Critical Areas in Advanced Driver Assistance Systems Safety: Point of Sale and Crash Reporting

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Automated assistive vehicle technologies vary from simple alerts to partially automated driving tasks that are increasingly available in today's vehicles. Advanced driver assistance systems (ADAS) seek to alert a driver to critical events (e.g., forward collision warning) or even intervene (e.g., emergency braking, lane-keeping steering) to prevent crashes. These technologies, however, are not available equally across the passenger vehicle fleet, nor is there standardization in how they are marketed to potential buyers or demonstrated at point of sale, including by increasingly popular online "dealerships" like Vroom and Carvana. The proliferation of ADAS has also outpaced current crash investigation forms. The current Model Minimum Uniform Crash Criteria includes limited guidance on crash avoidance technologies and most state crash reports do not include ADAS variables. Realizing the full benefit of ADAS relies on salespeople, consumers, and law enforcement understanding their benefits and limitations in improving traffic safety. This project investigated the state of knowledge and current practices on how ADAS technologies are marketed and sold, how ADAS are notated in crash reports, and what existing crash data reveal about ADAS in crash involvement to help illuminate and address gaps in current pre-sale and post-crash ADAS research.</td></tr>
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Abstract

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Table of Contents

List of Figures

List of Tables

Introduction

Automated assistive vehicle technologies vary from simple alerts to partially automated driving tasks that are increasingly available in today's vehicles. Advanced driver assistance systems (ADAS) seek to alert a driver to critical events (e.g., forward collision warning) or even intervene (e.g., emergency braking, lane-keeping steering) to prevent crashes. These technologies, however, are not available equally across the passenger vehicle fleet [1], nor is there standardization in their activation and function across different models, or in how their use and limitations are conveyed to potential buyers [2], demonstrated at point of sale, or conveyed via owners' manuals [3]–[5]. While there is a growing body of research exploring drivers' expectations and trust in these technologies [6], there is a dearth of research into how these technologies are marketed and sold, the degree to which they are available by model and trim, and how consumers can locate information about ADAS in the buying process.

The proliferation of ADAS has also outpaced updates to current crash investigation forms. On June 29, 2021, the National Highway Traffic Safety Administration (NHTSA) issued a Standing General Order requiring manufacturers and technology companies to report serious injury and fatality crashes involving Level 2 and above ADAS and Automated Driving Systems (ADSs). This signifies growing recognition that government policy and practices need better information about these technologies and their role in traffic safety. Yet, no similarly updated guidance or policy focused on crash reporting forms was issued at that time. ADAS variables are not currently included in the Model Minimum Uniform Crash Criteria (MMUCC) guidelines and are thus unlikely to exist on crash reports for most states. These gaps in data collection hinder safety researchers' ability to understand how ADAS are sold, demonstrated, used, and recorded in a crash.

Project Background

This project sought to examine the existing research and address gaps in how ADAS are marketed, sold, and included in post-crash data collection. These gaps may create a substantial safety risk where salespeople, drivers, and safety professionals have difficulty understanding the correct use and limitations of ADAS. In this project, we examined the following research questions:

1. What is the current scope of research on ADAS related to point of sale and crash reporting?

There has been a rapid proliferation of both driver-assistance and semi-automated driving technologies and related research in the last 5–7 years, during which some of the largest ADAS-related studies were first undertaken. However, a preliminary literature review suggests that the majority of this research focuses primarily on drivers or on the technology itself—e.g. driver distraction [7], driver behavioral adaptations [8], older drivers [9], and driver education and training [10]. Two recent meta-analyses looked at performance measures or safety evaluations [11], [12]. Little research has focused on the consumer or real-world safety impacts, resulting in a lack of insights about—including relevant gaps in—the pre-buying and post-crash aspects of ADAS.

2. How are ADAS technologies being marketed and sold to consumers?

Semantics and linguistics are rich fields that offer frameworks to understand how manufacturers target particular markets or sell safety features through values-based ideas of family, responsibility, or freedom. From the names chosen for particular features (e.g., Tesla's Autopilot and Ford's CoPilot 360) to the images and framing used in advertisements, better understanding the marketing of ADAS can help safety professionals understand how consumers form ideas of the potential importance, function, and limits of ADAS.

There has been particular attention paid to the percentage of SUVs and trucks purchased by American drivers and their role in the alarming increase in pedestrian deaths, in particular [13]. Yet safety technologies may be less likely to be available on larger vehicles, particularly at lower (i.e., less expensive) trim packages [14]. An inventory of popular vehicle types, models, and trim packages, and availability of ADAS provided potential insight into how disparities in the availability of ADAS across the vehicle fleet may affect safety outcomes.

Dealerships remain the primary point of contact between consumers and automobile manufacturers and the technologies they offer [15]. Increasingly, though, consumers interact with dealerships through their websites and online vehicle listings before going to a physical location. Additionally, in the last few years, the number of online dealerships, has increased. These sites purport to offer consumers lower stress related to "haggling," sales pressure, and time "wasted" at in-person dealerships. It is thus important to understand what information about vehicles' safety technologies are available to potential buyers on online dealer websites, which has not yet been examined in the transportation literature. Whether in-person or online, dealerships are a key piece of the education, information, choice, and acquisition of vehicles with these technologies.

3. What are the current practices and challenges in crash reporting related to ADAS?

Law enforcement, as the first responders on the scene of a crash and the investigators into the immediate and near-term post-crash information, are uniquely positioned to collect some of the most detailed information on what technologies were being used, and how, both immediately preceding and at the time of a collision. Importantly, they are typically the first people that drivers speak to, and thus may get the most unfiltered, least recall-biased information from drivers. However, police on scene are also responsible for immediate public safety concerns like managing medical response, directing traffic, and preventing further incidents. Early phases of the project used systematic review to explore the training provided to law enforcement and the forms and tools that police use on scene at crashes. Interviews provided the opportunity for richer, qualitative exploration with the experts themselves on how those training and tools might be improved, what challenges and opportunities there are on scene, the extent to which law enforcement are aware of the rapid proliferation of these technologies, and the sense of how frontline officers may be interacting with such technologies on-scene.

