Drivers' use of front crash prevention, lane departure warning and prevention, and speed warning systems

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Abstract

Introduction: Crash avoidance technologies can aid with driving and reduce crashes, but only if drivers use them. This study measured current use of front crash prevention, lane departure (i.e., lane departure warning or lane departure prevention), and speed warning systems (i.e., systems designed to alert the driver when they are traveling above the speed limit, either visually or both visually and audibly).

Methods: We observed activation rates of systems that retain their last setting with each ignition cycle on over 2,000 model year 2017 to 2023 vehicles from six manufacturers serviced at branded dealerships in the Washington, DC, metro area in 2023. We analyzed vehicle and driver demographic characteristics to study factors associated with system use.

Results: Automatic emergency braking was enabled on 93% of vehicles, ranging from 86% to 100% by manufacturer. Lane departure warning or prevention systems were activated on 87% of vehicles, ranging from 56% to 99% by manufacturer. The lane departure system activation rates were higher for systems with prevention capabilities than for systems with only warning capabilities. They were also higher for systems activated through a settings menu rather than a button. Visual speed warnings were activated on 70% of vehicles studied, and 14% of vehicles with an audible speed warning had the audible alert turned on.

Conclusions: This study provides evidence that driver use of lane departure systems has improved over time, which may be due to more lane departure prevention over lane departure warning systems and system design changes that made them more acceptable. Early use of visual speed warning alerts is strong, and we provide manufacturers and engineers suggestions of ways to improve the acceptability of audible speed warning alerts, which are effective at reducing speeding behavior.

Introduction

Crash avoidance systems refer to a suite of technologies that can provide drivers with warnings or interventions to avoid motor vehicle crashes. Front crash prevention is a crash avoidance technology that can help the driver prevent a forward collision. Early implementation of front crash prevention was in the form of forward collision warning (FCW), which alerts the driver of an impending forward collision with another vehicle, but the driver is responsible for applying the brakes. Automatic emergency braking (AEB) can actively apply the brakes for the driver when a front-to-rear crash is imminent. Today, FCW with AEB is standard equipment on virtually every new passenger vehicle, and technological advancements have led to pedestrian and cyclist detection capabilities in addition to that of other vehicles. Similarly, when lane departure systems were first available, the system capabilities were limited to alerting the driver when the vehicle began departing the travel lane without the driver having signaled an intent to do so, known as lane departure warning (LDW). Lane departure prevention (LDP) systems provide minor steering adjustments or light one-sided braking to prevent the vehicle from departing the travel lane and are more common than in the past. Standard or optional equipment of LDW, with or without LDP, increased from 20% for 2013 models to 88% for model year 2023 vehicle series (Highway Loss Data Institute, 2024).

Crash avoidance technologies have been in the U.S. fleet long enough to show real-world reductions of the crashes they were designed to prevent. FCW with AEB on passenger vehicles has been consistently found to reduce the risk of front-to-rear crashes by up to half (Cicchino, 2017; Fildes et al., 2015; Leslie et al., 2021; Ronne et al., 2022; Spicer et al., 2021). LDW systems on passenger vehicles are associated with modest reductions in lane-departure crashes from 3% to 11% (Cicchino, 2018; Leslie et al., 2021; Ronne et al., 2022), while slightly larger crash reductions have been estimated for passenger vehicles equipped with LDP (Dean & Riexinger, 2023; Dean & Riexinger, 2022; Leslie et al., 2021; Ronne et al., 2022).

One fundamental component to these systems achieving real-world crash reductions is that drivers must keep them activated. Theoretical work suggests that many factors are associated with the use of vehicle technology. Two constructs proposed to have strong influence on system use include "compatibility," or the match between a task performed by the automation and the driver's expectation about how it should perform the task, and the trust a driver has that a system will complete the task as designed (Ghazizadeh et al., 2012; Lee & See, 2004). Compatibility and trust are initially determined by external factors such as past experience with the task or the automation (e.g., Is the task difficult to complete manually? Was the automation useful or annoying?). Ghazizadeh and colleagues also propose that compatibility and trust influence intention to use a system through the mediating factors of perceived usefulness and ease of use. An appealing feature of the theoretical model presented by Ghazizadeh et al. are feedback loops that suggest that a driver's decision to use a technology is a dynamic process where each successive experience with a technology can potentially shape future acceptance and actual use of it.

Surveys of driver acceptance of the early implementation of these systems found the use and perceived usefulness of FCW to be higher than that of LDW, with drivers reporting more annoyance with audible alerts issued by LDW than those issued by FCW (Braitman et al., 2010; Eichelberger & McCartt, 2014, 2016; McDonald et al., 2018). The higher annoyance with LDW audible alerts not experienced with FCW likely stems from their much higher frequency under normal driving conditions (Flannagan et al., 2016) compounded by a common neglect to use turn signals while changing lanes (Ponziani, 2012), which would trigger an alert if traveling within the system's operational speed. These audible alerts likely then create an unnecessary sense of urgency, which is also associated with annoyance (Marshall et al., 2007).

Annoyance is a primary reason for turning warning systems off (McDonald et al., 2018) and greater annoyance with LDW than with FCW is likely responsible for lower use of LDW, which then minimizes its ability to be effective. Telematics-based and observational studies have found activation rates of FCW to be higher than LDW on General Motors (Flannagan et al., 2016) and Honda vehicles

(Reagan & McCartt, 2016). The same has been true when exploring use among vehicles equipped with a combination of the seminal FCW and LDW systems and the intervening AEB and LDP. Electronic data recorders of crash-involved Honda vehicles from model years 2016 and newer showed twice as many vehicles had FCW/AEB on than LDW with and without LDP in the moments leading up to the crash (Wiacek et al., 2023).

An observational study captured the activation rates of crash avoidance technologies on vehicles from nine different manufacturers in the greater Washington, DC, metropolitan area and found nearly identical activation rates as Wiacek et al. (2023), with FCW (with and without AEB) on in 93% of vehicles and LDW (with and without LDP) on in 51% of vehicles (Reagan et al., 2018). When Reagan et al. (2018) collected activation rates in 2016, LDW was more common than LDP, but vehicles equipped with LDP systems were 35% more likely to have their systems activated. The higher use rate could reflect that drivers find discrete steering inputs of LDP systems more useful for preventing unintentional lane-drift crashes than alerts from LDW systems and would be consistent with Ghazizadeh et al. (2012). The work of Reagan et al. (2019) supports this conclusion in finding that LDP systems with higher activation rates in Reagan et al (2018) intervened significantly earlier and prevented significantly more lane drifts than LDP systems with lower activation rates.

Speed warning systems, a form of intelligent speed assistance (ISA), are currently offered as optional equipment in the U.S. market and use GPS with a speed limit database, a forward-facing camera that reads speed limit signs as the vehicle passes them, or both to inform drivers of the posted speed limit and their travel speed relative to it. These systems can alert the driver visually when they are traveling above the speed limit, and some vehicles offer a visual with audible alert option.

