January 2024

CPSC Staff[1] Statement on SEA, Ltd. Report "Review of Automotive Safety Technologies Applicable to All-Terrain Vehicles (ATVs)"

The SEA, Ltd. (SEA) report titled "Review of Automotive Safety Technologies Applicable to All-Terrain Vehicles (ATVs)" presents the results of a literature search of collision mitigation automotive safety technologies and other safety technologies. SEA staff reviewed each safety technology for its potential applicability and adaptability to ATVs. This work was conducted for CPSC under Task Order 61320623F1010 of CPSC contract 61320618D0003.

The literature search for this report fulfills one of two objectives for Task Order 61320623F1010 of CPSC contract 61320618D0003. A test report for the other objective of this task order (enhanced ATV electronic stability control testing) will be separate from this report.

This report will assist CPSC staff as they continue to work to improve standards associated with ATV safety, including working with the Specialty Vehicle Association of America (SVIA) and other interested parties.

[1] This statement was prepared by the CPSC staff and the attached report was prepared by SEA staff. The statement and report have not been reviewed or approved by, and may not represent the views of, the Commission.

Review of Automotive Safety Technologies Applicable to All-Terrain Vehicles (ATVs)

for:
Consumer Product Safety Commission

December 2023

Vehicle Dynamics Division
7001 Buffalo Parkway
Columbus, Ohio 43229

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"These comments are those of SEA, Ltd. staff, and they have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission."

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1. OVERVIEW

This report is a literature review conducted by SEA, Ltd. (SEA) for the Consumer Product Safety Commission (CPSC) under CPSC contract 61320618D0003, a contract that covers general testing and evaluation of All-Terrain Vehicles (ATVs). This review was conducted during FY23, and completing it is one of the objectives under FY23 Task Order 61320623F1010.

The FY22 task order under this contract involved designing, constructing, and testing a rudimentary Electronic Stability Control (ESC) system on ATVs equipped with Anti-lock Braking System (ABS) capabilities to evaluate its effectiveness in improving ATV stability and reduce the likelihood of rollover. The report describing this work is titled *Development of Proof-of-Concept (POC) Electronic Stability Control (ESC) System for ATV Stability*.[1]

The first objective in the FY23 task order is to refine the ESC system that was developed in FY22 by enabling real-time algorithms to switch off ESC intervention once instability conditions subside. Then, based on the system refinement and testing, develop potential ESC performance and test requirements. The results from this first objective will be covered in a subsequent report to CPSC[2].

The second objective in the FY23 task order is to conduct a literature search of available automotive safety technologies that can be applicable to ATVs such as object detection systems to reduce likelihood of collisions. This report to CPSC contains the findings of this second objective.

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[1] *Development of Proof-of-Concept (POC) Electronic Stability Control (ESC) System for ATV Stability,* CPSC Contract 61320618D0003, SEA, Ltd. Report to CPSC, October 2022. **https://www.cpsc.gov/s3fs-public/SEAReportDevelopmentofProofofConceptPOCElectronicStabilityControlSystemforATVs.pdf?VersionId=bHw7fPfLsjO0HugwRDzpyDCsABLa6ZZe**

[2] *Development of Enhanced Proof-of-Concept (POC) Electronic Stability Control (ESC) System for ATV Stability,* CPSC Contract 61320618D0003, SEA, Ltd. Report to CPSC, Under Review December 2023.

2. INTRODUCTION

An All-Terrain Vehicle (ATV) is an off-highway vehicle with the distinctive characteristics of straddle seating and tiller steering. These vehicles are used for recreational activities, transport across off-road stretches of land, and so on. Due to their layout and use, safety features such as seatbelts and doors are not applicable to ATVs. ATVs make up about three-quarters of fatalities related to off highway vehicles, and while some safety features are not applicable or feasible, there is a significant opportunity to protect lives. If some of the technologies developed for conventional automobiles were deployed on ATVs, including collision avoidance systems, those crash modes common to both ATVs and automobiles could be mitigated. Automotive safety technologies are growing more mature, and both aftermarket and OEM systems have direct applicability and potential to save lives and prevent accidents on ATVs. By providing background on ATV accidents, automotive safety technologies, and current use cases, this document will highlight the ways in which safety systems could be implemented on ATVs.

3. ATV ACCIDENTS, FATALITIES, AND INJURIES

In CPSC's 2021 Off-Highway Vehicle (OHV) report, key data points regarding injuries and fatalities related to OHVs which include ATVs, Utility-Terrain Vehicles (UTV), and Recreational Off-Highway Vehicles (ROV) are presented.[3]

Of the 2,211 deaths reported during the 2016-2018 reporting time period, about 72% involved an ATV. These fatalities were distributed across varying age groups. Emergency-room requiring injuries were also heavily weighted towards ATVs among the group of OHVs considered. Of the 112,300 injuries over a five-year period (2016-2020), ATVs were listed as the vehicle involved in 96% of cases.

At 37%, collisions with vehicles or stationary objects such as trees was observed to be a common fatality hazard for ATVs.

- 61% of these collisions were with a stationary object, which could include trees, guard rails, and mailboxes.
- Over 30% of the collisions were related to striking other vehicles.
- Only a small portion (4%) involved striking animals or pedestrians.

The use of an Automatic Emergency Braking (AEB) or detection system to identify and respond to imminent collisions with trees and vehicles is discussed in subsequent sections.

Another common fatality hazard with ATVs was found to be overturns. While the ATV involved in fatal accidents was reported to have overturned in 65% of cases, the overturning may, in many of these cases, have been preceded by another event such as a collision. CPSC staff determined that the overturning event was the primary factor in 38% of the fatal ATV cases. A separate research activity involving studying enhanced Electronic Stability Control (ESC) is underway, which could positively impact these overturn events.

The Consumer Federation of America (CFA) also collects data related to OHV fatalities gathered

[3] Topping, J. *2021 Report of Deaths and Injuries Involving Off-Highway Vehicles with More than Two Wheels,* Consumer Product Safety Commission, 2021, **OHV Report 2021 (cpsc.gov)**

from news reports. Their 2023 Monthly report (including data from January - May) details known data for ATV fatalities by different crash types and information.[4] In 2023, 73.8% of fatalities with ATVs happened on the roadway, and 66.3% involved only a single vehicle crash. Of the 64.2% of ATV single vehicle fatalities involving a rollover, 41.5% occurred on-road and 22.6% occurred off-road. In 38% of ATV single vehicle fatalities involving a rollover, the occupant was pinned or struck by the vehicle, whereas in 35.3% the occupant was not pinned or struck.

The Insurance Institute for Highway Safety (IIHS) also has performed an analysis of ATV accidents and crash modes based on data from the Fatality Analysis Reporting System (FARS) database, specific to accidents which occur on public roads.[5] Their analysis compared ATV accidents to motorcycle and passenger vehicles. In 2021, 68% of ATV riders were killed in single-vehicle accidents, compared to 38% of motorcyclists and 44% of passenger car occupants. Likewise, they identified the high rollover tendency of ATVs. Sixty-two percent of ATV single-vehicle crashes involved a rollover in 2021, compared to 40% of cars, 58% of SUVs, 55% of pickup trucks, and 68% of large trucks. The high Center of Gravity (CG) of SUVs, pickup trucks, and large trucks, similar to ATVs, likely played a role in the comparable rollover rates.

Based upon the data compiled regarding the different accident modes most common for ATVs, the trend for rollover and collision with stationary objects and other vehicles were determined to be of interest. The use of applicable automotive safety technologies to resolve or decrease the likelihood of these crash modes is of interest.