In summary, we asked:

1. How are driver assistance systems marketed and available on different vehicles?
2. How are dealerships providing information about these systems to consumers who are shopping for a vehicle?
3. How are these technologies represented in crash statistics?
4. What tools do police have to account for these technologies in crashes and what updates should be made to current tools?

The project was divided into research tasks that addressed these important gaps in the knowledgebase about ADAS marketing, selling, use, and crash reporting. The data and methods, results, key findings, and recommendations are presented in each subsequent section in the following order: literature review; availability of ADAS technologies in best-selling vehicle models; analysis of the effect of ADAS in a national sample of crash investigations; and inclusion of ADAS in police crash reporting.

Data and Methods

Conceptual Model of the ADAS Ecosystem

To guide our synthesis of the existing literature into the selling and buying of vehicles with ADAS, we developed a conceptual model that includes the relevant systems and actors (Figure 1). The boxes in black represent the areas for which this article summarizes the existing literature and solid lines represent pathways described in that existing literature, while dashed connecting lines between boxes represent potential pathways; the potential for developing or strengthening these potential pathways will be examined further in the discussion section.

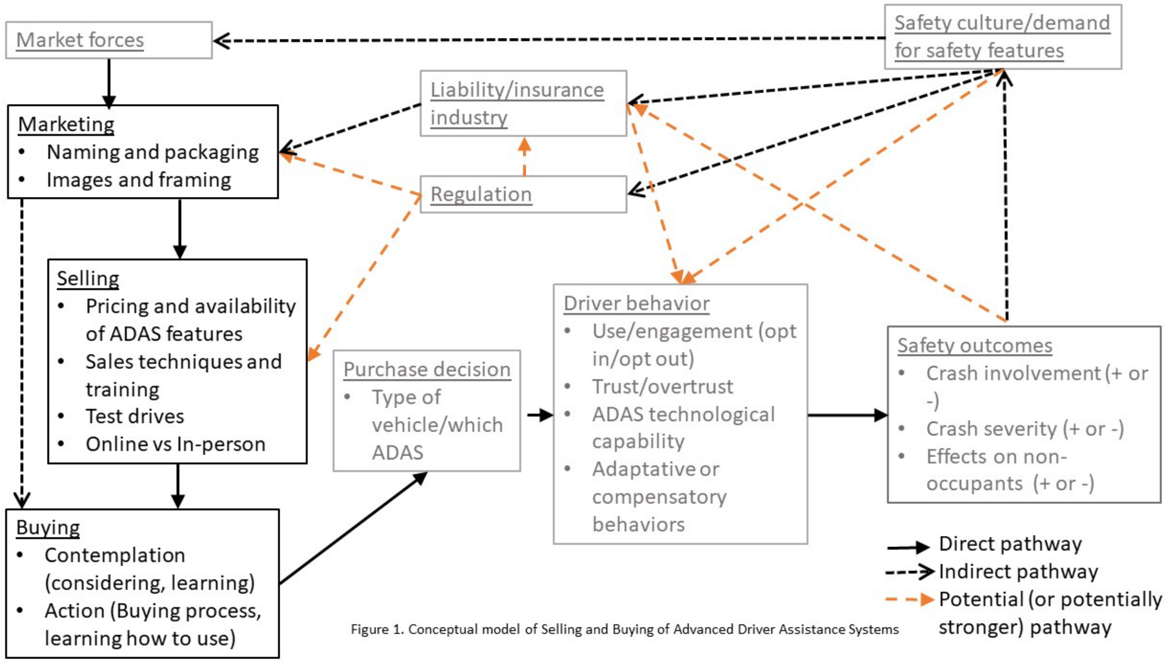

Figure 1. A conceptual model of the ecosystem for ADAS.

Literature Review of Research on ADAS and Pre-purchase and Post-crash Topics

The project began with an extensive scoping review of the existing ADAS literature. Using Scopus, Web of Science, and TRID, we compiled journal articles, grey literature, and news articles that included "ADAS," "Advanced Driver Assistance Systems," "crash avoidance," "automation," "autonomous," and the names of the individual ADAS equipment in both generic and branded terms (e.g., "Super Cruise" and "Autopilot"). We then excluded research focused on the technical aspects of the technology (e.g., sensors), driver use (e.g., driver response to audible vs tactile alerts), and SAE Level 4 or 5 autonomy, as we were interested in widely-available existing driver assistance technologies. As shown in Figure 1 in the greyed-out boxes, we also excluded research focused on liability and insurance, regulation, safety culture, and larger market forces. These are all critical issues in safety technologies, deserving of future research efforts, but were not within the scope of this project.

This process yielded 124 articles for inclusion, from which we developed an inventory with relevant information such as study location, methods, and key findings, which was categorized based on the conceptual model. The synthesis of these studies informed each of the research tasks, and relevant studies are included in each article produced from this study.

Availability of ADAS in Best-selling Vehicle Models in the US, Europe, and Asia

To understand the prevalence of ADAS within the marketed vehicle fleet, we collected data for 10 of the largest US, Asian, and European automakers and their top five selling models in the

US, including each major body type and their trim levels for model year 2021. Two of the three US manufacturers did not have a car in their top five selling models, while six of the seven largest international automakers either did not have a truck in their top-selling models or did not offer a truck.

We created an inventory of the following variables: body type (car, SUV, truck, van); trim level (base model, upgraded trims); cost (manufacturer's suggested retail price), and three common ADAS: blind spot detection (BSD), automatic emergency braking (AEB), and forward collision warning (FCW). We chose these three because they have been available the longest of most ADAS and we expected they would be widely available on enough models and trim levels for the study. Each model was available with different "trims," which refers to the different versions of a model, where "higher" trim levels include additional convenience, aesthetic, safety, and functional equipment in a variety of bundled packages. The final sample resulted in 290 combinations of make, model, vehicle type, and trim.

We used frequency tables, descriptive statistics, and, where appropriate, statistical hypothesis testing—e.g., correlations, Kruskal-Wallis H test (i.e., analysis of variance [ANOVA] on ranks])—to examine relationships between the presence of ADAS equipment and vehicle model, trim level, body type, and price. We restricted analyses to the three aforementioned ADAS technologies: AEB, BSD, and FCW.