Widespread adoption of audible speed warnings has been estimated to reduce fatal crashes by about 5% (Lai et al., 2012), but as is the case with crash avoidance technologies like FCW, LDW, and LDP systems, the first step toward effectiveness is that drivers must keep them activated. Reagan and Cicchino (2024) found that over 60% of the drivers they surveyed would be open to keeping an audible speed-warning alert on if their vehicle had it, and we were curious to what extent drivers who have the system are using it. Exploring acceptance of speed-warning systems was a priority with the current study because speed increases the likelihood of crashing and is associated with poorer injury outcomes (Elvik, 2005, 2012). Speeding, or traveling above the posted speed limit, is a behavior that has persistently plagued our nation's roadways by consistently contributing to over a quarter of our roadway fatalities over the last decade (Insurance Instititue for Highway Safety, 2024). Speeding behavior increased during the COVID-19 pandemic, resulting in a 30% spike in speeding-related fatalities from 2019 to 2021 (Insurance Instititue for Highway Safety, 2024). Although speeding fatalities declined slightly from 2021 to 2022, they are still well above pre-2019 levels.

We designed this study to update Reagan et al. (2018) by observing the activation rates of crash avoidance systems that retained their prior settings with each ignition cycle on vehicles brought in for service at manufacturer-branded dealership service centers. As mentioned, virtually every new vehicle comes equipped with standard AEB, thanks to a voluntary pledge among 20 U.S.-based automakers to equip new passenger vehicles with the system by the 2022 model year (Insurance Institute for Highway Safety, 2022). Though we expected to see more vehicles with AEB because of this pledge, participating manufacturers have largely removed the ability for drivers to deactivate AEB or designed it so that the system reactivates with each ignition cycle. As a result, we anticipated seeing fewer vehicles equipped with AEB that can be turned off or retain that off setting. LDP system characteristics that Reagan et al. (2018) found to be associated with higher use are more common in today’s vehicles, so we set to remeasure activation rates of that system, which most manufacturers have maintained the ability to retain their prior settings with each ignition cycle. We also set to establish activation rates of speed warning systems.

Methods

Vehicle manufacturers

We invited manufacturers that offered systems of interest through their corporate offices and asked those interested in participating to identify independently owned dealerships in the greater Washington, DC, area that were willing to have observations conducted in their service centers. Ford, Honda, Hyundai, Kia, Mazda, and Volvo accepted our invitations. Hyundai and Kia each provided one dealership per brand while the other participating manufacturers provided two dealerships, for a total of ten dealerships. For Ford, Honda, Hyundai, and Kia, observations ran 2 weeks per dealership, for a total of 2 weeks at Kia and Hyundai and 4 weeks at Ford and Honda. We spent 4 weeks conducting observations at each Mazda and Volvo dealership, for a total of 8 weeks of observations per brand. We oversampled Volvo and Mazda because relative to vehicles manufactured by other participants, vehicles manufactured by those brands were underrepresented in Reagan et al. (2018) and we attempted to have more of a balanced sample across brands. Furthermore, Mazda and Volvo were the first to offer speed warning systems among the manufacturers who participated and offered the option for audible overspeed alerts on the most makes and model years. Oversampling those brands maximized our chances of having a sufficient sample size of speed warning systems and speed warning systems with audible alerts for analyses. Data collection ran from August to October 2023. Vehicles observed were model year 2017 to 2023 and equipped with at least LDW or LDW with LDP.

Descriptions of systems studied

All systems studied retain their prior settings with each ignition cycle.

Front crash prevention. Most newer vehicles made by participating manufacturers prohibit disabling of the system, but select models were observed that do permit for disabling the AEB or warning and disabling AEB entirely. This is usually limited to older models, but some newer Hyundai and Kia vehicles allow for the warning-only setting to be selected, and the front crash prevention system on the Ford F-150 can be turned off to account for the possibility of external equipment being fixed to the front bumper such as a plow. Activation rates for each level of available intervention (off, only warning on, warning plus AEB on) were collected for the models that do not automatically turn AEB on with each ignition cycle.

Lane departure warning and prevention. We collected activation status for LDW and LDW with LDP systems and the level of intervention selected for LDP systems (warning only or prevention/warning plus prevention). Table 1 shows the systems and the characteristics of the systems offered by each participating manufacturer included in our sample. Ford, Mazda, and some Volvo vehicles are designed to allow for prevention without warning capabilities. Most manufacturers issue haptic steering-wheel vibration alerts for lane departure warnings, except Hyundai and Kia who primarily alert drivers audibly of a lane departure. Mazda drivers can select their preferred warning modality. Systems can either be turned on or off through one press of a button or through a series of steps using a settings menu. Most Volvo and some newer Honda and Mazda models feature a settings menu to activate/deactivate or modify the system.

The Mazda models that feature activation/deactivation in a settings menu also have a button that allows the driver to temporarily disable a suite of advanced driver assistance systems, including lane departure warning and prevention, during a trip. When the lane departure warning and prevention system is temporarily disabled via the button, it returns to the activation status set in the menu with the next ignition cycle. The activation status in the settings menu was recorded for these vehicles, as that is the setting that is maintained with each ignition cycle.

Speed warning systems. Table 2 displays the speed warning system interventions and overspeed threshold options offered by each participating manufacturer. The systems we observed can communicate the speed limit to the driver visually by displaying a speed-limit-sign icon in the instrument cluster and can issue visual warnings by either flashing the icon or changing its color from white to red. Some Hyundai, Kia, and Volvo vehicles, and all Mazda vehicles equipped with the speed limit warning system feature an optional audible alert in addition to the visual warning. Most systems provide a scaled threshold that allow the driver to select when the system should issue warnings, either when traveling at or above the posted speed limit. Volvo's infotainment system found on some 2017, 2022, and 2023 models is designed to alert the driver at 3 mph over the speed limit, and this cannot be modified. Speed warning alert activation rates and threshold settings were collected. Some Honda models could display the speed limit but could not issue warnings, and we measured activation rates of that system. All system settings were controlled through a settings menu.

Procedure

The principal investigator was responsible for developing training materials and survey instruments. IIHS contracted with Westat, a research organization located in Rockville, MD, to hire data collectors, schedule observations, and provide the data collection devices installed with the REDCap data collection application. Westat's Institutional Review Board reviewed the study protocol and survey instrument and determined the study to be exempt.

The principal investigator trained the data collectors based on the brand of dealership they were assigned to. Classroom training included a general overview of the driver assistance systems, the models and model years to observe, how to access system settings based on manufacturer design, and the REDCap survey and Android application used for data collection. Hands-on training using for-sale vehicles was then conducted, which provided the observers with practice identifying models, accessing settings, and collecting data. Two data collectors were assigned to each dealership for the full data collection period.

When a customer dropped a vehicle off at the service center, dealership staff checked the vehicle in. After initial dealership checks were conducted, the observer completed data collection. The following data were collected: model; model year; a photo of the Vehicle Identification Number (VIN); total mileage; front crash prevention activation; type of lane departure system; lane departure system activation; and speed limit warning activation. Manufacturer-specific data collected included speed limit warning threshold and warning modality.

