PARTS

PARTNERSHIP FOR ANALYTICS RESEARCH IN TRAFFIC SAFETY

Advanced Driver Assistance Systems: Insights into Performance Across Driver, Roadway, and Environmental Conditions

August 5, 2026

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Acknowledgments

PARTS is deeply grateful for the following individuals' contributions of time and expertise – as well as the in-kind contributions of their respective organizations – to this study and report. Without your spirited collaboration, this groundbreaking work would not have been possible.

Special thanks to the PARTS Research Working Group members and partners for their countless hours, expertise, and attention to detail in leading the execution of the study. They are denoted with an asterisk (*).

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Table of Contents

List of Figures

List of Tables

1 Executive Summary

This study examined how the proportion of vehicles equipped with certain Advanced Driver Assistance System (ADAS) features vary across different levels of driver, roadway, and environmental conditions that were significantly associated with vehicle equipage. The ADAS features studied were Automatic Emergency Braking (AEB), Pedestrian Automatic Emergency Braking (PAEB), and Lane Departure Warning (LDW) with Lane Keeping Assistance (LKA) and Lane Centering Assistance (LCA). Identifying conditions where feature equipage is overrepresented can help automakers, researchers, regulators, and infrastructure planners target future safety improvements where they are most likely to reduce crashes and injuries.

The findings demonstrate that, while ADAS technologies are important safety countermeasures, feature equipage varies across crashes under different conditions. These findings highlight several opportunities for further research or potential system improvement:

- AEB equipage is overrepresented among older drivers, on curved roads, and wintery surfaces
- PAEB equipage is overrepresented among interactions with teenage non-motorists
- Lane assistance equipage (LDW with LKA and LCA) is overrepresented for older drivers and complex lane configurations

The analysis linked two large-scale data sources: Original Equipment Manufacturer (OEM)-provided vehicle equipment data and police-reported crash data. The vehicle equipment data comprised 98 million passenger vehicles from model years 2015–2023, spanning 168 vehicle models sold in the United States and manufactured on or before July 31, 2023. These data were contributed by nine OEMs representing more than 80% of 2024 U.S. passenger car and light truck sales. The linked crash data comprised 21.2 million police-reported crashes involving 36.8 million vehicles from 16 states between January 2016 and September 2023, with some variation by state.

The study mapped each ADAS feature to a system-relevant crash type it was designed to address: AEB to front-to-rear striking crashes, PAEB to frontal non-motorist crashes (including pedestrians, cyclists, and personal conveyances), and lane assistance features to single-vehicle road-departure crashes. For each feature, the analysis compared equipage rates across driver, roadway, and environmental conditions with the overall equipage rate and control groups. In this study the authors make the supposition that when ADAS-equipped vehicles appeared more frequently in specific crash types than the average equipage, there may be opportunity for improved capability under those conditions; however, this was not a direct examination of effectiveness at the system level.

For AEB, the analysis identified several conditions in which equipped vehicles were overrepresented in front-to-rear striking crashes, including crashes involving older drivers, on curved roads, and on wintery or other low-traction surfaces. These findings identify conditions that warrant additional investigation to better understand potential limitations in AEB performance. The analysis was based on 495,253 front-to-rear striking crashes.

For PAEB, the analysis found that crashes involving non-motorists aged 15–19 were overrepresented among PAEB-equipped vehicles. This finding highlights a specific interaction between teenage non-motorists and PAEB-equipped vehicles that merits further study to better understand the circumstances contributing to these crashes. The analysis included 7,447 frontal non-motorist crashes with injuries classified as possible or more severe.

For the combination of lane assistance features, the analysis found that equipped vehicles were overrepresented in single-vehicle road-departure crashes involving drivers aged 65 and older and on roadways with 3 or 5 and more travel lanes. These findings suggest that more complex roadway configurations and driver characteristics may warrant additional research to better understand the circumstances associated with these crashes. The analysis included 78,607 single-vehicle road-departure crashes.

The study measured whether vehicles were equipped with ADAS, but could not determine whether the systems were enabled, activated, or functioning at the time of the crash. The study did not control for changes in ADAS capability or performance over the model years included. Police-reported crash data also contained known inconsistencies, missing fields, and state-to-state coding differences. The analysis identified associations between the vehicle's equipage of the relevant ADAS and the conditions, not causation.

The study identified several new findings warranting additional future research and highlighted the opportunities that new methodologies and data sources would bring.

2 Background

According to the United States Department of Transportation (USDOT), there were an estimated 6.2M police-reported traffic crashes in 2024 [1]. Over the last decade, the automobile industry has deployed many innovative Advanced Driver Assistance System (ADAS) solutions that have been shown to reduce the number and severity of traffic crashes [2], and prevent serious and fatal injuries [3]. Automobile Original Equipment Manufacturers (OEMs) continue to equip their vehicles with an increasing number of ADAS features, and some of these features are now standard on most new vehicles [4]. While ADAS such as Automatic Emergency Braking (AEB) have demonstrated effectiveness in preventing and mitigating system-relevant crashes [5] [6], there is a continued need to identify opportunities for improvement.

The Partnership for Analytics Research in Traffic Safety (PARTS) combined data from millions of vehicles and police-reported crashes to examine variation in ADAS feature equipage (i.e., whether a vehicle was equipped with a given feature) across driver, vehicle, environmental, and roadway characteristics within system-relevant crash groups. Proportional equipage was compared across categorical covariate levels (e.g., driver age groups) to identify statistically significant differences and better understand the conditions associated with ADAS equipage.

2.1 PARTS Overview

PARTS, established in 2018, is a public-private partnership between automobile manufacturers and the National Highway Traffic Safety Administration (NHTSA). The goal of this government-industry collaboration is to advance traffic safety through the collaborative analysis of automotive safety technologies, with partners voluntarily sharing safety-related data for joint analysis. MITRE operates PARTS as an independent third party (ITP) with technical consultation and support provided by the University of Michigan Transportation Research Institute (UMTRI).

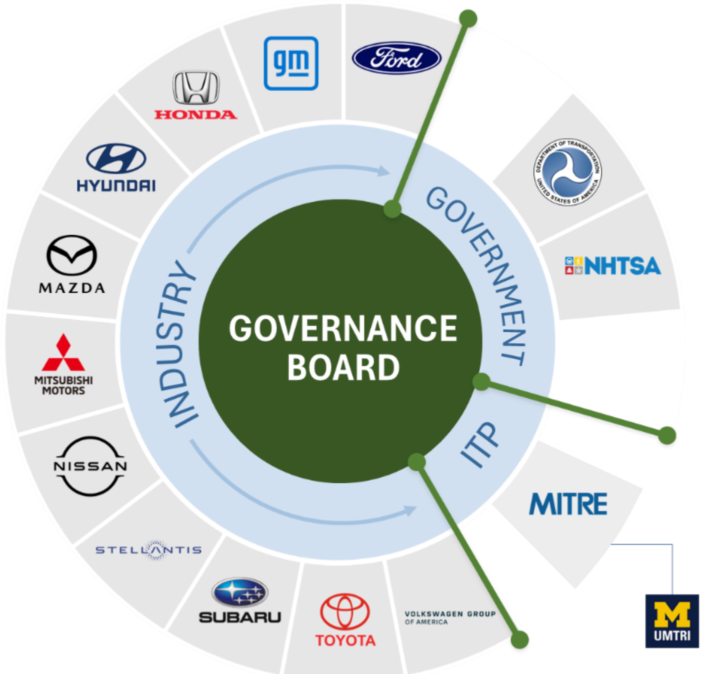

Figure 1. PARTS Participation

Of the 11 OEMs participating in PARTS (see Figure 1), nine provided vehicle data for this study. These 9 participating OEMs accounted for more than 80% of 2024 United States (U.S.) passenger car and light truck market sales [7].

2.2 Study Overview

Previous studies have examined ADAS effectiveness and identified vehicle, driver, and environmental factors associated with system performance [2] [5] [6] [8]. This study complemented the body of research by identifying the specific level of those factors at which ADAS-equipped vehicles are overrepresented in system-relevant crashes. Covariates were selected based on the linked dataset's ability to expand categorical covariate levels beyond previous studies, whether the selected methodology supported their inclusion, and through expert opinion.

Using a large, linked dataset of vehicle equipment and police-reported crashes, this study examined how ADAS feature equipage varied across driver, non-motorist, environmental, roadway, and vehicle characteristics. Equipage rates for system-relevant crashes were compared with the overall population average to identify statistically significant differences. The study addressed the following research questions:

- How does the proportion of equipage of AEB in system-relevant front-to-rear crashes vary across statistically significant covariates identified by logistic regression modeling of equipage?

- How does the proportion of equipage of Pedestrian Automatic Emergency Braking (PAEB) in system-relevant frontal non-motorist crashes vary across statistically significant covariates identified by logistic regression modeling of equipage?
- How does the proportion of equipage of Lane Departure Warning (LDW) with Lane Keeping Assistance (LKA) and Lane Centering Assistance (LCA) in system-relevant single vehicle road departure vary across statistically significant covariates identified by logistic regression modeling of equipage?

Observed differences in relative equipage identified conditions in which ADAS-equipped vehicles were overrepresented or underrepresented, highlighting areas for further investigation.

3 Data and Methodology

3.1 ADAS Features Studied

This study examined equipage proportions of three ADAS feature sets for system-relevant crashes, as shown in Figure 2.

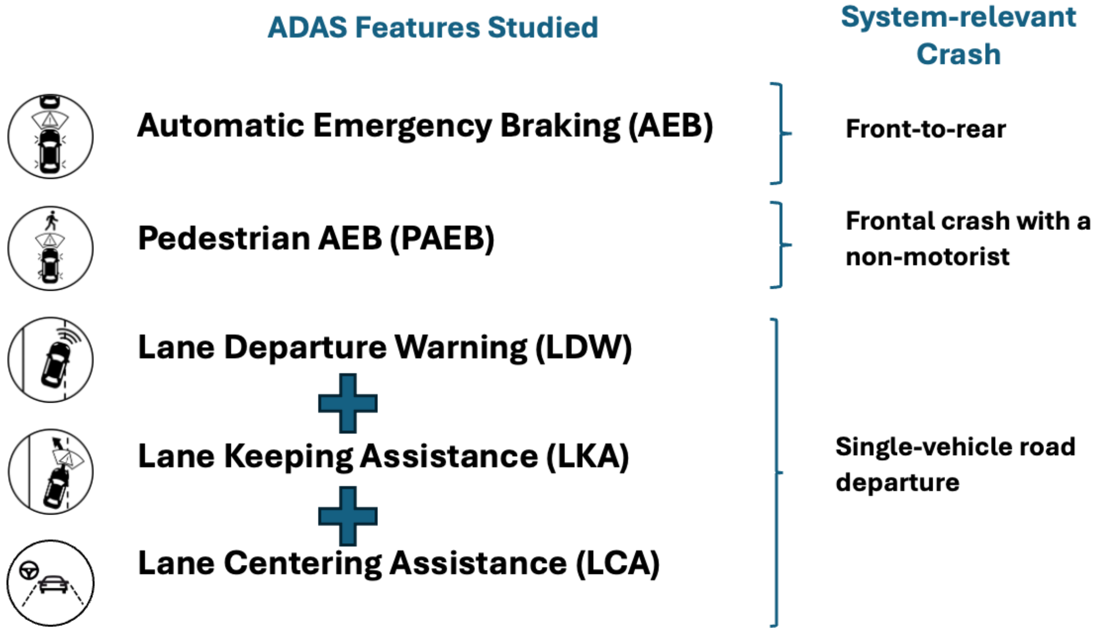

Figure 2. ADAS Features Studied

Note that all vehicles equipped with AEB in this study were also equipped with Forward Collision Warning (FCW). All vehicles equipped with PAEB were also equipped with AEB and Pedestrian Detection Warning (PDW).