Crash Investigation Sampling System (CISS) Database Analysis of the Effect of ADAS in Reducing Crash Type or Severity

This portion of the project consisted of an exploratory analysis of data from NHTSA's National Center for Statistics & Analysis' (NCSA) Crash Investigation Sampling System (CISS) to understand the relationship between the presence and type of ADAS features and crash outcomes. NCSA also publishes the Fatality Analysis Reporting System (FARS) and Crash Report Sampling System (CRSS). While all three datasets (CISS, FARS, and CRSS) draw primarily from police reports of motor vehicle crashes in the US, CISS also includes data from supplemental investigations completed by NHTSA technicians. These supplemental data provide detailed information about the specific sub-types of ADAS available to each vehicle, allowing a deeper examination of the role of ADAS features in crash outcomes. Therefore, CISS is the only national dataset available that provides the level of detail necessary to analyze ADAS features and is the dataset we used for this research.

Through this exploration, we aimed to provide additional insight into the potential connection between ADAS features and crash outcomes and severity, as well as to identify areas for future research in this rapidly changing field. For this analysis, we worked with data that described the characteristics of the crash, vehicle(s) involved, ADAS, and vehicle occupants.

Key Variables

Within the CISS dataset, we primarily used records related to crash avoidance (i.e., from the AVOID table) to categorize vehicles by the availability of four types of ADAS equipment: BSD, FCW with and without AEB, and lane keeping systems. The latter two equipment types have a spectrum of interventions available, ranging from a simple warning to more advanced automated braking or steering. Given the small sample size of vehicles with any of these systems, the co-occurrence of these systems among vehicles (e.g., many vehicles with ADAS had all three of these systems), and the exploratory nature of this paper, our analysis relied on a binary variable indicating whether the vehicle had one or more of these ADAS technologies available, versus none (or no data was available regarding ADAS technologies).

Injury severity outcomes were provided in the data using the Abbreviated Injury Scale (AIS), a standardized system for reporting injuries; e.g. at the occupant level, as well as the maximum AIS value (MAIS) for each vehicle and for the crash overall. Occupant deaths were coded as a separate fields in the occupant table. We combined the fatality and injury severity fields into an approximation of the KABCO scale, the more common scale for standard crash reporting forms.

We used frequency tables, descriptive statistics, and, where appropriate, statistical hypothesis testing (e.g., t-test, $\chi 2$ test) to examine relationships between the presence of ADAS equipment and crash outcomes, including "Delta V" (ΔV), which is a measure of the relative change in vehicle velocity pre- and post-crash that is considered a reliable proxy for injury severity and is assigned by NHTSA to each crash in the CISS database. We subset the data as appropriate to account for vehicle age, number of vehicles involved, and other confounding attributes.

Current Status and Opportunities for Inclusion of ADAS in Police Crash Data Collection

Our data for this research question comes from three major sources: a scoping review of the literature, a review of current crash report forms, and the two most recent versions of the Model MMUCC, available on the NHTSA website. All sections and fields on the crash report forms and MMUCC were reviewed to identify the ADAS- or automated vehicle (AV)-related terms, including the following key words: AV, autonomous, automated, driverless, automation, ADAS, driver assistance, automatic emergency braking, blind spot detection, cruise control, and technology. We created an inventory of the crash report forms for all 50 US states, using the latest publicly-available crash form or manual (whichever was the latest). Year of the latest information was identified from the form or manual.

Results

Availability of ADAS in Best-selling Vehicle Models in the US, Europe, and Asia [14]

Costs of ADAS by vehicle type and automaker

For every body type, the availability of each of the three safety-related features significantly increased the Manufacturer's Suggested Retail Price (MSRP). Cost differences were also correlated with automaker. The MSRPs of the top-selling international vehicles (M = $35,560, SD = $13,470) were significantly lower than US vehicles (M = $44,260, SD = $13,460), ($F(1,296) = 27.7$, $p < .001$). This corresponds to the top selling US models being more likely to be larger, more expensive vehicle types than the top-selling international models ($X^2(3) = 53.66$, $p < .001$).

One-fifth to one-quarter of the model/trim combinations of all body types in the sample did not have FCW or AEB equipped (Table 1). Although the difference was not statistically significant between body types, SUVs were less likely than cars or trucks to have either crash-avoidance feature.

Table 1. Availability of ADAS Among Top-selling Models by Vehicle Type and Automaker

	Car	SUV	Truck	Van	Total
Percent of sample (n)	26.9% (78)	54.5% (158)	16.9% (49)	1.7% (5)	100% (290)
Model/trim combinations with BSD	76.9% (60)	87.3% (138)	53.1% (26)	60% (3)	78.3% (227)
Model/trim combinations with AEB	70.5% (55)	65.8% (104)	77.6% (38)	100% (5)	69.7% (202)
Model/trim combinations with FCW	79.5% (62)	74.1% (117)	81.6% (40)	100% (5)	77.2% (224)
US automaker	4.3% (4)	59.1% (55)	31.2% (29)	5.4% (5)	32.1% (93)
International automaker	37.6% (74)	52.3% (103)	10.2% (20)	0% (0)	67.9% (197)

The top-selling vehicles from international automakers were significantly more likely than vehicles from the US automaker companies to have FCW (Figure 2). This was largely due to SUVs, where 80% of international SUV models (e.g. Honda Pilot) had FCW available, while only 65% of top-selling US SUVs (e.g. Jeep Wrangler) had that feature. Every one of the international truck model/trim combinations (n = 20) had AEB and FCW; in contrast, only 58% and 68% of the US trucks in the sample (n = 31) had AEB and FCW, respectively.

