Exploring relationships between observed activation rates and functional attributes of lane departure prevention

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ABSTRACT

Objective: Driver use of lane departure warning and prevention systems is lower than other crash avoidance technologies and varies significantly by manufacturer. One factor that may affect use is how well a system prevents unintended departures. The current study evaluated the performance of systems that assist in preventing departures by providing steering or braking input in a 2016 Chevrolet Malibu, 2016 Ford Fusion, 2016 Honda Accord, and 2018 Volvo S90. These vehicles were selected because a prior observational study found the percentage of privately owned vehicles that had lane departure prevention systems turned on varied among these four automakers.

Method: In each vehicle, a test driver induced 40 lane drifts on left and right curves by steering the vehicle straight into the curve so that vehicles departed in the opposite direction and 40 lane drifts on straightaways by slight steering input to direct the vehicle to left and right lane markers.

Results: Vehicles from automakers with higher observed lane departure prevention use rates (Volvo, Chevrolet) featured systems that provided steering input earlier and more often avoided crossing lane markers by more than 35 cm compared with vehicles from automakers with lower observed use rates (Ford, Honda).

Conclusion: The study identified functional characteristics of lane departure prevention systems that were strongly associated with observed activation of these systems in privately owned vehicles, and the findings support the hypothesis that functional characteristics of lane departure prevention systems affect their use. Designers may be able to use these results to maximize driver acceptance of future implementations of lane departure prevention.

Keywords: advanced driver assistance systems, driver acceptance, functional performance, lane departure prevention

INTRODUCTION

Crashes from unintentional lane drifts are relatively rare but frequently severe. Jermakian (2011) and Kusano and Gabler (2014) estimated that although lane departure warning and prevention systems would address a small percentage of all police-reported crashes (i.e., property-damage-only, injury, and fatal crashes), the systems would be relevant to a much larger percentage of fatal crashes. Two studies have found significant but smaller than expected decreases in police-reported crashes relevant to lane departure warning among vehicles equipped with the systems (Cicchino, in press; Sternlundet al. 2017). One factor likely limiting crash reductions is driver disuse of the systems. Reagan et al. (2018) found that 52% of 961 privately owned vehicles had their lane departure warning, lane departure prevention, or active lane-keeping systems turned off when their owners brought them to dealership service centers (Table 1). This low rate of use is consistent with research of lane departure warning systems produced by individual manufacturers (Flannagan et al. 2016; Reagan and McCartt, 2016). Self-report surveys of owners of vehicles with lane departure warning reveal that owners find lane departure warnings more annoying than forward collision warnings (Eichelberger and McCartt, 2014, 2016), and a greater proportion of owners whose lane departure warning or prevention systems were observed to be turned off agreed that warnings were unnecessary than owners whose systems were turned on (Reagan et al. 2018). Characteristics associated with increased use of lane departure warning include warning modality (vibrating warnings associated with higher rates of use than auditory warnings) (Flannagan et al. 2016; Reagan et al. 2018) and warning timing (earlier preferable to later timing) (Navarro et al. 2016).

This study focused on lane departure prevention systems that provide isolated steering and/or braking inputs when a vehicle is drifting out of its lane. Reagan et al. (2018) reported that activation rates of lane departure prevention systems were especially variable across manufacturers (Table 1). Lane departure prevention systems were significantly more likely to be turned on than systems that only provided warnings, yet the automaker with the lowest activation rate across all system types (Ford/Lincoln) offered a system with multiple functional modes including lane departure warning only, lane departure prevention with warning, and lane departure prevention only. The primary research objective was to assess whether on-road functional performance of lane departure prevention systems correspond with the rates of observed use by manufacturer reported in Reagan et al. (2018).

Table 1. Percent of vehicles with lane maintenance systems turned on by most active intervention level available, by manufacturer. (From Reagan et al. 2018).