Observers collected VINs because this allowed us to study driver demographics without dealership or customer interruptions. VINs that were legible were converted to text by hand and shared with the Highway Loss Data Institute (HLDI), which maintains a database of insured vehicles that represents 85% of the private passenger-vehicle insurance market. HLDI used the VINs to provide the age and gender of the rated driver on the vehicle's current insurance policy. The first and last coverage record were used to estimate if the vehicle was purchased new or used, which we estimated as new if the coverage records had the same rated driver year of birth and gender and as used if there were differences between those fields. Of the vehicles observed, 11% went completely unmatched to HLDI records, either because of typographical errors in converting the images to text format or because they were not in the HLDI database. An additional 3% could be matched to HLDI records but only some of the data elements were available, such as age but not gender.

Analysis

We excluded vehicles with fewer than 100 miles on the odometer, as they were not likely with the owner long enough for them to determine their system preferences. There were occasional discrepancies between what systems or system settings the observers recorded and what the model and model year combinations should have been equipped with based on information from the manufacturers, so some data cleaning was required. After cleaning and removing duplicate records, a total of 2,384 vehicles with a lane departure warning or prevention system were observed. Of those, we collected speed warning system settings on 1,214 and front crash prevention settings on 293 vehicles.

We calculated activation rates for the systems of interest by each manufacturer and study-wide. Four logistic regression models were applied to estimate the likelihood that a given system or setting was on. The first model estimated the association of lane departure system activation with manufacturer, vehicle age, vehicle mileage, the system type (LDW or LDP), system activation/deactivation method (through a button or a settings menu), and rated driver demographics of first owner, gender, and age. Lane departure systems were considered on if either the lane departure warning or prevention function was activated.

The second model estimated the relationship of speed warning system activation with manufacturer, vehicle age, vehicle mileage, and the same three predictors of rated driver demographics as model 1. Speed warning systems were recorded as on if the visual or visual with audible warning setting was turned on. The third model estimated the relationship of audible speed limit alerts being on for vehicles with that option with manufacturer, vehicle age, mileage, and the three rated driver demographics. The fourth model looked for an association between lane and speed safety system activation while controlling for manufacturer, vehicle age, mileage, and the same three driver demographic predictors.

Statistical significance was considered at the $\alpha = 0.05$ level. Missing observations and predictors were removed from all analyses. System activation was common, so we corrected odds ratios to relative likelihoods using the method described in Zhang and Yu (1998).

Results

Table 3 displays vehicle and rated driver characteristics of the entire study sample. As previously mentioned, we spent twice as long at Mazda and Volvo dealerships as the others. This resulted in Mazda and Volvo vehicles representing about a third of the overall sample each. The sample leaned female, and more than half of vehicles were estimated to be with a first owner. The proportion of vehicles increased by model year until 2021 before declining with newer vehicle age. A little less than half of vehicles observed had a button that could turn the lane departure system on or off with one press.

Activation rates by manufacturer and overall

The activation rates of the LDW and LDP systems for the 2,384 vehicles observed are in Table 4. We observed 22 vehicles (10 Hyundai and 12 Mazda) with only a LDW system, and 13 (59%) were turned on. We saw an additional 2,362 vehicles (99% of our sample) equipped with LDW and LDP. Of the vehicles observed with both systems equipped, 87% had either the warning-only function activated (11%) or the LDP function activated (76%) either alone or in conjunction with a warning. Among vehicles equipped with LDP, the warning-only activation rates ranged from 2% to 42% by manufacturer, with Mazda vehicles having the lowest rates and Ford vehicles having the highest rates. The rates for the LDP functionality ranged from 35% to 97%, with Ford having the lowest and Mazda having the highest. We observed 2,068 vehicles, or 87% of the vehicles observed, to have at least the warning function enabled. This ranged from 56% to 99% by manufacturer.

Activation rates approached a ceiling for both the LDP-equipped Mazda vehicles designed to allow temporary trip disabling with a button and maintained disabling through a settings menu (n = 254, 0% off, 4% warning only, 96% prevention) and those designed with a button that retains activation status of the system at ignition (n = 452, 1% off, 1% warning only, 98% prevention) (not shown). The overall activation rate of lane departure systems across manufacturers changed little, and was 85%, when excluding the 254 Mazda vehicles where systems could be temporarily disabled.

Figure 1 shows LDP activation rates for the four manufacturers (Ford, Honda, Mazda, and Volvo) that participated in both Reagan et al. (2018) and the current study to better demonstrate how use changed over time in systems with similar functionality, given that the current sample was heavily weighted toward two manufacturers with high use rates (Mazda and Volvo). The observed activation rates increased for Ford, Honda, and Volvo vehicles; for Mazda, both vehicles with LDP observed by Reagan et al. (2018) had their systems activated and use was similarly at a ceiling in the current study's much larger sample.

Table 5 displays the activation rates for the 293 vehicles we observed to have customizable front crash prevention systems that retain the previously selected setting with each ignition cycle. Of the Ford F-150s we observed, 14% of them had the system off. Select Hyundai and Kia vehicles allow the driver to turn the AEB off if the warning-only method is selected and a total of 3% of those two branded vehicles were observed to have the warning-only option selected. Of the vehicles with customizable FCW with AEB settings, 93% were observed to have AEB on, and 96% had FCW or AEB on.

We observed 1,214 vehicles with a speed warning system (Table 6), of which 70% had the visual or visual with audible warning on, 14% had the speed limit display on but the warning function off, and 16% had the system off entirely. Warning activation rates ranged from 22% to 90% by manufacturer. Of the vehicles equipped with a speed warning system, 763 vehicles were able to alert the driver audibly, and 14% of those vehicles had the audible alert on (Table 7). We also observed 124 Honda models that can display the speed limit but do not have warning capabilities, and 119 (96%) vehicles had the speed limit information setting activated (not shown).

Figure 2 displays the threshold settings observed on the 615 vehicles that had a speed limit warning activated and the overspeed threshold was customizable. The first series shows the observed threshold settings on vehicles that had only a visual alert active, even if the vehicle could provide an audible alert. Approximately 70% of vehicles with only the visual speed warning on were set to alert the driver of an overspeed at 0 mph. About a quarter of vehicles were set to visually alert drivers when traveling between 1 and 5 mph over the speed limit, and 5% set their overspeed warning to 10 mph. Few vehicles with visual alerts active and customizable overspeed alerts were set at 15 or 20 mph over (1% each), which were overspeed options only offered by Volvo. The second series shows the observed thresholds on vehicles that were observed to have the audible alert activated. Drivers who activated the optional audible alert were less likely to set the overspeed warning at 0 mph (53%) and at 1 to 5 mph (19%) than drivers who only had the visual alert option selected. These drivers were also more likely to have selected overspeed alerts at 10, 15, and 20 mph. Overspeed settings for each manufacturer can be found in the Appendix.

