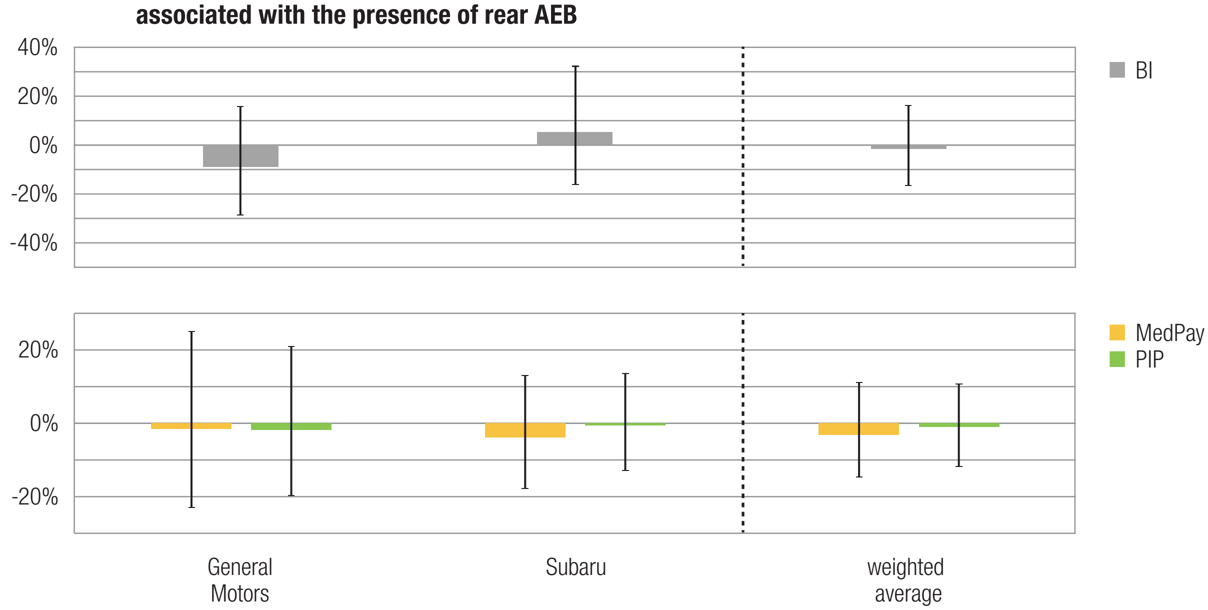
Rear AEB automatically applies the brakes if the driver does not respond to an object detected behind the vehicle while backing up. Figure 20 shows the effects of rear AEB on the frequency of PDL and collision claims for General Motors and Subaru vehicles. Rear AEB was associated with significant 26.3 and 28.9 percent reductions in the frequency of PDL claims and significant 13.1 and 8.0 percent reductions in the frequency of collision claims for General Motors and Subaru vehicles, respectively. Combined across manufacturers, the presence of rear AEB was associated with a significant 28.1 percent reduction in the frequency of PDL claims and a significant 9.6 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



The presence of rear AEB was associated with an 8.9 reduction for General Motors and a 5.2 increase for Subaru in the frequency of BI liability claims. Rear AEB was also associated with reductions in the frequency of MedPay and PIP claims for Subaru and General Motors vehicles (Figure 21). Rear AEB reduced the frequency of BI liability claims by 1.5 percent, the frequency of MedPay claims by 3.2 percent, and the frequency of PIP claims by 1.0 percent. None of these changes were statistically significant.