Manufacturer	Lane departure warning		Lane departure prevention		Active lane keeping		Total	
	%	(n)	%	(n)	%	(n)	%	(n)
Ford/Lincoln	–	–	23	93	–	–	21	93
Honda	33	201	53	38	–	–	36	239
Chevrolet	43	115	72	32	–	–	50	147
Cadillac	56	160	59	44	–	–	56	204
Lexus/Toyota	60	15	74	54	65	78	68	147
Volvo	50	32	87	73	–	–	75	105
Mazda	75	24	100	2	–	–	77	26
Total	45	547	58	336	65	78	52	961

Prior experience is one of several constructs proposed to affect perceived usefulness, which is one of the key determinants of an individual's intention to use a system (Venkatesh and Davis, 2000). Ghazizadeh et al. (2012) proposed that prior exposure to manufacturer-specific implementations of a driver assistance technology influences perceived usefulness, particularly when system use is voluntary. Drivers who purchase vehicles with lane departure prevention systems are likely to experience system steering or braking during normal driving or may intentionally test a system's capabilities to prevent departures and then form a judgement of whether the system is compatible with how they drive and whether they trust it.

Kidd and Reagan (2018b) assessed how adaptive cruise control and active lane keeping affected the overall driving experience among drivers who drove production-level vehicles for periods up to several weeks. Ratings of how much a technology improved the driving experience varied among vehicles with the same technology, and drivers' ratings of functional characteristics of the automated vehicle control inputs (e.g., smoothness of steering and speed adjustments) were highly predictive of how much drivers agreed that the system improved the overall driving experience. Relatedly, Kidd and Reagan (2018a) reported that increased driver agreement that warnings from lane departure prevention systems were useful was associated with increased agreement that they would keep the system turned on. These findings support Ghazizadeh et al.'s hypothesis about the influence of functionality on acceptance. The observed lane maintenance system on-off rates by manufacturer reported in Reagan et al. (2018) may reflect owners' estimations of system utility based on early interactions.

For the current study, lane departure prevention systems in production vehicles from Ford, Honda, Chevrolet, and Volvo were tested on a public highway to evaluate where system steering or braking input occurred relative to lane markings, and whether system input was sufficient to keep a vehicle from departing its travel lane. A test driver put each vehicle through a series of 80 trials, where the vehicle would be put on course to drift over lane markers on a 1,000 m radius curve or a straightaway to evaluate when the lane departure prevention systems provided input and whether the input kept the vehicle from departing the lane. Based on the results of Reagan et al. (2018) and Kidd and Reagan (2018a; 2018b), it was expected that the capability to prevent lane excursions would follow the activation rate patterns, with Volvo avoiding a greater percentage of departures than Ford. Regarding timing of the first steering input, Navarro et al.'s (2016) simulator work on lane departure warning found that earlier warning timing was more acceptable than later, which suggests that automakers that had higher activation rates may provide steering input further inside the lane.

METHOD

Vehicles

The test vehicles included a model year 2016 Chevrolet Malibu, Ford Fusion, and Honda Accord, and a model year 2018 Volvo S90. The 2016 model year vehicles were selected because they were included in the sample observed by Reagan et al. (2018). The 2018 Volvo S90 was included to restrict the testing to standard sedans, and the only 2016 model year Volvo available with the lane departure prevention system was a large SUV. Vehicle dimensions are listed in Table A1. Table A2 includes the descriptions of the lane departure prevention systems from the vehicle owner manuals.

Instrumentation

Vehicles were instrumented with a data logger (Racelogic, model Video VBOX Pro) that accommodated four video inputs. Cameras 1 and 2 were mounted on the outside of each vehicle and aimed toward the pavement. A grid overlay was superimposed on the video of Cameras 1 and 2 to measure distance (cm) from the vehicle relative to the lane marker (Figure 1). Given the standard resolution of the cameras, the calibration process resulted with accuracy of about ± 2 cm. Camera 3 was aimed at the steering wheel to record system steering input and the forward road scene. Camera 4 was aimed at the instrument panel to capture the timing of the visual lane departure warning. The data logger included a GPS antenna, which was used to record vehicle speed, latitude, and longitude, and featured a trigger that was used to identify trial starts in the data file. An inertial measurement unit (Oxford Technical Solutions, model RT2002) recorded yaw rate (degrees per second) at a sampling rate of 100 Hz. Within the VBOX Test Suite data logger software, yaw rate was filtered at 60 Hz to reduce noise.

