Optimizing Large Vehicles for Urban Environments

Advanced Driver Assistance Systems

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Notice

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Table of Contents

Introduction

Large vehicles move goods and services that support thriving, livable communities and urban centers. However, these vehicles are disproportionately responsible for fatalities on U.S. roads. Nationally, large trucks comprise 4% of the U.S. vehicle fleet,[1] yet are involved in 7% of pedestrian fatalities, 11% of bicyclist fatalities,[2] and 12% of car and light-truck occupant fatalities.[3] In 2017, 4,761 people were killed by trucks in the United States.[4] Troublingly, NHTSA's most recent analysis of traffic fatalities shows that, despite a slight decline in overall fatalities in 2017, fatalities involving large trucks increased 9% over 2016 numbers.[5]

When it comes to traffic fatalities, vehicle size matters. Large trucks typically have blind spots that are larger than those of the average car, making it harder for truck drivers to see people or objects directly next to or in front of them.[6] Decreased visibility can also cause drivers to react more slowly to impending collisions. The increased weight of large trucks also means that they stop more slowly than cars and, when they hit people, they do so with increased force. The relationship between vehicle size and increasing pedestrian and cyclist fatalities in the U.S. has also been documented beyond trucks. A recent Detroit Free Press report identified the increasing size of vehicles as the main factor in the U.S. rising fatality rate.[7]

Compounding the higher lethality risk inherent in large trucks, geometric street design choices are commonly constrained by the size and maneuverability of the largest vehicles on the road. The freight and delivery, municipal, construction, transit, and emergency response vehicles used in the U.S. often have wide turning radii and require significant space to maneuver and park. Designing streets around large vehicles increases the likelihood that drivers of smaller vehicles (cars and light-trucks) will travel at unsafe speeds. Although street redesign is widely recognized as a highly effective way to reduce traffic fatalities and injuries, the space needs of large vehicles often deter cities from implementing key safety treatments such as shorter crossing distances, reduced roadway widths and turn radii, pedestrian refuges at intersections, and physically protected lanes for pedestrians and bicyclists. Reducing the size, increasing driver visibility, and improving the maneuverability of large vehicles can give engineers the flexibility to make critical roadway safety improvements that can increase safety outcomes for everyone.

To address these safety challenges in the near-term, municipal and private fleet operators and policy makers can potentially reduce the number of fatalities involving large trucks by redesigning the vehicles themselves in ways that are more compatible with safe, vibrant city streets. Vehicle redesign is a near-term strategy that supports improved street design that can save lives. The spectrum of potential vehicle redesign ranges from minor retrofits that improve driver line-of-sight, to "downsizing," which means replacing aging fleets with newer, more maneuverable, and potentially more efficient vehicles. In addition, numerous technologies exist to improve a driver's ability to operate their vehicles safely, including in complex, multimodal, urban environments. As a significant percentage of trucks and buses in U.S. fleets are owned and operated by public agencies, vehicle redesign offers cities a unique opportunity to support Vision Zero efforts and increase safety on urban streets.

Key Findings

Advanced driver assistance systems (ADAS) refer to a variety of vehicle safety technologies that use onboard radar, camera, and other sensors to scan the vehicle's surroundings and either alert the driver or automatically intercede on the driver's behalf to prevent or mitigate a wide range of crash types.

- **Advanced Driver Assistance Systems (ADAS) on the market, which use cameras, radar, and other sensors, can reduce reaction times and mitigate crashes with other vehicles.** In the best case scenarios, automatic emergency braking (AEB) can reduce the stopping distance of a truck traveling at 25mph by almost half (60' vs 120') versus a driver relying on mirrors or other forms of indirect vision.
- **However, current forward collision warning (FCW) and automatic emergency braking (AEB) systems in large vehicles are limited in their ability to detect pedestrians and bicyclists on city streets.** While most systems can detect moving vehicles directly ahead in the current travel lane, only one can detect a moving person and none can currently reliably detect a stationary person. Low light and inclement weather worsens ADAS functionality. In addition, not all systems operate correctly at slower, urban speeds. There have been numerous reports of lane-assist systems encouraging overly-close passes of bicyclists by interfering with driver attempts to change lanes or partially change lanes to pass safely.
- **Coupling ADAS systems with driver training and education is essential to avoid over-reliance and worsened safety outcomes.** For example, initial research indicates that some drivers who become used to blind spot monitors may no longer check the side mirrors or look over their shoulders before turning, potentially leading to new crashes. Similarly, a Japanese study found that 64% of the general public believes, incorrectly, that AEB will stop a vehicle in all cases. The danger of this misconception was illustrated when journalists in a safety demonstration routinely hit a test dummy because they believed, perhaps implicitly, that the vehicle would stop on its own.
- **Forward Collision Warning (FCW) systems can be retrofit onto existing vehicles.** ADAS technologies range in cost from a few hundred to several thousand dollars. FWC is readily available aftermarket for large fleet vehicles.
- **ADAS can be linked with telematics systems to provide driver training tools and to identify "hot spots" where unsafe vehicle behaviors occur.** For driver training, telematics can help identify aggressive drivers for intervention and retraining while rewarding high-performing drivers for safe behaviors. For "hot spots," telematics data may be able to identify street design or contextual reasons for harsh braking, speeding, lane departure, or other unsafe maneuvers, which cities could address through roadway redesign projects.

Technology and Safer Streets

Automatic emergency braking (AEB), forward collision warning (FCW), and other advanced driver assistance systems (ADAS) technologies decrease the time it takes to see a person, apply the brakes, and come to a stop to avoid a crash. For example, AEB can reduce the stopping distance of a truck traveling at 25mph by almost half (60' vs 120') versus a driver relying on mirrors or other forms of indirect vision. The sooner a person is detected, the sooner the brakes can be applied, and the less likely the vehicle is to strike, injure or kill them. Critically, because larger vehicles have longer stopping distances, increasing the amount of time that the driver has to recognize and react to a conflict is key to reducing crashes and fatalities.