4. AUTOMOTIVE SAFETY TECHNOLOGIES

There are many safety technologies currently in use in the automotive on-highway space, which can be largely broken up into two types: warning systems and intervention systems (this language harmonized with SAE J3063).[6] A warning system provides some alert to the operator of the vehicle when there is a safety situation detected, which may include a visual, haptic, or audible warning. The driver is then expected to take action to avoid the danger. Examples of warning systems include blind spot detection systems (where typically a light in or near a mirror turns on to indicate the presence of a vehicle in the blind spot on either side of the vehicle), forward collision warning systems (where a warning is presented to the driver that a vehicle ahead is within some collision imminent envelope based on relative vehicle speed and distance), and rear cross-traffic alert systems (where a warning is presented to the driver that a vehicle or even pedestrian is crossing in the area behind their vehicle during a reversing maneuver). Since many of these warning systems have intervention counterparts, and because warning systems are unlikely to be able to catch an ATV operator's attention, these warning-only systems will not be discussed further.[7]

Intervention systems typically rely on the same or similar sensors as warning systems but will take action to avoid or mitigate the collision or danger. According to SAE J3063, intervention systems "directly influence vehicle motions/actions for only the time needed to avoid/mitigate a specific hazard in the driving environment, and without necessarily requiring action by the vehicle driver."

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[4] *2023 Monthly ATV Fatalities Report*, Consumer Federation of America, 2023, https://consumerfed.org/off-highway-vehicle-safety/

[5] *Fatality Facts 2021: Motorcycles and ATVs*, Insurance Institute for Highway Safety, 2023, https://www.iihs.org/topics/fatality-statistics/detail/motorcycles-and-atvs

[6] *SAE J3063, Active Safety Systems Terms & Definitions*, SAE International, November 2015.

[7] Warnings such as a haptic alert in the seat or handlebars, a sound, or a visual indicator are unlikely to work in an ATV due to the vibration, noise, and lack of display locations in this type of vehicle.

For instance, the intervention counterparts to the warning systems mentioned above are: blind spot avoidance systems (where a lane change will be prevented if a vehicle is in the blind spot), automatic emergency braking systems (where the vehicle will completely stop or slow to match the speed of a vehicle ahead within the collision imminent envelope), and rear cross-traffic emergency braking (where the vehicle brakes or kills engine if a vehicle or pedestrian is crossing in the area behind the car during reversing). Intervention systems are designed to respond even when the driver might not. By taking the driver out of the loop, the systems can provide an additional layer of safety.

Based on the previously discussed ATV accident modes, and since an ATV will encounter different driving situations than passenger vehicles, the types of intervention-based automotive safety technologies which are applicable will be detailed. Appendix A provides a list of the automotive safety technologies considered for this work. From this list, all warning-only systems were excluded for the reasons previously discussed. Additionally, all lane-detection, blind spot systems, rear-facing safety, and intersection/oncoming traffic systems were excluded for further review due to this accident mode being less common. Additionally, driver monitoring systems, backup cameras, and systems designed for congested traffic were excluded, as are seatbelt reminders and other systems not applicable due to vehicle architecture. Electronic Stability Control (ESC) and Antilock Braking Systems (ABS) have already been identified as systems of merit and are being studied in separate CPSC reports. The resulting list of forward collision avoidance systems (including vehicle, pedestrian, and braking support systems), automatically deploying airbags, and night vision systems were selected for review in this document. This review will include not only descriptions of the system operation and example architectures, but also information about types of sensors used, aftermarket and existing systems, and applicable effectiveness studies.

5. FORWARD COLLISION AVOIDANCE SYSTEMS

Forward Collision Avoidance (FCA) systems (Collision Avoidance Systems (CAS)) are designed to detect and respond to a collision imminent event in the forward direction of travel of the vehicle. Within the FCA umbrella, the system design and sensors used may vary based on the objects designed for – i.e. some systems may be designed to detect and avoid vehicle-on-vehicle collisions, while others may be designed for pedestrians, bicyclists, and other vulnerable road users. Forward collision avoidance systems can also take different forms or be derivatives of each other. For example, the same sensors and system can be used not only for Automatic Emergency Braking (AEB), but also for Dynamic Brake Support (DBS). AEB and DBS both involve a slower moving, decelerating, or stopped lead vehicle, but in the DBS case there is some insufficient braking input from the driver. The vehicle's FCA algorithm must determine that the braking force is insufficient to avoid the collision and act by applying the brakes harder – however, that same overall algorithm may be used if the brakes were not pressed by the driver at all. Similarly, an FCA system may match the speed of a slower moving lead vehicle, similar to an adaptive cruise control system and maintain some following distance before disengaging, meaning that the intervention-mode may be the same between two different systems, even though the algorithm and system itself is different.

To provide more context on the different types of FCA systems which are prevalent in automobiles and have some overlap in terms of functionality, Table 1 provides an overview of the intervention system types and actions.

Table 1: J3063 FCA Intervention System Types and Actions[8]	
Intervention System Type	**Intervention System Actions**
Dynamic Brake Support	If driver input braking force is insufficient to avoid a collision, automatically applies more braking force.
Brake Assist Systems	Boosts brake capacity beyond levels able to be input by the brake pedal when driver emergency braking is sensed.
Forward Vehicle Collision Mitigation Systems	Activates brakes automatically to reduce severity or avoid a collision between the vehicle and a vehicle ahead, when such a collision has been assessed to be likely.
Pedestrian Collision Mitigation Systems	Provides warning and automatic emergency braking to avoid or reduce the severity of pedestrian collisions.
Pre-Collision Throttle Management	If the system detects an object in front of the vehicle that is likely to be struck, reduces the available acceleration pedal capacity of the vehicle.

While all of these systems fall into the intervention category, the action that is taken when a collision is sensed is different depending on the inputs from the driver, the collision imminent object, and more.

The typical activation process is outlined in SAE 2015-01-1406 and illustrated in Figure 1, where there are three steps: Detection, Decision Strategy, and Intervention Strategy.[9] In the Detection step, sensors on board the vehicle collect data, which is fused into a data set, and passed to the Decision Strategy component. Here, the presence of a threat is determined and a decision regarding the Intervention Strategy is output. The Intervention Strategy may be a warning or autonomous intervention. The whole process is continuously being looped through, such that the decision strategy and intervention strategy may be updated based on feedback from sensors about the distance to an object ahead, the vehicle speed, the brake and throttle status, and more.

[8] *SAE J3063, Active Safety Systems Terms & Definitions*, SAE International, November 2015.
[9] Ljung Aust, M., et al., *Collision Avoidance Systems – Advancements and Efficiency*, SAE Technical Paper 2015-01-1406, 2015.

Figure 1: Activation Process for Intervention Systems[9]

5.1 Sensors

AEB systems used in today's automobiles use sensors such as radar, cameras (monocular or stereo), or lasers (such as LiDAR, Light Detection and Ranging) to detect an imminent collision. Each of these sensors, and variations within each category, have different fields of view, ranges, and other parameters which influence their ability to detect objects. Each automaker and model of car can have different sensors being used, and also different detection capabilities. For example, a 2020 Ford Explorer uses a camera as the primary sensor for the Pre-Collision Assist system, but also uses a radar sensor in vehicles which have been equipped with it.[10] If the vehicle has a radar, then the Brake Support and Active Braking functions are active up to the full speed of the vehicle, whereas without this additional sensor, the systems are only active up to 75 mph. The pedestrian component of the Pre-Collision Assist system is only active at speeds up to 50 mph.

Each sensor type (radar, lidar, camera, etc.) has different parameters and advantages. A camera, for example, can be used for traffic sign recognition, lane line detection, and detection of pedestrians and vehicles. Cameras have a limited range of vision and are susceptible to the effects of weather and sun-blinding. At night, they might have further limitations due to the reach of the vehicle headlights. As previously mentioned, AEB systems can use a camera as the primary detection means. Camera systems come in several varieties. Monocular cameras, with only one lens, are a common feature in many OEM and aftermarket ADAS systems. Stereo cameras, where two cameras are mounted some distance apart from each other, can be used as well to provide additional verification and information about distance.