Figure 1. View from driver-side outboard camera on rear door. Ruler overlay was used to estimate distance (cm) from vehicle to lane marker.

Roadway Environment

Tests occurred on a four-lane divided highway with a speed limit of 88.5 kph (55 mph). All departure attempts occurred in the left and right lanes of two contiguous road sections. Heading west, the first section was a 1,000 m radius left curve followed by the westbound straightaway, with both sections approximately 400 m (0.25 mi) in length. The same two sections were also tested in the eastbound lanes, so that the straightaway was driven before entering the 1,000 m radius right curve (Figure 2).


Figure 2. A view of the test route; left curve scenario shown.

Videos from the outboard cameras were used to calculate lane width. The lane widths on the two curves were estimated to be 3.5 m (11.4 ft), and the lane widths on the straightaways were 3.6 m (11.7 ft). Ten-cm-wide dashed (white) lane markings between lanes and solid (yellow and white) lane markings at the edge of the roadway had good contrast with the asphalt pavement.

Trial Scenarios

The 40 trials each on straightaways and curves were evenly distributed across left and right lanes, lane marker type (solid or dashed), and departure direction. The trials on left and right curves were made in the direction opposite of the curve.

For a trial to be valid, vehicle speed had to be within 1.6 kph (1 mph) of the 80.5 kph (50 mph) test speed, yaw rate could not exceed 1.0 deg/s, and lateral velocity towards the lane marker had to be within 0.1 to 0.6 m/s (0.3 to 2.0 ft/s) with a target velocity of 0.5 m/s. Video footage was used to calculate lateral velocity for each trial by measuring the distance from the vehicle to lane marker at two points in time (and recording the associated time stamps) after the trial began when the driver was not steering and before system steering/braking occurred. These criteria were the same as or similar to those used by the National Highway Traffic Safety Administration's (NHTSA) procedure for testing lane departure warning for its New Car Assessment Program (NCAP) (NHTSA 2013). The 80.5-kph (50-mph) speed used in this test differed from the 72.4-kph (45-mph) speed used by NHTSA in the NCAP test and was selected to reduce conflict with other traffic on the 88.5-kph (55-mph) highway.

Procedure

Testing was performed in dry weather with good visibility in late morning or early afternoon, when the sun would not interfere with camera sensors.

The test driver began each pass through the test course about 1 km (0.6 mi) before the westbound curve. The driver accelerated the vehicle to 80.5 kph (50 mph) and engaged cruise control with the vehicle approximately centered in the lane. The test driver provided a verbal cue for a research associate to press an event trigger to note the start of trials. When conditions permitted, the driver completed two trials in each 400 m scenario. Thus, given the layout of the course, the driver completed two trials in the westbound left curve, completed two trials in the westbound straightaway, made a U-turn, accelerated the vehicle to 80.5 kph (50 mph), reengaged cruise control, and then completed two departure trials on the eastbound straightaway and two on the eastbound right curve. The driver re-centered the vehicle before attempting subsequent trials, and the driver aborted trials if other traffic was near the test vehicle. The same test driver operated all vehicles during data collection.

Testing proceeded serially, so that all 80 trials were completed in one vehicle before removing and installing equipment in the next. Vehicles progressed through trials following a matrix that split the 80 trials in half, so that the driver repeated the same conditions (lane (left/right), curve direction (left, right, straight), and departure direction (left/right)) until the first 40 trials were complete before driving a vehicle's 40 remaining trials.

Video data were coded manually. Coded data elements included elapsed time from the initialization of the data logger to the start and end of a trial; minimum and maximum values for vehicle speed and yaw rate; lateral velocity; timing of lane departure warning; distance to the lane marker at time of lane departure warning; and distance to the lane marker when steering input first occurred. The start of a trial was defined as when the driver loosened his grip from the steering wheel. The end of the trial was defined as approximately when either the vehicle re-centered itself in the lane, or when the driver's first input occurred to avoid run-off when the system did not prevent departure. Each trial was then inspected to ensure that speed, yaw rate, and lateral velocity met criteria.