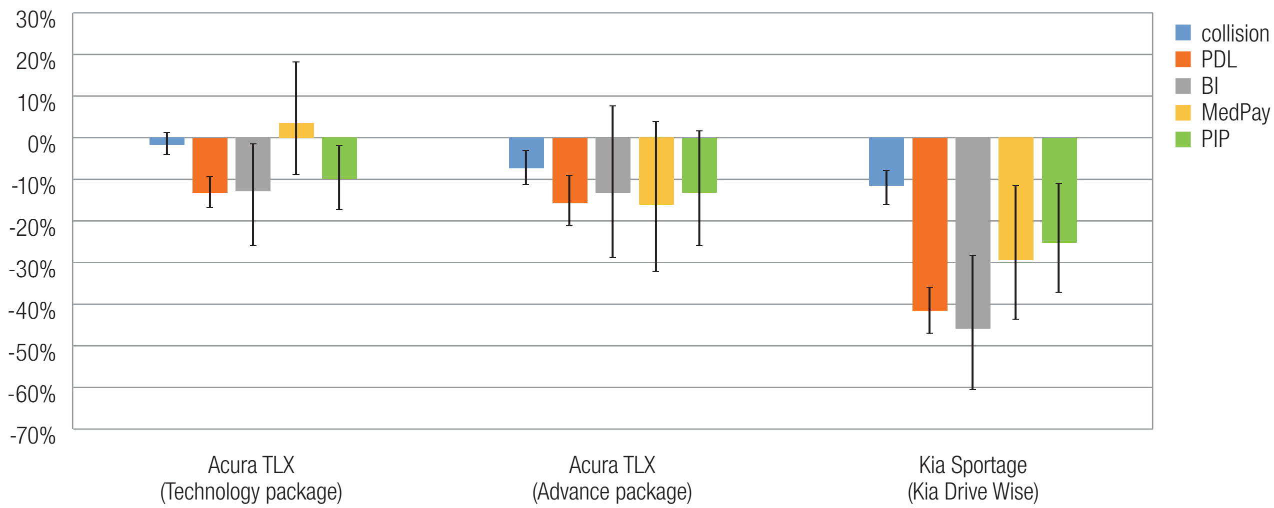
Figure 21: Percent change in BI liability, MedPay, and PIP claim frequency associated with the presence of rear AEB



Collision avoidance technology bundles

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 all those features plus front AEB, ACC, and parking sensors. Kia offered the Kia Drive Wise system on the 2017-19 Kia Sportage. The system included AEB with pedestrian detection, ACC, BSW, lane-keeping assist, lane-following assist, adaptive front-lighting system, high-beam assist, rear cross-traffic collision-avoidance assist, reverse parking collision-avoidance assist, rear parking assist and Surround View Monitor. The changes in claim frequencies associated with these three collision avoidance technology bundles 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 Acura and Kia



Each collision avoidance technology bundle was associated with claim frequency reductions under all coverage types, with the exception the Technology package for MedPay claims (**Figure 22**). The frequency of PDL claims was significantly reduced by 13.2 percent, BI liability claims by 12.9 percent and PIP claims by 9.9 percent for Acura TLX vehicles with the Technology package, but the reductions observed for collision and MedPay claim frequencies were not statistically significant. Similarly, the frequency of PDL claims was significantly reduced by 15.7 percent and collision claims by 7.4 percent for Acura TLX vehicles with the Advance package. The package was also associated with a reduced frequency of claims under every other coverage type, but these reductions were not statistically significant. Finally, there were statistically significant reductions in claims frequency under all five coverages for Kia Drive Wise. The system reduced the frequency of PDL claims by 41.5 percent, collision claims by 11.6 percent, BI liability claims by 45.9 percent, MedPay claims by 29.4 percent, and PIP claims by 25.2 percent.

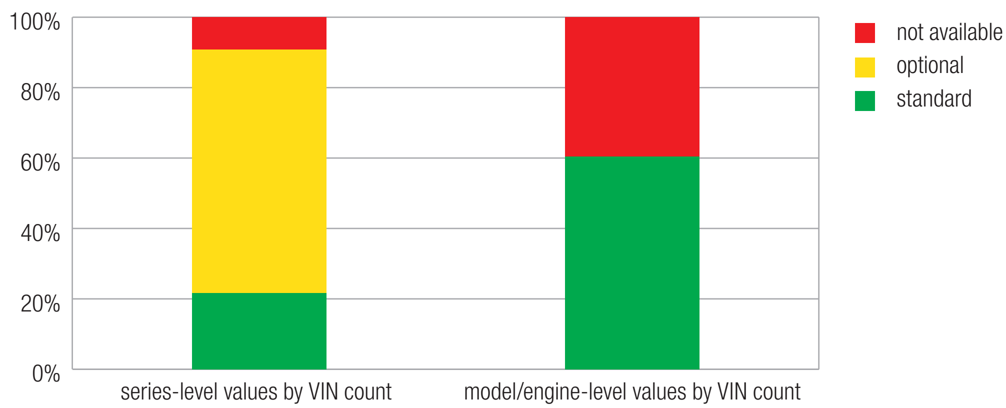
Engine-level feature data analysis

In addition to the VIN level feature data analyses described above, HLDI has begun analyzing advanced driver assistance systems using model/engine-level feature data. Traditionally, HLDI collected information for the presence of driver assistance technologies such as front crash prevention systems, blind spot warning, and parking assist systems at the model year, vehicle make, and vehicle series level. For example, information was collected about the 2017 Mazda 3 four-door car. Starting with the 2018 model year, HLDI began collecting this information at the narrower level of model (trim) and engine type. Information is now collected about the 2018 Mazda 3 four-door Sport, Touring, and Grand Touring. If multiple engine options are available for a given model, information is collected separately for each of those engine options.