Radar, which can range in detection distance up to 300 meters (depending on the designed range of the sensor), are used for many highway speed applications due to fast detection speeds. Radar is an acronym, RADAR, which means Radio Detection and Ranging, though it will be referred to as radar henceforth. Since radar is well suited for detecting metal objects, it is used for detecting other vehicles on the road in systems such as AEB, adaptive cruise control, blind spot detection, and rear crash alerts.[11]

[10] *2020 Ford Explorer Owner's Manual*, 2020, https://www.fordservicecontent.com/Ford_Content/vdirsnet/OwnerManual/Home/Content?variantid=6725&languageCode=en&countryCode=USA&Uid=G1977333&ProcUid=G2006521&userMarket=USA&div=f&vFilteringEnabled=False&buildtype=web

[11] Smith, G., *Types of ADAS Sensors in Use Today*, Dewesoft, 2021, https://dewesoft.com/blog/types-of-adas-sensors

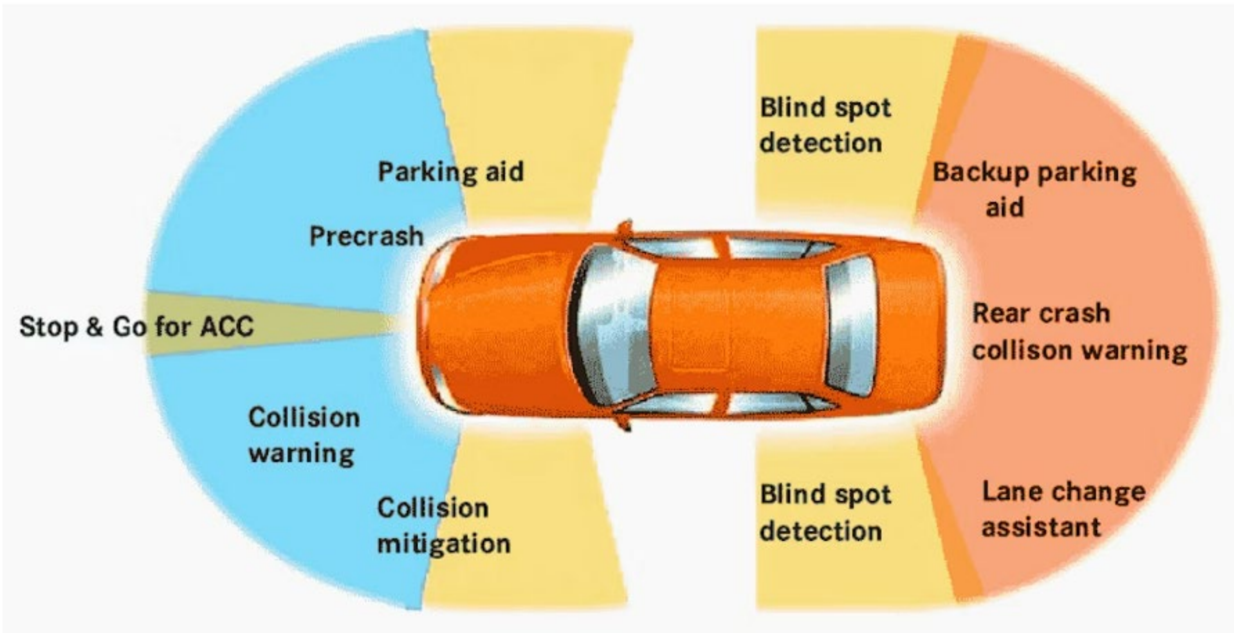

Figure 2: Radar Applications[12]

Like radar, LiDAR is another sensor which is in use on automated vehicles, though it has not yet become a commonplace sensor in a typical OEM Advanced Driver Assistance Systems (ADAS) suite. LiDAR uses lasers which are bounced off objects and the reflected beam's time of flight is used to measure distance.[12] LiDAR systems typically construct "point cloud" 3D-view of the environment. LiDAR sensors can be either built to be rotating or solid state. They are sensitive to weather interference, and smoke, fog, rain, and other atmospheric particles can influence response. Compared to camera systems, there is no light dependence on the system's ability to map and "see" the environment, but LiDAR cannot distinguish color to detect brake lights or distinguish road signs.

5.2 Effectiveness

Many studies have been performed to examine the effectiveness and accident reduction potential of AEB systems. IIHS found that Automatic Emergency Braking systems decreased front to rear crashes by 50% when comparing rates of police reported crashes and insurance claims on vehicles with and without these systems.[13] The number of front-to-rear crashes with injuries were also reduced by 56%. Similarly, AEB systems with pedestrian detection capability reduced pedestrian crashes by 27% and pedestrian injury crashes 30%. Similar studies have been performed at an OEM level. Toyota and Lexus vehicles were studied using police-reported crash data that found that AEB equipped vehicles were 43% less likely to be the striking vehicle in front-to-rear crashes, compared to Toyota and Lexus vehicles without these systems.[14]

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[12] Ibid.

[13] *Real-world benefits of crash avoidance technologies*, Insurance Institute for Highway Safety, 2022.

[14] Shannon-Spicer, R. and Vahabaghai, A., *Effectiveness of forward collision warning and auto emergency braking in reducing front-to-rear crashes in the U.S. market*, FAST-Zero 5th International Symposium, 2019.

5.3 ATV Forward Collision Avoidance Systems

At the time of this review, there are not any ATVs on the market which have incorporated AEB functionality. However, AEB systems have been designed and incorporated into offroad vehicles in other applications. One example of this is the S-E-A Vision Safety System.[15] The Vision Safety System is connected to the Automated Test Driver system, which combines steering and brake/throttle robotics to allow for unmanned maneuvers to be performed. S-E-A developed the Vision Safety System to provide an additional layer of safety functionality for ATVs travelling unmanned through closed test courses. If the system detects one of four objects (pedestrians, pickup trucks, ATVs, or ROVs) within a certain forward envelope, it will automatically abort the unmanned test and apply the brakes to stop the vehicle. Figure 3 depicts an image from the Vision Safety System user interface.