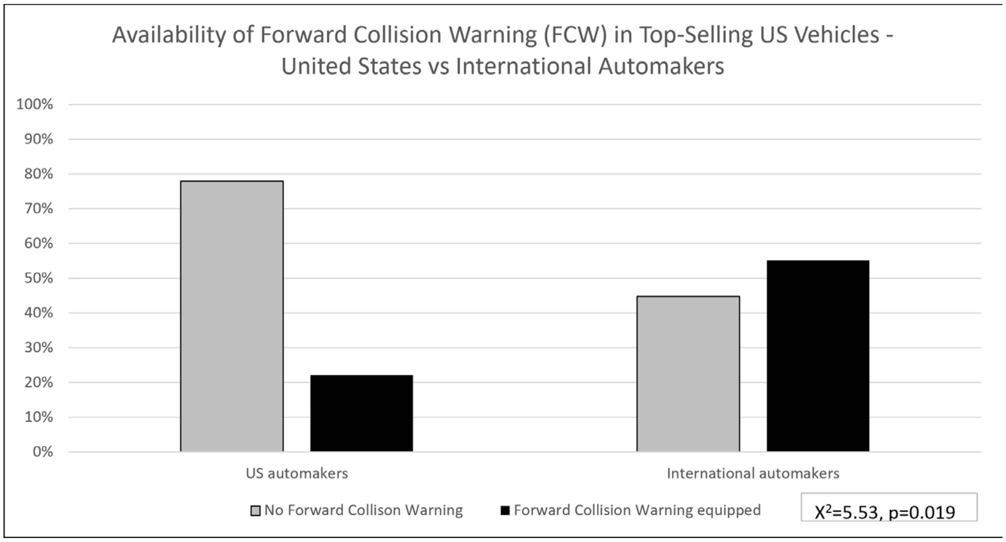

Figure 2. Availability of FCW on US and international automakers' top-selling US models.

As trim level is an ordinal variable, we used a Kruskal-Wallis H test (i.e., ANOVA on ranks), which showed each ADAS feature was significantly more likely on a higher trim level (BSD $X^2(1) = 40.98$, $p < .001$); AEB $X^2(1) = 5.36$, $p = .021$; FCW $X^2(1) = 4.97$, $p = .026$). It was not possible to find reliable, uniform data on the precise price differences between trim levels for each model; for the models at the time of this study, trim packages that included one or multiple ADAS ranged from $750–$2295 USD. Because MSRP increases with trim level and ADAS are more likely to occur on higher trims, these safety technologies add to the cost of a vehicle for the consumer.

Crash Investigation Sampling System (CISS) Database Analysis of the Effect of ADAS in Reducing Crash Type or Severity [16]

ADAS Availability

In the CISS sample, only 3.8% of vehicles in transport (i.e., not parked) in 2017 were recorded as having one or multiple of the four ADAS systems of interest in this paper: BSD, lane departure/lane keeping, and FCW systems with and without AEB. By 2020, this percentage had nearly tripled, to 10.4%. Simultaneously, the percentage of vehicles 2009 and older in the sample fell from 56.1% in 2017 to 43.5% in 2020. Without the ability to determine the percentage of vehicles equipped with ADAS in the general population, it is not possible to determine whether these percentages match general trends or whether vehicles with ADAS are more or less likely to be involved in crash types that end up in a CISS sample.

ADAS features have a higher availability rate in the CISS sample among SUV-type vehicles than other vehicles: 11% of SUVs have 1+ ADAS type present, compared to 7.2% of sedans/autos and 2.3% of pickups. This difference has implications for how we understand ADAS' role in injury severity outcomes, since research has shown that because of their size, weight, and shape, SUVs tend to both protect their own occupants better than other vehicles and cause greater harm to occupants of people outside the vehicle and in other, especially smaller, vehicles [17] .

Occupant Injury Severity Outcomes

Because crash injury severity is so closely linked to a vehicle's age, weight, and other characteristics that are correlated with ADAS, our exploratory analysis looked at several variations of injury severity outcomes, stratified by relevant attributes.

1. Are vehicles equipped with ADAS under-represented among sampling strata defined by higher injury severities?
2. Do occupants of ADAS-equipped vehicles experience a lower injury severity than occupants of other vehicles?
3. Do occupants of any vehicle involved in a crash with an ADAS-equipped vehicle experience lower injury severities than crashes with no ADAS-equipped vehicles?
4. Are ADAS-equipped vehicles under-represented among types of crashes that tend to cause greater injury severity?

Sampling domain

To explore whether ADAS vehicles are less likely than non-ADAS vehicles of similar age to be in the fatal and severe injury sampling domains, we looked within each sampling domain to see if there were correlations between presence/absence of ADAS and vehicle-level crash outcomes (injury severity, ΔV). Because the definitions of the sampling domains excluded vehicles by age, we were unable to tell whether vehicles with ADAS were over- or under-represented in any one domain. Instead, we need to make a narrower comparison on only the domains where a vehicle with ADAS would be eligible and compare between crashes involving similarly aged vehicles with and without ADAS.

Our results suggest that crashes involving only vehicles without ADAS were over-represented among fatal crashes by over 13% (125 observed vs 108 expected). Crashes in which one or more vehicles had ADAS appeared to be under-represented among fatal crashes by nearly 46% (37 observed vs 54 expected; $\chi^2=8.87$, $p \leq 0.032$). In theory, this comparison should isolate the effect of ADAS separately from vehicle age by ensuring that all crashes in the comparison involved at least one recent-year vehicle, and the injury severity level was specific to the recent vehicle. The differences between other domains were much smaller, with no difference exceeding ± 3.5%.

Vehicle Body Type

Examining injury severity by vehicle age and presence of ADAS according to body type suggested some trends, but the small sample size limited our capacity to draw conclusions with statistical significance. For example, among vehicles which CISS classifies as passenger automobiles and automobile derivatives ("autos," excluding utility vehicles/SUVs and light/pickup trucks), the presence of ADAS appeared to be positively correlated with lower injury severity, in contrast to SUVs and light trucks. It is possible that the benefits of ADAS features are offset by the larger mass of SUVs and light trucks, but it is equally plausible that the sample sizes for SUVs and light trucks were too low (n = 31 and n = 17 for fatal and severe crashes, respectively) to allow any confidence in the results.

Further, we found that ADAS equipment was not distributed uniformly across vehicle body types; understanding these relationships is essential for teasing out whether and to what extent ADAS may affect crash outcomes. This is an area in which additional research is urgently needed, as SUVs and light trucks continue to comprise an increasingly large share of the vehicle fleet.