Collecting data at the model and engine levels allows for a much more detailed and precise understanding of the systems that a given vehicle is equipped with. This is illustrated by **Figure 23** which is from prior research (HLDI, 2020a). The figure compares the availability of forward collision warning with autobrake for 2018 model year Honda vehicles at the series level versus the model/engine level. When a feature is optional, it may or may not be present on a given vehicle. Thus, the lower the optional percentage in HLDI's information about a series or model, the more precise that information is.

For Honda, using series-level values, nearly 70 percent of VINs would have forward collision warning with autobrake as optional, compared with no optional values using model/engine-level values. With the model/engine-level values, it is fully known if a 2018 Honda vehicle was equipped with forward collision warning with autobrake.

Figure 23: Availability of forward collision warning with autobrake for 2018 Honda vehicles



The vehicles in the latest HLDI model/engine-level feature data study included 2018–19 model year vehicles. Although HLDI collected data on a wide array of specifications and features, for the purpose of this analysis, only information on the following systems was included: forward collision warning (FCW), automatic emergency braking (AEB), low-speed AEB, blind spot warning (BSW), rear cross-traffic alert (RCTA), lane departure warning and prevention (LDW, LDP), front and rear parking sensors, parking cameras, and adaptive headlights. Vehicles that had any combination of FCW, AEB, or low-speed AEB were treated as having a front crash prevention system.

Figure 24 shows that vehicles with standard front crash prevention and lane departure prevention were associated with the largest reduction in PDL claim frequency at 16 percent. Collision claim frequencies were also reduced by a significant 3 percent. Vehicles in which the system was optional were associated with a significant 5 percent reduction in PDL claim frequency and a significant 3 percent reduction in collision claim frequency.

When standard, the combination of blind spot warning and rear cross-traffic warning was also associated with a 14 percent reduction in PDL frequency, while the reduction in collision claim frequency was 7 percent. On vehicles where these systems were optional, a reduced benefit was observed of 8 percent for PDL and 4 percent for collision. Both the changes were statistically significant.

Standard front parking sensors were associated with a significant 2 percent increase in collision claim frequency but a 2 percent reduction to PDL claim frequency. When the system was optional, collision claim frequency was reduced by 2 percent and PDL frequency by 5 percent. Rear parking sensors, both standard and optional, were also associated with significant reductions in both PDL and collision claim frequencies.

Figure 24: Change in physical damage claim frequencies associated with driver assistance technologies