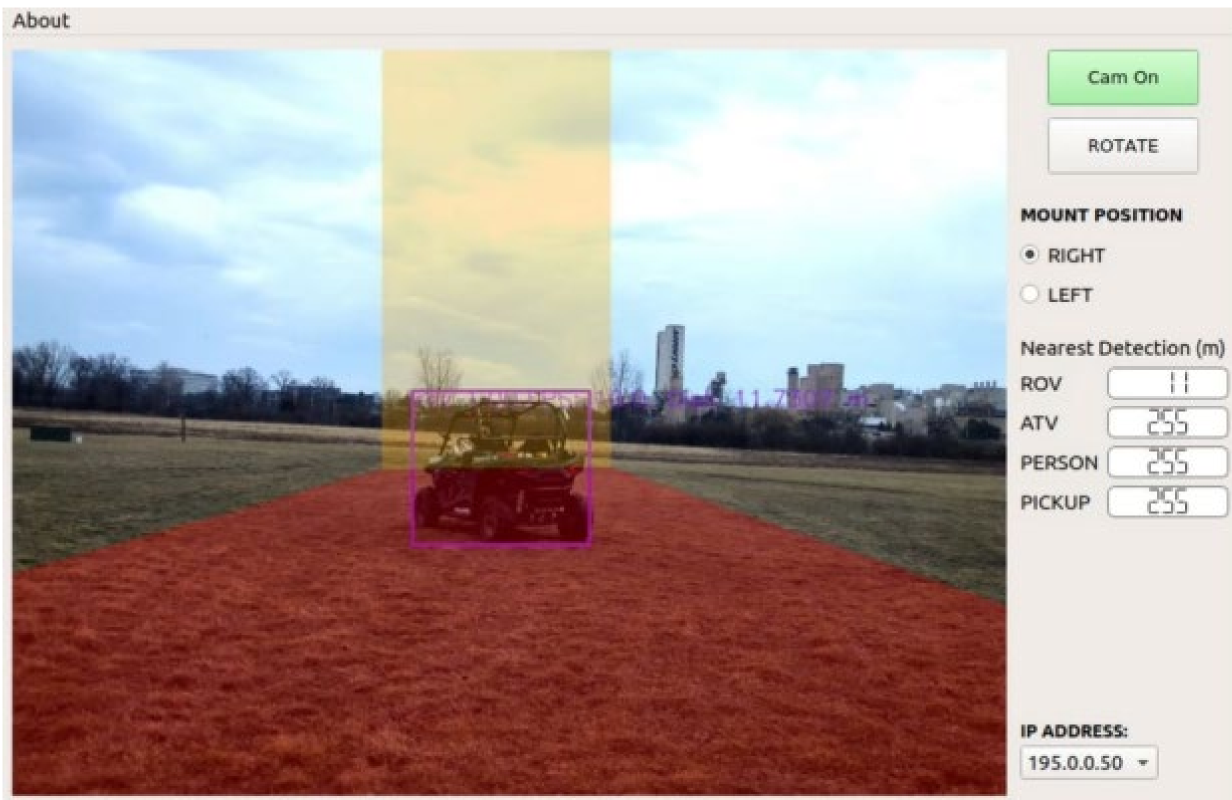

Figure 3: Detection of ROV in forward envelope[15]

The S-E-A Vision Safety System consists of monocular camera and onboard computer, shown in Figure 4, which has been trained using images and videos for the specific detectable objects. The Vision Safety System communicates to the Automated Test Driver via an ethernet interface, and a remote operator of the ATV or ROV can see a live video feed from the camera.

[15] *Vision Safety System*, S-E-A Limited, 2023, **https://sealimited.com/capability/vision-safety-systems/**

Figure 4: S-E-A's Vision Safety System mounted to ROV[16]

While this aftermarket system is being used with separate, non-OEM actuators, the conceptual system design and actuation could be used by an OEM to provide ATV riders with protective safety against the hazards of vehicles and trees ahead.

Another off-road specific study by researchers at Mississippi State University involved the use of LiDAR to map the terrain and forward path of off-road vehicles.[17] In their work, 8-beam and 16-beam LiDAR systems were used on simulated data generated from their automated vehicle simulator while performing off-road maneuvers. Using segmentation methods, the environment, trail, vegetation, trees, and obstacles were classified. Looking back at Figure 1 and the concepts of SAE 2015-01-1406, these are the first steps towards determining decision and intervention strategies for these off-road scenarios using LiDAR as the primary sensor.

5.4 Aftermarket Forward Collision Avoidance Systems

Due to the prevalence and growth of ADAS in the automotive market over the last decade, there are some aftermarket systems of merit which can be examined. Most ADAS systems available aftermarket are warning-only, which means that they would still rely on the driver to perform the braking in a collision-imminent scenario. Some examples of aftermarket warning only ADAS systems include the Mobileye, the ADAS ONE HM310 and AXON 3.2. These systems all share the common feature of a monocular camera which can act upon situations in its field of view.

Likely due to liability and interface integration concerns, there are many examples of warning-only ADAS systems (as listed above) with many published works documenting their performance but only one intervention-based aftermarket AEB system of note. If an intervention-based system were available as an aftermarket option on vehicles, the issue of appropriately applying the brakes and interfacing with the OEM hardware without causing override conflicts would likely be an

[16] Ibid.
[17] Dabiru, L, et al., *LiDAR Data Segmentation in Off-Road Environment Using Convolutional Neural Networks (CNN)*, SAE International Journal of Advances & Current Practices in Mobility, SAE 2020-01-0696, 2020.

issue.

An interesting example of an aftermarket AEB system is the ADAS ONE HX515, which combines a forward-looking monocular camera and a radar unit, along with an ECU and an actuator to provide automatic braking capability. [18] The use of an external actuator, shown in Figure 5, driven by its own small motor and attached to the vehicle brake pedal, makes this system independent of the vehicle's braking system. This system has not been evaluated as part of this review, and no additional documentation is available for the system to understand its implementation and efficacy.

Figure 5: ADAS ONE HX515 aftermarket AEB actuator[18]

6. AUTOMATICALLY DEPLOYING AIRBAGS

ATV rider safety opportunities with roots in the automotive industry are not limited to ADAS systems. Automatically deploying airbags are a feature mandatory (in the front airbag case) since 1999 and are estimated to reduce driver fatalities in frontal crashes by 29%.[19] There are many other types of airbags, both conventional and newly introduced, which provide specific protections to occupants both inside and outside automobiles. For example, side curtain airbags provide protection for the head and chest of an occupant during a side impact collision and can additionally protect from ejection during rollover events. Concept airbags which cover the external sides of a vehicle and provide additional protection during side collisions have also been proposed by companies such as ZF.[19]

[18] *HX-515 World First AEB System for After-Market,* ADASONE, 2023, http://eng.adasone.com/products/hx515/#

[19] *Airbags*, IIHS, 2023, https://www.iihs.org/topics/airbags#:~:text=Front%20airbags%20have%20been%20required,meet%20federal%20side%20protection%20requirements.

Figure 6: Side airbags (left) and external airbags (right)[20]

Airbag technology has been around for more than 30 years. The configuration of sensors which detect crash forces, rollover, or other events is determined by the design and scope of the airbag's protective system, but the core architecture remains consistent. A sensor or series of sensors feeds data to an airbag ECU which, when conditions are met, triggers an actuator which rapidly fills the airbag with gas.

6.1 Sensors

Airbags rely on different sensors and control algorithms to deploy correctly, and these sensors are driven by the application and crash modes. For automotive frontal airbags, sensors such as acceleration or impact sensors communicate to the airbag system ECU (called the Supplemental Restraint System, or SRS) to determine deployment timing. The SRS controls airbag deployment as well as seatbelt restraints.[21] It uses information from both the crash specific sensors, such as pressure sensors to detect crush, and other sensors such as IMUs, which detect vehicle yaw rate, to deploy systems. A joint NHTSA and NASA report document, "Advanced Airbag Technology Assessment," details the state of the art in 1998 – crash sensors consisted of "all-mechanical switches, and/or electronic inertial sensors… [with a] recent trend towards single-point or multipoint electronic sensing." [22] Following this, the next generation of designs mostly used ECU and satellite electronic accelerometers to detect crashes. In some side impact systems, pressure sensors were also employed to detect crush. Current technology primarily relies on electronic chip-mounted accelerometers for both ECUs and the satellite sensors involved for detecting both front and side impacts, with rollovers typically requiring different sensors located near the vehicle CG. For example, the latest 12th generation Bosch airbag control unit has capacity to analyze data reported from 18 different external acceleration and pressure sensors, while also controlling the reactions of up to 48 different restraint points.[23]

Other sensors might also contribute information to the ECU about things such as wheel speeds,

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[20] Ibid.

[21] *Pressure Sensors for Side Crash Detection*, Infineon, 2023, https://www.infineon.com/cms/en/product/sensor/pressure-sensors/pressure-sensor-for-side-crash-detection-sab/

[22] Phen, R.L., et al, *Advanced Air Bag Technology Assessment – Final Report*, Jet Propulsion Laboratory, April 1998.