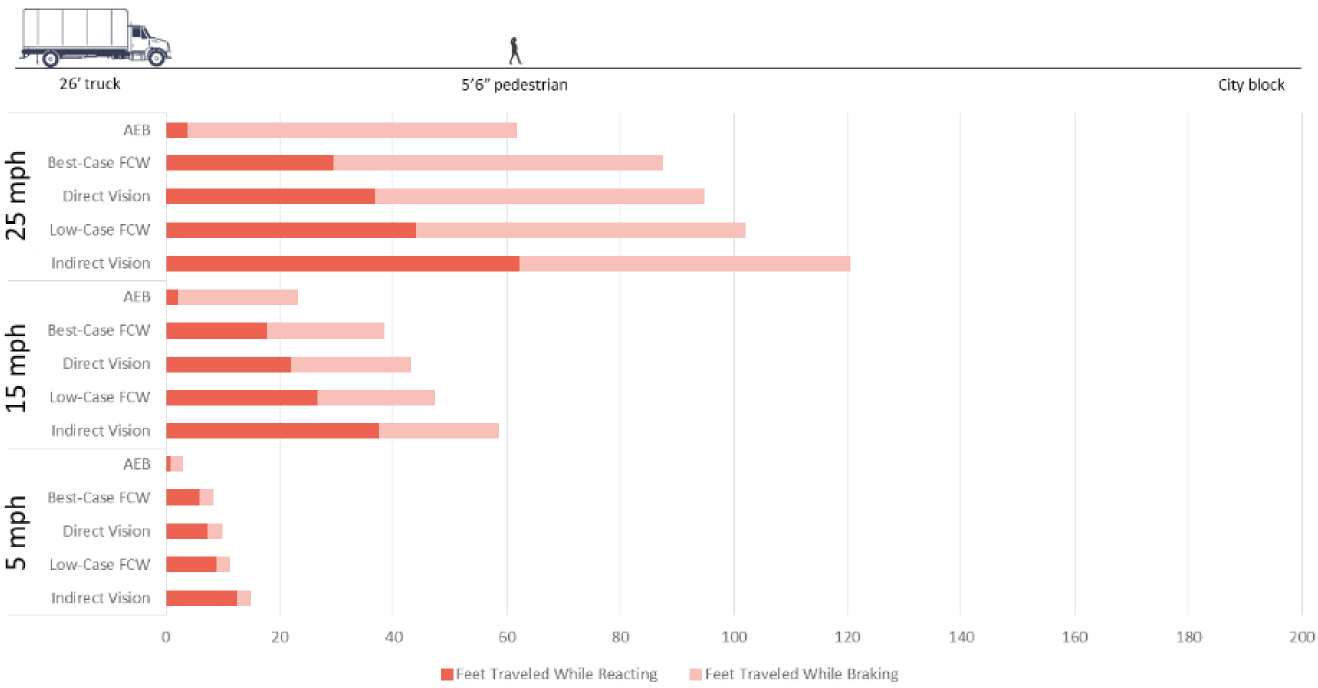

Figure 1: Response times and truck braking distances by speed and technology type. The objective at any speed is to move from the bottom bar (indirect vision) to the top three bars (direct vision, best-case Forward Collision Warning/FCW, and Automatic Emergency Braking/AEB) because the driver or vehicle will detect a person sooner.

The increased blind spot size in trucks and other large vehicles makes ADAS technology solutions attractive. For example, the blind spots of a "worst-in-class" conventional cab dump truck can hide the entire width of a crosswalk at an intersection. While most current intersection and bike facility designs account for passenger car blind spots, trucks' blind spots are typically larger and vary more extremely by make and model. By requiring or retrofitting in AEB, FCW, and other ADAS technologies, fleet managers can take a first step at reducing conflict, injury, and fatalities.

Blind spot sizes vary by truck model and pedestrian height

Figure 2: A vehicle with smaller blind spots better allows a median-height driver to see people in a bike box or a crosswalk, especially children. For the 50% of drivers who are below median height, the blind spots are actually larger than shown.

ADAS represents one of a trio of safety enhancement solutions. Cities and fleet managers can reduce truck blind spots by requiring ADAS or retrofitting fleets, and by downsizing fleet vehicles and improving truck direct vision. At the same time, holistic changes to streets can be implemented to increase separation and improve sightlines, e.g. advanced stop lines, protected intersections, and near-side traffic lights, that can reduce conflicts before they occur.

Today, while most ADAS systems can detect other vehicles, the technology is significantly less advanced when it comes to detecting pedestrians and cyclists. As a result, to reduce crashes and fatalities, ADAS technologies should be considered complementary and not substitutional. For example, FCW is relatively inexpensive, fast to implement, and in the best case may reduce stopping distance more than direct vision. However, direct vision, typically through vehicle downsizing, offers other opportunities by allowing the driver to establish eye contact and communicate, see and anticipate people to the left and right, and to do so reliably at night or in bad weather. Thus, cities and fleet operators looking to improve safety outcomes should peruse parallel tracks, retrofitting FCW into vehicles that are not scheduled for replacement or overhaul in the near future, while including other ADAS and downsizing requirements into procurement contracts for future vehicles.

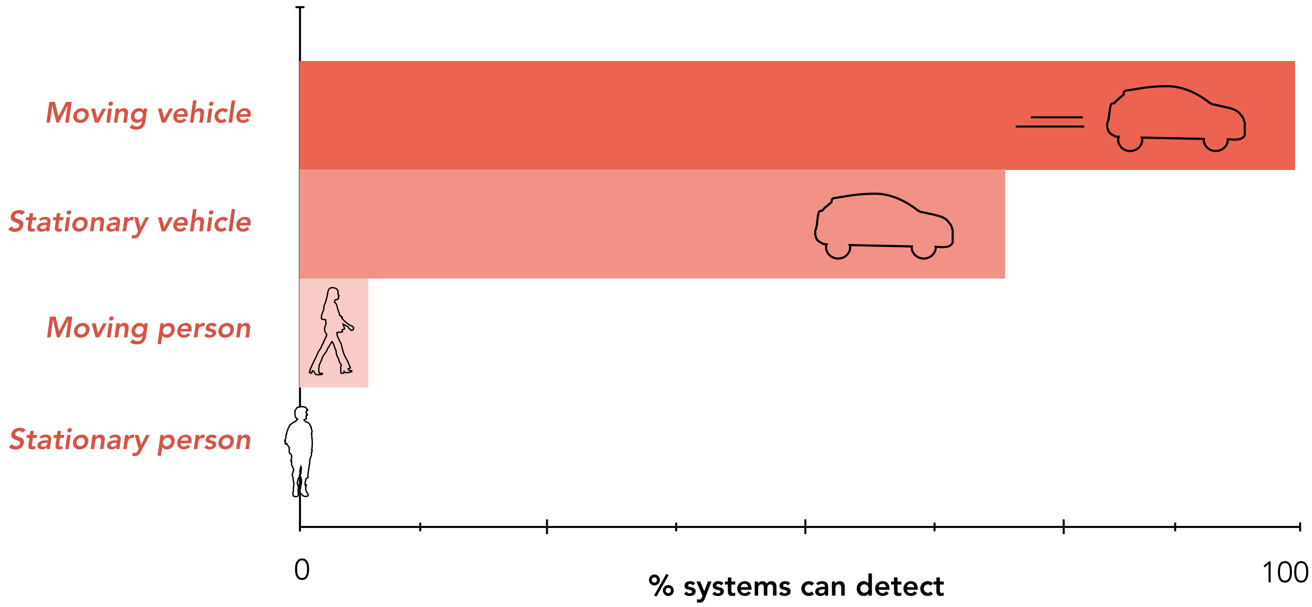

Figure 3: Large truck AEB systems cannot detect everything. Image adapted by NACTO.

As with vehicle downsizing, ADAS technologies are largely driven by customer demand, which in turn is largely driven by awareness, policy, and economics. Crucially, a significant percentage of trucks and buses in U.S. fleets are owned and operated by public agencies.[8] A critical mass of coordinating city fire departments, for instance, could likely influence the design of future fire apparatus offered in the U.S.[9] With city fleets leading implementation, additional vehicles such as garbage trucks, public works trucks, and transit vehicles could follow fire apparatus in incorporating downsizing and pedestrian-focused ADAS as part of fleet replacement and vendor procurement. As municipal fleets demonstrate demand, new opportunities might also present themselves for the private market. This dynamic presents cities with an opportunity to lead the implementation of safer large vehicle designs through retrofits and new purchases of certain vehicle-based safety technologies.

Advanced Driver Assistance Systems (ADAS)

Advanced driver assistance systems (ADAS) refer to a variety of vehicle safety technologies that use onboard radar, camera, and other sensors to scan the vehicle's surroundings and either alert the driver or automatically intercede on the driver's behalf to prevent or mitigate a wide range of crash types. It is this situational awareness and active feedback to the driver that distinguish ADAS from mirrors or backup cameras that require the driver to check and perceive the presence of a hazard.

A 2015 study by the Intelligent Transportation Society of America (ITS America) and the University of Michigan Transportation Research Institute (UMTRI) compares the market penetration of these systems on large truck fleets (i.e., fleets with over 300 vehicles) and shows moderate adoption of electronic stability control systems and early adoption of other ADAS systems. The report predicts that these systems will be more commonplace in the near future, with Forward Collision Warning or Mitigation systems reaching 40% market penetration by 2019.[9]

This section provides overview information about the benefits, limitations, and implementation considerations associated with ADAS generally and then provides deeper, best practice information for two ADAS technologies:

- **Forward Collision Warning (FCW)**
- **Automatic Emergency Braking (AEB)**

Best Practice

Forward Collision Warning (FCW) + Automatic Emergency Breaking (AEB)

Description
The system uses lidar, radar, and/or camera technology to identify collisonrisks. FCW warns the driver, and AEB applies the brakes if the driver doesn't react in time.