Video from the outboard cameras with the ruler overlays and the video aimed at the steering wheel were used to estimate distance to the lane marker when steering input first occurred. The outboard cameras were used to judge whether a vehicle crossed lane markers by more than 35 cm on any of its trials. Peak absolute difference in yaw rate associated with the steering/braking intervention was calculated for each trial, by subtracting the most positive (or negative) value from the least positive (or negative) yaw rate during the portion of the trial when the driver was not steering the vehicle.

Dependent Measures

The primary dependent measures included the distance (cm, measured with an accuracy of about ± 2 cm) from the outside edge of the vehicle's front tire on the side of the departure direction to the inside edge of the lane marker when steering input first occurred, and the proportion of trials in which vehicles avoided crossing the inside edge of a lane marker by more than 35 cm. The 35-cm threshold was selected because it was a midpoint between the 30-cm pass/fail threshold used in NHTSA's NCAP confirmation test for lane departure prevention and the 40-cm threshold used in NHTSA's lane keeping aid support research test program (NHTSA 2013). Due to the measurement precision (± 2 cm), trials had three outcome categories: the vehicle tire clearly crossed the inside edge of the lane marker by more than 35 cm, bordered on having crossed by 35 cm, or clearly did not cross the lane marker by 35 cm. A third measure was the mean absolute change in yaw rate associated with the system's steering/braking input.

Reliability of visually coded dependent measures: Reliability of coding of the distance from the outside edge of the front tire to the edge of the lane marker when steering input first occurred was established by having a second coder manually code 10 (12.5%) of each vehicle's trials and computing Pearson's correlation coefficients to measure the strength of the relationship between the coders' estimates. The coefficients for each vehicle were: Chevrolet Malibu (r= 0.94), Ford Fusion (r=0.88), Honda Accord (r= 0.98), and Volvo S90 (r= 0.96).

Reliability of whether a vehicle crossed a lane marker by more than 35 cm was established by having two coders classify each trial into the three outcome categories (crossed by more than 35 cm, bordered crossing by 35 cm, did not cross by 35 cm). Classifying trials where vehicles departed toward dashed lane markers and crossed over by a fair amount was problematic; the outboard cameras and the measurement grid did not capture underneath the vehicle or extend far enough into the periphery to confidently judge whether a tire that had crossed a dashed lane marker did so by more than 35 cm. This was not a problem on trials with solid lane markers because the road edge could provide additional information on departure distance in such situations. Therefore, the 40 departure trials each vehicle made toward dashed lane markers were excluded from the analysis of this categorical variable. The Pearson's correlation coefficient between the two coders' classifications of the departure trials toward solid lane markers was r = 0.91. Differences between the two coders' judgments were reconciled by having a third individual review video of each trial where outcomes differed to serve as tie-breaker.

Analysis Plan

General linear models assessed whether mean distance to the lane marker and mean peak change in yaw rate on valid trials varied as a function of vehicle, departure direction, or scenario type (left curve, right curve, straightaway); the interaction between vehicle and departure direction; or the interaction between vehicle and scenario type. Type 3 tests were performed to determine whether effects were statistically significant at the 0.05 level. Least Square Means (LSM) estimates and 95% confidence intervals were computed to examine pairwise differences between conditions. Pairwise comparisons were adjusted using the Tukey-Kramer method to control for alpha inflation. Analyses were conducted using the GLM Procedure in SAS 9.4.

Differences between the lane departure prevention systems' capabilities to keep the vehicles from crossing the inside edge of solid lane markers by more than 35 cm were assessed by computing the proportion that did so and computing the 95% confidence interval of that proportion (Wilson 1927). Wilson's method allows confidence intervals to be computed even when the observed binomial proportion is 0 or 1.

RESULTS

Trial Validity and Missing Data

Postprocessing of data indicated that 315 of 320 trials met the criteria for a valid test run. Of the five invalid trials, one occurred with the Malibu (right curve scenario), three occurred with the S90 (two on the right curve and one straight scenario), and one occurred with the Accord (straight scenario). The five invalid trials were excluded from analyses. Additionally, 9 of the 20 trials in the left curve scenario with the Accord occurred with no steering or braking input by the system, resulting in 9 missing values for the measure of mean distance to lane maker when steering input first occurred. Thus, the analysis of mean distance to the lane marker was based on 306 observations and explains the difference in denominator degrees of freedom for sets of model results in Table 2.