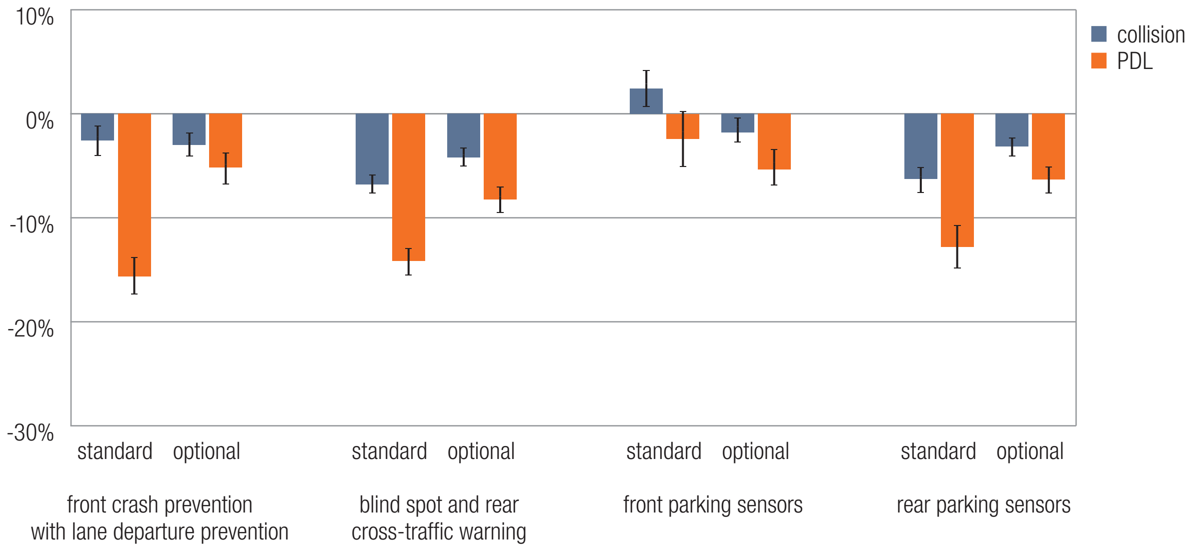
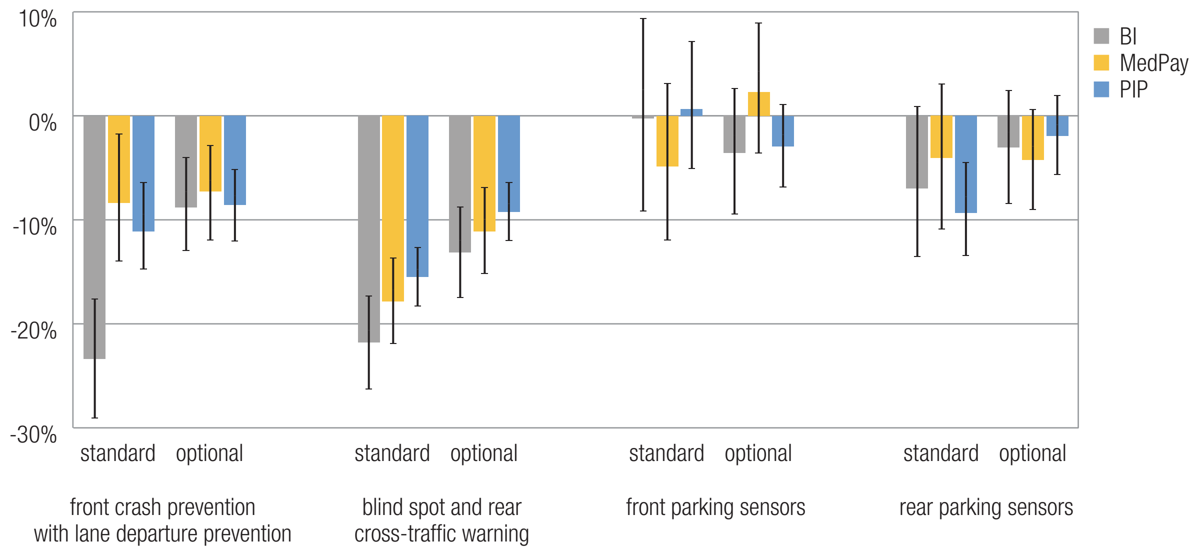


Figure 25 shows estimated differences in injury claim frequencies. Front crash prevention with lane departure prevention was associated with a significant 23 percent reduction in BI claim frequency when standard and 9 percent when optional. These systems were also associated with significant reductions in MedPay and PIP claim frequencies. The combination of blind spot warning and rear cross-traffic warning was associated with significant reductions to claim frequency for all three injury coverages when standard and optional. Results for parking sensors were generally not significant, with wide confidence bounds, although rear parking sensors were consistently associated with reductions across all three injury coverages.

Figure 25: Change in injury claim frequencies associated with driver assistance technologies



The results for this model/engine-level feature data analysis were generally consistent with the results obtained using VIN level data provided by manufacturers and outlined above. Front crash prevention systems with lane departure prevention were associated with significant reductions to PDL and BI liability claim frequencies that cover third-party property damage and injury. Blind spot and rear cross-traffic warning significantly reduced the frequencies of PDL and BI liability as expected. These technologies also were associated with significant reductions in collision claim frequency.

Discussion

HLDI has conducted more than 80 studies analyzing the association between collision avoidance technologies and changes in claim frequencies, severities, and overall losses. 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, parking sensors and rear AEB have been shown to reduce the frequency of collision, PDL, BI liability, MedPay, and PIP claims; many of these reductions are statistically significant. LDW and rear cameras reduce the frequency of claims under most coverage types. This compendium includes information on collision claim severity and overall losses only for curve-adaptive headlights, FCW, and front AEB because these technologies involve 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 (without AEB) increased claim severity.