Retrofittable?
FCW: Yes
AEB: No

Timeline
FCW: 6-12 months
AEB: 1-3 years

Cost per Vehicle
FCW: $500-$1,000
AEB: $2,000-$3,000+

Key Procurement Considerations

Does the system detect pedestrians and cyclists?

Does the system operate at city driving speeds (0-30 mph)?

Does the system operate in low-light conditions and in inclement weather?

Drivers will need to be trained in the correct use of a) FCW to ensure effectiveness, and b) AEB to avoid unintentional activations.

Unintentional activations of AEB in buses at high speeds may be hazardous for standees.

What is ADAS?

ADAS technologies have a variety of names as a result of different manufacturer branding, but the most common components of truck-based ADAS on the market include:

- **Collision mitigation systems (CMS)** - employ several layers of technologies to reduce the chance of a rear-end collision. When the system's radar (and, in some cases, camera) detects a slower-moving or stationary object ahead, CMS will issue audible, visual, or haptic (touch) alerts—this initial stage is **forward collision warning (FCW)**. In more advanced systems, if the driver applies the brakes, but not hard enough, **dynamic brake support (DBS)** will increase the force above and beyond what the driver applies in order to avoid a collision. Additionally, if the driver fails to intervene, CMS will deploy **automatic emergency braking, or AEB,** applying brakes and de-throttling the engine.[68]

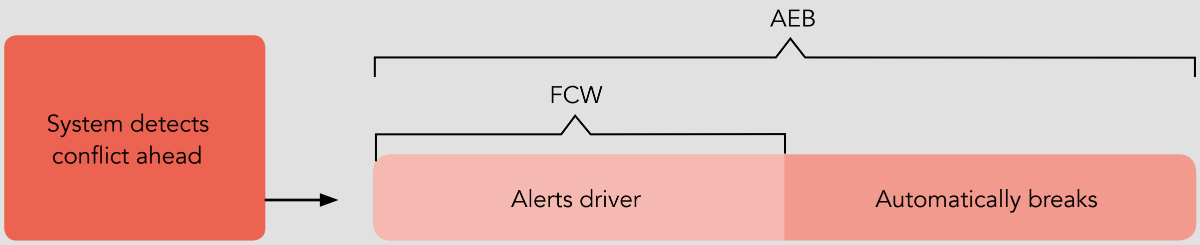

Figure 4: Relationship of FCW and AEB in avoiding crashes. (Adapted from NTSB)

- **Electronic stability control systems** - use sensors to monitor the vehicle's directional control. When the system senses loss of control, it automatically engages brakes and/or reduces engine throttle to help the driver regain control.
- **Lane departure warning systems** - use cameras to track the lane markings and road paint on either side of the vehicle. If the vehicle begins to leave its current lane and the driver hasn't applied the turn indicator, the system can provide audible, visual and/or haptic alerts to signal the driver to take corrective action.
- **Blind spot detection systems** - use sensors and cameras to alert drivers to the presence of objects like cars and people located outside the driver's field of view. Warnings can be audible, visual, or both, and newer models include optional intervention systems that provide resistance in the steering wheel if a driver attempts to change lanes while there is an obstacle in their blind spot.

ADAS Benefits & Challenges

This report identifies a number of benefits associated with ADAS. These include:

- The potential for significant decreases in crashes and pedestrian and cyclist fatalities
- Some ADAS technologies can be retrofitted into existing vehicles at affordable prices
- Opportunities to link ADAS to telematics data that can identify close calls as well as "hot spots" for conflict in the street network

At the same time, research suggests that additional considerations must be taken into account when adopting ADAS systems. In particular, these include:

- Limited or inconsistent ability of ADAS to detect pedestrians, cyclists, and other vulnerable road users
- Public perception and trust in ADAS may lead to over-reliance
- ADAS only works at peak effectiveness when combined with driver training
- Risk of ADAS leading to "close passes" and other unintended consequences
- Challenges with ADAS in transit vehicles that travel at high speeds

Benefits of ADAS

ADAS crash reduction potential for pedestrians and cyclists

The 2015 ITS America/UMTRI study[10] estimates the safety benefits of ADAS by comparing crash and crash cost reductions of large truck fleets that deployed various ADAS systems at between 9 and 20 percent (see Figure 2: Percent Reduction in Crashes and Associated Costs). Reduced crash costs can yield insurance cost savings for private fleets and operators, while self-insured municipal fleets such as the New York City fleet have the potential to reduce a crash cost budget that can exceed $100 million per year. A 2017 white paper series published by the AAA Foundation for Traffic Safety estimates that 170 fatal crashes could be avoided each year with lane departure warning systems and automatic emergency brakes deployed on all trucks nationally.[11] Notably, the scope of both studies was limited to truck-on-vehicle and single-vehicle crashes; their analyses did not consider the approximately 450 pedestrians and bicyclists killed annually in large truck crashes in the U.S.[12]

Existing studies demonstrate the potential of ADAS to reduce fatal pedestrian and cyclist crashes by up to 30 percent or more in some circumstances. A 2013 study by German Insurers Accident Research estimates the pedestrian and cyclist safety benefits of certain ADAS technologies based on an analysis of truck crashes.[13] The report estimates that 18.1 percent of truck-pedestrian fatalities in Germany could be prevented by full adoption of reverse assist cameras with automatic braking and that 31.4 percent of truck-pedestrian/cyclist fatalities could be prevented by full adoption of turning assistance systems.[14]

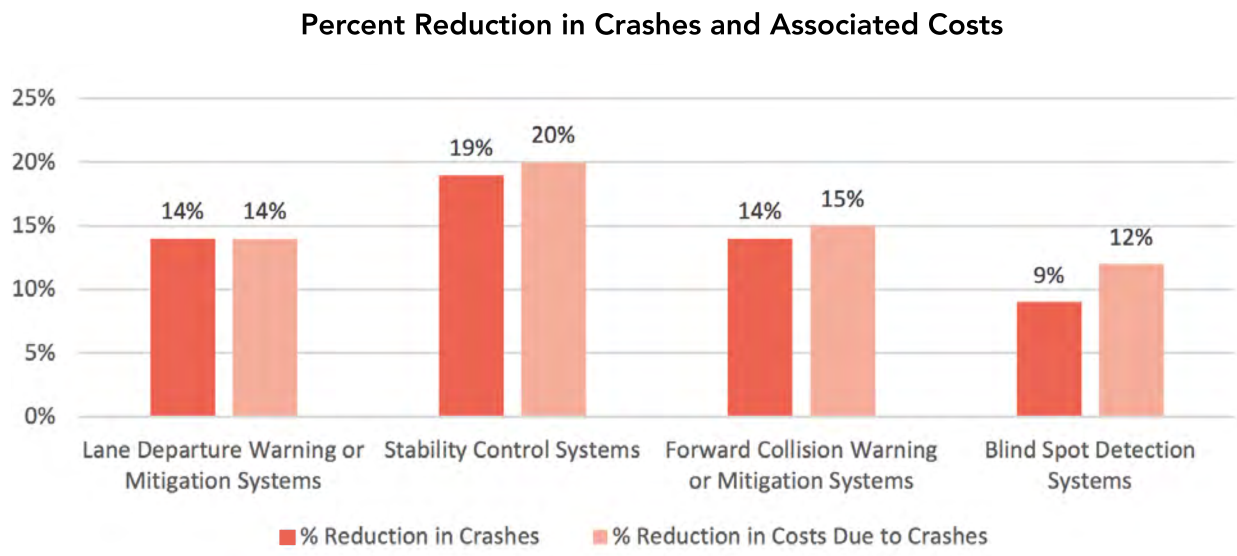

Figure 5: Crash benefits of ADAS systems on large truck fleets. Adapted from "Deploying Safety Technologies in Commercial Vehicles," by B. M. Belzowski and J. Herter, 2015, University of Michigan Transportation Research Institute.