Primary Results

Table 2 presents results of the omnibus *F* tests for the two general linear models. For each model, only main effects with nonsignificant interactions are interpreted.

Table 2. Summary omnibus test results of the effects of vehicle, departure direction, scenario type, and interactions between vehicle and scenario type and vehicle and departure direction on mean distance to lane marker and mean absolute peak change in yaw rate.

Dependent measure and model effects	*df*	*F* ratio	*p*
Mean distance to lane marker			
Vehicle	3,290	375.99	<0.0001
Departure direction	1,290	14.24	0.0002
Scenario type	2,290	9.87	<0.0001
Vehicle x scenario type	6,290	2.14	0.04
Vehicle x departure direction	3,290	1.96	0.11
Mean absolute peak change in yaw rate			
Vehicle	3,299	8.22	<0.0001
Departure direction	1,299	17.32	<0.0001
Scenario type	2,299	25.01	<0.0001
Vehicle x scenario type	6,299	0.50	0.81
Vehicle x departure direction	3,299	0.73	0.54

Mean distance to lane marker when steering first occurred: The main effect of departure direction indicates that mean steering input occurred further inside the lane markers on trials when vehicles made departures to the right (*LSM* = 37.1 cm, 95% CI [34.7cm, 39.5cm]) than to the left (*LSM* = 29.9 cm, 95% CI [27.5cm, 32.3cm]).

Pairwise comparisons to assess the nature of the interaction between vehicle and scenario type revealed that system input occurred significantly further inside the lane with the Malibu and S90 than the Fusion and Accord, irrespective of scenario (Figure 3). The paired comparisons of the Accord and Fusion across the three curve scenarios showed that mean first steering input in the Accord occurred significantly further inside the lane than the Fusion, but only in the straightaway (p<0.0001) and right curve scenarios (p=0.0002). Mean distance when steering input first occurred for departures on left curves did not vary between the two vehicles (p=0.34). Comparisons between the Malibu and S90 show that mean first steering input on departures in curves generally occurred further inside the lane than on straightaways. For example, mean first steering input in departures on right curves in the S90 occurred further inside the lane than departures on straightaways in the S90 (p = 0.005) and Malibu (p = 0.04), and mean first steering input in left curve departures in the Malibu occurred significantly further inside the lane compared with departures on straightaways in the S90 (p = 0.01), but not the Malibu (p = 0.09). Mean distance to the lane marker when steering first occurred did not vary significantly between the S90 and Malibu when comparing within each scenario type (left curve: p = 0.27; straightaway: p = 0.99; right curve: p = 0.54).