Additionally, body type itself affects crash outcomes, all other things equal, so our next analysis attempted to control for the influence of body type on crash outcomes by examining two-vehicle crashes by matched body type. Given small sample sizes for SUVs and light trucks, this analysis was only meaningful for auto + auto crashes. Among two-vehicle crashes involving only autos, in which at least one vehicle was 2010 or newer and had ADAS available, 4.9% resulted in death or serious injury, versus 95.1% (not shown) that resulted in minor injury, possible injury, or property damage only. Within this same category of auto + auto crashes, in contrast, 9.2% of crashes involving only vehicles 2009 and older (i.e., definitively without ADAS) resulted in death or serious injury. Slightly fewer crashes (7.1%) had a severe outcome among crashes in which at least one of the vehicles was 2010 or newer but neither had ADAS. Among crashes in which at least one of those vehicles was equipped with ADAS, this rate fell to 4.9%. These differences were marginally statistically significant ($\chi^2 = 5.8$, $p \leq 0.056$).

Crash type

We also examined crashes by crash type to see whether there were patterns plausibly related to ADAS features. Crashes involving an ADAS-equipped vehicle were less likely to be head-on, rear-end, or “Not collision with vehicle in transport” (which mostly represents solo vehicle crashes) than crashes involving a 2010 or newer vehicle without ADAS or a 2009 or older vehicle. In contrast, crashes involving one or more vehicles with ADAS available were relatively more likely to be angle crashes. Note that the distribution of these data relative to the sampling does not necessarily suggest that ADAS-equipped vehicles were more likely to be involved in angle crashes than non-ADAS-equipped vehicles of the same age within the general population. However, these distributions do suggest that when an ADAS-equipped vehicle was involved in a crash, it may have been more likely to be involved in angle crashes than head-on crashes, in a way that appears to differ from the distribution crashes involving only non-ADAS-equipped vehicles of the same age. This may be explained by technologies like FCW and AEB moderating longitudinal (i.e. head-on or rear-end) crashes, not angled collisions like “side-swipes.” Solo vehicle crashes were overrepresented among crashes only involving vehicles 2009 and older. This may be related to other safety improvements that have happened over time, such as electronic stability control.

Change in velocity (Delta V) outcomes

The variable Delta V (“ΔV”) represents the change in velocity of a vehicle from before to after a crash event. NHTSA uses this metric because previous research has found it to be a reliable predictor for injury severity in a crash [18]. For each vehicle in the CISS dataset, either a numeric ΔV value or an ordinal approximate ΔV range (where a precise numeric ΔV cannot be calculated) is provided. The ordinal values of ΔV for each vehicle include:

- **Low**: 0–25 kmph (0–15.5 mph)
- **Moderate**: 25–40 kmph (15.5–24.6 mph)
- **High**: ≥ 40 kmph (≥ 24.6 mph)
- Missing or unknown values

Among vehicles in transport (i.e., not vehicles that are parked or unmoving) and excluding vehicles with missing or unknown ΔV, vehicles with 1+ ADAS features available appeared to have a lower chance of a high ΔV and a greater chance of having a low ΔV than vehicles without ADAS. Older vehicles (model years 2009 and earlier) were more likely to have a missing or unknown value for ΔV than newer vehicles (model years 2010 and later) both with and without ADAS.

These differences in frequency distributions of ΔV by ADAS availability and vehicle age were statistically significant ($\chi^2 = 6623$, $p \leq 0.0001$). Repeating the test on only the subset of 2010 and newer vehicles with and without ADAS, and excluding both missing ADAS vehicles and older vehicles, revealed a lower but still significant test statistic ($\chi^2 = 14.51$, $p \leq 0.003$). These results suggest that vehicles with ADAS, when involved in a crash, may experience a lower change in velocity pre- and post-crash. Whether this is due to ADAS technologies (e.g., AEB) or other factors is not possible to determine from the data.

Current Status and Opportunities for Inclusion of ADAS in Police Crash Data Collection

Presence and Type of ADAS Technologies in Police Crash Report Forms

Each state develops its own crash report form, which may be informed by the MMUCC, published by NHTSA. The crash report form for each of the 50 states contains a mix of checkboxes and open-ended questions to record information about contributing circumstances or narratives. Eighteen of the crash report forms and their manuals were developed in 2018 or later; however, only 11 crash report forms (all of which were developed in 2018 or later) include terms or check boxes related to ADAS or autonomous technology. Of those 11 forms, eight include a place to notate the automation system level in vehicles following the SAE levels of driving automation. Those eight forms also include a place to note whether the automation system/ ADAS feature was engaged at time of crash. Among those, five include the potential to record the SAE level of the engaged automation system. These five crash reports comprise, relative to the forms for all states, the most extensive potential for recording crash-avoidance technology in the crash report, and are used in Illinois, Michigan, Minnesota, Mississippi, and Nebraska.

Evaluation of the Model Minimum Uniform Crash Criteria's Recent and On-going Updates

The most recent approved edition of the MMUCC, the 5th edition, was published in 2017. In that edition, NHTSA added the "Dynamic Data Elements" section. The Dynamic Data Elements "focus on issues that are so fluid and changeable that they must be evaluated more frequently than once every five years" [19]. The first new element of this new section was "DV1. Motor Vehicle Automated Driving System(s)," a multi-choice selection to choose the applied level(s) of automation for the cars involved in a crash. The MMUCC explains that the element was added "to address the rapidly developing automated vehicle systems technology. Advanced levels of automation and the push to deploy this technology into the motoring arena are creating a paradigm shift to the traditional notion of all aspects of the operation of motor vehicles" [20].

On February 2, 2023, NHTSA published a Request for Comments (RFC) on the Draft Model MMUCC Guideline, 6th Edition. Per the Federal Register, one objective of the MMUCC 6th Edition is to reduce the discrepancies between the MMUCC and other national standards. The RFC closed on May 3, 2023. The MMUCC is currently in the revision process and NHTSA anticipates publishing the MMUCC Guideline 6th Edition in 2024.

We reviewed the draft 6th edition for changes related to ADAS and automated and crash avoidance technologies. One relevant addition is New System Populated Data Elements, which enables checking the data recording process and linking multiple data sources. As some states have their own state-level data source for AV collisions, this provides the ability to link MMUCC data with state data using "S1. State Unique Crash ID." The "Dynamics Section" is proposed to be removed, and the element "DV1. Motor Vehicle Automated Driving System(s)" introduced in the 5th edition is proposed to be replaced with "Attributes incorporated at the Vehicle Level." A new element, "V44. Related Factors - Vehicle Level," introduces this newly added data field. The options related to ADAS and AVs are: "Vehicle was equipped with Automated Driving System(s)" and "Suspect that Automated Driving System(s) engaged at the time of the crash or leading up to the crash." The MMUCC 6th edition removes the information about "level of automation" in the MMUCC 5th edition and mentions that "If the State collects more detailed information on Automated Driving Systems (e.g., system equipped and if system engaged) the data attributes may align to Vehicle was equipped with Automated Driving System(s) and Suspect that Automated Driving System(s) engaged at the time of the crash or leading up to the crash if the definitions match."