Affordable retrofit potential

ADAS technologies are relatively low-cost (from several hundred to several thousand dollars), and human-in-the-loop systems can be installed aftermarket onto existing vehicles. Compared to large vehicles that can cost hundreds of thousands of dollars, these are relatively small expenditures and can in many cases be implemented more quickly without waiting for vehicles in a fleet to turn over. In general, AEB is not generally available as a retrofit solution. However, FCW technology is readily available aftermarket to retrofit existing large vehicles today.

Connections between ADAS and telematics

In general, ADAS can be linked to telematics systems that then support driver coaching and training based on actual risky behavior or near misses, for example due to incorrect use of the ADAS.[15] Fleet safety managers may then more completely monitor driver performance in real time and create scorecards based on events such as harsh braking or cornering, insufficient following distance, lane departure warnings, and speeding. Safety managers can target aggressive drivers for intervention and retraining while rewarding high-performing drivers for safe behaviors. A study by the Virginia Tech Transportation Institute estimated that trucks and buses equipped with the DriveCam Program could reduce an average of 727 fatal truck and bus crashes (20.5 percent of the total fatal crashes) and save 801 lives (20.0 percent of the total fatalities) each year.[16]

An additional benefit of ADAS linkages with telematics systems is its potential to identify "hot spots" where unsafe vehicle behaviors occur. There may be environmental reasons for harsh braking, speeding, lane departure, or other unsafe maneuvers, which cities could address through roadway redesign projects, if they had access to data identifying the locations of such activity.

Challenges & Considerations for ADAS

Limited or inconsistent ability to detect pedestrians, cyclists, and other vulnerable road users

The AEB and FCW systems currently available are not capable of detecting pedestrians in all scenarios. For example, the Toyota Camry owner's manual describes 23 situations in which AEB may not properly "see" people because it fails to recognize the silhouette or pattern they produce.[17] These include: people walking in groups, people pushing objects such as strollers, wheelchairs or bicycles, people standing on manhole covers or steel plates, people carrying things like umbrellas or luggage, and children and people shorter than 3.2 ft (1 meter). In general:

- Radar-based systems can typically detect repeating patterns such as the characteristic motion of a walking pedestrian or a pedaling bicyclist but they have a harder time detecting people who are not moving, people in groups, or people pushing or carrying objects.
- Vision based systems are better able to detect stationary people but are limited to daylight operation in well-lit environments. Drivers and the public at large are often overconfident about the ability of ADAS systems which may increase the likelihood of crashes, injuries, and fatalities as drivers assume the ADAS system can see people when it, in fact, cannot.
- No AEB systems in the U.S. appear to market themselves as explicitly capable of detecting cyclists. However, based on interviews, the Detroit Assurance 4.0 AEB's Moving Pedestrian Warning feature will also detect moving bicyclists and apply up to one-third of full braking power.

Risk of ADAS leading to close passes and other unintended consequences

While certain ADAS components offer projected benefits for pedestrian and bicyclist safety, others may present unintended consequences. For example, there have been reports[18] of lane-keeping assist systems encouraging close passes of bicyclists by interfering when a motorist attempts to change lanes to provide a safe passing distance.[19] Recently, the European Parliament adopted a resolution to make it compulsory in the European Union to "incorporate only those driver assistance systems that improve road safety significantly as demonstrated by scientific evidence," including "automatic emergency braking with detection of pedestrians, cyclists, light powered two-wheelers and motorcyclists in cars…buses, and [trucks]."[20]

Public perception and trust in ADAS may lead to over-reliance

The public's understanding of AEB functionality and limitations may exacerbate issues with effective implementation. A Japanese study revealed a wide range of beliefs among both drivers and non-drivers about whether automatic braking systems can detect pedestrians and bicycles. Notably, 64 percent of the people surveyed in the study believed that automatic braking systems completely stop a vehicle in all cases rather than only slow the vehicle, suggesting that the public may place too much trust in such safety systems and that driver education may be important to reduce complacency.

Illustrating this point, in one demonstration of the 2016 Toyota Prius pedestrian detection braking system, journalists consistently hit the pedestrian dummy despite the fact that the system was working as designed. The software engineers instructed the system to defer to driver input: sensors apply the brakes automatically, but if the driver then hits the brake, the driver's input overrules the computer's braking. Most of the journalists testing the system who hit the brake did so with less force than the automatic system was using to save the dummy.[21]

Complicating matters, driver response times can worsen when drivers become primed to expect a warning and the warning does not occur or occurs late. Human response time to a warning light or sound can be as low as 0.8 seconds in the best case scenario when a driver is primed to expect the warning. However, it can be as long as 1.2 seconds or even double the normal response time when the warning is late or when the hazard itself is not visible until the last few seconds. As a result, while well-implemented FCW systems can reduce driver response times, poorly-implemented ones can *increase* response times. Researchers report faster driver response times when drivers are alerted by multiple types of signals, such as an auditory/visual or auditory/haptic, instead of a single sensory cue. In contrast, an AEB system can have a virtually instantaneous response time to detected hazards.

ADAS only works at peak effectiveness when combined with driver training

There is considerable uncertainty about the real-world effectiveness of some driver aids. There are documented risks of complacent drivers placing too much trust in the systems and of situations where the brakes can unintentionally activate. As with any new technology, ADAS presents a potential for overreliance and complacency. For example, initial research indicates that some drivers who become used to blind spot monitors may no longer check the side mirrors or look over their shoulders before turning, potentially leading to new crashes.[22] Other research suggests that drivers can over-rely on pedestrian collision warning systems. Training and driver resources may be needed to ensure drivers maintain the same or better situational awareness when introducing ADAS to a fleet.

Training programs should also prepare drivers for unexpected events, such as unintentional activation of Automatic Emergency Braking systems (AEB). For example, as automobile manufacturers make clear, the brakes can be accidentally activated if the driver approaches pedestrians in a crosswalk too quickly. One training-based solution is to train drivers to brake sooner and farther in advance of the crosswalk whenever people are present. Training can be most effective when combined with road design changes. For example, jurisdictions can reinforce such training by adopting NACTO standards in the placement of advanced stop bars (set back at least 8 feet) at all crosswalks.[23]

Challenges with ADAS in transit vehicles that travel at high speeds

One concern for ADAS adoption on transit vehicles is its impact on unbelted, standing passengers. For urban buses and other slower-moving transit vehicles with standing, unbelted passengers, current research suggests that the benefits of AEB may outweigh potential drawbacks, although the application of AEB to city buses is still quite new:there are currently pilots on Pierce Transit,[24] while partial PAEB is being natively equipped in the first transit buses by Daimler in Europe.[25] There have not yet been studies evaluating the benefits of AEB on faster moving intercity buses and shuttles that operate on highways or with higher speeds, although multiple tour bus models now come with standard PAEB in Europe.[26] There may be some risk to these occupants in an AEB activation if they are unbelted. Driver training on appropriate stopping distances may help mitigate these issues.

Best Practice: Forward Collision Warning & Automatic Emergency Braking

Forward Collision Warning and Automatic Emergency Braking represent best practices in ADAS. Non-pedestrian AEB has become widely available on new trucks, and FCW is already universally available as a retrofit, while truck Pedestrian AEB (PAEB) availability is emerging but still limited by manufacturer. In the next couple of years, PAEB is expected to become available from more OEMs based on Volpe research and industry engagement, and the technology could save lives in urban, low-speed crashes.

While AEB and PAEB are human-out-of-the-loop systems, driver education will still be relevant for achieving maximum benefit. As for any technology, vehicle operators should learn how to place an appropriate level of trust in the system and be aware of its operational limits, thus avoiding potential problems associated with mode confusion, unintentional activation, and ineffective operation that could lead the driver to turn the system—and its associated safety benefits—off.

How do Forward Collision Warnings & Automatic Emergency Braking Work?