[23] Simon, B., *The history of airbag control units,* Bosch, 2023, https://www.bosch.com/stories/history-of-airbag-control-units/

brake pressure, seatbelt use, seat position and seat occupancy.[24] When the ECU determines that airbag deployment is necessary, a hot gas is formed and released to rapidly inflate the bag.[25] The hot gas can be carbon dioxide from a cylinder, or can be nitrogen gas, which is created by igniting sodium azide (NaN_3) and potassium nitrate (KNO_3). The inflation time of an airbag is typically less than 0.05 sec, and deployment speeds can be at up to 200 mph.[24]

Since not all crashes happen at the same speed or in the same configuration, some airbag systems have several different inflators for the same bag which allows for variable deployment speeds. For example, variables such as the level of crash, seating position within the vehicle, weight of the passenger, and whether a seatbelt is worn might all be used as inputs to determine inflator speed. Per FMVSS 208, vehicle airbags must also detect a child seated in the front passenger seat, which is typically performed via a weight sensor and some defined thresholds for average weight of a 13-year-old.[24]

The length of time which the bag stays inflated is determined by the application. For example, a side airbag might be designed to protect the occupants from ejection during many rollover rotations of the vehicle, so it may stay inflated for longer than some other airbags.

6.2 Effectiveness

Despite trouble with recalls related to unintentional or faulty deployment issues over the years, airbags have saved many lives. NHTSA estimates that from 1987 to 2017, frontal airbags saved 50,457 lives.[25] While only frontal airbags are currently mandated, OEMs in the automotive industry have leveraged the relatively simple design principle with airbags in other areas of the vehicle, such as hood airbags which are designed to protect a struck-pedestrian's head from the hard components on the vehicle.[26] Overall, automotive airbags are designed to work best with seat belts, and NHTSA estimates combining airbags with three-point belts reduces the risk of death in frontal crashes by 61%.[25,26]

6.3 ATV Airbags

While airbags are standard equipment on automobiles, which also have other safety considerations such as seatbelts and crumple zones, they have yet to make it onto ATVs. However, another vehicle with tiller steer and straddle seating, the motorcycle, provides airbags on a very limited basis. Honda is the only manufacturer to offer airbags on their motorcycles, and they are only offered on the Gold Wing model. They were introduced in 2005, first offered in 2006 and are still offered on 2023 models today.[27] Honda performed crash data analysis and found that most motorcycle accidents which resulted in injury occurred during forward collisions, whether with obstacles or automobiles, as shown Figure 7.

[24] *Airbag Deployment Systems,* Clemson University Vehicular Electronics Laboratory, n.d., **https://cecas.clemson.edu/cvel/auto/systems/airbag_deployment.html**

[25] *Airbags*, National Highway Traffic Safety Administration, 2023, **https://www.nhtsa.gov/equipment/air-bags**

[26] *Airbags*, IIHS, 2023, **https://www.iihs.org/topics/airbags#:~:text=Front%20airbags%20have%20been%20required,meet%20federal%20side%20protection%20requirements**.

[27] *Motorcycles Technology*, Honda Motor Company, 2023, **https://global.honda/innovation/technology/motorcycle/Airbag-picturebook.html**

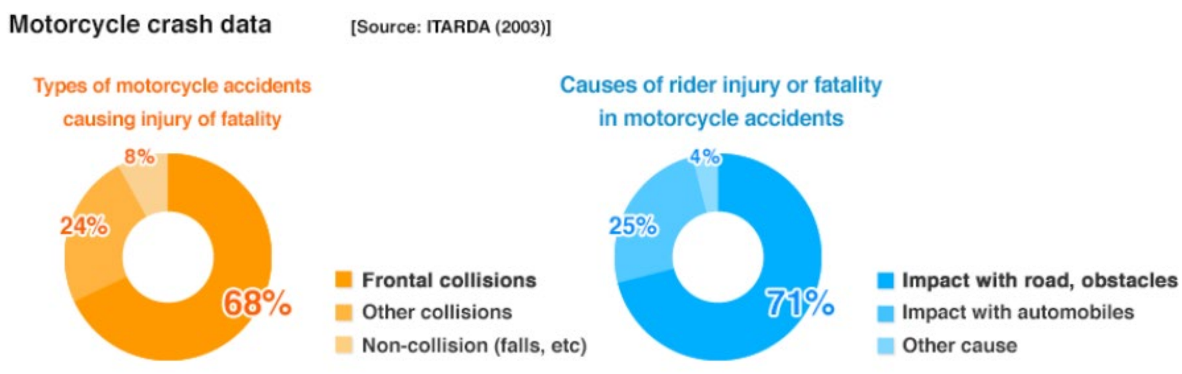

Figure 7: Crash Data Analysis[28]

Since forward collisions were determined to be an area of opportunity for rider protection, Honda's airbag system, shown in Figure 8, is focused on providing protection for this crash mode. Tethers keep the airbag secured to the motorcycle frame, since there is not a rigid surface ahead of the rider.[28] Honda has stated that the airbag will only deploy when a severe frontal collision with forces above a preset value are detected, such that it will not deploy if struck from behind or during a fall. However, a deployment risk is a large shock to the front tire, such as falling into a deep pothole or ditch, or a collision with the curb. Sensors on the bike will detect an impact at 0.015 sec, deploy the airbag at 0.06 sec, and the airbag will stay inflated through the 0.15 sec interval, at which point the crash timeline has been met.

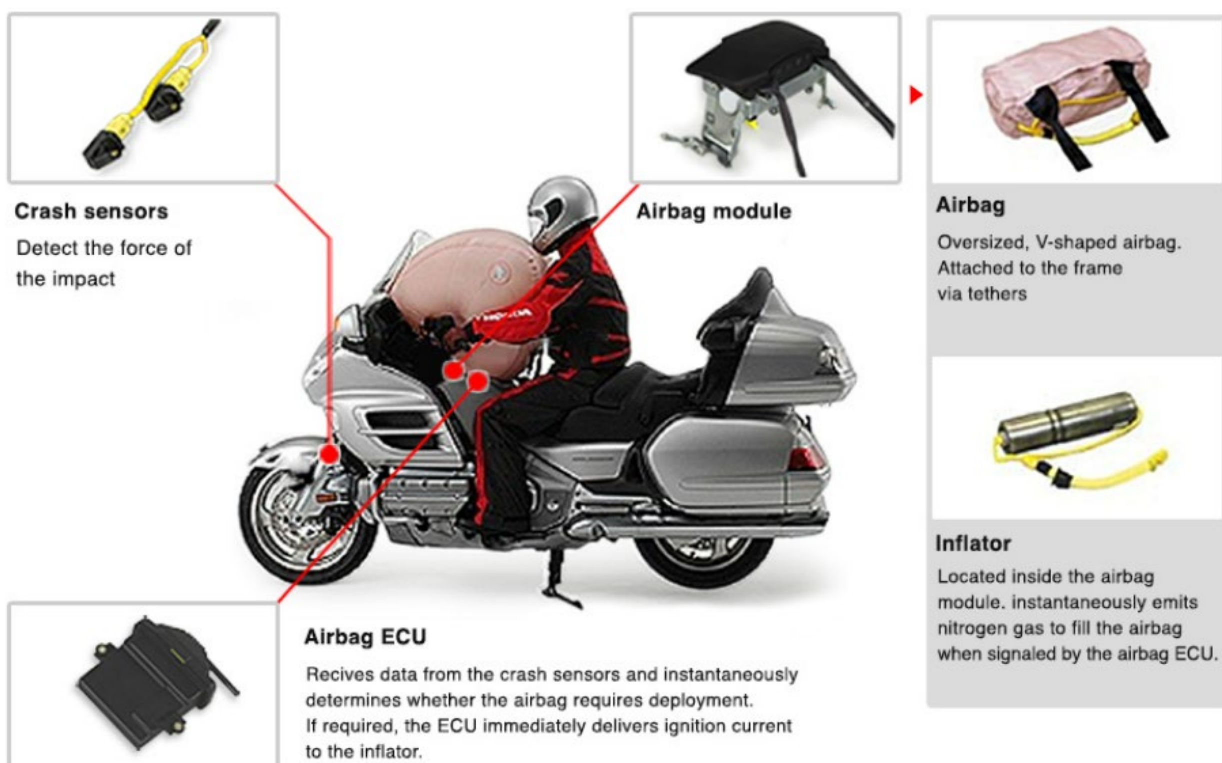

Figure 8: Honda Gold Wing Airbag Components[28]

[28] Ibid.