Activation rates by driver and vehicle characteristics and relative likelihood of system activation

Table 8 shows the lane departure system and speed warning activation rates by vehicle and rated driver characteristics. Relative to Kia vehicles, lane departure systems on vehicles manufactured by Ford, Honda, Hyundai, Mazda, and Volvo were 10%–76% more likely to be turned on, and this was statistically significant for Ford, Mazda, and Volvo vehicles (Table 9). Every 1-year increase in vehicle age was associated with 2% higher likelihood of the lane departure system being on, however with each 10,000-mile increase in vehicle mileage recorded, the system had a 2% lower likelihood of being turned on. Vehicles equipped with LDP were significantly more likely to have the system on than vehicles equipped only with LDW (54% higher likelihood), as were vehicles with systems activated or deactivated though a settings menu rather than a button (15% higher likelihood).

Model 2 predicted the likelihood of speed warning system activation (Table 10). Relative to Mazda models, activation of the system was 64%–318% more likely among vehicles produced by other manufacturers. Each 1-year increase in vehicle age was associated with a 5% higher likelihood that the speed warning system would be on. No other associations between vehicle or rated driver characteristics and speed warning activation were significant when controlling for other model predictors.

Model 3 (Table 11) displays the associations between vehicle and rated driver characteristics and the likelihood that the audible warning function of the speed warning system was activated. Hyundai, Kia, and Volvo vehicles had 8.57 to 50.51 times as high a likelihood of having the audible speed warning alert option activated compared with Mazda, and all associations by manufacturer were statistically significant. Vehicle age was also significantly associated with a 23% greater likelihood of the audible speed warning activation for each 1-year increase. The final model (Table 12) explored the association between lane departure and speed safety system activation while controlling for the same covariates as model 2. Vehicles with the lane departure system on were nearly twice as likely to have the speed warning system on than vehicles observed to have the lane departure system off.

Discussion

This study provides evidence that user acceptance of the visual implementation of speed warning systems is positive, with 70% of vehicles having the visual warning active. However, the current implementation of the audible speed alerts was observed at 14% overall. The activation rates of front crash prevention systems remained steady from the 93% observed in Reagan et al. (2018), with 93% of our sample having AEB on. As expected, we saw far fewer vehicles with customizable AEB settings because manufacturers in our sample have designed today's systems to either turn on with each ignition cycle or they have removed the ability to turn AEB off. While the mix of vehicles from each participating manufacturer contributed to an increase in the overall lane departure system activation rate to 87% from the 51% observed in Reagan et al. (2018), we provide evidence that the activation rates of LDP increased or remained high for the four manufacturers who were observed in both studies.

The decision by manufacturers to increase the number of vehicles equipped with LDP over LDW only could result in improved crash reductions. Ninety-nine percent of the vehicles observed in this study were equipped with LDP versus 44% in Reagan et al. (2018). Both studies found vehicles with LDP were more likely to have LDP turned on than vehicles with LDW only were likely to have LDW turned on, giving LDP more opportunity to reduce lane departure crashes by virtue of more drivers keeping the system activated. Greater real-world crash reductions for vehicles with LDP have been estimated (Dean & Riexinger, 2023; Dean & Riexinger, 2022; Leslie et al., 2021; Ronne et al., 2022) over vehicles with LDW only (Cicchino, 2018; Dean & Riexinger, 2023; Dean & Riexinger, 2022; Leslie et al., 2021; Ronne et al., 2022) because the vehicle is capable of directing itself back into the travel lane rather than relying on the driver to respond to LDW alerts (Dean & Riexinger, 2022). Three quarters of LDP-equipped vehicles had the prevention capabilities activated, so it is clear that drivers in our sample favor and are comfortable with having the vehicle assist with maintaining its lane placement over having to solely respond to the LDWs.

This study also allowed us to identify ways that design changes to lane departure systems have likely encouraged greater use. When observations were conducted for Reagan et al. (2018), all vehicles except the Volvo XC90 were designed so that the lane departure system could be turned off with one push of a button. Manufacturers appear to have shifted toward using a settings menu to control lane departure system functionality, with slightly over half of our sample of vehicles featuring this design. Systems designed this way were 15% more likely to be on than systems that could be deactivated with a button, so making it a bit more complex to turn the system off while continuing to allow drivers to do so appears to have increased use. We do not know what Mazda's hybrid system might have on lane departure system use, as drivers could regularly use the button to temporarily deactivate the multiple advanced driver assistance systems controlled by that button rather than setting their preferred lane departure settings in the menu where the activation status is maintained with each ignition cycle. However, activation rates at ignition were similar between the two Mazda system designs.

Another example of a thoughtful engineering design that seems to have increased use is how most manufacturers who participated in the current study have designed their LDP systems to alert drivers haptically of a lane departure, which deviates from the audible warnings common in earlier LDW systems. Drivers have indicated annoyance with audible alerts for lane departures (Braitman et al., 2010; Eichelberger & McCartt, 2014, 2016), and Reagan et al. (2018) found that in vehicles with haptic lane departure alerts, these alerts were 16% more likely to be activated than alerts in systems that alerted drivers of a lane departure audibly. One large-scale field study found that drivers assigned to a vehicle with customizable warnings favored the vibrating seat alert over the audible beep by 9 to 1, and that vehicle's LDW system was on twice as much as a vehicle that could only provide audible lane departure alerts (Flannagan et al., 2016). Our manufacturer-level results also make preference for haptic alerts clear, as those that still use audible alerts had the highest observed off rates.

Studies that have explored the functional attributes that influence use suggest that systems that perform well are more likely to be used than those that perform poorly, so ongoing improvement of existing technologies could be another avenue for manufacturers to influence driver use. Reagan et al. (2019) found LDP systems that provide steering sooner and better prevented vehicles from veering out of the lane were more likely to have been on. Similarly, Navarro et al. (2017) discovered drivers experiencing LDW in a simulator study thought earlier warnings were more effective and trustworthy than delayed warnings. Kidd and Reagan (2019) found increased agreement among drivers that an LDP system that consistently detected lane lines significantly predicted that the driver would keep the system on all the time, where a different simulator study found drivers who experienced an LDW system that gave fewer false warnings indicated that using the system was more pleasing and agreeable than drivers who experienced a more unreliable system that provided more false alerts (Navarro et al., 2016).

Design modifications could potentially also promote use of audible speed warning systems. Speeding is common in the U.S. (AAA Foundation for Traffic Safety, 2023; De Leonardis et al., 2018) and because audible alerts are considered annoying under driving scenarios perceived as low urgency (Marshall et al., 2007), there may be a disconnect with the perceived and actual need of audible speed alerts in their current design. However, opportunities exist to strike a better balance between effectiveness and use. Since audible speed warning alerts reduce speeding (Biding & Lind, 2002; National Highway Traffic Safety Administration, 2014) and visual-only speed warnings can easily go unseen (European Commission, 2022), finding an acceptable and effective speed warning with an audible or haptic component is preferred. Although we observed just 14% of vehicles that could provide an audible warning had the system (Kia vehicles) on or a supplemental warning feature (Mazda and select Volvo and Hyundai vehicles) on, the appetite for audible speed warning systems alerts in the U.S. is strong as Reagan and Cicchino (2024) found most drivers surveyed felt they would leave the system turned on if their vehicle were equipped. This suggests there are ways to close the gap between perceived and current use.