Due to data limitations, the study was unable to identify which vehicles in two-vehicle crashes initially left their lane. As such, this study focuses on the effectiveness of LDW with LKA and LCA in single-vehicle road-departure crashes, rather than in sideswipe crashes involving vehicles traveling in the same or opposite directions.

3.2 Summary of the Dataset

This section provides an overview of the nature and scope of data sources used for this PARTS study and how the data sources are prepared for analysis. Table 1 shows a summary of the base dataset.

Table 1. Summary of Study Size and Scope

Description	Size and Scope
Total number of crash-involved vehicles	1,076,560
System-relevant crashes	581,307
Number of OEMs providing data	9
Number of vehicle models and vehicle segments	168 across 10 vehicle segments
Model years	2015–2023
Number of states and timeframe	16 states providing crash data from 2016–2023

This PARTS study used two primary data sources:

- **Vehicle Equipment Data** includes OEM-provided data on all passenger vehicles from model years 2015-2023 sold in the U.S. that met the selection criteria, at the 17-digit Vehicle Identification Number (VIN) level.
- **Crash Data** includes police-reported crash data from 2016–2023, provided by NHTSA and Michigan State Police, at the 17-digit VIN level.

3.2.1 Vehicle Equipment Data

As detailed in the PARTS 2025 study [9], OEM-supplied vehicle data included the ADAS features on each vehicle, build date, sold or customer delivery date, sales market (used to filter U.S.-only car market), and sale type (retail or fleet). This study's results are based on data from the following OEM partners:

- American Honda Motor Company – includes the Honda and Acura brands
- Ford Motor Company – includes the Ford and Lincoln brands
- General Motors – includes the Buick, Cadillac, Chevrolet, and GMC brands
- Hyundai Motor Company – includes the Hyundai and Genesis brands
- Mazda North American Operations
- Mitsubishi Motors R&D of America
- North American Subaru
- Stellantis (Fiat Chrysler Automobiles U.S.) – includes the Alfa Romeo, Chrysler, Dodge, Fiat, Jeep, and Ram brands
- Toyota Motor North America – includes the Toyota and Lexus brands

Vehicle models were selected for inclusion based on the following criteria:

- **Sufficient Sample Size:** A minimum sales threshold of 5,000 units per model per year helped ensure a sufficient sample size for analysis.
- **ADAS Feature Equipage:** At least one model year for each model must have at least one ADAS feature in the scope of the analysis.
- **Passenger Vehicle Study Scope:** To target passenger vehicle populations, Gross Vehicle Weight Rating (GVWR) was limited to less than 10,000 pounds.
- **Non-attribution:** Among other data protection measures, PARTS required vehicle models from at least three OEMs in a vehicle segment to maintain anonymity of the results.

The resulting dataset included 98 million vehicles from 168 models, covering model years 2015–2023, manufactured on or before July 31, 2023.

3.2.2 Crash Data

This study used police-reported crash data from 16 states. NHTSA provided data from 15 of these states through its Consolidated State Crash (CSC) database, which consolidates police-reported crashes submitted through the new Electronic Data Transfer (EDT) process. In addition to the CSC data, UMTRI provided Michigan crash data with permission from the Michigan State Police. The data used in each case was a census of all police-reported crashes in those states. Data was limited by what was available in the original state-level crash report. Specific fields and data elements varied by state.

This study focused on crashes that occurred between January 2016 and September 2023, with some variation across the 16 states included in the analysis, as shown in Figure 3. Although additional states were available in the EDT-driven CSC data, they were not included in this study due to insufficient data history or a lack of critical fields necessary for analysis.[1] The crash data encompassed a total of 21.2 million crashes involving 36.8 million vehicles across the 16 states.

[1] PARTS considered and ultimately decided not to use available crash data from California, Illinois, Maine, Nebraska, and Washington.

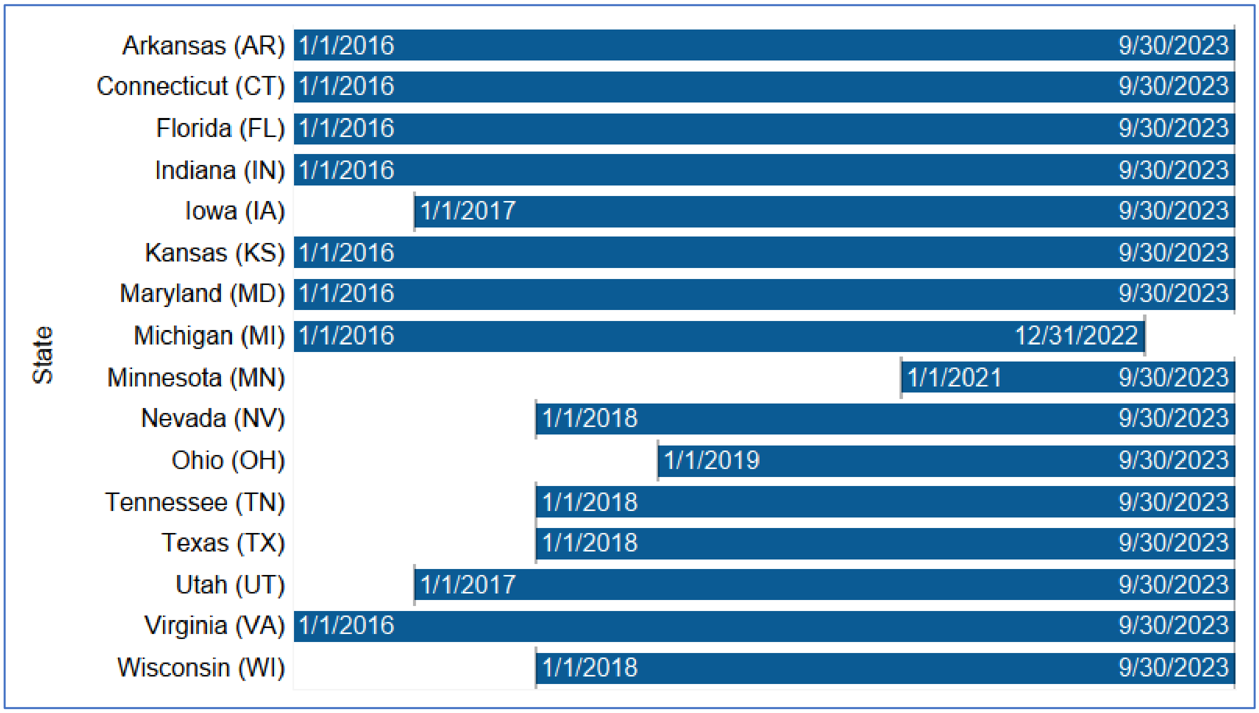

Figure 3. Crash Data by State and Time Period Covered

3.2.3 Crash Types Studied

Each ADAS feature studied was mapped to a system-relevant crash type based on the feature's intended function and the availability of police-reported crash data needed to identify that crash scenario. Equipage rates were measured within the system-relevant crash type for each ADAS feature. Table 2 summarizes the system-relevant crash types and their corresponding crash definitions. To evaluate differences in equipage across covariates, these rates were compared with a control crash population. An ideal control crash would occur randomly as exposure increases. Consistent with previous PARTS research, front-to-rear struck crashes (i.e., crashes in which a vehicle is struck from behind while moving or stationary) were selected as the control crash type because they are widely used as a system-irrelevant comparison and are generally considered unrelated to the struck vehicle or the struck vehicle driver's behavior. Recent PARTS research incorporating vehicle miles traveled further supported the suitability of this control group [10].

Table 2. System-relevant Crash Types by ADAS Feature and Crash Type Definitions

ADAS Feature	Target Crash Type	Definition
AEB	Front-to-rear Striking	Manner of Crash = Front-to-rear AND Initial Contact Point = [11, 12, 1] AND Motor Vehicle Maneuver Action NOT [backing, parked] Crash Vehicle Count = 2
PAEB	Single-vehicle Frontal Crashes	Crash Non-motorist Count > 0 AND Crash Vehicle Count = 1 AND First Event or First Harmful Event = Non-motorist AND

	with Non-motorists	Initial Contact Point = [11, 12, 1] AND Motor Vehicle Maneuver Action NOT [backing, parked] AND Police Reported Injury = [K, A, B, C]
LDW+LKA+LCA	Single Vehicle Road Departure	Crash Vehicle Count = 1 AND First Event or First Harmful Event IN [Ran Off Road, Cross Centerline, Cross Median, Collision with Fixed Object, Rollover] AND Vehicle Maneuver Action IN [Going Straight, Negotiating a Curve, Leaving Traffic Lane, Run Off Road]
Control	Front-to-rear Struck	Manner of Crash = Front-to-rear AND Initial Contact Point = [5, 6, 7] AND Motor Vehicle Maneuver Action NOT [backing, parked] AND Crash Vehicle Count = 2

The system-relevant crash types were agreed upon by PARTS participants and are the same as those used previously by PARTS [2] [11]. Non-motorists were defined as pedestrians, bicyclists, or people on a personal conveyance.

3.2.4 Preparing and Linking Data Sources

The data linkage process harmonized police-reported crash data with OEM-provided vehicle equipment data to support a comprehensive analysis. For crash data, raw values from police reports and state formats were mapped to standardized values, such as by using a clock-face reference for vehicle initial contact points. This process also added additional derived fields such as crash type and whether a vehicle was striking or struck. For vehicle equipment data, MITRE worked directly with participating OEMs to map their VIN-level records to standardized ADAS feature definitions using consistent mapping procedures and quality assurance checks. The standardized datasets were then linked using the 17-digit VIN, resulting in a dataset containing 7.7 million crash-involved vehicles with matched OEM build information, including 1.1 million vehicles involved in crashes relevant to the ADAS features examined in this study.

3.3 Descriptive Statistics of the Study Dataset

System-relevant crash counts with associated control crash counts and related ADAS equipage rates are presented below. Summary information is provided for covariates identified as statistically and contextually meaningful in the analysis.

3.3.1 Automatic Emergency Braking Descriptive Statistics

Figure 4 compares the driver age distribution for AEB system-relevant front-to-rear striking crashes with the control population of front-to-rear struck crashes. Drivers aged 35–54 represented the largest age group in both populations, accounting for 30.4% of system-relevant crashes and 40.1% of control crashes. In contrast, drivers aged 14–24 were overrepresented in system-relevant crashes, comprising 24.3% of those crashes compared with 11.7% of the control population.