In the area of occupant crush/asphyxiation protection, there are opportunities for ATVs to add airbags for survival space creation. While Occupant Protection Devices (OPDs) have been studied for their risk/benefit analysis by many studies, none of these involved the use of an airbag device to create survival space.[29,30] A common misgiving about OPDs is the inability of the rider to jump off the back of the ATV. An airbag based OPD could mitigate this complaint and deploy only when onboard sensors indicate a need based on vehicle rollover or impact.

One concern voiced by a paper titled "Factors and Status of Motorcycle Airbag Feasibility Research" listed concerns with the interaction between a partially inflated airbag and a helmeted, forward leaning rider.[31] The partially inflated airbag could catch between the chin and the rider's chest and continue to inflate, creating large forces on the neck. A cited study by Ramet in 1994 with four forward-leaning, helmeted cadavers resulted in neck fractures or dislocations in each cadaver tested. This is something to be considered by OEMs and regulators when designing systems for use with helmeted drivers.

6.4 Aftermarket Airbags

A large market for wearable airbags has come about in the last several years. These backpack or vest-based systems provide those riders of motorcycles or ATVs the option to add personal protection on systems that do not come equipped with this technology. Because the rider wears these systems while onboard the motorcycle, ATV, or bicycle, they could be considered an aftermarket airbag. The primary function of the airbag vests/jackets is the immobilization of the spine and neck during a fall or crash, which reduces the danger to the spinal cord.[32]

Some examples of this technology include airbag vests actuated with a tether, airbag vests actuated via sensors inside the vest itself, and backpack style airbags. For tether actuated airbags, a coiled wire lanyard or some other device links the rider to their bike. If the rider becomes separated from the bike, a pin is pulled and the airbag is actuated via a CO2 cylinder located in the vest. This idea and concept has been around since the 1970s, but did not become popular until the 1990s with the HIT-AIR system.[32]

Non-tethered versions are also becoming more popular. By taking the tether connection out of the loop, in some cases where the rider became separated from the bike but at a low enough speed as to not pose danger, the airbag vest/jacket will not deploy. These systems involve sensors such as GPS, accelerometers, gyroscopes and microprocessors to determine whether an accident occurred.[32] An example of this is the In&motion, a unit which can be plugged into several different standalone airbag vests and jackets. It contains a microcontroller which determines whether some "unrecoverable imbalance" occurred and actuates the inflator accordingly within 60 msec.[33] What

[29] Zellner, J., Kebschull, S., and Van Auken, R., *Evaluation of Injury Risks and Benefits of a Crush Protection Device (CPD) for All-Terrain Vehicles (ATVs)*, SAE International Journal of Passenger Cars – Electronic and Electrical Systems, SAE 2013-32-9173, 2013.

[30] Heydinger, G., et al, *Rollover Tests of ATVs Outfitted with Occupant Protection Devices (OPDs)*, SEA report to CPSC, **https://www.cpsc.gov/s3fs-public/SEA-Report-to-CPSC-ATVs-OPDs-final-redacted_0.pdf**

[31] Rogers, N., and Zellner, J., *Factors and Status of Motorcycle Airbag Feasibility Research*, Paper 01-S9-O-207, **https://smarter-usa.org/wp-content/uploads/2017/12/22.-2001-June-Factors-and-Status-of-Motorcycle-Airbag-Feasibility-Research-.pdf**

[32] *Global Motorcycle Airbag Market 2021-2026,* Mobility Foresights, 2023, **https://mobilityforesights.com/product/motorcycle-airbag-market/**

[33] Milbank, J., *In&motion airbag review | Safety vest system tested*, Bennets, **https://www.bennetts.co.uk/bikesocial/reviews/products/motorcycle-armour-and-base-layers/inemotion-airbag-vest-review-safety**

makes this unit unique is that data from riders is cloud-shared back to the company such that the algorithm is continuously improving with real world data. At this point, there are over 65 million miles and 6,000 crashes worth of data collected by the system.[34] EVOC has also developed a bicyclist backpack with an auto-deploying airbag. The bag, called the Commute Air Pro 18, has a chest strap which activates sensors when buckled. These sensors monitor the position and orientation of the rider at 1000 Hz and will automatically deploy if any change indicates a fall. The airbag is deployed via a CO_2 cannister within 200 msec, and cushions the neck, shoulders, collarbone, and chest for 5 sec before deflating.[35]

Helite is another manufacturer of worn airbags tailored to motorcycle use. An image of one model of a Helite wearable airbag is shown in Figure 9 in its inflated state. The airbag has inflated to reduce the amount of rearward tilt available in the head and stabilize the neck.

Figure 9: Helite Airbag Vest[36]

The model shown in Figure 10, from Highmark, is specifically geared towards snowmobile riders and has a different design altogether. It is designed to create survival space for breathing during an avalanche.[37] A similar design could be used to create survival space under an overturned ATV.

[34] Ibid.
[35] Coxworth, B., *EVOC cycling backpack features an auto-deploying airbag*, New Atlas, September 8, 2021, **https://newatlas.com/bicycles/evoc-commute-air-pro-18-airbag-backpack/**
[36] Helite retailer website, **https://revco.ca/helite-e-gp-airbag-vest-black-white/**
[37] Highmark website, **https://highmarkairbags.com/pages/technology**

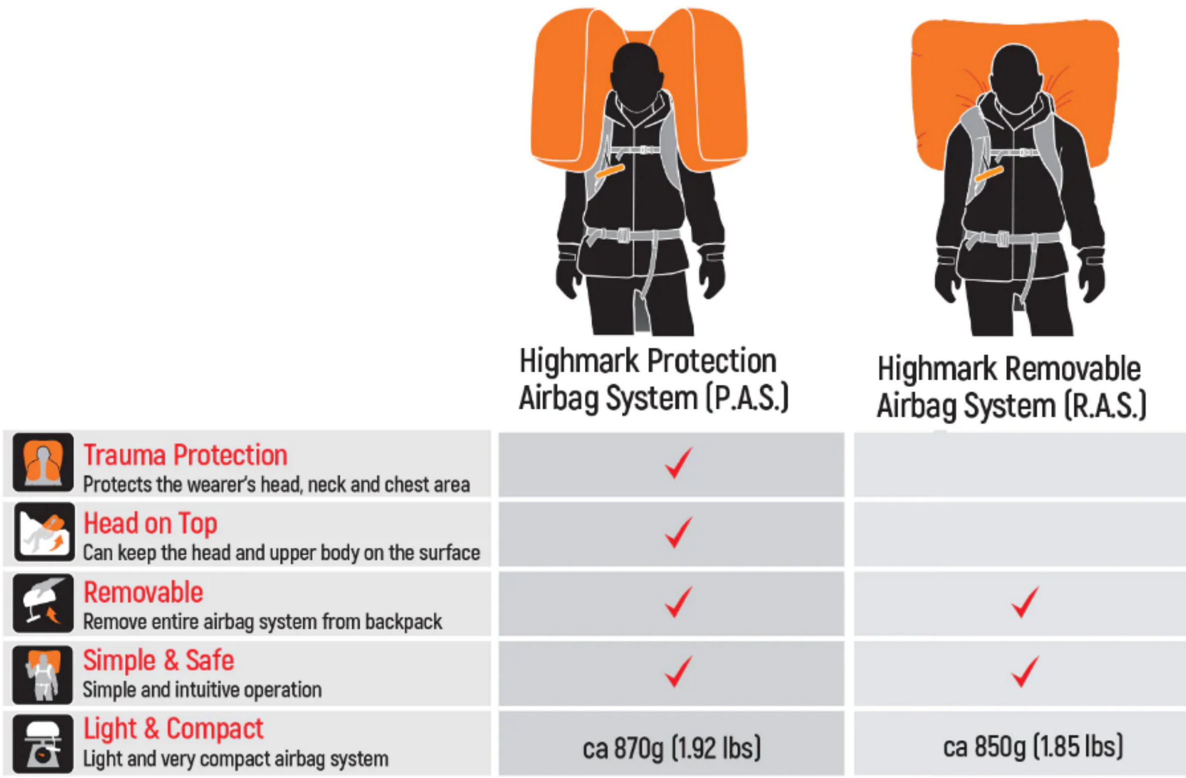

Figure 10: Highmark Airbag[38]

7. INFRARED/THERMAL DETECTION SYSTEMS

Infrared or thermal systems can be used to detect pedestrians, deer, and other animals near the vehicle. In warning only systems, the system may highlight the thermal source (with the driver display or headlights) and the longitudinal range of detection gives the driver time to respond. In intervention systems, the vehicle may automatically brake if a thermal signature associated with a pedestrian, deer, or other object enters the forward path of the vehicle. Infrared/thermal systems unlock opportunity to enhance collision avoidance systems during fog, beyond headlights, and through sun-glare, three shortcomings of traditional camera systems.