Just as manufacturers ramped up equipping vehicles with LDP in recent years, comparably equipping speed warning systems with audible alerts as standard across models and trims instead of as an optional feature as it is now could increase use in the future when the feature permeates the fleet. Most drivers agreed they would want an audible speed warning system in their vehicle if 60%–80% of the fleet were equipped, and that equipment rate range was significantly associated with these participants indicating they would accept and keep the system on (Reagan & Cicchino, 2024). Some drivers speed or take risks when they feel pressure from a driver behind them or that they need to keep up with the traffic flow (Musselwhite, 2006; Paine, 1996), and lowering traffic speeds through widespread ISA use and other effective means (i.e., traffic calming, speeding enforcement) would reduce this pressure. Strengthening the argument to increase equipment, exposure to the technology is positively correlated with positive perceptions of it (Ryan, 2018).

Though we do not know all the factory delivery settings of the speed warning systems for each participating manufacturer, having the systems turned on when delivering vehicles to the customer appears to encourage higher activation. For example, the 2017 Mazda CX-5 owner's manual indicates that the factory setting for their speed safety system features the display on and the warning off (Mazda North America, 2017), meaning drivers would need to manually change the setting to be audibly and visually alerted. Assuming this factory setting applies to all Mazda vehicles in the study, this helps explain why 77% of the Mazda vehicles we observed had the display on, 22% had the visual warning on, and 2% had the audible warning on. Conversely, the Honda owner's manuals of the five model and model year combinations equipped with the speed warning system in our study indicate the default setting for visual speed limit warnings is on for three (Honda Motor Company, 2022, 2023a, 2023b, 2023c, 2023d). Honda does not provide an audible alert, but the fact that over half of models are delivered to buyers with the visual warning on likely contributes to why we observed a much higher activation rate for visual speed warnings on Honda-made vehicles in our sample. Likewise, delivering vehicles with the audible speed warning on could enhance use of the warning found to be effective.

To further advance use of the audible speed alerts while balancing acceptance, manufacturers could adjust the factory-default overspeed threshold to a nonzero value. On the Mazda and Honda models we have factory settings for, the default speed limit threshold is set at 0 mph (Honda Motor Company, 2022, 2023a, 2023b, 2023c, 2023d; Mazda North America, 2017). If this is another factory delivery setting by most or all participating manufacturers, it helps explain why vehicles set to alert visually were most likely to have a 0-mph threshold setting observed. However, drivers who activated their audible speed warnings were less likely to have the overspeed threshold set at 5 mph or less and more likely to have it set at 10 mph or over than those who selected visual only alerts. This was expected, as 80% of drivers said they would accept an audible alert when driving 10 mph over the posted speed limit versus 30% at 1–2 mph over (Reagan & Cicchino, 2024). Setting audible alerts at a slightly lower limit of 8 mph over the speed limit resulted in drivers significantly decreasing their mean times driving over 8 mph and over 20 mph (National Highway Traffic Safety Administration, 2014), suggesting some allotment to travel above the posted speed limit can still be effective at reducing the most egregious speeding offenses.

Engineers could also configure overspeed alerts as a percentage over the speed limit instead of a set number of miles per hour over, which is an option on aftermarket systems outside of the U.S. (Samsara Inc., 2024). Under this design, a vehicle might sound a warning when the driver has driven a percentage over the speed limit for a certain length of time; for example, after driving 11% over the speed limit for 10 seconds. This continues to provide some speeding allowance of about 8 mph on many interstates, around what drivers indicated they would accept in Reagan and Cicchino (2024) and shown effective in (National Highway Traffic Safety Administration, 2014). However, this would promote much safer travel speeds in residential areas and other lower speed roads where vulnerable road users are common. Fatality risk rises sharply when pedestrians are struck at around 35 mph versus 25 mph (Tefft, 2013), making a standard 10-mph alert far less beneficial than one sounding around 28 mph, or 11% over on a 25-mph speed-limit street.

U.S.-based manufacturers might also consider implementing cascading audible alerts, which the European Union approved in their newly introduced ISA mandate (European Commission, n.d.). Cascading audible alerts would first allow a driver to see and respond to a primary visual alert. If the driver does not lower their speed, a secondary audible alert would follow, with a delay varying depending on the percentage of speed traveled over the limit. Europe also requires systems to turn on with each ignition cycle if the system was turned off on the previous trip, another approach U.S.-based manufacturers could easily follow to increase use while providing drivers with the option to turn the system off on a trip-by-trip basis.

Use of these systems has increased to the point that historical questions of demographic differences in use appear less relevant today. Older drivers have downplayed the value of crash avoidance features (Oxley et al., 2019; Zhan et al., 2013) and have voiced concerns that the alerts are distracting (Zhan & Vrkljan, 2011), which led to questions of lower use among older drivers than among younger drivers. However, more recent work has found that older drivers trust these technologies (Braun et al., 2019; Reagan et al., 2023) more than and display stronger understandings of the systems than younger drivers (Reagan et al., 2023). Older drivers have also exhibited a stronger willingness to use assistance technologies, which our study focused on, than automation (Abraham et al., 2017), which we did not explore. Reagan et al. (2018) surveyed some customers when dropping off their vehicles for service and found driver age did not significantly predict the observed activation rates of lane departure systems at that time, which aligns with our lane departure system findings. Speeding is most common among younger drivers (AAA Foundation for Traffic Safety, 2023; Reagan & Cicchino, 2024), so they could most benefit from these systems. While older age is associated with increases in agreement of ISA acceptability (Reagan & Cicchino, 2024), drivers between the ages of 25 and 34 indicated the strongest willingness to use a system that helped them control their speed (Abraham et al., 2017). These findings that drivers across age groups see some advantages to using a speed warning system might explain why we did not find significant associations between rated driver age and the likelihood of speed warning or audible speed alert activation.

We did not find differences in the likelihood of lane departure system activation by gender, where the previous study found that males had significantly higher activation rates than females (Reagan et al., 2018). Males have exhibited more trust in, awareness of (Reagan et al., 2023), and acceptance of (Braun et al., 2019) different technologies than females have. However, reported comfort in using crash avoidance technologies is higher for females but was high for both genders (Abraham et al., 2017), so the nature of lane departure prevention as a crash avoidance technology could be why we found similar use across genders. Due to gender differences with speeding behaviors (AAA Foundation for Traffic Safety, 2023; Reagan & Cicchino, 2024), males could benefit more from speed warning systems for the same reason younger drivers would. Males have indicated they would be more comfortable than females receiving help to control their speeding (Abraham et al., 2017), yet we found no differences in the likelihood of speed warning system activation or audible alert activation by gender. Our finding mirrors those in Reagan and Cicchino (2024), who found no significant gender differences in agreement that ISA would remain on or would be accepted if their vehicle were equipped.