Automatic emergency braking (AEB) is one of a range of ADAS technologies aimed at helping drivers avoid crashes. AEB systems serve as a last line of defense to avoid or mitigate a forward crash. AEB systems use LIDAR, radar, and/or camera technology to identify collision risks, taking into account a vehicle's speed and trajectory. AEB is typically activated after a Forward Collision Warning (FCW) system alerts a driver about a potential forward collision and the driver fails to respond. If a potential collision is detected, the system responds by first warning the driver through the FCW, supplements the force the driver applies to the brakes if necessary through dynamic brake assist (DBS), and then automatically applies the brakes if no action is taken. Some AEB systems also include crash imminent braking (CIB).

The AEB may apply either partial or full braking force. Some of the current AEB systems are designed to prevent collisions (up to certain speeds), while others may be capable only of collision mitigation. While AEB for passenger and commercial vehicles operate similarly, differences in vehicle size and weight require the manufacturers of AEB components to consider differences in vehicle stopping distances.

In contrast to most other ADAS systems that require driver intervention, AEB is a driver-out-of-the-loop technology. Like air bags or side guards, AEB can function automatically without driver involvement in an emergency, which means that crashes involving impaired, distracted, or unconscious drivers who fail to respond to driver alerts can still benefit from AEB. AEB systems are only available factory-installed on new vehicles.

All AEB systems can detect moving vehicles directly ahead in the current travel lane, but not all systems can detect stationary vehicles or large metallic objects, and fewer still can detect pedestrians and other vulnerable road users. AEB systems that can detect vulnerable road users are known as Pedestrian AEB (PAEB). Current PAEB systems are more capable of detecting moving pedestrians or bicyclists, since these produce a recognizable radar signature, while detecting stationary people generally relies on camera recognition and fusion systems.

Standalone forward collision warning (FCW) systems do not automatically apply the brakes and still require driver intervention to prevent a crash. This best practice document includes FCW because the technology is readily available aftermarket to retrofit existing large vehicles today, whereas AEB is not generally available as a retrofit solution. When FCW alert data are recorded and reviewed by fleets, they can also offer an objective way of evaluating improvement in safe driver behavior over time, measuring whether drivers are learning to operate with more care in driving scenarios that can trigger an alert.

Evidence of Effectiveness

There is a wealth of data available indicating the effectiveness of AEB in reducing crashes and injuries, especially in vehicle-vehicle crashes for both trucks and passenger cars. For example, a 2016 National Highway Traffic Safety Administration (NHTSA) study of drivers operating 150 AEB-equipped trucks reported over 3 million miles of data collected with zero rear-end crashes.[27] A large-scale implementation of AEB by freight carrier Con-Way in 2011-2013 demonstrated a 71 percent reduction in rear-end collisions and a 63 percent reduction in unsafe following distance.[28] Further, two studies[29,30] documented approximately 30 percent rear-end crash reductions for passenger cars equipped with AEB.[31] However, AEB system effectiveness can vary depending on the sensor type(s) used. The more sophisticated stereo camera and multi-sensor systems that are capable of pedestrian detection can also stop safely from the highest initial speeds.[32]

AEB stopping performance by sensor type

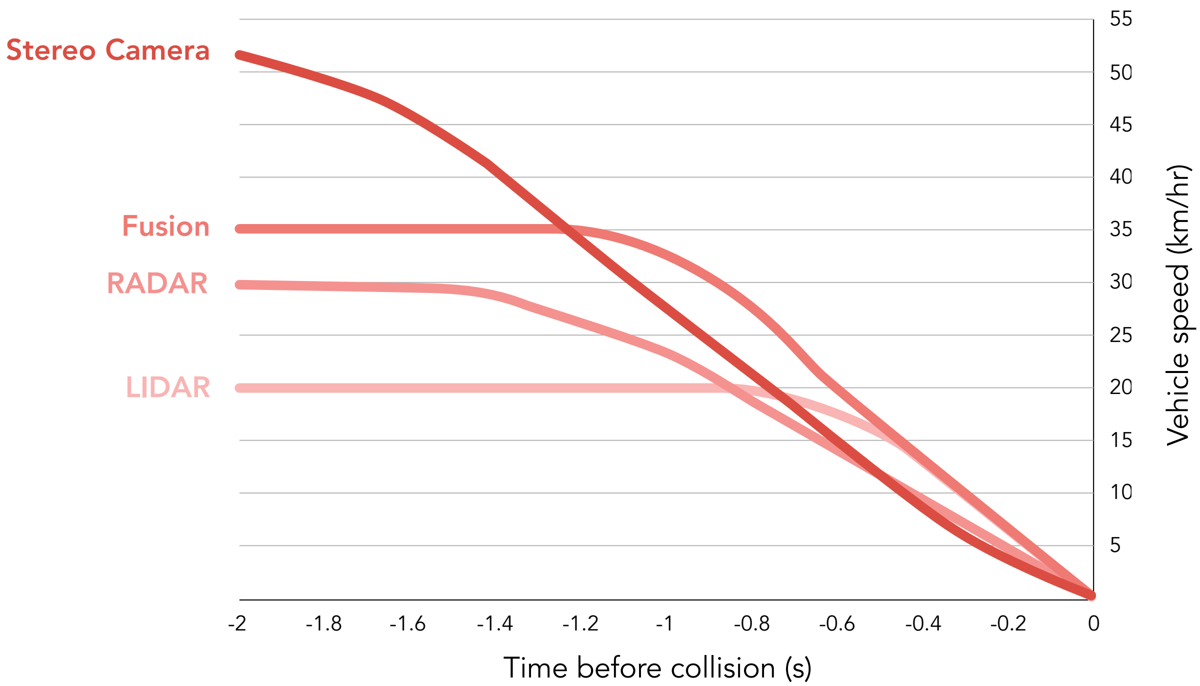

Figure 6: In passenger cars, AEB systems that use stereo cameras and fusion sensors can stop from higher speeds than other sensors.

A 2016 Insurance Institute for Highway Safety (IIHS) study across passenger cars found that FCW alone and FCW with AEB reduced rear-end crash rates by 23 percent and 39 percent, respectively.[33] FCW with AEB reduced rates of rear-end striking crash involvements with injuries by 42 percent and rates of rear-end striking crash involvements with third-party injuries by 44 percent. Notably, though, injury reductions with FCW alone were not statistically significant (6 percent and 4 percent, respectively). Some systems were capable of detecting imminent collisions with pedestrians in addition to with vehicles.

There is also evidence of effectiveness for pedestrian-detecting AEB systems on passenger cars. For example, a 2016 NHTSA study performed by Volpe found that current, commercially available pedestrian AEB systems in cars can conservatively reduce 5,000 vehicle-pedestrian crashes and at least 810 fatal vehicle-pedestrian crashes per year.[34] Total police-reported car-pedestrian crashes that could be addressed by more robust future AEB systems amount to 21,090 per year (out of 62,917 total), including about *two-thirds* (2,193 out of 3,337) of such fatal crashes.[35]

For truck-VRU crashes, the evidence of PAEB safety benefit is less established but emerging out of Europe, given the shorter history of truck PAEB technology. In 2015, the expansion of AEB to avoid or mitigate collisions involving people topped the list of measures considered likely to be cost-beneficial for possible future legislation by the EU in a Transport Research Laboratory report.[36] The Volvo Trucks Safety Report 2017, based on European crash data, indicates that pedestrian-capable AEB or FCW could be relevant for preventing or mitigating about *40 percent* of crashes between large trucks and bicyclists or pedestrians in Europe.

Considerations for Implementers

AEB systems are not all the same. Each vehicle maker has its own software engineers, its own hardware and its own perceptions of the system's objectives. Differences in how AEB systems work in different vehicle makes and models impacts what vehicles can detect, when detection will occur, and how vehicles will respond.

As a result, when implementing AEB and FCW systems, cities and private operators must look carefully to ensure that the selected technologies meet their safety goals, be cognizant of system limitations, and identify resources and opportunities to develop associated programming, training, and policies.