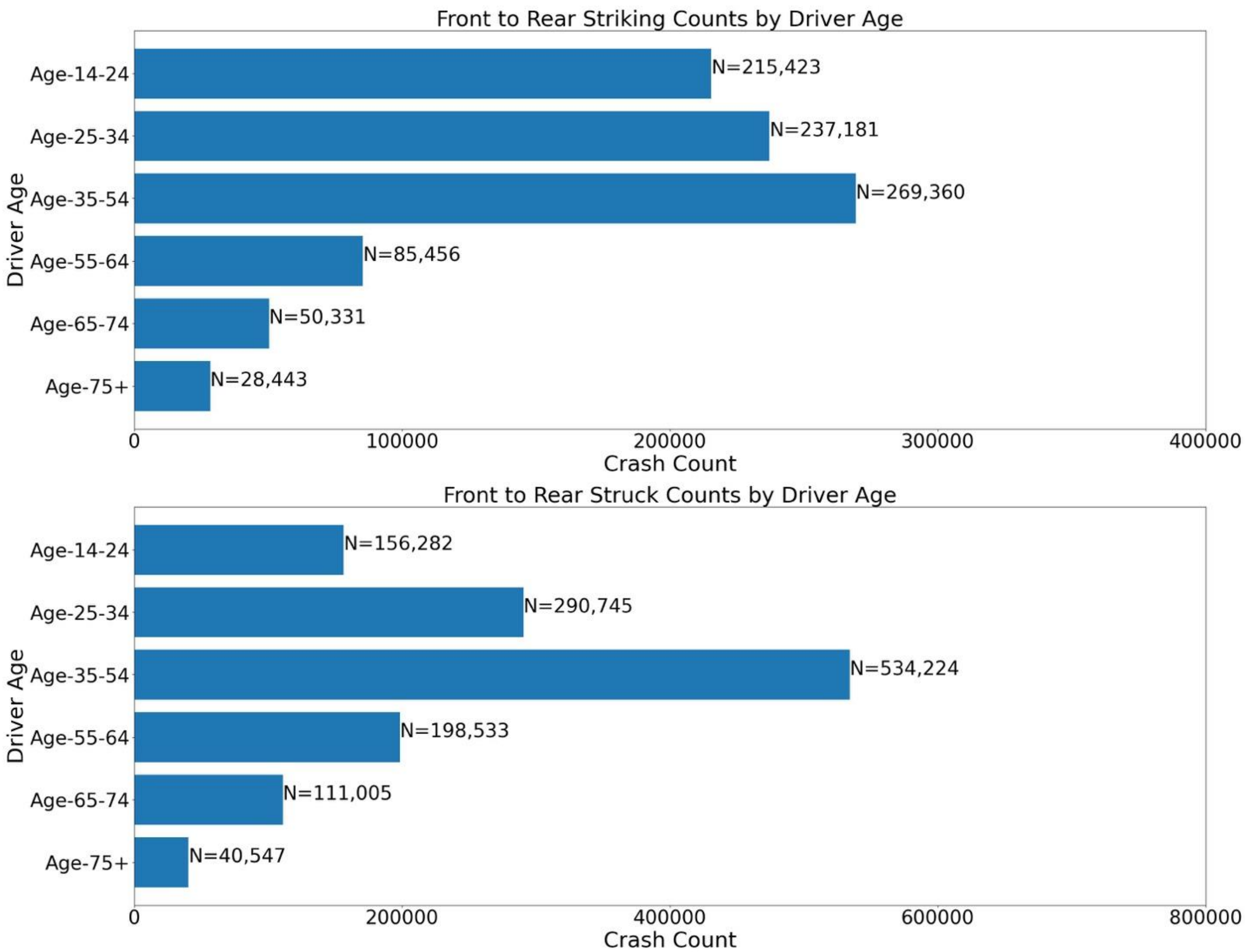

Figure 4. Front to Rear Striking and Control Crash Counts by Driver Age Group

Figure 5 below presents linked data counts for front-to-rear striking (system-relevant) and front-to-rear struck (system-irrelevant or control) crashes by road surface condition. Approximately 98% of the relevant crash populations are represented in either dry or wet road conditions.

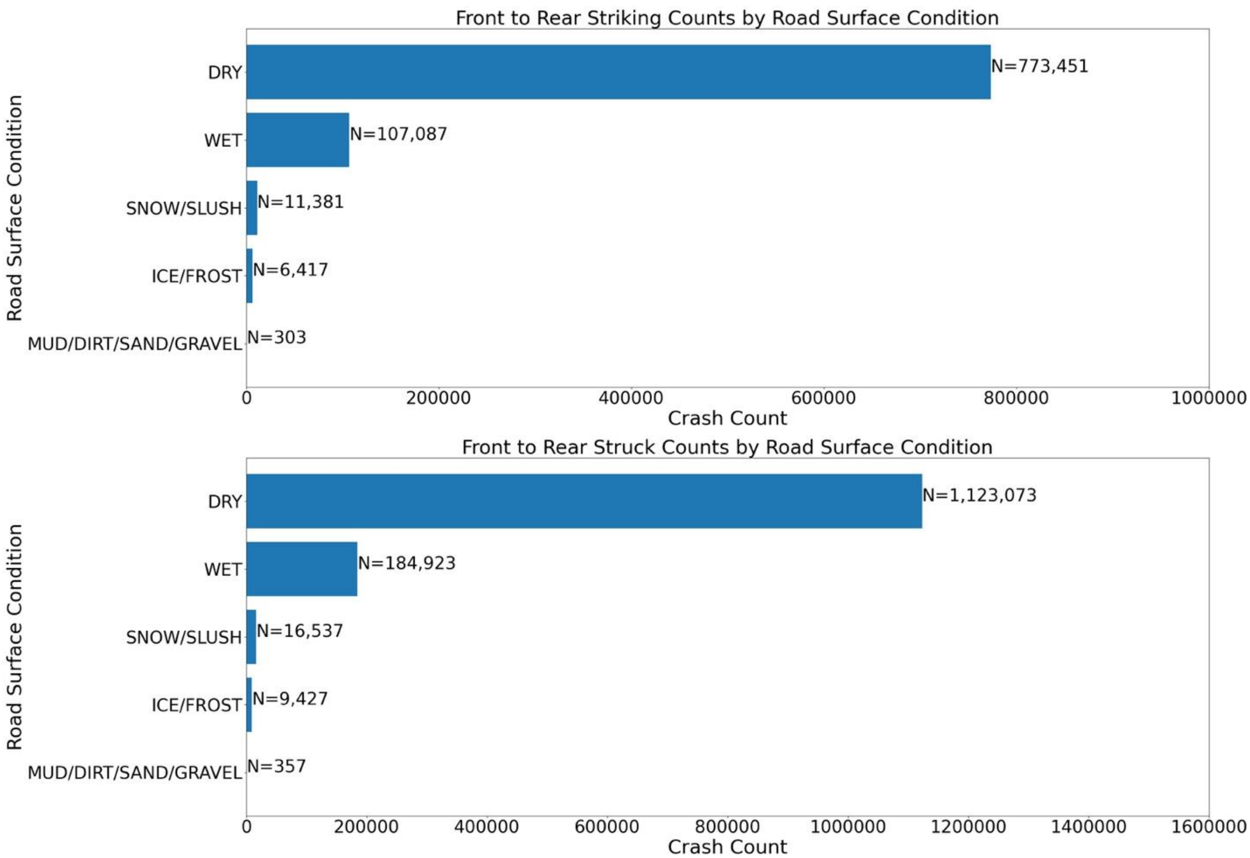

Figure 5. Front to Rear Striking and Control Crash Counts by Road Surface Condition

Figure 6 compares the roadway alignment distributions for AEB system-relevant front-to-rear striking crashes and the control population of front-to-rear struck crashes. In both populations, the vast majority of crashes occurred on straight roadways, accounting for 89.1% of system-relevant crashes and 89.5% of control crashes. The "OTHERGROUP" category included transitional roadway segments (e.g., entrance and exit ramps), ambiguous roadway alignment codes (e.g., intersection or freeway), and coded as not applicable.

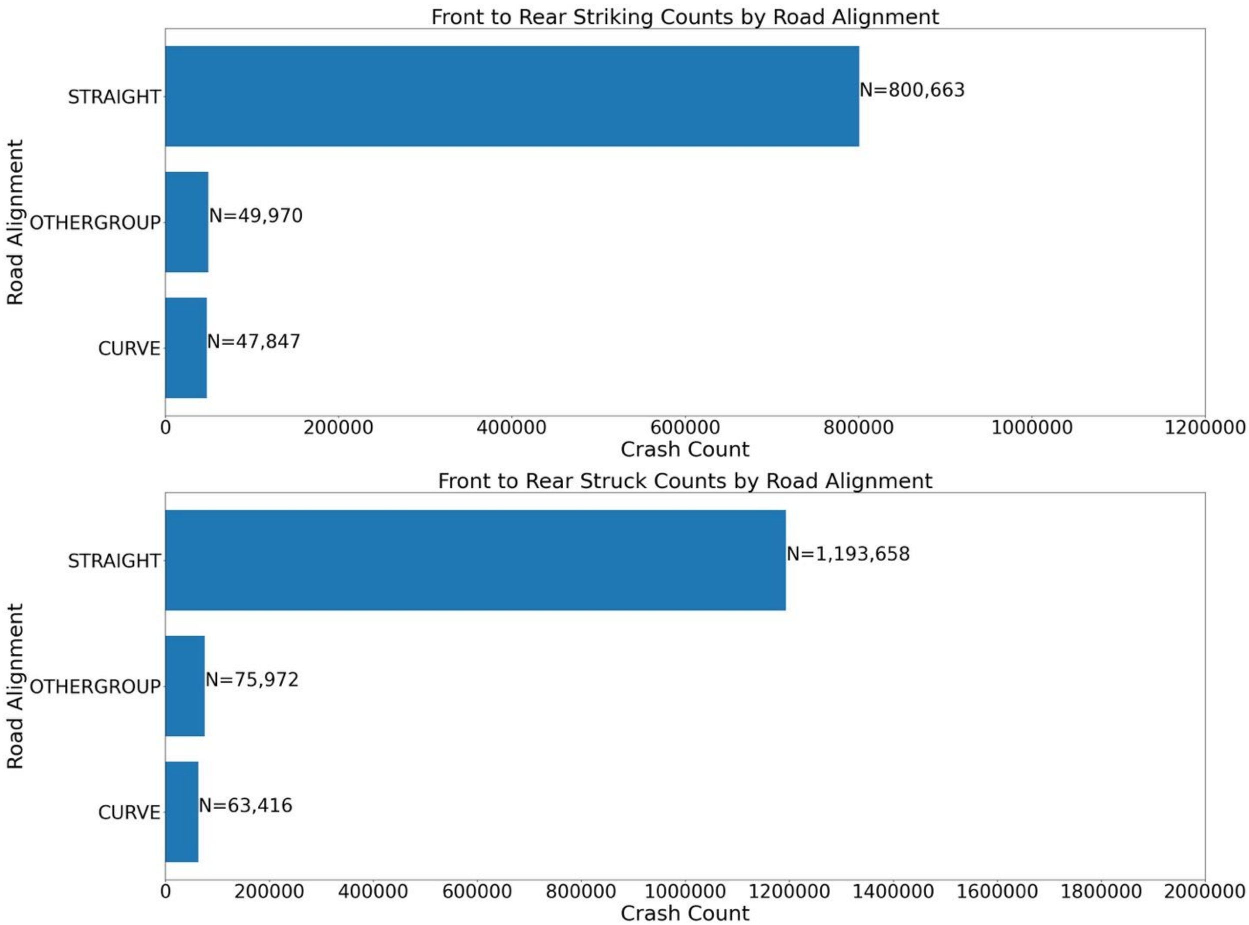

Figure 6. Front to Rear Striking and Control Crash Counts by Roadway Alignment

3.3.2 Pedestrian Automatic Emergency Braking Descriptive Statistics

Figure 7 compares the driver age distributions for PAEB system-relevant frontal non-motorist crashes and the front-to-rear struck control population. In both crash populations, drivers aged 35–54 represented the largest age group, accounting for 32.1% of system-relevant crashes and 40.1% of the control population.