Claim frequency

Most collision avoidance technologies influenced claim frequency as expected. FCW, front AEB, and BSW are designed to mitigate or prevent collisions with other vehicles, and the findings suggest that the technologies have been successful in this regard. FCW, front AEB, and BSW significantly reduced the frequency 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 9.0 percent and BI liability claims by 17.4 percent, but front AEB reduced the frequency of PDL claims by 14.4 percent and BI liability claims by 24.4 percent. Likewise, rear AEB reduced the frequency of PDL claims by 28.1 percent, which was more than 5 times the reduction in the frequency of PDL claims associated with parking sensors and rear cameras.

Some collision avoidance technologies influenced claim frequency 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 greatly reduce the frequency of collision claims. However, 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. One possible explanation is that the additional light from curve-adaptive headlights helps oncoming drivers detect equipped vehicles earlier on curved roads.

Similarly, LDW, which should help prevent single-vehicle run-off-road crashes, was not associated with a significant reduction in collision claim frequency. 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, 2020c). Consequently, curve-adaptive headlights elevate repair costs for many collision claims as evidenced by an associated 4.2 and 8.1 percent increase in collision claim severity for Subaru and BMW, respectively, and a 4.7 percent increase across manufacturers.

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 9.3 percent for Honda Accord vehicles equipped with a radar unit mounted in the front bumper, but severity was reduced by 0.3 percent 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, though Honda Accord vehicles equipped with a radar unit also had LED headlights. A HLDI (2016) 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 2.1 percent across manufacturers but significantly reduced the frequency of collision claims by 3.1 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 the types of 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 all reduced backing-crash involvement rates (Cicchino, 2017b; 2018b). In contrast 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, 2020d). 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 or 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) that the technology is designed to mitigate or prevent (HLDI, 2018g).

More nuanced analyses of claim frequencies, severities, and overall losses 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 (2017b) 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 information from other 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 (2020c) analysis of the point of impact distribution for matched pairs of collision and PDL claims found that 46 percent were front-impact collision claims and rear-impact PDL claims. Each bundle of collision avoidance technologies equipped to the 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, have only 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
FCW	Collision	-3.1	-3.9	-2.4
	PDL	-9.0	-10.2	-7.9
	BI liability	-17.4	-20.2	-14.5
	MedPay	-19.6	-22.4	-16.7
	PIP	-10.0	-12.4	-7.5
Front AEB	Collision	-3.0	-3.5	-2.4
	PDL	-14.4	-15.3	-13.6
	BI liability	-24.4	-26.6	-22.1
	MedPay	-5.7	-8.4	-3.1
	PIP	-3.3	-5.4	-1.2
Curve-adaptive headlights	Collision	-1.1	-1.7	-0.5
	PDL	-5.8	-6.7	-4.9
	BI liability	-6.6	-9.0	-4.1
	MedPay	-5.3	-8.0	-2.6
	PIP	-4.4	-6.5	-2.3
LDW	Collision	-0.3	-3.1	2.5
	PDL	-0.2	-5.2	5.1
	BI liability	6.2	-7.7	22.0
	MedPay	-0.8	-14.2	14.8
	PIP	-5.2	-15.6	6.4
BSW	Collision	-2.5	-3.0	-1.9
	PDL	-7.2	-7.9	-6.5
	BI liability	-9.3	-11.4	-7.1
	MedPay	-9.5	-11.8	-7.2
	PIP	-7.5	-9.2	-5.8
Parking sensors	Collision	-0.8	-1.4	-0.1
	PDL	-5.2	-6.2	-4.2
	BI liability	-0.5	-3.0	2.0
	MedPay	-5.6	-8.3	-2.9
	PIP	-4.4	-6.5	-2.1
Rear camera	Collision	0.5	0.0	1.0
	PDL	-4.7	-5.4	-4.0
	BI liability	-2.4	-4.5	-0.4
	MedPay	-5.4	-7.5	-3.2
	PIP	-4.7	-6.3	-3.1
Rear AEB	Collision	-9.6	-12.0	-7.1
	PDL	-28.1	-31.3	-24.6
	BI liability	-1.5	-16.6	16.3
	MedPay	-3.2	-15.2	10.6
	PIP	-1.0	-11.2	10.4

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The Highway Loss Data Institute is a nonprofit public service organization that gathers, processes, and publishes insurance data on the human and economic losses associated with owning and operating motor vehicles. DH