In particular, implementers should consider:

- When can the system detect pedestrians and cyclists?
- Does the system operate at typical city driving speeds (0-30 mph)?
- Does the system operate in low-light conditions and inclement weather?
- How easily can the system be accidentally deactivated?
- How often does the system fail (e.g., create false positives)
- What resources are available for training and telematic monitoring and adjustments?

When can the system detect pedestrians and cyclists?

AEB and FCW systems are not capable of detecting pedestrians in all scenarios. In general:

- Radar-based systems can typically detect repeating patterns such as the characteristic motion of a walking pedestrian or a pedaling bicyclist (e.g., Daimler ABA 4.0), but they have a harder time detecting people who are not moving, people in groups, or people pushing or carrying objects.
- Vision based systems (e.g., Mobileye) are better able to detect stationary people but are limited to daylight operation in well-lit environments.
- No AEB systems in the U.S. appear to market themselves as explicitly capable of detecting cyclists.
- AEB cannot detect latent hazards.

Based on interviews, it seems likely that the Detroit Assurance 4.0 AEB's Moving Pedestrian Warning feature will detect moving bicyclists as well as pedestrians and apply up to one-third of full braking power. The Wingman Fusion AEB can apply up to two-thirds of full braking power, including drive, steer, and trailer axle brakes. Meritor WABCO OnGuardActive AEB can apply up to half the braking power of the vehicle. In all systems, an AEB activation is accompanied by a distinct audiovisual alert from the LCD display.[37] Based on review of the Wingman Fusion and Meritor WABCO systems' published manuals and specifications, it appears that they **may** be able to detect pedestrians, cyclists, and other vulnerable road users, but that this capability is not currently advertised as implemented. Thus there appears to be only one commercially available truck PAEB system at the time of writing, available on only one make and up to two models.[38]

In addition, AEB systems generally cannot detect latent hazards, the things that a person might expect but cannot see (for example, a driver might see a ball roll into the street and expect that a child might follow). Increasing visibility by "daylighting" crosswalks, mid-block crossings, areas near schools, and other places where pedestrians are to be expected may improve the ability of drivers and PAEB systems alike to avoid crashes.

Does the system operate at typical city driving speeds (0-30mph)?

Almost all U.S. cities have speed limits in all or parts of the city that are 25 mph or below. However, while some FCW/AEB systems are active only below 25 mph, others are designed to operate only at highway speeds. Systems that do not operate at slow speeds are not viable in urban areas where pedestrians and cyclists are most common.

Does the system operate in inclement weather and low-light conditions?

Forward collision warning systems assist drivers in two things humans do not typically do well: detecting closing speed and seeing in the dark. However, FCW/AEB pedestrian detection is less effective in inclement weather and is also less effective in the dark when it relies solely on a camera. Fusion systems that rely on more than one sensor type may be more robust and reliable. Unreliable detection can lead to mode confusion, wherein the driver either assumes that AEB is active when it is not, or forgets that the AEB is active.

How easily can the system be accidentally deactivated?

The detection and warning components of all three systems described above (PAEB, pedestrian FCW, and non-pedestrian AEB) are always on, including Detroit Assurance's ABA system.[39] For AEB systems, however, automatic braking can be inadvertently suppressed by the driver, leading to situations where the driver believes that the AEB system is active when, in fact, it is not.[40] In general, automatic braking is suppressed when the driver:

- Uses the turn signal during an audible warning
- Rapidly presses the accelerator
- Presses the accelerator pedal beyond the pressure point ("kickdown")

How often does the system fail (e.g., create false positives)?

As noted above, unintentional activation is something that needs to be considered, especially for vehicles transporting standing passengers. In a Consumer Reports study of passenger cars, an average of 18 percent of the drivers had at least one false AEB event, with the low being 11 percent among Hyundai owners and the high being 40 percent among Jeep drivers.[41] Altogether, the Toyota Camry owner's manual (2017) describes 23 scenarios in which the car's AEB system may unintentionally activate. Other AEB systems may have similar operational limits, though professional driver training can help to avoid or limit unintentional activations.

What resources are available for training and telemetric monitoring and adjustments?

Even for fully automatic safety technologies such as AEB, some driver education and training is still needed for maximum benefit. Driver training, e.g., on virtual reality (VR) devices, can help the driver apply what he or she learns in scenarios that mimic the visual, manual and cognitive load during driving situations relevant to AEB or another safety technology. Such training programs have been shown to work, can take little time to administer (an hour or less), and have a demonstrated effect on reducing crashes.[42] Training can be most effective when matched with changes to road design that encourage slower speeds in urban areas and designate protected physical space for vulnerable road users.

Implementation Examples

ADAS technologies are increasingly common, especially in Europe. The domestic and international examples of ADAS, pedestrian AEB and FCW systems deployed on trucks are provided below to illustrate how some public and private fleets are rolling out these safety strategies.

Fleet-wide strategies

- **Schneider National** is retrofitting its existing fleet and procuring new vehicles with the Meritor WABCO OnGuard collision mitigation system, which offers forward collision warnings and assisted braking.[43]
- **New York City Department of Citywide Administrative Services (DCAS)** is implementing a Safe Fleet Transition Plan, including AEB on all new light-duty vehicles since 2017 and phasing in AEB as available on heavier trucks. The Plan also includes blind spot monitors and driver alert systems such as FCW, and in 2018 it is expected to phase in PAEB.[44]
- **CEMEX** has implemented a combination of cameras and radar side sensors specifically to detect bicyclists on its UK fleet, and these may be expanded to the U.S. in the future. The sensors are mounted on the front corner of the cab and on the side guard.[45]

Figure 7: This CEMEX dump truck, used to supply sand and gravel to London concrete plants, features a high-visibility cab and cameras and radar side sensors to detect cyclists.

Pedestrian AEB deployed on trucks

- In Europe, Daimler's Active Brake Assist 4 and Sideguard Assist systems, which include pedestrian-capable AEB, are deployed on Mercedes-Benz trucks used by a number of freight and trucking companies. SiloNet, a company based in northwest Germany, is using 52 Mercedes-Benz Actros 1843 outfitted with the full Daimler PAEB system to transport bulk construction materials on routes that travel through urban areas.[46, 47] As of December 2017, Eurotrans Budexpol is testing vehicles with the Daimler PAEB system.[48]
- In the U.S., Daimler Trucks North America includes pedestrian-detecting FCW and AEB as part of its Detroit Assurance 4.0 safety suite, which recently became standard on the Freightliner

Cascadia, beginning with model year 2017. The system is based largely on existing Mercedes-Benz passenger car and European truck technologies and has proprietary integration with Detroit engines, transmissions and braking systems.[49] Another Freightliner truck model, the EconicSD, is also expected to include PAEB as soon as 2019.

- On buses, the Federal Transit Administration awarded Pierce Transit $1.66 million in 2017 to install collision-avoidance technology and emergency braking technology. Pierce Transit is equipping all of its 176 buses with Generation 2 Mobileye Shield+ collision avoidance warning systems and 30 buses with a PAEB system that works in conjunction with the collision avoidance system and automatically decelerates the vehicle when an imminent pedestrian or vehicle collision is detected.[50] In Europe, Mercedes-Benz and Setra transit bus and motor coach models began including partial ("Partial Brake Assist") and full PAEB, respectively, as a factory feature in 2018, capable of detecting bicycles up to 160 meters away and pedestrians up to 80 meters.[51,52]

Pedestrian FCW deployed on trucks

- Recent examples show pedestrian FCW becoming available from truck manufacturers and through insurers. Mitsubishi Fuso Trucks of America announced that Fuso FE and FG Series trucks will be available with factory-installed the Mobileye 6 Series pedestrian FCW beginning with the 2017 model year.[53] Munich Reinsurance America will also make available Mobileye's aftermarket system to its clients, including commercial fleets.[54]
- Fleet implementation examples include Holland Trucking, which retrofitted 4,000 trucks in 2017, and New Penn Motor Express, which has added the system to its 750-truck fleet.[55] As part of a $450,000 pilot program, the Virginia Department of Rail and Transit is providing funding to 10 public transit agencies to retrofit up to 50 buses with pedestrian FCW systems.[56]