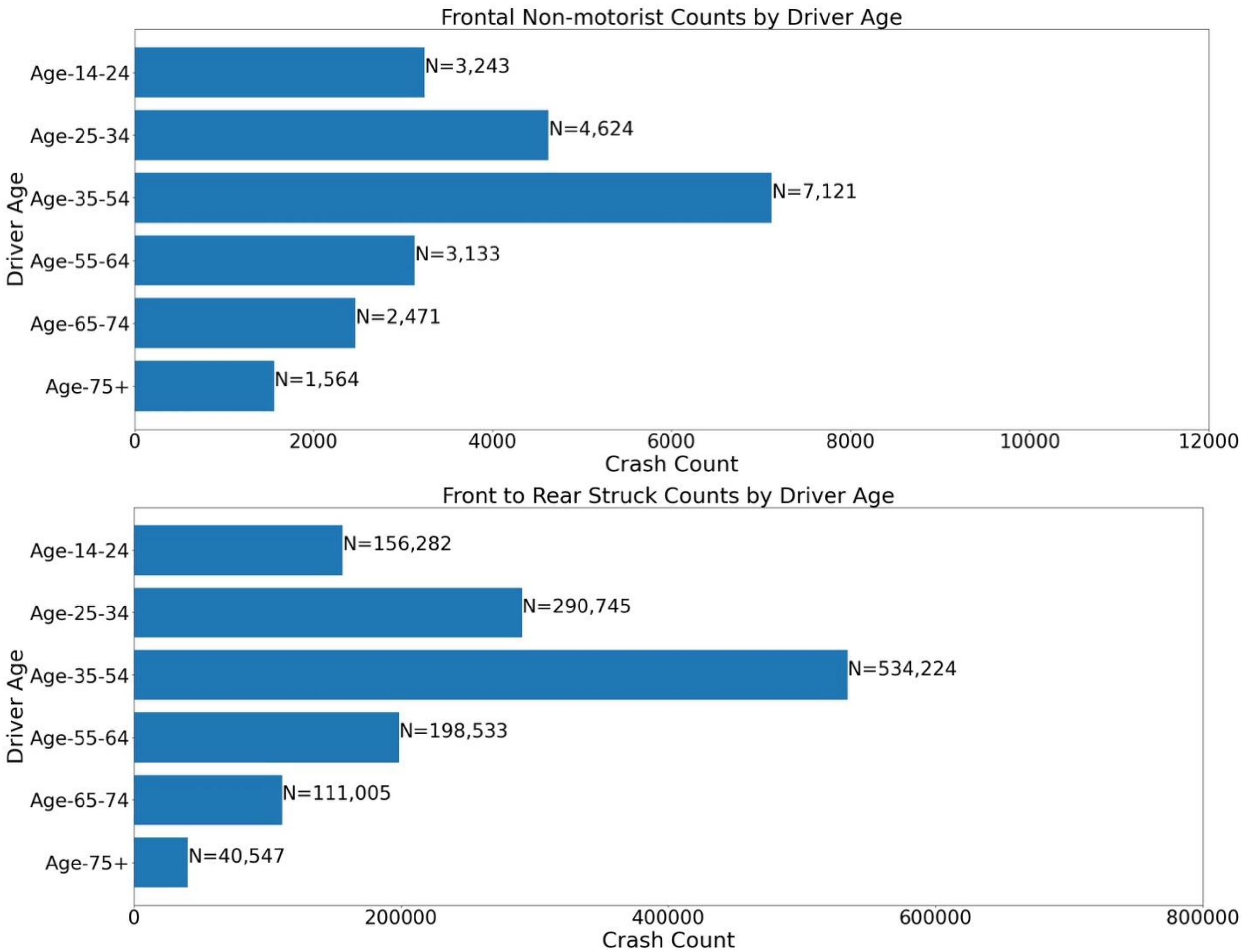

Figure 7. Frontal Non-motorist and Control Crash Counts by Driver Age Group

Figure 8 presents the non-motorist age categories for system-relevant frontal non-motorist crashes. The mature adult age group representing people aged 26-64 accounts for 54% of the relevant study population.

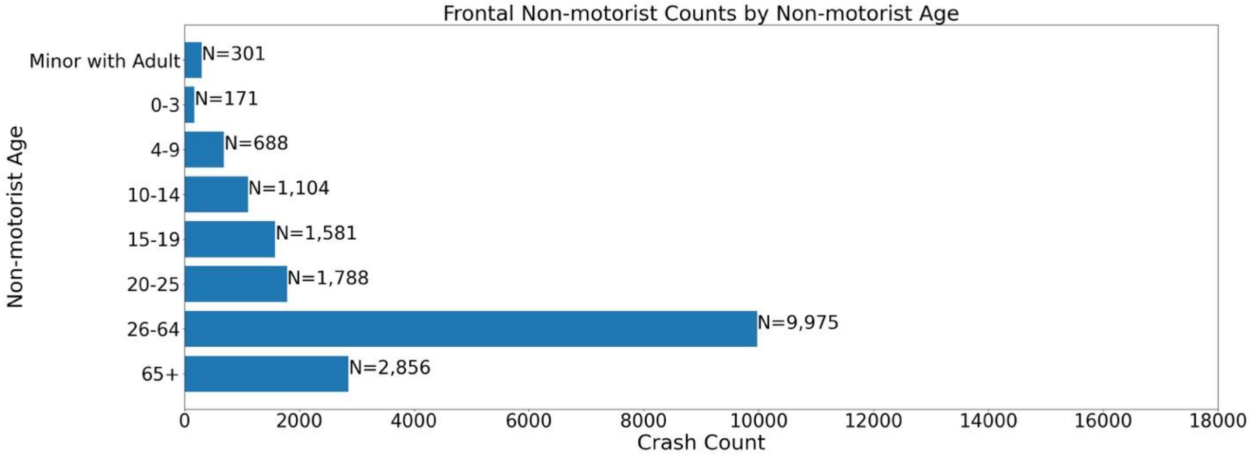

Figure 8. Frontal Non-motorist Crash Counts by Non-motorist Age Group

3.3.3 Lateral – Lane Departure Warning with Lane Keeping Assistance and Lane Centering Assistance Descriptive Statistics

Figure 9 shows LDW+LKA+LCA system-relevant single-vehicle road departure crash counts by driver age group, alongside the front-to-rear struck control population. Drivers aged 14-24 driver represented 27.5% of the system-relevant crash population, compared with 11.7% of the control population.

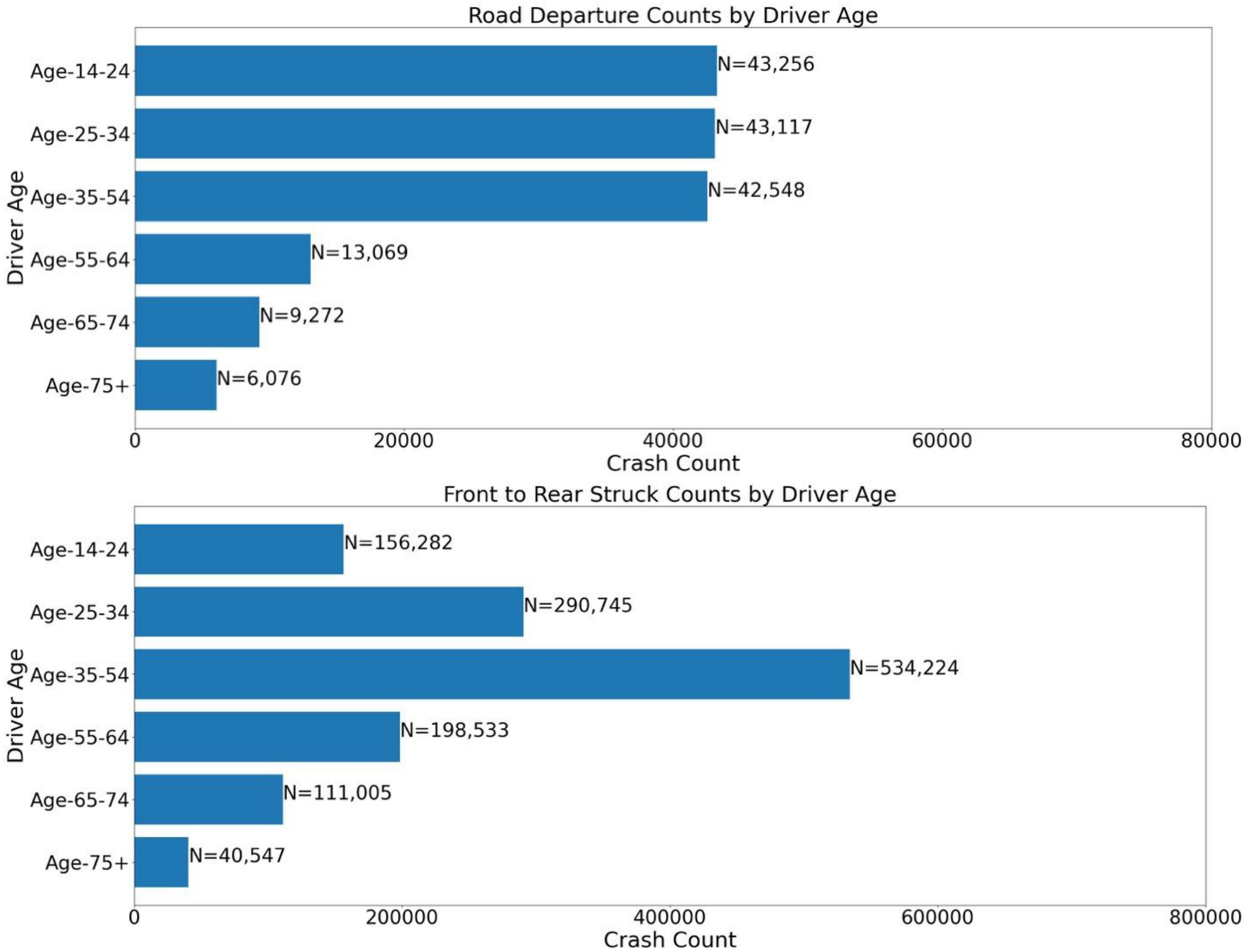

Figure 9. Single Vehicle Road Departure and Control Crash Counts by Driver Age Group

Figure 10 compares system-relevant single-vehicle road-departure crash counts with the front-to-rear struck control population across roadway lane categories. Two-lane roadways represented the largest category in both populations, comprising 62.8% of system-relevant crashes and 31.0% of the control population.