We expected to observe higher activation rates on vehicles purchased new than used because survey participants who bought their vehicles new displayed more trust and understanding in different crash avoidance or driver convenience systems (Reagan et al., 2023), and we were surprised to find the opposite to be true. Experiences during the sale and the underlying characteristics of used vehicles in our sample could help explain why. New vehicle buyers were significantly more likely to indicate the seller spent time describing how to turn the systems on and off and how to adjust system settings than buyers of used vehicles (Reagan et al., 2023). Not receiving this training when buying a used vehicle could result in the higher activation rates we observed, particularly if drivers purchased their used vehicles with the systems on and the vehicles have other design features associated with higher use.

One limitation of this study is that it is not generalizable to the U.S population. Dealership service centers were largely located in densely populated urban areas. Although some participating dealerships have more of a rural reach than others, this study may not be well representative of drivers in more rural areas. Drivers living in urban areas seem to see a greater benefit to ISA than rural dwellers, as urban-living drivers were more open to leaving ISA on (Reagan & Cicchino, 2024), so our observed activation rates for speed warning systems in particular could be higher than what we might expect to find if the study had been conducted in an area with lower urbanicity. Another consideration is this study examined use at a single point in time, or when the driver dropped the vehicle off for service. These urban drivers' use may vary situationally depending on the driving environment. Additionally, residents of Washington, DC, and the surrounding counties in Virginia and Maryland report a higher educational attainment (U. S. Census Bureau, 2022a) and income (U. S. Census Bureau, 2022b) than national averages. These demographic characteristics could influence higher use rates of these technologies. We examined rated driver age and gender so that our observers would not need to intrude when customers dropped of their vehicles for service, but this decision introduced some error into demographic analyses because the person on the insurance policy may not have been the person who most recently drove the vehicle.

Conclusion

Many drivers in the greater Washington, DC, metro area with a speed warning system on their vehicle are amenable to visual speed warnings, but few vehicles with the additional option of audible speed alerts were activated. To increase use, we suggested ways manufacturers could consider modifying their systems. Through system improvements, manufacturers appeared to have successfully encouraged increased use of lane departure prevention systems by increasing equipment of prevention capabilities and changing warning modalities.

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Tables

Table 1

Primary lane departure warning methods and activation methods

Manufacturer	System type	Primary warning modality	Intervention modes	Primary activation method
Ford	W + P	V + H	W, P, or W + P	B
Honda	W + P	V + H, escalates to A	W or W + P	B or M [a]
Hyundai	W W + P	V + A V + A	 W or W + P	B
Kia	W + P	V + A	W or W + P	B
Mazda	W W + P	Choice of H or A (either rumble strip sound or beep)	 W, P, or W + P	B or M [a]
Volvo	W + P	V + H	W, P, or W + P	B or M [a]

Note. W = lane departure warning, P = lane departure prevention; V = visual, H = haptic steering-wheel vibration, A = auditory; B = button, M = settings menu.

[a] Indicates variation by model.

Table 2

Primary speed warning system interventions and overspeed threshold options

Manufacturer	Speed warning system interventions	Threshold options
Ford	D + V	1-mph increments between 0 and 5 mph
Honda	D D + V	0, +3, +5, +10 mph
Hyundai	D, D + V D, D + V, D + V + A	−10, −5, 0, +5, +10 mph −5, −3, 0, +3, +5 mph
Kia	D, D + V D, D + V, D + V + A	−10, −5, 0, +5, +10 mph −5, −3, 0, +3, +5 mph
Mazda	D, D + V, D + V + A	0, +3, +5 mph 0, +5, +10 mph 0, +3, +5, +10 mph
Volvo	D, D + V D, D + V, D + V + A	Set +3 mph (no choice) 0, +5, +10, +15, +20 mph

Note. D = display, V = visual warning, A = audible warning.

Table 3

Rated driver and vehicle characteristics

Variable	% in sample (n = 2,384)
Rated driver age	
16–34	19.9
35–54	39.9
55 and older	26.6
missing	13.6
Rated driver gender	
Female	46.7
Male	38.9
Missing	14.4
First vehicle owner	
Yes	62.0
No, used	26.7
Missing	11.3
Model year	
2017	5.2
2018	9.3
2019	12.8
2020	15.5
2021	20.1
2022	18.6
2023	18.5
Manufacturer	
Ford	13.6
Honda	15.7
Hyundai	8.5
Kia	1.7
Mazda	30.1
Volvo	30.4
Lane departure system activation method	
Button	47.7
Settings menu	52.4
Mileage (mean, SD)	31,310 (24,488)

Table 4

Activation rates for lane departure systems by manufacturer and overall

	Lane departure warning systems (n = 22)	Lane departure prevention systems (warning and prevention features) (n = 2,362)			Total (n = 2,384)
		Warning and prevention off	Warning on, prevention off	Prevention on, prevention and warning on	Lane departure warning or prevention on
Manufacturer					
Ford (n = 325)		22%, 72	42%, 138	35%, 115	78%, 253
Honda (n = 374)		25%, 94	19%, 72	56%, 208	75%, 280
Hyundai (n = 202)	10%, 1 (n = 10)	34%, 66	7%, 14	58%, 112	63%, 127
Kia (n = 41)		44%, 18	10%, 4	46%, 19	56%, 23
Mazda (n = 718)	100%, 12 (n = 12)	1%, 5	2%, 15	97%, 686	99%, 713
Volvo (n = 724)		7%, 52	4%, 28	89%, 644	93%, 672
Total (n = 2,384)	**59%, 13**	**13%, 307**	**11%, 271**	**76%, 1,784**	**87%, 2,068**

Table 5

Activation rates for vehicles with customizable front crash prevention settings

	System off	Warning on, AEB off	AEB on
Manufacturer			
Ford [a] (n = 96)	14%		86%
Honda (n = 9)	0%		100%
Hyundai (n = 152)		5%	95%
Kia (n = 35)		3%	97%
Total (n = 293)	**4%**	**3%**	**93%**

[a] F-150 only

Table 6

Activation rates for speed warning systems by manufacturer and overall

	Display and warning off	Display on, warning off	Display and warning on
Manufacturer			
Ford (n = 181)	70%		30%
Honda (n = 60)	2%	20%	78%
Hyundai (n = 64)	11%	8%	81%
Kia (n = 21)	24%	0%	76%
Mazda (n = 164)	1%	77%	22%
Volvo (n = 724)	7%	3%	90%
Total (n = 1,214)	**16%**	**14%**	**70%**

Table 7

Activation rates for audible speed warning system alerts by manufacturer and overall

	Audible warning off	Audible warning on
Manufacturer		
Hyundai (n = 11)	18%	82%
Kia (n = 8)	13%	87%
Mazda (n = 164)	98%	2%
Volvo (n = 580)	85%	15%
Total (n = 763)	**86%**	**14%**

Table 8

Characteristics of rated drivers and vehicles with lane departure system and speed warning systems on

Variable	Lane departure system on, %	Speed warning on, %
Rated driver age		
16–34	89.5	67.2
35–54	86.6	74.1
55 and older	86.6	69.4
Rated driver gender		
Female	88.1	73.9
Male	86.3	67.9
First vehicle owner		
Yes	86.5	68.4
No, used	89.0	78.5
Model year		
2017	78.9	70.8
2018	89.2	78.6
2019	86.6	86.6
2020	85.4	73.1
2021	91.7	66.4
2022	86.0	63.6
2023	84.3	65.0
Lane departure system activation method		
Settings menu (n = 1,136)	93.4	-
Button (n = 1,248)	80.7	-
Lane departure system function		
Warning	59.1	-
Prevention	87.0	-