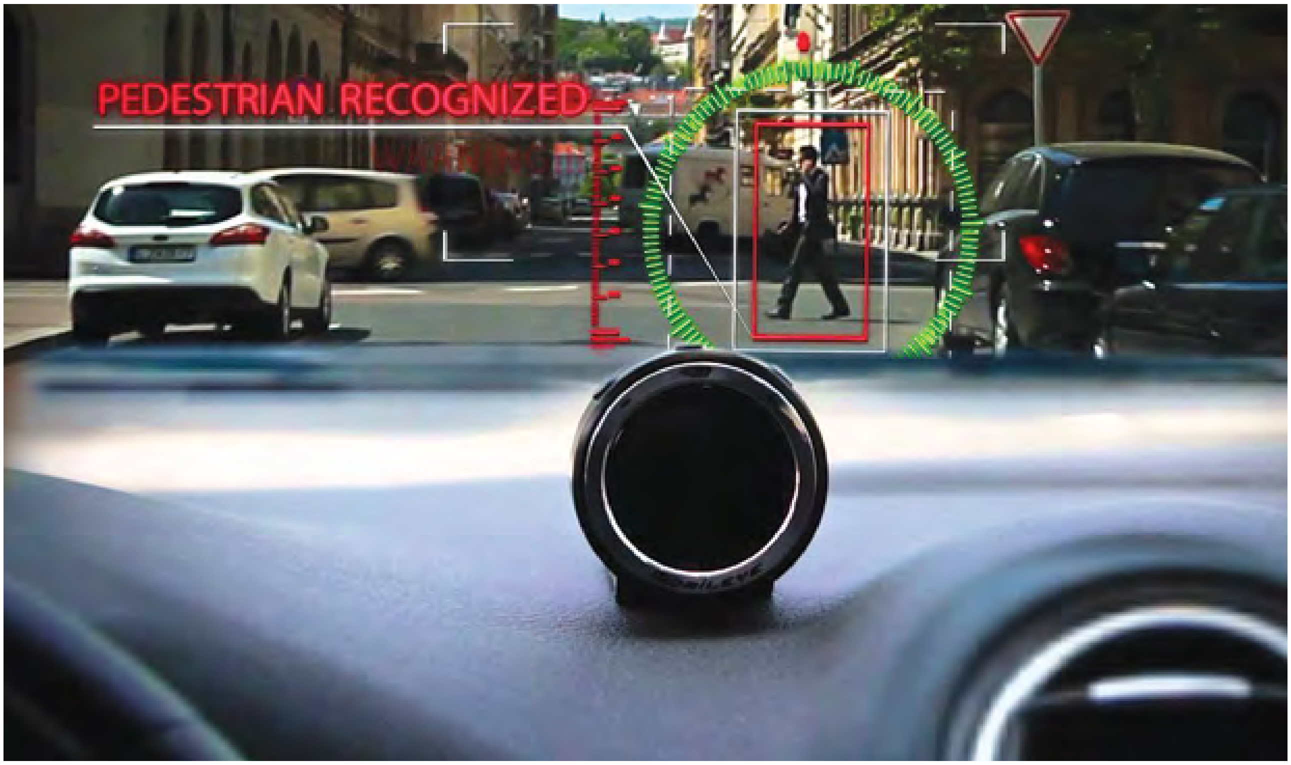

Figure 8: After-market FCW system by Mobileye

Appendices

Appendix A: Project Scope and Structure

Appendix B: Pedestrian AEB Capability and Availability

Appendix C: Figures

Appendix D: References & Citations

Appendix A:
Project Scope and Structure

To better understand the opportunities for large vehicle redesign to improve safety outcomes on urban streets, the National Association of City Transportation Officials (NACTO) partnered with the United States Department of Transportation (USDOT) John A. Volpe National Transportation Systems Center (Volpe) to convene the Vision Zero Vehicle Safety Technology Working Group (Working Group). Two companion reports, "Optimizing Large Vehicles for Urban Environments: Downsizing" and "Optimizing Large Vehicles for Urban Environments: Advanced Driver Assistance Systems" are the work products of that Working Group.

The purpose of the Working Group was to identify vehicle-based safety technology priorities, support Volpe in the development of actionable best practices, and inform an implementation roadmap for the Working Group member cities. The Working Group focused on two technology themes and developed a best practice for each.

The first theme, vehicle downsizing, was explored as a long-term strategy and included a preliminary capacity analysis comparing conventional U.S. fire trucks and commercial freight vehicles with similar vehicles in Europe and Asia. Volpe focused its best practice research a short-term, often retrofitable option within the broad topic of vehicle downsizing: blind spot reductions through direct vision improvements to the truck cab. Including direct vision, the design technologies explored by the Working Group include:

- Direct vision improvements/high-vision cabs,
- Reduced wheelbase/turn radius (may result in reduced weight), and
- Curtain-side loading/unloading.

In the second theme, advanced driver assistance systems (ADAS), Volpe focused best practice research into two near-term technologies for reducing vehicle stopping times: forward collision warning (FCW) and automatic emergency braking (AEB). Since 1995, the National Transportation Safety Board (NTSB) has annually published the "Most Wanted List of Transportation Safety Improvements" to advocate for safety technologies. The 2017-2018 Most Wanted List marked the second consecutive year that the agency recommended increased implementation of collision avoidance technologies, including forward collision warning systems, automatic emergency braking, adaptive cruise control and lane departure warning systems.[57] NTSB called for commercial vehicle operators to install forward collision warning systems at a minimum. Including FCW and AEB, the technologies explored by the Working Group include:

- Driver alerts:
    - Blind spot monitoring
    - Forward collision warning
    - Lane departure warning
    - Smart detection cameras
- Closed-loop automatic driving systems:
    - Adaptive cruise control
    - Automatic emergency braking
    - Lane centering

Defining the Scope:

In selecting themes and best practices, the Working Group looked to for opportunities that met a short list of criteria with clear fatality reduction benefits. In short, the Working Group focused on technologies that could:

- Improve both crash avoidance and crash mitigation capabilities (e.g. by improving drivers' situational awareness and reducing reaction time)
- Represent a mix of short- and long-term implementation strategies
- Represent a mix of open-loop, closed-loop, and/or passive technologies
- Require minimal additional driver training

In particular, technologies that could address both crash avoidance and crash mitigation were particularly of interest because they are the fundamental strategies to improving the safety of heavy-duty vehicles operating in dense urban environments. Crash avoidance can be achieved through infrastructure changes, road user education, improved situational awareness, and reduced reaction time. Crash mitigation, meanwhile, represents the last line of defense in situations in which a crash is not avoided, and is intended to reduce the severity of crashes, primarily by redirecting road users away from critical danger points (e.g., as with side underride guards and wheel guards) or reducing the speed and therefore force of impact (e.g., as with automatic braking). Given that heavy-duty vehicles are less maneuverable and take longer to stop than light-duty vehicles, reduced driver reaction time was an important criterion for selecting a focus technology.

Exploring technologies with both shorter- and longer-term implementation timelines was intended to give Working Group members flexibility in considering technologies and practices that are responsive to their unique contexts and priorities. Finally, it was important to balance the implications of technology complexity: open-loop technologies (advisory to a human who must take action) are currently more available, while closed-loop technologies (automated without a human taking action) can be less susceptible to driver error and may require less driver training. More advanced automation technology (sometimes referred to as "driverless" vehicles) is still likely a decade or more from large-scale availability, especially in more complex urban environments, and was therefore not a Working Group focus for this study.