Discussion and Recommendations

Our research revealed important insights—and additional knowledge gaps—about the buying process, real-world safety outcomes, and the potential to systematically capture crash data related to ADAS features, as described further below.

Marketing and Consumer Information Related to ADAS

Customers receive explanations of ADAS technology that differ in accuracy and thoroughness depending on the type of dealership they go to (safety, luxury, or mass-market). Automakers that have a strong safety-related brand identity, like Volvo, tend to give thorough education while brands such as Ford and Chevrolet give unsatisfactory explanations and even discourage questions about ADAS [2]. This is consistent with more recent research showing that many people do not receive ADAS training at the dealership [3], [21]. This is concerning because dealerships and salespeople are a preferred source of information in the car-buying process for many people [22].

There are considerable opportunities for future research into how ADAS are marketed and sold to US consumers in particular, since most existing research has been conducted in Australia and the Netherlands [3], [5]. One way to improve data collection would be to survey buyers at the point of sale instead of retrospectively. It is also recommended that future research ask more questions to assess consumers' prior knowledge of ADAS and assess the level of acceptance of each ADAS system separately.

Future research should also investigate the most effective methods of educating users of ADAS to compensate for existing evidence of the ineffectiveness of user manuals. Additionally, because the existing research only includes user manuals distributed in Australia, future research could investigate the contents and readability of American user manuals if sufficiently different. Regarding hand-off procedures at the point of sale, future research is suggested in three directions: collecting behavior data to validate the online training findings, testing a wider range of ADAS features, and testing longer-time effects.

The one US case-study of car dealerships and selling practices suggested fruitful avenues for future research into car salesperson training and dealership practices. This could inform dealership practices and suggest policy and regulation solutions to standardize and improve driver education on ADAS.

Availability of ADAS in Best-selling Vehicle Models in the US, Europe, and Asia

ADAS are more likely to be present on more expensive trim packages of new cars, potentially discouraging or even pricing consumers out of safety-related assistance technologies and their potential life-saving benefits, at least in popular SUV and truck models. Even consumers who might be able to afford the additional expense to opt into these technologies may not choose to if those technologies are seen as a luxury rather than a necessity or are packaged with unwanted upgrades; any of these scenarios limits the potential for widespread consumer use and wide-reaching safety improvements. Furthermore, the continuing popularity and increased danger posed by larger vehicles like SUVs warrants particular attention to increase the presence of these crash-avoidance technologies. NHTSA may want to explore regulation to require safety-critical systems at every trim level, and pursue policy that standardizes the naming and function of these technologies and increases the use of these systems as always-on, rather than allowing drivers to easily disable alerts or features. Future research should explore the legal and liability environment to determine the most effective way to ensure that both automakers and consumers are deploying and using these technologies to their maximum safety benefit.

Crash Investigation Sampling System (CISS) Database Analysis of the Effect of ADAS in Reducing Crash Type or Severity

This is the first study we are aware of that used the CISS database to look at safety effects of ADAS, making valuable contributions to our baseline understanding of the potential effect of ADAS features on safety within the general population. Our findings reveal important initial insights about the potential of ADAS to positively reduce injury severity and crash outcomes, as well as gaps in data and the need for additional research. We found indications of improved safety outcomes associated with the presence of three ADAS features: LDW, FCW, and BSD, which provides additional evidence of the potential for ADAS to improve safety [23]. This is a promising finding for technology that has been widely touted as critical to improving safety.

At the same time, our analysis uncovered multiple limitations associated with the CISS dataset regarding the ability to dig deeper into the effects of ADAS features on vehicle occupant safety, and these limitations were even more substantive for non-occupants (e.g., pedestrians and bicyclists) involved in these crashes. Where safety improvements are more mixed in our findings, for example, it is unclear whether this is a limitation of the technology and drivers' use of it [24] or limitations of the data itself. Both need further study, particularly as these technologies proliferate rapidly in the vehicle fleet. The CISS database is relatively new and provides an excellent opportunity for detailed and nuanced investigations into the complex factors in transportation safety. The current limitations, however, prevent this investigation process from fulfilling its full potential in aiding safety professionals. As data increasingly become available, we urge fellow scholars and practitioners to build on our work and deepen our understanding of the effects of ADAS features on transportation safety.

Key Finding #1 – ADAS Equipment Appears to Have a Slightly Protective Effect, with Caveats

We found that the presence of ADAS equipment appeared to be associated with a lower likelihood of a vehicle being involved in a fatal crash compared to non-ADAS-equipped vehicles of a similar age. Additionally, occupants of ADAS-equipped vehicles may have experienced slightly lower rates of death and serious injury in comparison to occupants of similarly aged vehicles without ADAS. Both of these findings suggest a possible protective effect of ADAS. However, these results may be confounded by other vehicle characteristics, such as body style, size, and other premium features. For example, SUVs in the CISS sample were more likely to have ADAS features than sedans and other vehicles, but SUVs also tend to weigh more, protect their own occupants better, and cause greater harm to other occupants and people outside the vehicle (pedestrians and bicyclists), in addition to making it harder for other drivers to see around them, than sedans.

We attempted to control for confounding due to body type by examining injury severity by vehicle age and presence of ADAS within each body type category, and found evidence of a significant association between the presence of ADAS and lower injury severity in crashes involving only autos. However, small sample sizes for SUVs and light trucks prohibited robust additional exploration for those categories. Thus, despite the promise of these results, it was difficult or impossible to disentangle the injury severity-related outcomes we observed from the effects of vehicle body style and size in the current sample. More research in this area and changes to the CISS process itself are critically needed to better tease out the true effects of ADAS on safety outcomes.