	Lane departure system on	Lane departure system off	Speed warning system on	Speed warning system off
Mileage, mean (SD)	30,616 (23,909)	35,834 (29,915)	32,407 (23,668)	26,623 (23,730)

Table 9

Relative likelihood of lane departure system activation

	Relative likelihood ratio (95% CI)
Manufacturer (ref = Kia)	
Ford	1.34 (1.04, 1.55) *
Honda	1.10 (0.75, 1.40)
Hyundai	1.13 (0.79, 1.41)
Mazda	1.76 (1.72, 1.78) *
Volvo	1.45 (1.10, 1.64) *
Vehicle age	
Every 1-year increase	1.02 (1.00, 1.03) *
Mileage	
Every 10,000-mile increase	0.98 (0.97, 0.99) *
Lane departure system function (ref = warn)	
Prevention	1.54 (1.14, 1.66) *
Activation method (ref = button)	
Settings menu	1.15 (1.10, 1.19) *
First owner (ref = yes)	
No, used	1.03 (0.98, 1.06)
Rated driver gender (ref = male)	
Female	1.01 (0.96, 1.04)
Rated driver age (ref = 55 and older)	
16–34	1.02 (0.96, 1.06)
35–54	0.99 (0.94, 1.03)

Note. CI = confidence interval.

* $p < 0.05$

Table 10

Relative likelihood of speed warning system activation

	Relative likelihood ratio (95% CI)
Manufacturer (ref = Mazda)	
Ford	1.64 (1.10, 2.27) *
Honda	3.90 (3.24, 4.26) *
Hyundai	3.94 (3.32, 4.27) *
Kia	3.63 (2.51, 4.22) *
Volvo	4.18 (3.97, 4.32) *
Vehicle age	
Every 1-year increase	1.05 (1.00, 1.09) *
Mileage	
Every 10,000-mile increase	0.98 (0.95, 1.01)
First owner (ref = yes)	
No, used	1.10 (0.97, 1.21)
Rated driver gender (ref = male)	
Female	0.98 (0.86, 1.09)
Rated driver age (ref = 55 and older)	
16–34	1.12 (0.97, 1.23)
35–54	1.08 (0.97, 1.18)

Note. CI = confidence interval.

* $p < 0.05$

Table 11

Relative likelihood of speed warning audible alert activation

	Relative likelihood ratio (95% CI)
Manufacturer (ref = Mazda)	
Hyundai	47.40 (23.69, 52.68) *
Kia	50.51 (25.35, 52.68) *
Volvo	8.57 (2.95, 20.70) *
Vehicle age	
Every 1-year increase	1.23 (1.04, 1.44) *
Mileage	
Every 10,000-mile increase	0.97 (0.87, 1.08)
First owner (ref = yes)	
No, used	0.96 (0.61, 1.45)
Rated driver gender (ref = male)	
Female	1.08 (0.71, 1.58)
Rated driver age (ref = 55 and older)	
16–34	1.73 (0.91, 3.00)
35–54	1.22 (0.77, 1.87)

Note. CI = confidence interval.

* $p < 0.05$

Table 12

Relative likelihood of speed safety activation when lane departure system is active

	Relative likelihood ratio (95% CI)
Lane departure system activation (ref = off)	
On	1.94 (1.79, 2.04) *
Manufacturer (ref = Mazda)	
Ford	1.61 (1.08, 2.24) *
Honda	4.13 (3.59, 4.38) *
Hyundai	4.27 (3.86, 4.44) *
Kia	4.20 (3.46, 4.46) *
Volvo	4.27 (4.09, 4.38) *
Vehicle age	
Every 1-year increase	1.03 (0.98,1.08)
Mileage	
Every 10,000-mile increase	0.98 (0.94, 1.01)
First owner (ref = yes)	
No, used	1.09 (0.95, 1.20)
Rated driver gender (ref = male)	
Female	0.98 (0.85, 1.09)
Rated driver age (ref = 55 and older)	
16–34	1.11 (0.95, 1.23)
35–54	1.09 (0.97, 1.19)

Note. CI = confidence interval.

* $p < 0.05$

Figures

Figure 1

Number of vehicles observed with LDP and their activation rates among manufacturers that participated in Reagan et al. (2018) and the current study