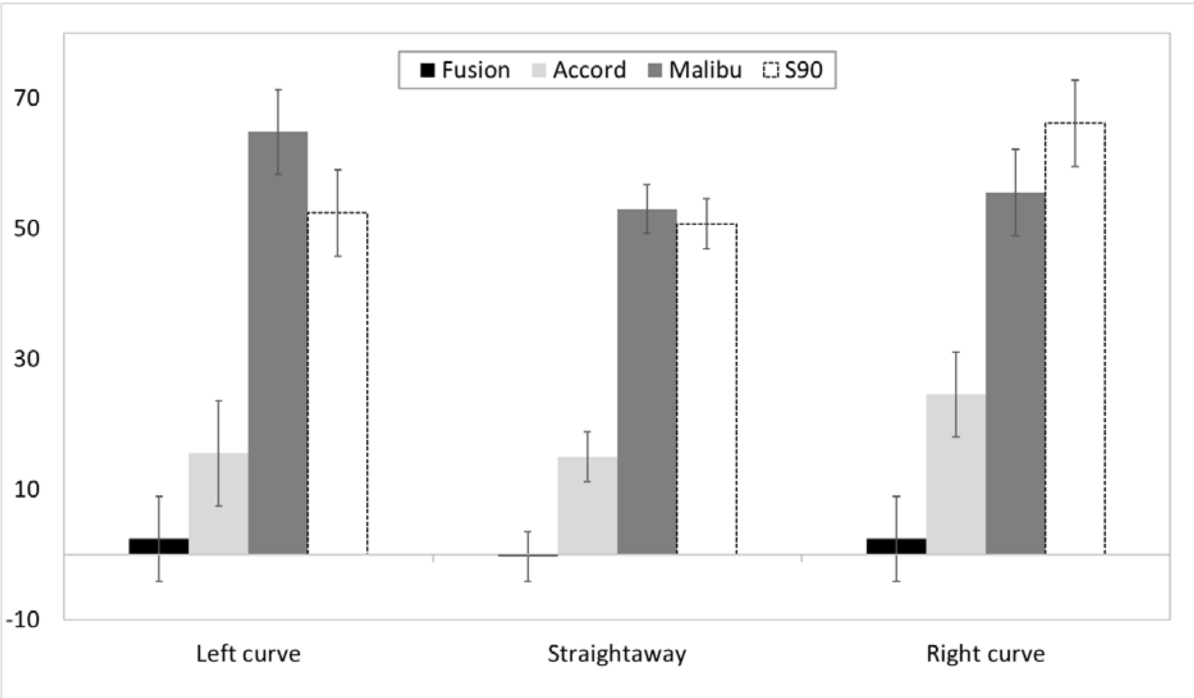

Figure 3. LSM estimates of distance from outside edge of front tire to inside edge of lane marker when steering first occurred by vehicle and scenario type. Error bars reflect 95% confidence intervals.

Mean absolute peak change in yaw rate: Post hoc tests for the main effect of vehicle indicated that the mean peak change in yaw rate for the Fusion (*LSM*= 0.30 deg/s, 95% CI [0.27, 0.33]) was significantly greater than the Malibu (*LSM*= 0.20 deg/s, 95% CI [0.17, 0.24]) and the S90 (*LSM*= 0.20 deg/s, 95% CI [0.17, 0.24]). Mean peak change for the Accord (*LSM*= 0.25 deg/s, 95% CI [0.22, 0.28]) fell between and did not differ significantly from the Fusion (p=0.15), Malibu (p=0.14), or S90 (p=0.16). The main effect of departure direction indicated that mean peak change in yaw rate was significantly greater when vehicles departed to the left (*LSM*= 0.29 deg/s, 95% CI [0.26, 0.31]) compared with the right (*LSM*= 0.20 deg/s, 95% CI [0.17, 0.22]). Post hoc tests on the main effect of scenario type indicated that mean peak change in yaw rate differed significantly among all scenarios (Left curve: *LSM*= 0.35 deg/s, 95% CI [0.32, 0.39]; straightaway: *LSM*=0.22 deg/s, 95% CI [0.20, 0.24]); right curve: *LSM*= 0.15 deg/s, 95% CI [0.11, 0.19]).

Proportion of trials where solid lane markers were crossed by more than 35 cm, by vehicle: There were 40 valid departure trials toward solid lane markers each for the Accord, Fusion, and Malibu, and there were 39 for the S90, with one straightaway departure trial in the S90 trials excluded for exceeding the lateral velocity threshold of 0.6 m/s. Figure 4 shows the observed percentage of trials where a vehicle did or did not cross the lane marker by more than 35 cm. No lane crossings greater than 35 cm were observed for the S90, and the Malibu avoided crossing lane markers by more than 35 cm on 80% of the trials. In contrast, the Accord and Fusion avoided crossing lane markers by more than 35 cm on 15% and 17.5% of trials in each vehicle, respectively. All trials where the Malibu crossed a solid lane marker by more than 35 cm were on straightaways, and all but one of these occurred when the vehicle was departing left toward the median. The Accord and Fusion avoided crossing the lane marker by

35 cm or more on 50% and 70% of departure trials on the left curve, respectively, but the two vehicles crossed solid lane markers by more than 35 cm in 90% or more of the straightaway and right curve scenarios.

The lack of overlap in confidence bounds indicates that the S90 (1.00=proportion of successful trials, 95% CI [0.91, 1.00]) avoided a significantly greater proportion of crossings greater than 35 cm than the Malibu (0.80= proportion of successful trials, 95% CI [0.65, 0.90]). The S90 and Malibu avoided a significantly greater proportion of lane marker crossings greater than 35 cm than the Accord (proportion of successful trials= 0.15, 95% CI [0.07, 0.29]) and the Fusion (proportion of successful trials= 0.18, 95% CI [0.09, 0.32]).