Key Finding #2 – ADAS Equipment Appears to Mitigate Speed Differential

While there was no discernible difference in crash severity outcomes for vehicle occupants between ADAS-equipped vehicles and similarly aged non-ADAS-equipped vehicles, ADAS-equipped vehicles did appear to have a lower ΔV at the time of the crash, which suggests that the ADAS features may be directly or indirectly linked to reducing speeds in advance of a crash (e.g., through AEB). This finding is promising given the correlation between ΔV and injury severity [18]. However, larger sample sizes and further analysis are necessary to try to isolate the effects of ADAS and fully understand causal pathways through which ADAS may affect both ΔV and ultimately safety outcomes in a crash.

Key Finding #3 – ADAS Equipment Appears to Be Correlated with Crash Type

Crashes involving an ADAS-equipped vehicle appeared to be less likely to be head-on collisions or rear-end crashes than crashes involving a similarly-aged vehicle without ADAS. In contrast, when an ADAS-equipped vehicle was involved in a crash, it was more likely to be an angle crash. Within these crash types, ADAS-involved angle crashes appeared to have lower chances of resulting in death or serious injury than angle crashes with non-ADAS vehicles. While these findings may again be related to other patterns observed in the CISS data (e.g., greater ADAS prevalence among SUVs), they also indicate some potential in terms of improved safety outcomes and need to be further studied in a larger sample.

Key Finding #4 – More Robust Data is Urgently Needed to Better Detect the Effect of ADAS on Vehicle Safety Outcomes in the General Population

Despite the promising findings listed above, there is an urgent need for a larger, more robust dataset to address limitations in this study. First, a much larger sample size is needed to examine the association of ADAS features—individually and as a group—and control for model year, vehicle body type, and crash type, among many additional associations that could be studied. As stated earlier, the correlation between injury severity and both car age and body type make it essential to have a large enough sample size to perform within-category and more advanced multivariate analyses of ADAS features and other vehicle characteristics. The larger sample size would also provide a buffer for mis-coded records such as non-fatal crashes that are separately coded as fatalities (i.e., inconsistent coding between separate but related variables).

Second, there is a need for more holistic, consistent, and accurate coding of ADAS attributes. In this analysis, we focused on a binary indicator of whether a vehicle had one or more of the following types of systems: BSD, FCW with or without AEB, and LDW with or without lane keeping assistance. The database includes fields to indicate whether the technologies were not only available but equipped or activated at the time of the crash, but the definitions and coding criteria for these statuses are unclear, and the high prevalence of missing values makes the variables hard to analyze. Information about additional ADAS types would also be useful additions to the database, such as data about the presence of 360-degree cameras or other vision support tools.

Key Finding #5 – More Robust Data is Urgently Needed to Better Detect the Effect of ADAS on Pedestrian and Bicyclist Safety Outcomes in the General Population

In addition to findings related to single- and multi-vehicle crashes, there is no way in the current dataset to study the effects of ADAS features on crashes with roadway users outside of vehicles, despite significant and increasing disparities between driver safety and pedestrian and bicyclist safety outcomes and a national commitment to improve those outcomes [25]. CISS data does not include information about people outside the vehicle (e.g., pedestrians or bicyclists). Post-crash investigations that include this data would provide critical evidence to complement recent research on the role of ADAS in improving non-occupant safety by increasing overtaking distance and time to collision [17]. While the data does indicate if a vehicle strikes a pedestrian, in the same way it indicates if the vehicle strikes a telephone pole, the data cannot inform us whether the pedestrian was killed or injured. This, along with other sampling choices that result in limited numbers of pedestrian and bicyclist crashes in the dataset, is a clear limitation of the CISS sample, particularly as manufacturers increasingly advertise vehicles equipped with ADAS features including pedestrian AEB. Increased sample size, inclusion of pedestrian and bicyclist collisions even when no vehicle must be towed, and greater detail about non-occupants involved in a crash would improve the dataset and our understanding.

Key Finding #6 – A Better Understanding of ADAS Prevalence within the Fleet is Necessary to Contextualize Safety Findings

The results of this study suggest promise for the effect of ADAS features on vehicle occupant safety outcomes, but an understanding of the extent of these effects is limited by a lack of publicly available data regarding the prevalence and type of ADAS features in vehicles in use today. Data on vehicle fleet distribution would also help us understand whether ADAS-equipped vehicles are underrepresented in samples like CISS, and whether that could be attributable to ADAS preventing crashes from occurring (in addition to or instead of ADAS reducing crash severity).

We also critically need data on the actual use of ADAS features among those vehicles that technically have the features. A vehicle on which the ADAS features have been disabled has no more safety potential than a vehicle lacking those features. Extrapolation from any analysis on sample data to the more general population requires access to this data.

Current Status and Opportunities for Inclusion of ADAS in Police Crash Data Collection

Our study contributes to understanding ADAS crash data collection and optimal techniques for handling and validating crash reports data, making it a key resource for practitioners and scholars interested in using police-reported crash databases to assess the safety outcomes of ADAS features. We also aimed to answer whether and how ADAS information should be collected by crash reports, and provide recommendations and guidelines for enhancing crash reporting processes and future revisions of the MMUCC.

A consistent and trustworthy data source for ADAS and traffic accidents is vital for assessing ADAS's safety outcomes, leading to better ADAS development and management. Unfortunately, no existing data sources can serve this purpose. In the MMUCC 6th edition, NHTSA has reduced content about ADAS and Automated Driving to reduce the workload of police officers. By emphasizing the ability to link the MMUCC data with state-level data, NHTSA now relies on state-level agencies to collect detailed information on ADAS- and AV-involved collisions.

Police crash report data could help address this shortage of empirical data on ADAS and transportation crashes for three key reasons. First, police crash reports employ a standardized approach to data collection that is less sensitive to employee turnover, contributing to more reliable data over time [26]. Past studies have highlighted the importance of consistent terminology and compliance with standardized data collection in cross-state transportation safety trend analysis [27]. When analyzing complicated systems such as ADAS, the inconsistencies of ADAS naming [2] pose a challenge to combining ADAS crash data collected by different entities if the data collection does not follow a consistent protocol. Police crash report data is informed by the MMUCC guidance to some degree. Although MMUCC is a voluntary document without any legal power, it is well prepared and commonly followed, leading to greater consistency in data collection.