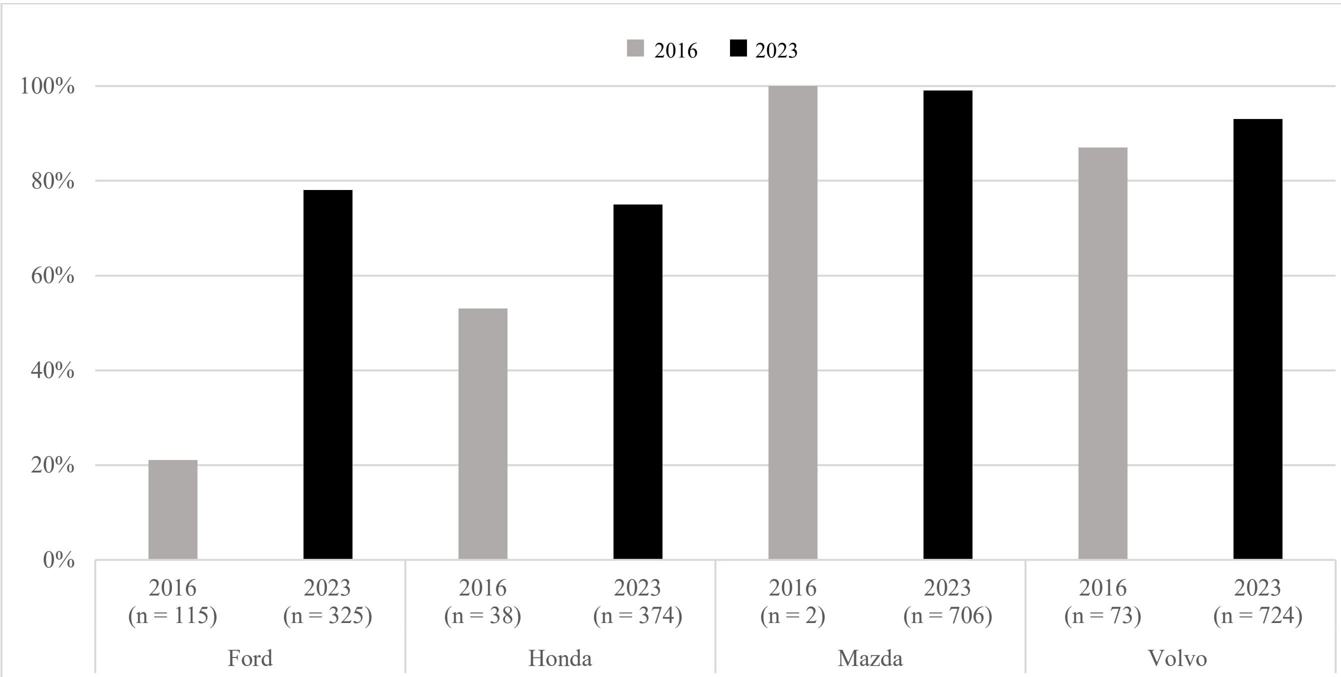
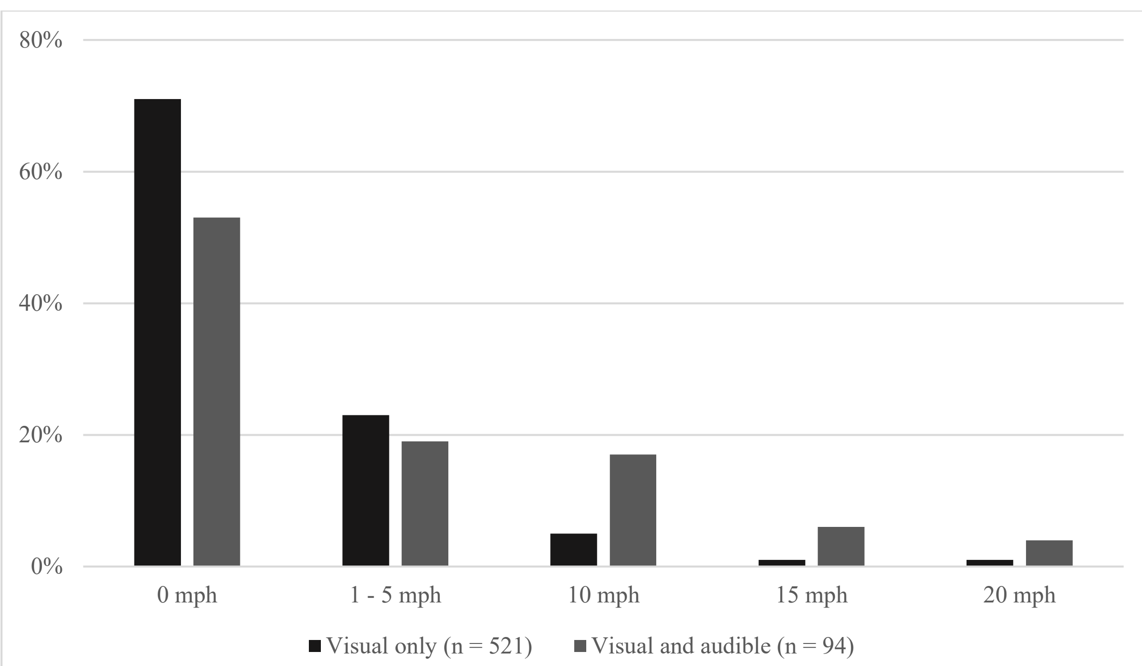


Figure 2

Observed threshold settings for configurable systems when speed limit alert was on and when visual only or visual and audible alerts were selected (n = 615)



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Appendix

Figure A1. Speed limit threshold, Ford vehicles

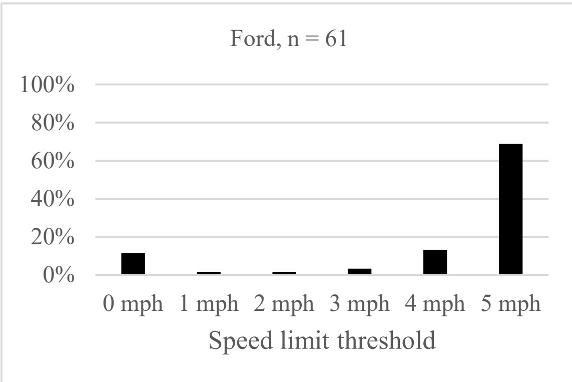

Figure A2. Speed limit threshold, Honda vehicles

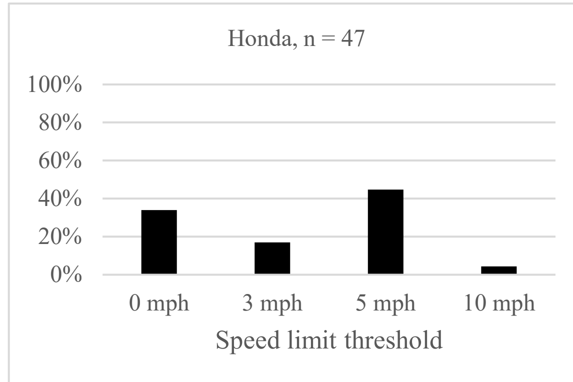

Figure A3. Speed limit threshold, Hyundai vehicles

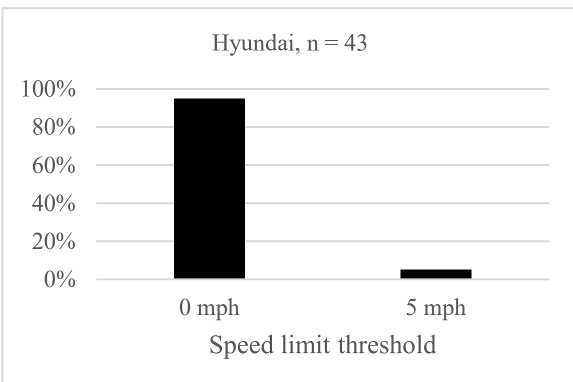

Figure A4. Speed limit threshold, Kia vehicles

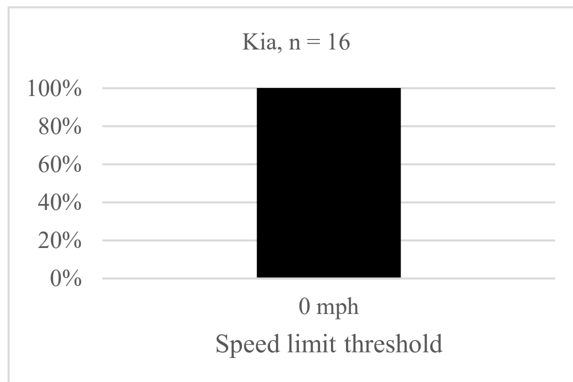

Figure A5. Speed limit threshold, Mazda vehicles

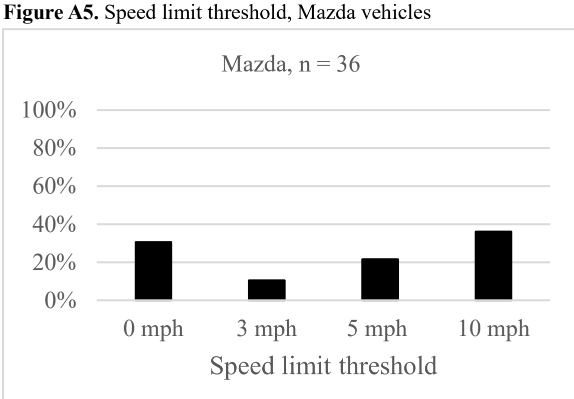

Figure A6. Speed limit threshold, Volvo vehicles