7.1 Sensors

Veoneer's thermal sensing systems are an interesting case study into the sensors and architecture of an automotive thermal system.[39] The sensor used by the system is an infrared video camera located on the front of the vehicle. The thermal image generated by the video camera has temperature difference granularity of 1/10th of a degree, and algorithms process this thermal data to classify objects. The range of detection is more than 100 meters ahead of the vehicle. Drivers are alerted to a detected object via an in-car display, which provides real-time video. Figure 11 shows a visual of both what the driver can see illuminated by the vehicle headlights (in the top half of the image), as well as a deer with a thermal signature both highlighted on the driver display and indicated by a deer-warning icon (right side of the display).

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[38] Ibid.

[39] *Thermal Sensing*, Veoneer, 2022, https://www.veoneer.com/en/thermal-sensing

Figure 11: Display highlighting detected object[40]

An additional option for the system is object spotlighting, which shines a light on the detected object so that the driver can keep their eyes on the road and away from vehicle displays. This is enabled by relatively new technologies such as adaptive headlighting systems where individual beams of light can be controlled by onboard systems. Figure 12 shows a thermal object being spotlighted by a beam of the headlight to draw driver attention to the potential collision.

[40] Ibid.

Figure 12: Spotlighting highlights the detected object[41]

Teledyne FLIR, another company in the thermal vision space, also has both thermal Automotive Development Kits (ADK), for use by OEMs and researchers to develop thermal detection and braking systems on vehicles, and their own aftermarket systems.[42] Free thermal training sets provide training material to train neural network systems thus decreasing the development time of detection algorithms. By developing in-house detection algorithms, OEMs can assign outputs for steering, braking, and highlighting via their own system hardware.

7.2 Effectiveness

Teledyne FLIR sponsored a study performed at the American Center for Mobility in which the detection and braking systems of four OEM vehicles were compared to a special research vehicle equipped with a fused thermal and vision system with a convolutional neural network (CNN).[43] In this study, the fused system was successful in 100% of tests at preventing injury in simulated maneuvers with a thermal soft pedestrian target. The soft pedestrian target used was a heated version of standardized pedestrian target mannequin used in EuroNCAP pedestrian braking system tests. The four vehicles which were used for comparison had varying combinations of camera and radar sensors in the OEM configurations. The five test scenarios performed included Daytime Oversized Clothing, Daytime Clothing Blending, Daytime Tunnel Dazzle, Child at Night, and Dark Clothing at Night. The results of this study are compiled in Figure 13.

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[41] Ibid.

[42] *PathFindIR II,* Teledyne FLIR, 2023, https://www.flir.com/products/pathfindir-ii/

[43] *Fused AEB with Thermal Can Save Lives,* FLIR, 2020, https://www.flir.com/globalassets/industrial/oem/adas/flir-thermal-aeb-white-paper---final-v1.pdf

Figure 13: FLIR Fused Thermal and Vision testing comparison[44]

It is noteworthy that in this same document, FLIR advocates that a thermal-only system is insufficient at capturing enough information for reliable AEB systems. The radar charts shown in Figure 14 illustrate the relative merits, as rated by FLIR, of thermal, camera, and radar sensors. As shown, while thermal systems can provide a high degree of fidelity in the areas of glare resistance, darkness operation, and sun blinding, they are weak in areas such as velocity and marking detection. On the other hand, radar and camera (RGB / Visible in Figure 14) sensors provide strong performance in these two areas respectively, though these both have weaknesses in other areas.

[44] Ibid.

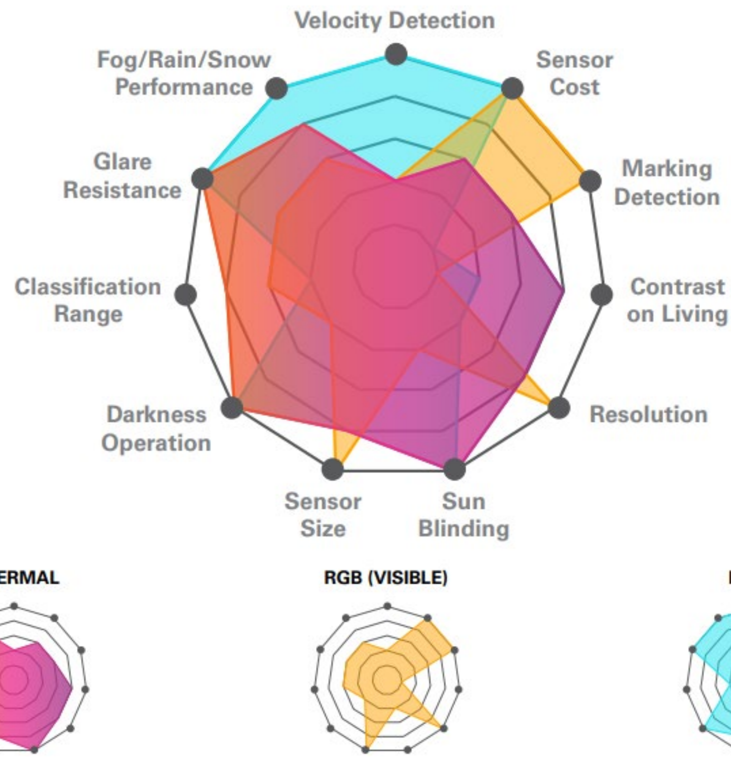

Figure 14: Camera, Thermal, and Vision system characteristics[45]

Since thermal-based braking systems have not yet entered the public domain, little additional information on effectiveness in implementation is available, especially for comparison with traditional AEB sensors.

7.3 ATV Thermal / Infrared Detection

Without a high rate of adoption of thermal detection and braking systems on automobiles, there is also a lack of information about ATV specific applications. ATVs commonly encounter forward objects such as vehicles, trees, pedestrians, and animals. By using additional thermal data, it is possible to segment the surroundings somewhat to better detect and avoid hazards in low light and low-visibility conditions. It is noted that of the three sources used for a review of ATV accident modes and outcomes, none provide data about the time of day during which the accident occurred.[46,47,48]

7.4 Aftermarket Thermal / Infrared Detection

The Teledyne FLIR PathFindIR II is a thermal night vision system with a range of about 600 meters and performance through dust, smoke, and fog.[49] There are configurations available for animal detection and pedestrian detection, with outputs visible on an available LCD monitor and at different sampling frequencies. An example of FLIR's pedestrian detection algorithm is shown

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[45] Ibid.
[46] Topping, J. *2021 Report of Deaths and Injuries Involving Off-Highway Vehicles with More than Two Wheels,* Consumer Product Safety Commission, 2021, **OHV Report 2021 (cpsc.gov)**
[47] *2023 Monthly ATV Fatalities Report*, Consumer Federation of America, 2023, **https://consumerfed.org/off-highway-vehicle-safety/**
[48] *Fatality Facts 2021: Motorcycles and ATVs*, Insurance Institute for Highway Safety, 2023, **https://www.iihs.org/topics/fatality-statistics/detail/motorcycles-and-atvs**
[49] *PathFindIR II,* Teledyne FLIR, 2023, **https://www.flir.com/products/pathfindir-ii/**

in Figure 15, where pedestrians have been bounded by yellow boxes.