About the Working Group:

The Working Group met approximately bimonthly over the course of one year and is scheduled to conclude in fall 2018. At the time of the project kickoff in September 2017, the member cities included the following:

- Boston, Massachusetts
- Chicago, Illinois
- Los Angeles, California
- San Francisco, California
- Seattle, Washington
- Washington, District of Columbia

Appendix B:
Pedestrian AEB Capability and Availability

		Bendix		Meritor WABCO		Detroit Assurance
		Wingman Advanced	Wingman Fusion	OnGuard	OnGuard Active	Detroit Assurance 4.0
System capability	Following Distance Alerts	x	x	x	x	X
	Impact Alerts	x	x	x	x	X
	Stationary Object Alerts	x	x	x	x	X
	Active Engine Braking	x	x	x	x	X
	Active Foundation Braking	x	x	x	x	X
	Vehicle-vehicle collision mitigation	x	x	x	x	X
	AEB pedestrian detection	N/A	Stationary Object Alert may detect (not guaranteed)[58]	N/A	Stationary object may detect (not guaranteed)[59]	Moving Pedestrian Warning[60]
	Functional speed	N/A	Above 10 mph	Above 15 mph	N/A	Partial braking up to 25 mph (not guaranteed for highway speeds)
	Default status	N/A	On	N/A	On	On
	User alert	N/A	Audible and visual	N/A	Audible, visual, and haptic	Audible and visual
	Nighttime capability (weather/lighting robustness)	N/A	Yes, if detection implemented		Yes, if detection implemented	Yes (radar only at present)

Figure 9: PAEB Capability and Availability

		Bendix		Meritor WABCO		Detroit Assurance
		Wingman Advanced	Wingman Fusion	OnGuard	OnGuard Active	Detroit Assurance 4.0
Availability on popular truck models	Freightliner/Western Star			Cascadia, Cascadia CNG, M2, Western Star 5700	Cascadia, Cascadia CNG, M2, Western Star 5700	Cascadia (from 2017); potentially Econic SD (2018-19)
	International	LT	ProStar; LT; Medium-duty DuraStar	ProStar, LoneStar, TranStar	LT	
	Kenworth	Select Class 8 models; Medium -duty T270, T370	T680, T880		T680	
	Mack	Pinnacle (natural gas)	Anthem[61]			
	Peterbilt	All on-highway models; Medium-duty 337, 348	Models 579, 567	569, 579	569, 579	

Figure 9, continued: PAEB Capability and Availability

The following are excerpts from manufacturer documentation about each AEB system detailing operational parameters and pedestrian detection capabilities.

Meritor WABCO OnGuardACTIVE [62]

Collision Mitigation System Limitations: The OnGuardACTIVE™ CMS **only brakes for moving objects located directly in front of your vehicle and does not operate when your speed is less than 15 mph or more than 77 mph**. Accordingly, OnGuardACTIVE™:

- **Will not react and alert you to objects crossing in front of you** or oncoming traffic.
- Should not be relied on to track lead vehicles when traveling through a severe curve in the road. Because of this, ACC is not recommended for use on winding (curving) roads.
- **Should not be relied upon to track smaller objects (e.g. motorcycles, mopeds, bicycles, pedestrians, etc.)**
- Should not be relied on to alert drivers to vehicles in an adjacent lane.

Bendix Wingman Advanced [63]

Does the Bendix Wingman Advanced system warn on stationary objects? How about non- metallic objects such as people, animals, or vehicles primarily constructed of limited metallic?

Stationary Metallic Objects: Yes, the Bendix Wingman Advanced system does warn on stationary metallic objects. The "Stationary Object Alert" (SOA) feature of the system provides audible and visual alerts to the driver when approaching a stationary metallic object – such as a car, steel drum, or other sizable metallic obstruction – in the vehicle's lane of travel. This alert is typically given up to 3.0 seconds before a potential collision with a stationary metallic object in the vehicle's lane of travel. This enables the driver to either slow down or maneuver in an attempt to avoid the object. Stationary Object Alerts are warnings only; there is no active braking with SOA. The driver should always be attentive to stopped vehicles on the roadway. The Bendix Wingman Advanced system will only warn and will not decelerate the vehicle when approaching stationary metallic objects. This feature is continuously on and will provide warnings in all types of weather situations – including rain, snow, or fog – and at night. During testing, drivers have found this to be an especially useful feature in limited visibility situations. **As you approach objects with limited metal surfaces (such as recreational vehicles, horse-drawn buggies, motorcycles, logging trailers, etc.) traveling in your lane, the Bendix Wingman Advanced system may not be able to react to them** and automatically manage the set following distance between your vehicle and the forward vehicle. You should always be alert and aware when driving and approaching all types of vehicles and objects.

Non-Metallic Objects: No, the Bendix Wingman Advanced system will not warn or react on animals or people. In addition, the system will not react or warn on other non-metallic objects.

Bendix Wingman Fusion [64]

At **speeds above 15 mph**:

- Stationary Vehicle Braking can automatically alert the driver up to 3.5 seconds before impact and apply vehicle brakes if the **large, stationary, in-lane object is definitively identified as a licensed motorized vehicle**

- Collision Mitigation automatically applies the foundation brakes to mitigate, or potentially prevent, a potential collision with a **forward moving vehicle**

The **Stationary Object Alert is enabled whenever the vehicle is moving 10 MPH (16 KPH) or faster**. The Fusion™ system will activate an alert when approaching a detected, **sizable, radar-reflective, stationary object in the vehicle's lane of travel**. This alert indicates that a collision with a stationary object is likely and the driver must immediately act to potentially avoid, or lessen the severity of, a collision. **If the system cannot definitively identify the stationary object as a vehicle, the driver will get an alert of up to 3 seconds to address the situation ahead. No automatic braking will be applied.**

To prevent property damage, personal injury, and/or death, be aware that the Bendix Wingman Fusion system **may provide little to no warning or stationary vehicle braking for some hazards, such as pedestrians, animals, oncoming vehicles, and cross traffic**.[65]

Detroit Assurance 4.0

With Moving Pedestrian Warning (ABA 4.0),[66] the radar system on the new Cascadia can detect most pedestrians in motion and, as long as they stay in motion, can act to **help mitigate a collision at vehicle speeds below 25 MPH. Moving Pedestrian Warning can detect most pedestrians that are moving within the truck's path. If the Moving Pedestrian Warning system detects a pedestrian in motion within the radar system's parameters for potential danger, the truck will engage in partial braking. Moving Pedestrian Warning is not functional at highway speeds and may not detect pedestrians in every possible situation**, nor is it a substitute for cautious driving.

Bendix Side Object Detection: This feature helps professional drivers with vehicle blind-spots by alerting them to large metallic objects within the range of the radar sensor mounted on the right side of the vehicle.

The New Cascadia Driver's Manual[67] Driver Assistance Features section carries a disclaimer on pedestrian detection: "The Detroit Assurance system will not warn of hazards such as pedestrians, animals, oncoming vehicles, or cross traffic."

However, it also states:

> If your vehicle is equipped with ABA, it can (within system limitations):
>
> - react more quickly to an object in your path of travel;
> - perform emergency braking; and
> - react to moving people with a warning and partial braking

ABA can also detect people who are moving along the edge of the lane.

> The audio-visual warning and partial braking are described as follows:
>
> - Warning (ABA): An alert appears on the driver display, the radio is muted, and an intermittent warning tone sounds.
> - Partial Braking (ABA): An alert appears on the driver display, and an intermittent warning tone sounds. In addition, ABA slows the vehicle with automatic partial braking. ABA brakes the vehicle with around 50 percent of the vehicle's maximum braking power.

Mobileye

The relevant Mobileye capabilities for city street safety are:

Forward collision warning, including urban forward collision warning

- Alerts drivers of an imminent rear-end collision with a car, truck, or **motorcycle**.
- Red vehicle icon warns of an imminent rear-end collision up to 2.7 seconds in advance.
- Active at any speed.

Pedestrian & cyclist detection & collision warning

- Notifies the driver of a pedestrian or cyclist in the danger zone, and alerts drivers of an imminent collision with a pedestrian or cyclist.
- Active **under 31 MPH** (can be increased to 43.5 MPH), giving the driver time to react and take corrective action.
- Red pedestrian icon warns of an imminent collision.
- Operational during **daylight hours only**.

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Appendix D:
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