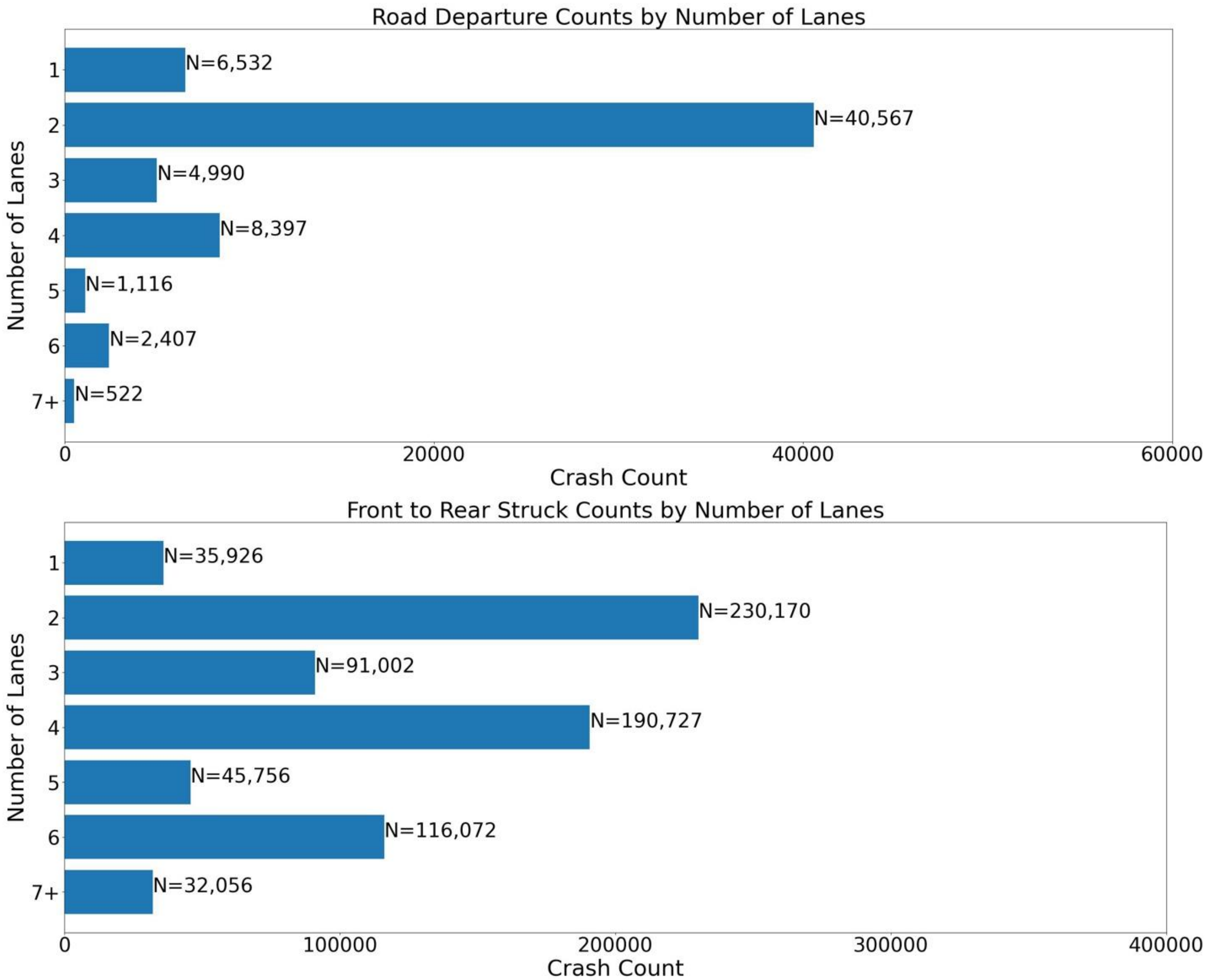

Figure 10. Single Vehicle Road Departure and Control Crash Counts by Number of Roadway Lanes

3.4 Methodology Overview

The analysis used logistic regression to model the relationship between ADAS equipage in system-relevant crashes and the candidate explanatory covariates described in Table 3. Because the response variable of *Equipped or Not Equipped* was dichotomous, logistic regression provided an appropriate generalized linear modeling framework by estimating the log-odds of the outcome as a function of the selected predictor covariates. Each covariate was evaluated using nested logistic regression models, comparing a model without the relevant covariate being assessed to the full model with all predictor variables. All covariates were treated as categorical for the analysis.

Each ADAS feature studied was evaluated using a separate set of nested logistic regression models. All the feature models included explanatory covariates for lighting condition, intersection, roadway alignment, number of lanes, driver age, weather and road surface condition. For the PAEB nested models, additional covariates for non-motorist age and non-motorist action prior to event were also included.

Nested models are defined as models in which the reduced model contains a subset of the parameters included in the full model. This structure allows an assessment of whether the additional covariates in the more complex model provide a statistically meaningful improvement in model fit beyond the covariates already included. In this analysis, nested model comparisons were used to evaluate whether individual predictors contributed explanatory value.

Type 3 likelihood ratio tests were used to assess the contribution of each covariate while controlling for the remaining predictors in the model. This approach compares the likelihood of a full model containing the covariate of interest with that of a reduced model in which the covariate has been removed. The resulting likelihood ratio test statistic is based on the difference in model log-likelihoods. It is evaluated against a chi-square distribution with degrees of freedom corresponding to the number of parameters removed. This test is well suited for nested logistic regression models because it directly evaluates whether the added model complexity yields a significant improvement in goodness-of-fit.

Covariates were retained in the final model when they demonstrated statistically meaningful improvement in fit, were theoretically justified, or improved the interpretability of the model. This nested-modeling strategy supported the identification of statistically significant covariates for use in the pursuant analyses. Statistical significance was identified using a threshold value alpha of 0.05 throughout this analysis.

Table 3. Covariate Levels

Covariate	Levels
Lighting Condition	Daylight, Dark Lighted, Dawn/Dusk, Dark not Lighted, Dark Unknown, Other
Intersection	Not Intersection, 2-way, 3-way, 4-way, 5+-way, Roundabout, Ramp, Other
Roadway Alignment	Curve, Straight, Other
Number of Lanes	1, 2, 3, 4, 5, 6, 7+
Driver Age	14-24, 25-34, 35-54, 55-64, 65-74, 75+
Weather	Clear, Overcast, Precipitation, Frozen Precipitation, Fog/Smoke, Strong Wind/Blowing Sand/Dirt/Gravel, Other
Road Surface Condition	Dry, Wet, Ice/Frost, Snow/Slush, Mud/Dirt/Sand/Gravel
Non-motorist Age	0-3, 4-9, 10-14, 15-19, 20-25, 26-64, 65+, Minor with Adult
Non-motorist Action Prior to Event	Adjacent to Roadway, Crossing Roadway, In Roadway, On Sidewalk, Other

A supplemental assessment was conducted for all statistically significant covariates. Equipage rates for system-relevant crash scenarios were evaluated across covariate levels and compared to average equipage rates for the study population. The equipage rates were also compared to rates for a control population of front to rear struck vehicles. Average equipage and differences across covariate levels were normalized to improve consistency and make comparisons easier to evaluate. Significant results were identified by the partnership research working group based on expert opinion.

When interpreting the normalized proportional equipage across covariates, it is important to note that if equipage were perfectly uniform across covariate levels, then the relative equipage rates would all fall precisely along a horizontal line at 1.0 (where all covariate level equipage rates equal the overall normalized system-relevant equipage rate). If relative equipage rates for covariate levels are identical between system-relevant crashes and control crashes, then there is no identifiable difference in equipage across the categories. This would indicate the proportional equipage differences across the covariate levels are unrelated to the crash.

Relative rates below 1.0 would indicate fewer than expected equipped vehicles were observed in system-relevant crashes, which may be related to higher performance in system-relevant crashes. Relative rates above 1.0 indicate more than expected equipped vehicles were observed in system-relevant crashes, which may be related to reduced performance in system-relevant crashes.

The following section examines the statistically significant output from the nested models for each studied ADAS feature that was identified by the research working group as contextually meaningful. Road surface condition and roadway alignment for AEB; non-motorist age for PAEB; number of lanes for LDW with LKA and LCA. Driver age was included for all features studied.

3.5 Automatic Emergency Braking

The logistic regression model for AEB equipage included 495,253 front-to-rear striking vehicle crash observations. All evaluated covariates were statistically significant. Sample-size metrics were also derived to estimate the number of records required to detect statistical significance for each covariate group. For all covariate groups, no more than approximately 10% of observed system-relevant crashes were needed to detect significance ($\alpha = 0.05$). The driver age group needed the fewest samples (0.3% of observations) to achieve statistical significance, whereas intersection presence needed the most (10.7% of observations).

Figure 11**Error! Reference source not found.** below compares driver age group equipage rates for system-relevant crashes to equipage rates for control crashes, with each group normalized to the overall average equipage rates for each of the system-relevant and control crash sets. Confidence bounds are overlaid on the system-relevant equipage rates, derived from the logistic regression model results. The dashed line indicates average equipage rates for the full population across all age groups. The blue points estimate the normalized proportion of equipped crash vehicles found in each categorical age group with confidence intervals. The orange points estimate the normalized proportion of equipped vehicles in the control crash group by the categorical age groups with confidence intervals.

The PARTS 2025 study [2] found that AEB effectiveness in preventing system-relevant crashes varied significantly by driver age[2]. In that analysis, effectiveness point estimates were developed

[2] Prior PARTS studies used Quasi-Induced Exposure (QIE) with logistic regression to estimate ADAS effectiveness defined as 1 – ADAS odds ratio. For these studies, the response variable was whether a

for the total relevant population (49%), and categorical driver age groups: under 25 years of age (52.3%), 25-64 (49.7%), 65-74 (42.4%), and 75+ (35.3%). The interpretation of the current study results on AEB equipage rates for driver age are generally consistent findings from the earlier PARTS research. The prior analysis showed equipped vehicles with drivers under age 35 were underrepresented in system-relevant crashes and equipped vehicles with drivers 35 and over being progressively overrepresented with increasing age.

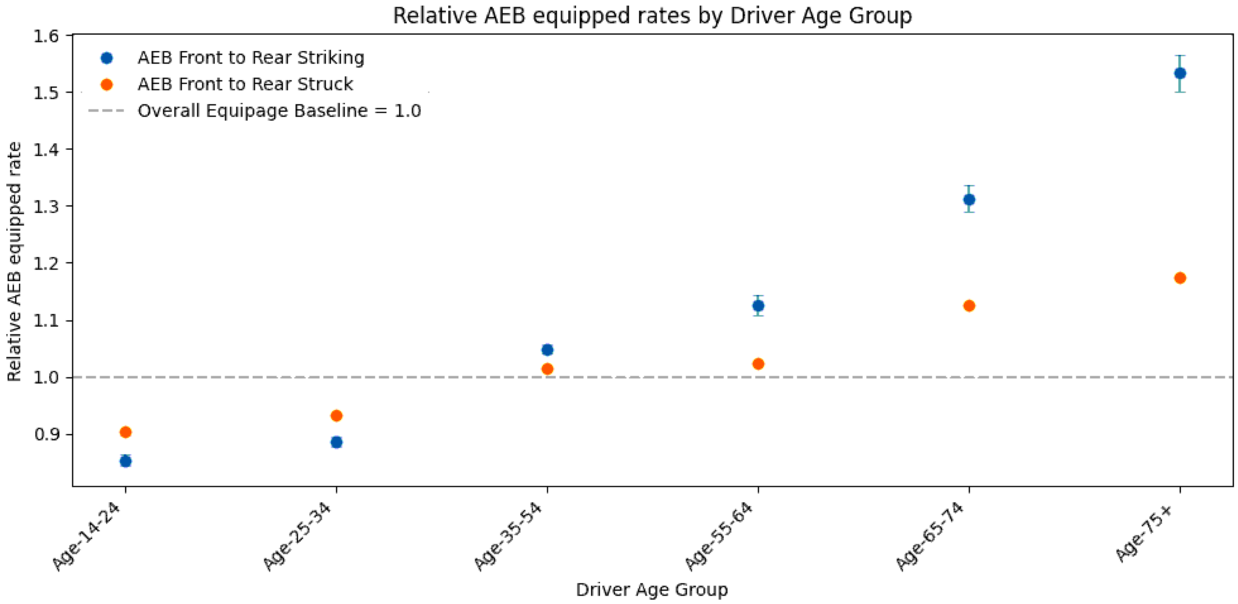

Figure 11. Relative AEB Equipage by Driver Age Group

The road surface condition covariate (Figure 12) has similar crash rates for wet and dry road surfaces and is of a nearly identical magnitude between control and system-relevant crashes. Ice/frost, snow/slush, and mud/dirt/sand/gravel covariate levels each have elevated system-relevant crash rates with respect to control crashes. This could indicate potential reduced capability for AEB in these conditions, possibly due to reduced traction or limitations to system sensors. The wide confidence interval around the mud/dirt/sand/gravel point estimate reflects the small sample size of relevant crashes included in the model (83 system-relevant crashes with this road surface condition). Despite the limited sample size, the result remained statistically significant relative to the normalized exposure control group.

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vehicle was involved in a system-relevant crash or a control crash with a binary explanatory variable representing ADAS equipage.