Figure 15: Example pedestrian detection using PathFindIR II[50]

Another development kit, which could be integrated into an OEM or aftermarket system, is the Owl Autonomous Imaging 3D Thermal Ranger system. The 3D Thermal Ranger provides a monocular thermal camera with object classification, thermal fusion, and accurate distance measurements.[51] The system has outputs which can be integrated into braking algorithms to provide automatic braking capability. It is quoted to provide a significant improvement in resolution and cloud density when compared to LiDAR and has already been equipped with the capability to classify pedestrians, bicyclists, animals, and vehicles while also calculating their position, direction, and speed.

8. CONCLUSION

While the defining vehicle characteristics of tiller steering and straddle seating keep ATVs in a separate category from automobiles, the technologies which have been developed by the automotive sector still have applications to keep ATV riders safe. By examining the automotive safety technologies available in the crash avoidance, airbag, and night vision sub-categories, this overview provides information about the current state of the art in the automotive space. For each technology, the sensors used, effectiveness, and applications for ATVs are considered. Future work, both by CPSC and OEMs, can leverage the current technology of the automotive industry to more quickly bring safety solutions to ATV riders and the off-road vehicle industry.

[50] Ibid.
[51] *3D Thermal Ranger*, Owl AI, 2023, https://www.owlai.us/

APPENDIX: AUTOMOTIVE SAFETY TECHNOLOGIES OVERVIEW

Item #	Technology Title	High-level description
1	Electronic Stability Control	An active safety system which detects a loss of traction and automatically applies brakes to wheels individually and sometimes modulates engine output to help the driver regain control of the vehicle.
2	Antilock Braking System	A system which monitors the wheel speed of individual tires. If lockup (skidding) is detected, the system pumps the brakes automatically to prevent wheel lockup and allow for steering during stopping.
3	Lane Detection Warning	A passive camera/vision-based safety system which detects lane lines and alerts the driver (haptic, visual, or audible) when the vehicle deviates from the current lane.
4	Lane Keeping Assist	An active camera/vision-based safety system which detects lane lines and actively keeps the vehicle centered in the lane by providing small steering inputs.
5	Forward Collision Warning	A passive safety system which detects an impending forward collision (slower moving, stopped, or other obstacle in the forward path of the vehicle and likely to be struck at current rate of speed and closing distance) and alerts the driver (haptic, visual, sound). Detection method may be vision, radar, or lidar, or some combination.
6	Automatic Emergency Braking	An active safety system which detects an impending forward collision (slower moving, stopped, or other obstacle in the forward path of the vehicle and likely to be struck at current rate of speed and closing distance) which alerts the driver (haptic, visual, sound) as well as automatically applies the brakes to avoid or reduce the severity of the collision. Detection method may be vision, radar, lidar, or some combination.
7	Dynamic Brake Support	An active safety system similar to AEB which detects an impending forward collision and compensates for any insufficiencies in the driver-applied braking force. Detection modes are the same as AEB, with additional calculation of additional braking force required.
8	Pedestrian Collision Warning	A passive safety system which detects an impending forward collision with a pedestrian or bicyclist and alerts the driver (haptic, visual, audible). Detection could be vision, radar, lidar, or thermal-based.

9	Pedestrian Automatic Emergency Braking	An active safety system which detects an impending forward collision with a pedestrian or bicyclist and alerts the driver (haptic, visual, audible) as well as automatically applies the brakes to avoid or reduce the severity of the collision. Detection could be vision, radar, lidar, or thermal-based.
10	Seatbelt reminder	A passive safety system which alerts the driver (typically visually and audibly) that the seatbelt is not being worn by a vehicle occupant.
11	Tire pressure monitoring	A system which monitors tire pressure and alerts the driver to a low-pressure issue.
12	Automatically deploying airbags	A system in which airbags are automatically deployed following some trigger condition being met.
13	Rear Cross Traffic Alert	A passive safety system which alerts the driver (visual, audible, or haptic) to the presence of a vehicle or pedestrian whose path may intersect the path of their reversing vehicle.
14	Rear Cross Traffic Emergency Braking	An active safety system which alerts the driver (visual, audible, haptic) to the presence of a vehicle or pedestrian whose path does or may intersect the path of the reversing vehicle, and automatically stops the vehicle to avoid or reduce the severity of the collision.
15	Blind Spot Detection	A passive safety system which alerts the driver (visually) to the presence of a vehicle in the blind spot of their vehicle. Typically, indicators will be installed in the mirror or near the mirror on each side of the vehicle. Detection may be done with visual, radar, or even lidar sensors. Visual alerts alone are used to prevent nuisance sounds/vibrations during highway driving when these systems are in heavy use.
16	Blind Spot Assist	An active safety system which alerts the driver to the presence of a vehicle in the blind spot of their vehicle and will actively avoid a lane change or return to the lane if a lane change is initiated. Detection may be done with visual, radar, or lidar sensors.
17	Traffic Jam Assist	An active safety system designed for stop and go traffic in which the vehicle regulates speed and following distance in densely packed, slow-moving traffic. Typically uses visual, radar, or lidar sensors and works only under a certain speed threshold.

18	Intersection Safety Assist	An active safety system designed for the avoidance of turning or oncoming vehicles in intersections. Typically uses visual, radar, or lidar sensors and works only at low speeds. This is a developing safety technology which is not currently readily available on vehicles in the US.
19	Oncoming Traffic Assist	An active safety system designed for the avoidance of vehicles driving in an opposing lane by performing an action when: 1) Oncoming vehicle swerves into your lane 2) Your vehicle veers into oncoming traffic The system may respond by reducing speed (case 1) or steering the vehicle back into the lane (case 2). In Case 2, this is differentiated from LKA by looking for the presence of an oncoming vehicle before acting.
20	Adaptive Cruise Control	An active system designed to provide the benefits of cruise control while additionally performing speed matching of lead vehicles when relevant. The user sets a target speed, which is maintained when possible. When a slower moving vehicle ahead is detected, the vehicle slows to match speed, until such a time as the forward vehicle is no longer present. Then, the target speed is resumed.
21	Night Vision	A system which uses infrared or thermal systems to detect pedestrians, deer, and other animals near the vehicle. In detection only systems, the vehicle highlights the thermal source with the vehicle technology (on a driver display, or via headlights) and the horizontal range of detection is wide to allow time/distance for driver response. In active systems, the vehicle may automatically brake if the thermal source enters the forward path of the vehicle, and the width of the response zone is decreased compared to the detection-only system.
22	Driver Monitoring System	A safety system designed to monitor the vehicle's driver and provide feedback on: 1) Their level of attention to the road 2) Their alertness Many systems provide an audible and visual warning to the driver that they need to keep their attention on the road or will tell the driver that it may be time for a break. Most systems work via camera systems which perform analysis on the driver.

23	Backup Camera	A camera system installed in the rear of the vehicle which provides the driver an image of the area behind their vehicle. Many systems will trace lines based on the wheel position outlining the likely backup trajectory of the vehicle.
24	Automatic High Beams / Adaptive Headlights	An active safety system designed to direct the beam of the vehicle headlights such that: 1. Oncoming traffic is not blinded. Turns off specific lighting elements to only block out oncoming traffic blinding, while ensuring the best remaining visibility 2. Brights are used as needed. 3. When vehicle turns are performed, headlights pivot to follow forward path of vehicle