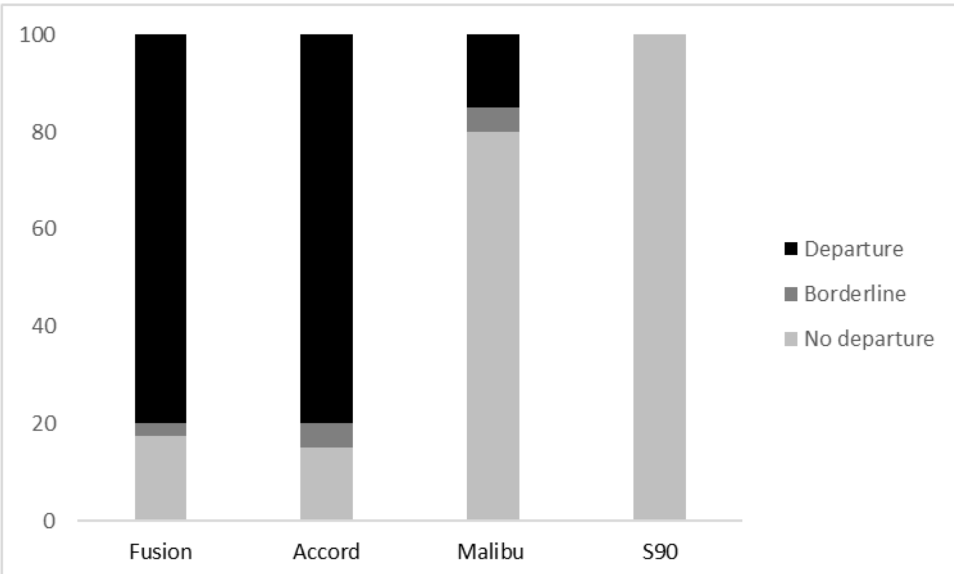

Figure 4. Proportion of trials where solid lane markers were not crossed by more than 35 cm, by vehicle.

DISCUSSION

Identifying features of lane departure prevention systems that predict their use is important, due to their potential to reduce run-off-road crashes and the regularity with which systems are turned off. The current research found a strong relationship between observed use of lane departure prevention systems in privately owned passenger vehicles and functional characteristics of the system. Reagan et al. (2018) reported that Volvo and GM (Cadillac and Chevrolet) vehicles equipped with lane departure prevention were more likely to have systems turned on compared with Ford vehicles (Table 1). During this study, the Volvo S90 and Chevrolet Malibu provided steering input significantly further inside the lane than the Ford Fusion and Honda Accord. Further, the S90 avoided crossing the inside edge of solid lane markers by more than 35 cm on 100% of trials, and the Malibu avoided doing so on 80% of trials. In contrast, the Accord and Fusion avoided crossing lane markers by more than 35 cm in less than 20% of trials. Although this observed relationship does not imply causation, the results support the hypothesis that perceived usefulness is a predictor of system acceptance and use (Ghazizadeh et al. 2012).

Prior research showed that increased agreement that an active lane-keeping system provided smooth, gentle steering inputs predicted increased agreement that the system improved the overall driving experience (Kidd and Reagan 2018). Wiacek et al. (2017) noted that a potential issue with a lateral control system that provides gentle, smooth inputs is the prevention of road departure crashes on curves. Specifically, preventing such crashes would likely require stronger automated steering/braking interventions compared with road departures on straightaways. In the current study, the vehicles that avoided crossing lane markers by 35 cm on most or all trials (i.e., Malibu and S90) had significantly lower mean peak changes in yaw rate than the Fusion. The earlier intervention used by the S90 and Malibu may be a design option that, when used with gentler steering inputs, helps drivers avoid drifting out of travel lanes in a way that drivers find acceptable.