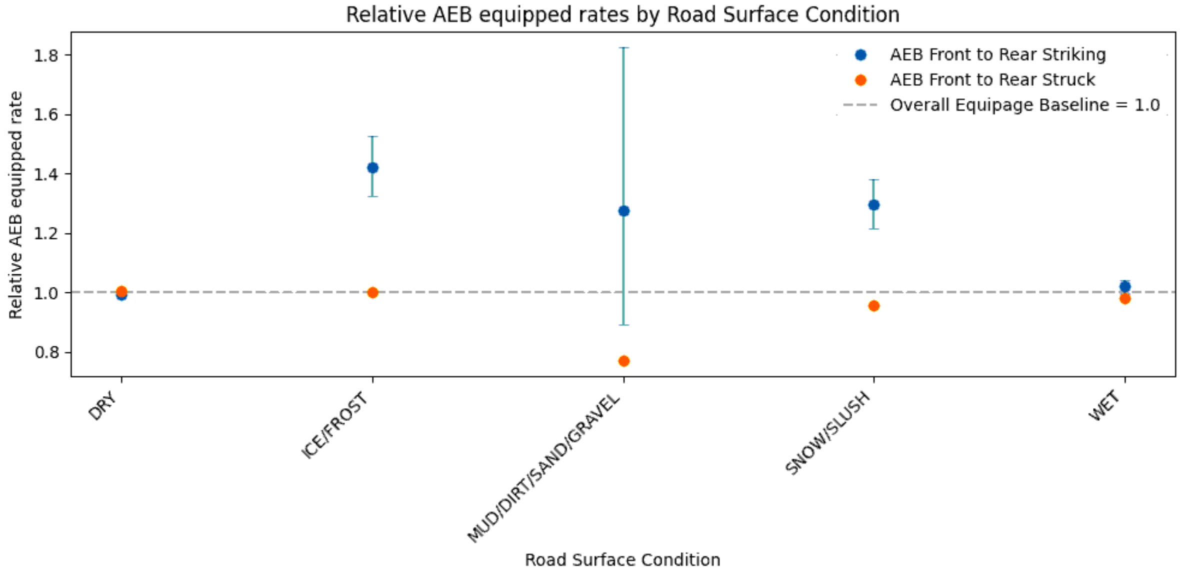

Figure 12. Relative AEB Equipage by Road Surface Condition

Road alignment (Figure 13) results reveal elevated system-relevant crash rates for equipped vehicles on curved roads, which aligns with observations in prior research. The other group categorical level, made up of ambiguous or unrelated coding in police crash reports (such as "straight and level/curved" or "on/off ramp") did not show a statistical difference to the normalized control group.

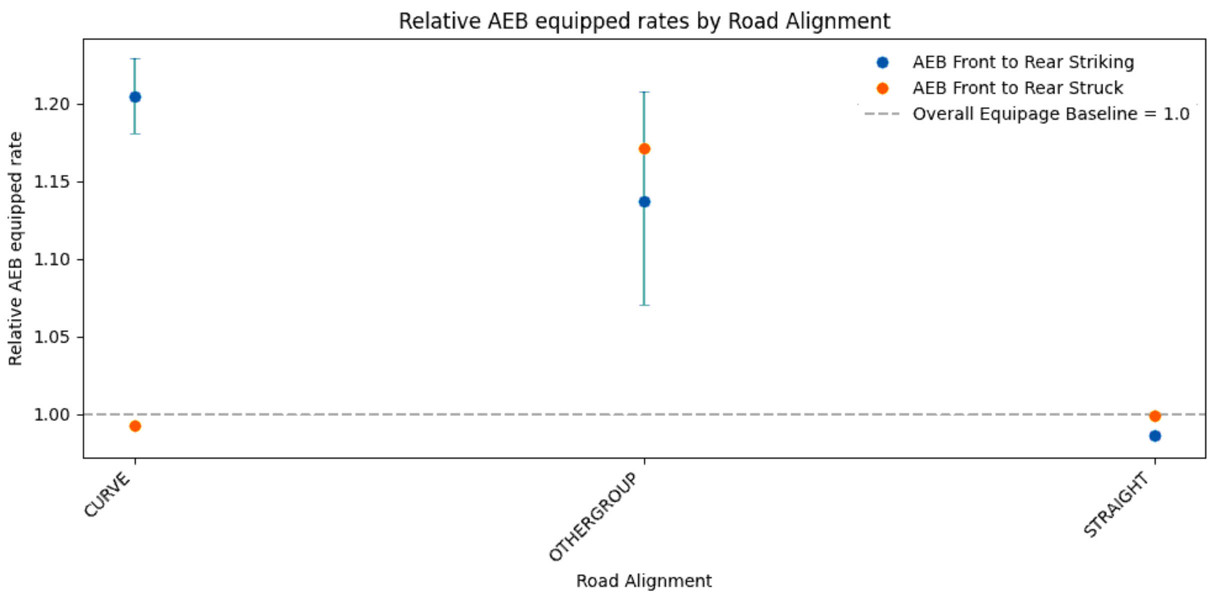

Figure 13. Relative AEB Equipage by Road Alignment

3.6 Pedestrian Automatic Emergency Braking

The logistic regression model for PAEB equipage included 7,447 crashes involving pedestrians, cyclists, and personal conveyance users with police-reported injury severity of Possible Injury or greater (KABCO scores of K, A, B, and C). Among the covariates evaluated, only driver age and non-motorist age were statistically significant.

Figure 14 below presents the relative PAEB equipage rates by driver age. Unlike the AEB results, equipage rates for system-relevant crashes closely tracked those of the front-to-rear struck control population across nearly all driver age groups. The primary exception was drivers aged 65-74, whose relative equipage differed from the control population. Although driver age was statistically significant, the overall similarity between system-relevant and control equipage rates suggests little evidence of meaningful differences in PAEB performance across driver age groups.

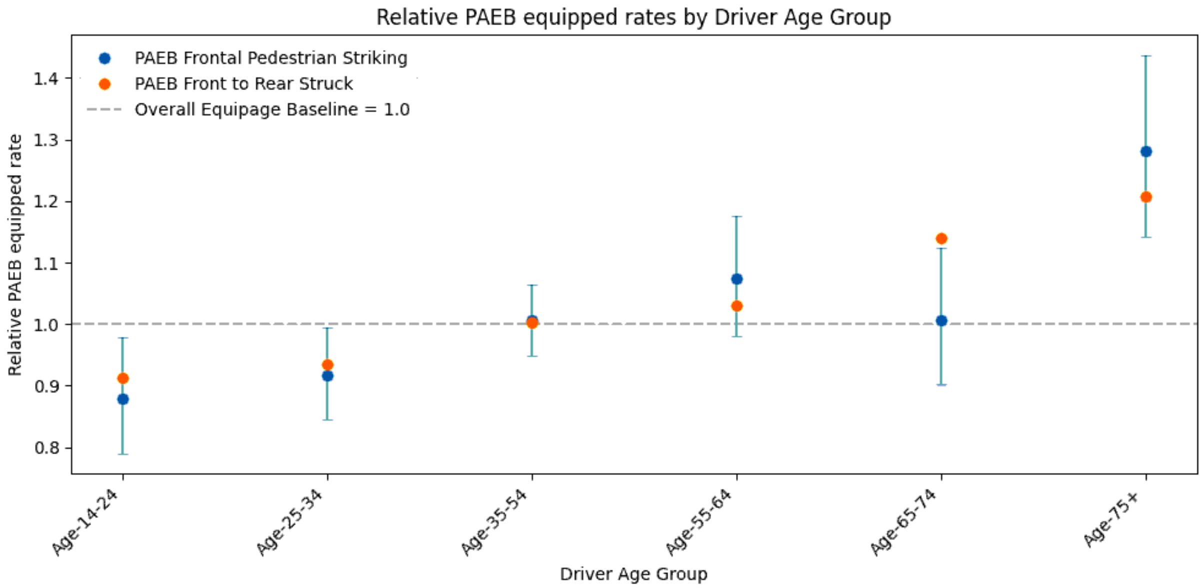

Figure 14. Relative PAEB Equipage by Driver Age Group

Figure 15 below presents relative equipage rates for non-motorist age. Because non-motorist age is not defined for the front-to-rear struck control population, no corresponding control comparison is available. The observed variation in equipage rates across non-motorist age groups was sufficient for the Type 3 test to identify non-motorist age as a statistically significant covariate. In particular, crashes involving non-motorists aged 15–19 and those aged 65 and older exhibited higher relative equipage rates than the population average. Because higher relative equipage may indicate conditions in which PAEB-equipped vehicles are overrepresented in system-relevant crashes, these age groups warrant further investigation.

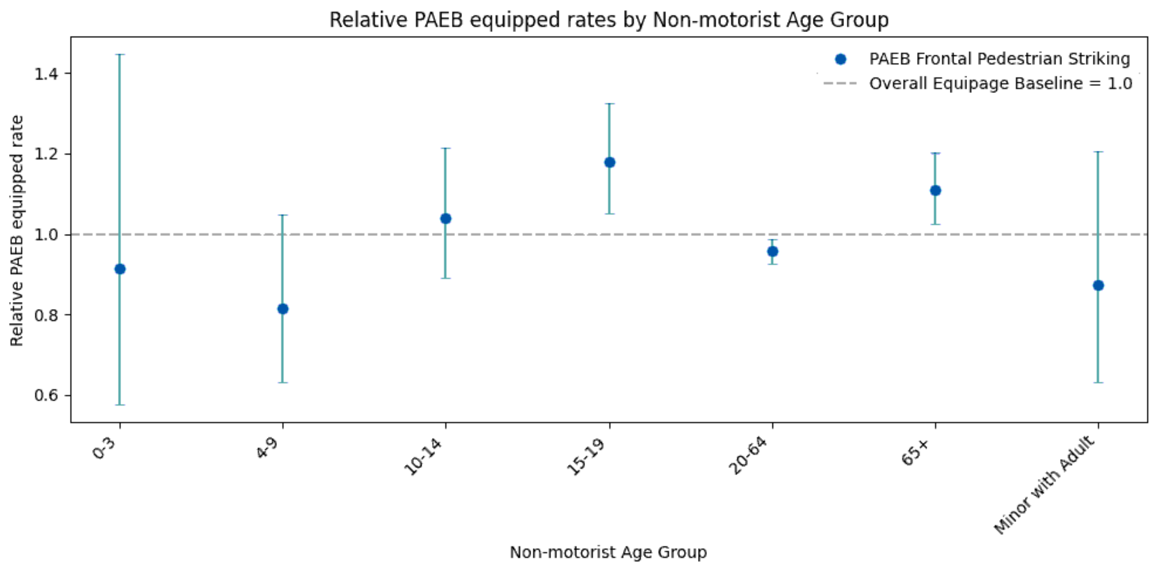

Figure 15. Relative PAEB Equipage by Non-motorist Age Group

Only two covariates were statistically significant for PAEB, and the regression results and proportional equipage comparisons provide limited evidence of meaningful differences in real-world PAEB operation across the evaluated conditions.

3.7 Lateral – Lane Departure Warning with Lane Keeping Assistance and Lane Centering Assistance

The logistic regression model for Lane Centering equipage included 78,607 lateral system-relevant single-vehicle road departure crashes. Five covariates were statistically significant: lane count, driver age, road alignment, light condition, and road surface condition. Among these, driver age and lane count exhibited the most notable differences in both regression results and proportional equipage comparisons and were therefore examined in greater detail.

Figure 16 below presents relative equipage rates for driver age. Observed equipage rates for lateral system-relevant crashes are elevated for older drivers with respect to control crashes, which aligns with the AEB findings.