Second, previous studies suggest that crash data obtained from police reports is more reliable and accurate than that obtained from self-reported crashes [28] or medical records [29]. It also provides comprehensive information on the location, injury severity, vehicle models, and demographic details of drivers and victims. Police reports also include unstructured data such as descriptions of crashes and diagrams of crash scenes [30], the greater details of which can be used to provide important insights into ADAS design and real-world effects. Police crash reports can also be linked with other data sources, including emergency records and medical treatment data, to provide additional layers of information [31] and greater detail of the long-term health implications of people involved in vehicle collisions.

Conclusion

This research project took an exploratory and wide-ranging look at current topics that are largely absent from the literature related to crash avoidance and driver assistance technologies: marketing, selling, and post-crash analysis of ADAS. This work revealed both concerning gaps and promising opportunities for better understanding, deploying, and regulating these technologies. Both consumers and safety professionals need to move quickly to keep up with the rapid proliferation of these technologies, which exposes the need for better data collection and potentially their greater oversight and regulation. Given the evidence that at least some of these technologies can provide safety-critical benefits, ensuring they are widely available in the passenger fleet and properly used requires understanding how they get into the hands of consumers and how and whether they "work." This research aimed to illuminate some of these issues and points the way toward multiple promising avenues for future research into these topics.

Additional Products

Project site:

https://safed.vtti.vt.edu/projects/critical-areas-in-advanced-driver-assistance-systems-safety-point-of-sale-and-crash-reporting/

Education and Workforce Development Products

The project's education and workforce development plan focused on undergraduate and graduate students and law enforcement instructors. The undergraduate and graduate students were an integral part of the research team and benefited from direct mentoring and participation in the research process. Dr. Goddard oversaw two to three undergraduates through the DeBakey Executive Research Leadership Program (https://aggieresearch.tamu.edu/debakey/). This provided a unique opportunity to engage undergraduates in high-level research and introduce them to research design, data analysis, and project management that they typically would not otherwise have a chance to be a central part of during their studies. The undergraduates received scholarships for their participation in the project.

The project employed four graduate students over the course of the project. All students participated in project management meetings, were involved in all steps of the research, and had opportunities for co-authorship and presentations. The graduate students gained valuable experience in integrating quantitative and qualitative methods, which expands on any methods they learned in courses. This provided perspective on the rich opportunities that mixed methods provide to understand complex transportation topics. The undergraduate students benefited from working with the graduate students and gained experience in all aspects of the research experience, in addition to exposure to transportation topics they might not have had access to in their undergraduate program. The opportunity to work together as students from different departments (i.e., engineering and planning) provided excellent interdisciplinary experience aligned with the values of the University and the UTC program.

Technology Transfer Products

Published articles:

Goddard, T., McDonald, A.D., Wei, R.* & Batra, D.* (2022)."Advanced Driver Assistance Systems in Top-Selling Vehicles in the United States: Cost, Vehicle Type, and Trim Level Disparities." *Transport Findings*. https://doi.org/10.32866/001c.38291.

Schoner, J., Sanders, R., & Goddard, T. “Effects of Advanced Driver Assistance Systems on Impact Velocity and Injury Severity - An Exploration of Data from the Crash Investigation Sampling System.” *Transportation Research Record*. (Accepted)

In-preparation articles:

Goddard, T., Sanders, R, Brasseaux, K.*, & Sun, Q.* “Buying and selling safety: Review of pre-purchase factors in Advanced Driver Assistance Systems.”

Goddard, T. & Sun, Q.* “The role of police crash reporting in determining safety implications of vehicle technologies.”

Graphical briefs:

https://safed.vtti.vt.edu/projects/critical-areas-in-advanced-driver-assistance-systems-safety-point-of-sale-and-crash-reporting/

While there is expanding focus on consumers and users of ADAS (i.e., drivers), there are few resources focused on point of sale or law enforcement industries and agencies. Thus, the team identified several important areas for technology transfer. Local, regional, and state law enforcement agencies will benefit from improved data collection and training related to ADAS. Regulatory and advisory agencies may benefit from better understanding how automotive OEMs and other car dealerships market and provide information to consumers about ADAS. The academic community will benefit from filling in some of the gaps in the knowledgebase about ADAS, and improvements to data collection for future research.

The potential market for the project outcomes includes regulatory and advisory agencies like NHTSA and the National Transportation Safety Board, as well as state governments in all 50 states. The findings from this study can be used to compete for additional funding from State Departments of Transportation, automotive companies, or the National Science Foundation. We did not generate any intellectual property during this project; however, we believe that the products generated can contribute to improving knowledge and thus reducing loss of life due to ADAS-related crashes.

An important expected audience for this project is government agencies like NHTSA that are wrestling with the rapidly changing landscape of ADAS. The project developed policy and regulatory recommendations aimed at both point of sale and crash data collection, including for the MMUCC and the CISS, which will be disseminated through webinars, press releases, conference presentations, and direct outreach to staff at the appropriate agencies, and will be included on the project site.

The primary academic contributions include: a review of the ADAS literature focused on point of sale and law enforcement, especially focused on the last 6 years, and four articles/conference proceedings focused on sub-tasks of the project. In addition, the team plans to publish at least one journalism-style article (e.g., *The Conversation*) related to the project, aimed at a more general audience, including consumers. For law enforcement stakeholders, the team plans to present at the 2023 Texas Traffic Safety Conference and the 49th Annual Traffic Safety Records Forum. Regulatory and policy recommendations for sales and marketing and MMUCC and crash reporting tools will be included in the final report and disseminated through stand-alone graphical briefs.

Data Products

Goddard, Tara; Sanders, Rebecca; Schoner, Jessica, 2023, "Critical Areas in Advanced Driver Assistance Systems Safety: Point of Sale and Crash Reporting (06-003)", https://doi.org/10.15787/VTT1/HEU2CL

This dataset was developed for an exploratory analysis of ADAS features and safety outcomes. The dataset is built on NHTSA's CISS database. Related tables from CISS were retrieved and imported. Variables describing crash injury severity, vehicle style, and ADAS features were derived from across the related CISS tables and stored at the crash level or vehicle level. This dataset includes reproductions of the crash and vehicle tables from 2017, 2018, 2019, and 2020 CISS, harmonized for consistency across years. Columns have been added to both the crash and vehicle table, representing the result of further calculations across multiple tables from the CISS dataset.

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