Additional considerations that may increase activation rates of driver assist technologies include transparency of system deactivation and “default to on" status at ignition, but it is unknown how these design decisions affect long-term driver acceptance of driver assist systems. The current study is limited in that transparency may have inflated the strength of the relationship between observed activation rates from Reagan et al. (2018) and functional performance reported here. Deactivation of the S90’s lane departure prevention requires navigation through the menu-based driver-vehicle interface on the center stack, whereas the other vehicles tested have physical on-off lane departure prevention buttons. Although the activation rate of the Volvos with lane departure prevention observed in Reagan et al. (2018) was the highest among the automakers studied, more research is needed to measure the relationship between driver acceptance of a system and activation transparency.

In the interim, designers must continue to address driver disuse of lane departure warning and prevention systems and implement those that drivers find acceptable and use consistently. This study identified functional performance features of lane departure prevention that were strongly associated with observed activation rates and adds to the knowledge base about design characteristics associated with increased acceptance of lane departure warning and prevention, such as warning modality, amount of intervention, and warning timing (Reagan et al. 2018; Flanagan et al. 2016, Navarro et al. 2016). Hopefully, designers can use this information to improve the acceptance of future driver assist systems.

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APPENDIX A

Table A1. Dimensions of tested vehicles

Vehicle	*Wheel Base (cm)*	*Length (cm)*	*Height (cm)*	*Weight (kg)*
2016 Chevrolet Malibu	283.0	492.3	146.3	1,400.0
2016 Ford Fusion	285.0	486.9	147.6	1,555.0
2016 Honda Accord	277.6	486.2	146.6	1,437.9
2018 Volvo S90	306.1	508.3	145.0	1,836.0

Table A2. Descriptions of the lane departure prevention systems of tested vehicles (from the owner manuals)

Vehicle and system brand name	*Owner manual description*
2016 Chevrolet Malibu – lane keep assist	If equipped, LKA may help avoid crashes due to unintentional lane departures. It may assist by gently turning the steering wheel if the vehicle approaches a detected lane marking without using a turn signal in that direction. It may also provide a Lane Departure Warning (LDW) system alert as the lane marking is crossed. The LKA system will not assist or provide an LDW alert if it detects that you are actively steering. Override LKA by turning the steering wheel. LKA uses a camera to detect lane markings between 60 km/h (37 mph) and 180 km/h (112 mph). https://cdn.dealereprocess.net/cdn/servicemanuals/chevrolet/2016-malibu.pdf
2016 Ford Fusion – lane keeping system	The system notifies you to stay in your lane through the steering system and the instrument cluster display when the front camera detects an unintentional drift out of your lane is likely to occur. The system automatically detects and tracks the road lane markings using a camera mounted behind the interior rear-view mirror. The system has optional setting menus available. Alert + Aid – Provides an assistance steering torque input toward the lane center (This was the mode tested in current study, parenthetical added). If your vehicle continues drifting out of the lane, the system provides a steering wheel vibration. http://www.fordservicecontent.com/Ford_Content/Catalog/owner_information/2016-Fusion-Owners-Manual-version-1_om_EN-US_03_2015.pdf
2016 Honda Accord – road departure mitigation	Alerts and helps to assist you when the system determines a possibility of your vehicle unintentionally crossing over detected lane markings. If your vehicle is getting too close to detected lane markings without a turn signal activated, the system, in addition to a visual alert, applies steering torque and alerts you with rapid vibrations on the steering wheel, to help you remain within the detected lane. https://carmanuals2.com/get/honda-accord-sedan-2016-owner-s-manual-73385
2018 Volvo S90 – Lane Keeping Aid	The Lane Assistance functions are designed to help reduce the risk of accidents in situations where the vehicle unintentionally leaves its lane on highways or other major roads. Lane Keeping Aid (LKA) actively steers the vehicle to help keep it in its traffic lane and/or alerts the driver using an audible signal or through vibrations in the steering wheel. The driving lane assistance system is active at speeds between approx. 40-125 mph (65-200 km/h) on roads with clearly visible traffic lane marker lines. Assistance type Assist is activated: when the vehicle approaches a traffic lane marker line, LKA will provide active steering assistance to help steer it back into the lane. https://carmanuals2.com/get/volvo-s90-2018-owner-s-manual-109893