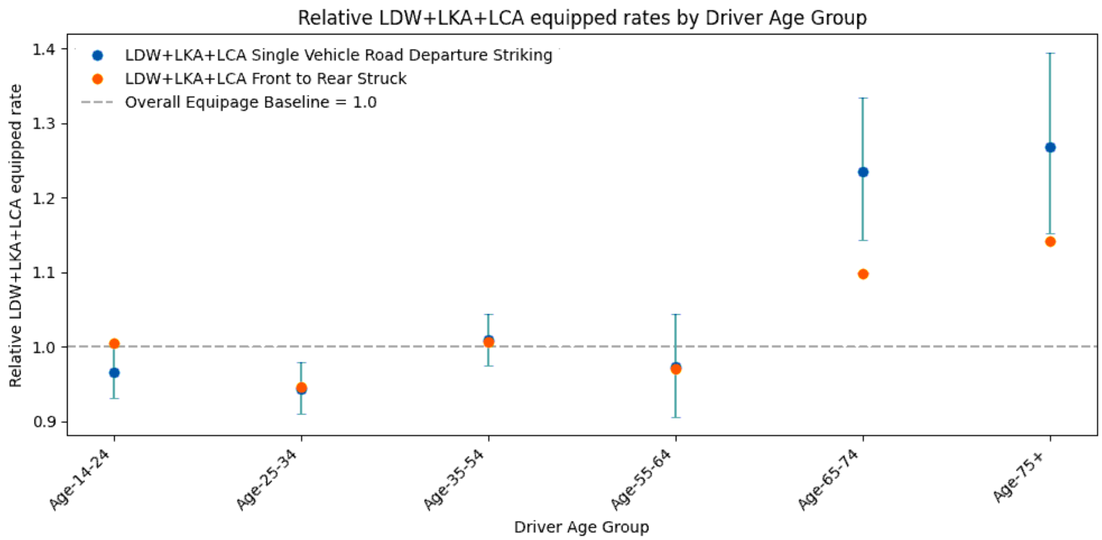

Figure 16. Relative LDW+LKA+LCA Equipage by Driver Age Group

Figure 17 shows that single-vehicle road-departure crashes on three-lane roadways and roadways with five or more lanes had higher relative equipage rates than the comparison groups, indicating potentially reduced capability for these roadway types.

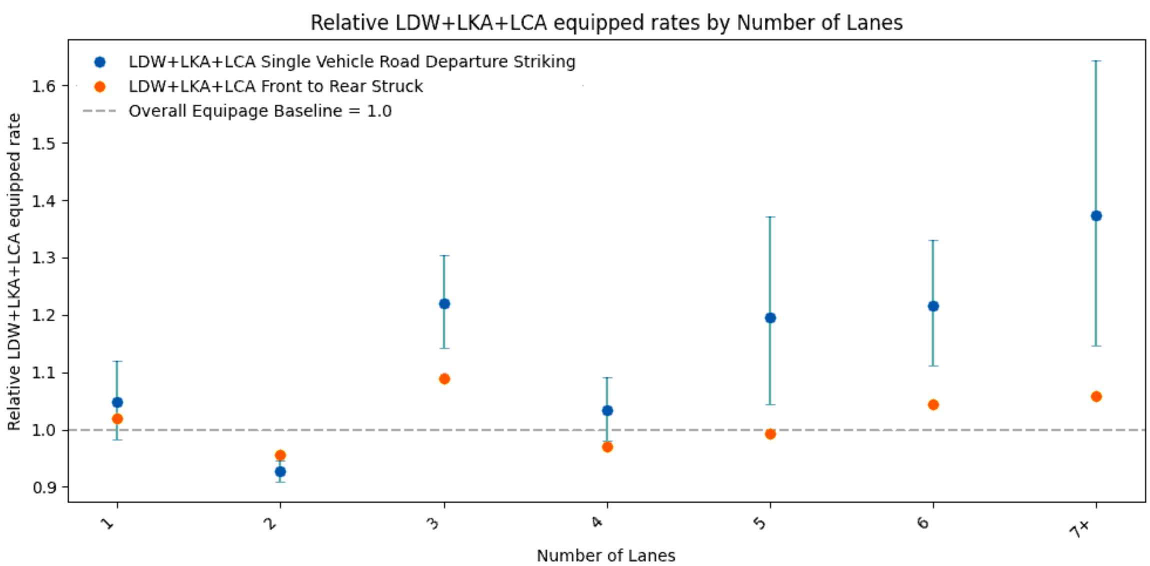

Figure 17. Relative LDW+LKA+LCA Equipage by Number of Lanes

4 Discussion

This analysis has identified differences in equipped crash population proportions across statistically significant covariates. These results suggest specific human, environmental, and infrastructure factors correlate to overrepresentation of equipped vehicles in the system-relevant crash group. This overrepresentation could simply indicate variation in system performance or confounding factors not controlled for in the study.

The findings of this study indicate drivers aged 55 and over are overrepresented in the equipped crash population. Differences in driving behavior among older drivers may create more frequent situations in which AEB effectiveness is reduced, such as when a lead vehicle changes lanes into the path of the AEB-equipped vehicle [12]. Because this analysis did not investigate or control for struck vehicle pre-crash maneuvers, this interpretation remains speculative and warrants further study.

Additionally, relative equipage rates were similar on wet and dry roadways but were elevated on winter road surfaces, including ice, frost, snow, and slush, indicating an overrepresentation of equipped vehicles in these crash conditions. The relative equipage rates did not control for potential differences in regional average equipage across the road condition covariate. It is possible the differences seen for winter road conditions are at least in part due to varying geographic average equipage rates.

This analysis found overrepresentation of equipped vehicles in curved roadway crashes compared to straight roadways. Recent PARTS analyses have found reduced effectiveness for AEB on curved roadway segments [2]. This suggests an opportunity for further research and development to better understand and characterize the radius of curvature distribution at the location of the crashes in the data set. Curve radius is not a coded data element in the current data set.

Initial findings identified differences in PAEB equipage proportions based on driver age. However, after normalization using the front-to-rear struck control population, most of these differences were consistent with overall equipage trends rather than unique to PAEB system-relevant crashes. Drivers aged 65-74 were an exception to this trend, for whom the observed pattern remains unexplained. This finding may reflect the relatively small sample size or an unmeasured confounding factor and warrants further research.

A new finding in this study identified that 15–19-year-old non-motorists were overrepresented in the PAEB equipped crash population. Additional analyses investigating potentially related interactions, such as lighting condition, did not provide additional statistical insights. It is unclear why PAEB would be overrepresented for only 15–19-year-old non-motorists. It could be indicative of unique behaviors or riskier actions resulting in shorter reveal time to vehicle sensors, or other conduct or exposure not controlled for in this study.

This study identified two novel findings related to lane assistance features: an overrepresentation of older drivers and an overrepresentation of crashes occurring on roadways with 3 lanes or 5 and more lanes among equipped crash population. While prior PARTS research did not identify a significant interaction for driver age [2], the current study found drivers aged 65 and older were present in a higher proportion of equipped system-relevant crashes, warranting additional research. The differences in equipped crash proportions related to lane configurations are somewhat counterintuitive. Increased number of lanes are highly related to arterial roadways including interstates, other freeways and highways, and other principal arterials [13]. These roadways would typically be considered within the intended operational design domain of the lane assistance features studied. Additional research is recommended to better understand the factors contributing to this observed overrepresentation.

5 Study Limitations

While several statistically significant results were identified in this study, it is important to note that current data and methods cannot identify causation.

This study evaluated the proportion of ADAS-equipped vehicles involved in system-relevant crashes varied across covariate levels. Although overrepresentation of equipped vehicles may indicate conditions in which ADAS feature performance differs, the analysis did not directly account for differences in driving behavior or on-road exposure that may also have influenced the observed association.

This study considered vehicles equipped with ADAS features at the time of manufacture but was unable to account for actual ADAS usage or activation. Some systems provide customer selectable usage and have various implementations for default state (i.e., on, off, last known). Similarly, system operational domains and triggers vary across executions and could lead to differences in availability or activation of a given system at the time of the crash. Data related to driver selected feature enablement or ADAS feature activation at the time of crash was not available for the study.

The use of police crash reports as a primary source of data presented a series of well-known limitations. Variations in coding protocol across different states or jurisdictions, biased reporting of low severity crashes, and incomplete or erroneous content limit the extent to which crash dynamics and driver behaviors can be analyzed.

6 Conclusion

The findings of this study demonstrate that ADAS equipage varies across driver, roadway, and environmental conditions within system-relevant crash populations. While the observed differences do not establish variations in ADAS effectiveness, they identify conditions in which ADAS-equipped vehicles were overrepresented in system-relevant crashes and therefore warrant additional investigation. Across the features evaluated, the analysis consistently identified opportunities to better understand the influence of driver age, roadway characteristics, environmental conditions, and interactions with vulnerable road users on real-world ADAS performance.

This study extends previous PARTS research by leveraging large-scale linked OEM vehicle equipment and police-reported crash data to evaluate relative equipage across detailed covariate levels. The results highlight several priorities for future research, including the influence of older driver behavior on AEB performance, system operation on curved and winter roadways, interactions between PAEB systems and teenage non-motorists, and the relationship between lane assistance performance and more complex roadway environments. Additional work incorporating data not typically found in police crash reports such as details of human behaviors, system activation status, roadway design, and expanded crash characteristics would further improve understanding of these observed associations.

As ADAS technologies continue to evolve and become more widely deployed, methodologies that combine large-scale vehicle equipment data with real-world crash information provide an important means of identifying conditions that may benefit from future system refinement. These analyses can help guide manufacturers, researchers, regulators, and infrastructure planners toward targeted improvements with the greatest potential to reduce crashes and injuries.

Appendix A

Covariate significance was evaluated using Type III likelihood ratio tests, which compared the full logistic regression model with a reduced model excluding each covariate. Table A 1, below, summarizes the results, including the degrees of freedom, likelihood ratio test statistic, associated *p*-value, and the chi-square significance threshold for α = 0.05. The table also reports the estimated sample size required to detect statistical significance for each covariate, along with a sample size significance ratio representing the proportion of the observed sample needed to achieve significance. Ratios greater than 1.0 indicate that the available sample was insufficient to detect statistical significance for that covariate.

Table A 1. Logistic Regression Type 3 Test Statistics

ADAS	Sample Size	Covariate	Degrees of Freedom	Likelihood Ratio Test Statistic	P-Value	Chi2 Significance Threshold	Sample Size for Significance	Sample Size Significance Ratio
AEB	495233	Driver Age Group	5	3261.56	0.000	11.0705	1681	0.003
		Road Alignment	2	316.09	0.000	5.991465	9388	0.019
		Light Condition	4	267.25	0.000	9.487729	17582	0.036
		Number of Lanes	6	255.98	0.000	12.59159	24361	0.049
		Weather Condition	5	149.77	0.000	11.0705	36609	0.074
		Road Surface Condition	4	111.49	0.000	9.487729	42146	0.085
		Intersection	2	56.26	0.000	5.991465	52744	0.106
LDW+LKA+LCA	78607	Number of Lanes	6	84.61	0.000	12.59159	11698	0.149
		Driver Age Group	5	53.88	0.000	11.0705	16151	0.205
		Road Alignment	2	25.42	0.000	5.991465	18526	0.236
		Light Condition	4	29.71	0.000	9.487729	25107	0.319
		Road Surface Condition	4	23.34	0.001	9.487729	31948	0.406
		Weather Condition	5	4.26	0.512	11.0705	204148	2.597
PAEB	7447	Driver Age Group	5	24.74	0.000	11.0705	3332	0.447
		Non-motorist Age Group	6	18.29	0.006	12.59159	5126	0.688
		Number of Lanes	6	9	0.173	12.59159	10413	1.398
		Light Condition	4	6.46	0.167	9.487729	10938	1.469
		Intersection	2	2.5	0.287	5.991465	17880	2.401
		Road Surface Condition	4	2.12	0.714	9.487729	33349	4.478
		Weather Condition	5	2.31	0.804	11.0705	35631	4.785
		Non-motorist Prior Action	4	1.22	0.875	9.487729	57888	7.773
		Road Alignment	2	0.05	0.977	5.991465	959184	128.801

Tables A.2–A.4 present equipage rates and crash counts for each covariate level based on the observations included in the regression models. Because the fully specified models required complete (non-missing) data for every covariate, only observations with no missing values were included. Consequently, the crash counts are lower than those reported in Section 3.3, and the corresponding equipage rates differ slightly.

Table A 2. Covariate Level Equipage Rates for AEB

			Counts		Equipage	
ADAS	Covariate	Level	System Relevant	Control	System Relevant	Control
AEB	Lighting Condition	DARK LIGHTED	66,043	92,889	22.8%	37.3%
		DARK NOT LIGHTED	14,964	19,240	21.0%	34.1%
		DARK UNKNOWN	913	1,323	19.3%	30.9%
		DAWN DUSK	20,134	29,806	20.0%	36.7%
		DAYLIGHT	393,199	590,630	20.5%	38.2%
	Road Alignment	CURVE	28,337	37,164	25.4%	37.3%
		OTHERGROUP	3,486	5,329	23.0%	43.6%
		STRAIGHT	463,430	691,395	20.5%	37.9%
	Number of Lanes	1	25,462	34,907	23.5%	38.1%
		2	153,741	227,322	20.1%	36.9%
		3	60,996	89,593	22.0%	39.5%
		4	125,515	189,240	20.0%	37.2%
		5	30,149	45,411	20.1%	38.4%
		6	77,844	115,558	21.6%	39.3%
		7+	21,546	31,857	21.3%	39.4%
	Driver Age	14-24	116,083	83,650	17.8%	34.3%
		25-34	130,914	157,751	18.5%	35.4%
		35-54	152,095	294,334	21.8%	38.5%
		55-64	49,249	111,156	23.3%	38.8%
		65-74	29,560	63,045	27.1%	42.6%
		75+	17,352	23,952	31.5%	44.5%
	Weather Condition	CLEAR	380,311	551,819	20.9%	38.4%
		FOG OR SMOKE	1,138	1,671	19.9%	33.0%
		FROZEN PRECIPITATION	5,534	7,648	26.7%	34.0%
		OVERCAST	71,991	109,176	19.2%	36.9%
		PRECIPITATION	35,931	63,111	21.6%	36.6%
		STRONG WIND OR BLOWING SAND OR SOIL OR SNOW	348	463	33.0%	29.6%
	Road Surface Condition	DRY	427,674	620,752	20.6%	38.2%
		ICE/FROST	1,944	2,684	30.5%	36.0%
		MUD/DIRT/SAND/GRAVEL	83	105	26.5%	28.6%
		SNOW/SLUSH	4,710	6,535	27.7%	33.8%
		WET	60,842	103,812	21.0%	36.5%
	Intersection	INTERSECTION	157,394	231,625	21.6%	37.2%
		NOT AN INTERSECTION	326,634	485,681	20.4%	38.3%
		OTHERGROUP	11,225	16,582	19.9%	35.2%

Table A 3. Covariate Level Equipage Rates for PAEB

			Counts		Equipage	
ADAS	Covariate	Level	System Relevant	Control	System Relevant	Control
PAEB	Lighting Condition	DARK LIGHTED	2,056	92,889	23.9%	32.0%
		DARK NOT LIGHTED	804	19,240	22.4%	28.9%
		DARK UNKNOWN	54	1,323	24.1%	26.4%
		DAWN DUSK	372	29,806	24.5%	30.9%
		DAYLIGHT	4,161	590,630	26.5%	32.4%
	Road Alignment	CURVE	315	37,164	25.7%	31.6%
		OTHERGROUP	37	5,329	24.3%	36.2%
		STRAIGHT	7,095	691,395	25.2%	32.2%
	Number of Lanes	1	807	34,907	26.8%	32.4%
		2	3,740	227,322	24.6%	31.2%
		3	614	89,593	26.2%	33.8%
		4	1,365	189,240	24.2%	31.6%
		5	230	45,411	25.2%	32.5%
		6	581	115,558	28.1%	33.4%
		7+	110	31,857	26.4%	33.5%
	Driver Age	14-24	1,042	83,650	22.0%	29.4%
		25-34	1,587	157,751	23.1%	30.1%
		35-54	2,352	294,334	25.3%	32.3%
		55-64	1,070	111,156	26.9%	33.1%
		65-74	835	63,045	25.6%	36.7%
		75+	561	23,952	33.0%	38.8%
	Weather Condition	CLEAR	5,951	551,819	25.5%	32.6%
		FOG OR SMOKE	42	1,671	23.8%	28.4%
		FROZEN PRECIPITATION	38	7,648	15.8%	28.2%
		OVERCAST	803	109,176	23.7%	31.1%
		PRECIPITATION	609	63,111	25.5%	31.0%
		STRONG WIND/ BLOWING SAND/SOIL/ SNOW	4	463	25.0%	24.4%
	Road Surface Condition	DRY	6,474	620,752	25.4%	32.5%
		ICE/FROST	10	2,684	10.0%	30.3%
		MUD/DIRT/SAND/GRAVEL	10	105	20.0%	27.6%
		SNOW/SLUSH	23	6,535	13.0%	27.7%
		WET	930	103,812	24.5%	30.9%
	Intersection	INTERSECTION	3,260	231,625	25.3%	31.6%
		NOT AN INTERSECTION	3,910	485,681	25.4%	32.6%
		OTHERGROUP	277	16,582	20.9%	29.1%
	Non-motorist Age Group	0-3	61		23.0%	
		4-9	233		20.6%	
		10-14	429		26.1%	
		15-19	618		29.3%	
		20-64	4,698		24.0%	
		65+	1,280		28.8%	
		Minor with Adult	128		21.9%	
	Non-motorist Action Prior	Adjacent to Roadway	482		26.1%	
		Crossing Roadway	5,228		25.0%	
		In Roadway	516		25.6%	
		On Sidewalk	252		25.0%	
		Other/Unknown/Null	969		25.5%	

Table A 4. Covariate Level Equipage Rates for LDW+LKA+LCA

			Counts		Equipage	
ADAS	Covariate	Level	System Relevant	Control	System Relevant	Control
LDW+LKA+LCA	Lighting Condition	DARK LIGHTED	14,706	92,889	10.8%	14.9%
		DARK NOT LIGHTED	19,286	19,240	8.6%	12.9%
		DARK UNKNOWN	579	1,323	8.3%	11.3%
		DAWN DUSK	4,146	29,806	9.6%	13.9%
		DAYLIGHT	39,890	590,630	9.5%	15.0%
	Road Alignment	CURVE	23,326	37,164	9.5%	14.3%
		OTHERGROUP	2,124	5,329	12.3%	15.5%
		STRAIGHT	53,157	691,395	9.4%	14.9%
	Number of Lanes	1	7,149	34,907	10.3%	15.0%
		2	48,158	227,322	8.8%	14.2%
		3	6,335	89,593	11.4%	16.2%
		4	11,006	189,240	9.7%	14.4%
		5	1,591	45,411	11.5%	14.7%
		6	3,575	115,558	11.3%	15.7%
		7+	793	31,857	13.0%	15.8%
	Driver Age	14-24	20,470	83,650	9.1%	14.9%
		25-34	21,447	157,751	9.0%	14.1%
		35-54	22,078	294,334	9.6%	15.0%
		55-64	6,926	111,156	9.2%	14.4%
		65-74	4,655	63,045	11.6%	16.3%
		75+	3,031	23,952	11.9%	16.9%
	Weather Condition	CLEAR	44,944	551,819	9.9%	15.1%
		FOG OR SMOKE	843	1,671	8.4%	12.9%
		FROZEN PRECIPITATION	6,459	7,648	8.5%	11.7%
		OVERCAST	11,908	109,176	9.0%	14.2%
		PRECIPITATION	14,023	63,111	9.0%	14.2%
		STRONG WIND OR BLOWING SAND OR SOIL OR SNOW	430	463	10.5%	11.2%
	Road Surface Condition	DRY	49,578	620,752	10.0%	15.0%
		ICE/FROST	2,196	2,684	8.0%	13.6%
		MUD/DIRT/SAND/GRAVEL	278	105	5.8%	10.5%
		SNOW/SLUSH	5,806	6,535	8.3%	11.4%
		WET	20,749	103,812	8.8%	14.1%

Abbreviations and Acronyms

Acronym	Definition
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AEB	Automatic Emergency Braking
AIS	Abbreviated Injury Scale
CSC	Consolidated State Crash
EDT	Electronic Data Transfer
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
GVWR	Gross Vehicle Weight Rating
HLDI	Highway Loss Data Institute
IIHS	Insurance Institute for Highway Safety
ITP	Independent Third Party
KABCO	Police-reported injury severity scale (K=fatal injury, A = Suspected Serious Injury, B = Suspected Minor Injury, C = Possible Injury, O = No Apparent Injury)
LCA	Lane Centering Assistance
LDW	Lane Departure Warning
LKA	Lane Keeping Assistance
MITRE	The MITRE Corporation
MMUCC	Model Minimum Uniform Crash Criteria
MY	Model Year
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturer
PAEB	Pedestrian Automatic Emergency Braking
PARTS	Partnership for Analytics Research in Traffic Safety
PDW	Pedestrian Detection Warning
QIE	Quasi-Induced Exposure
UMTRI	University of Michigan Transportation Research Institute
U.S.	United States
USDOT	United States Department of Transportation
VIN	Vehicle Identification Number

References

[1] United States. Department of Transportation. National Highway Traffic Safety Administration. National Center for Statistics and Analysis, "Overview of Motor Vehicle Traffic Crashes in 2024 [Traffic Safety Facts]," United States. Department of Transportation., Washington D.C., 2026.

[2] PARTS, "A Study on Real-world Effectiveness of Model Year 2015–2023 Advanced Driver Assistance Systems," The Partnership for Analytics Research in Traffic Safety, McLean, 2025.

[3] PARTS, "Effectiveness of Advanced Driver Assistance Systems in Injury Crashes," in *28th Enhanced Safety of Vehicles*, Toronto, 2026.

[4] PARTS, "PARTS: Market Penetration of Advanced Driver Assistance Systems (ADAS)," The Partnership for Analytics Research in Traffic Safety, McLean, 2024.

[5] A. J. Leslie, R. J. Kiefer, C. A. Flannagan and S. H. Owen, "Analysis of the Field Effectiveness of General Motors Year 2019-2023 Advanced Driver Assistance System (ADAS) Features," University of Michigan Transportation Research Institute (UMTRI), Ann Arbor, 2025.

[6] Highway Loss Data Institute, "Compendium of HLDI Collision Avoidance Research," Highway Loss Data Institute, 2023.

[7] Statista, "Estimated U.S. market share held by selected automotive manufacturers in 2024," 20 November 2025. [Online]. Available: https://www.statista.com/statistics/249375/us-market-share-of-selected-automobile-manufacturers/..

[8] J. B. Cicchino, "Effects of Automatic Emergency Braking Systems on Pedestrian Crash Risk," *Accident Analysis & Prevention,* p. vol. 172, 2022.

[9] PARTS, "A Study in Real-world Effectiveness of Model Year 2015-2023 Advanced Driver Assistance Systems," The Partnership for Analytics Research in Traffic Safety, 2025.

[10] PARTS, "Advanced Driver Assistance System Crash Rate Assessment Using Vehicle-Specific Mileage Data," Partnership for Analytics Research in Traffic Safety, McLean, 2025.

[11] PARTS, "Real-world Effectiveness of Model Year 2015 - 2020 Advanced Driver Assistance Systems," MITRE Corp, McLean, VA, 2022.

[12] J. B. Cicchino and D. S. Zuby, "Characteristics of rear-end crashes involving passenger vehicles with automatic emergency braking," *Traffic Injury Prevention,* pp. 112-118, 2019.

[13] Federal Highway Administration, "Highway Functional Classification Concepts, Criteria and Procedures 2023 Edition," FHWA, 2023.