Research and Testing to Accelerate Voluntary Adoption of Automatic Emergency Braking (AEB) on Commercial Vehicles

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

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FOREWORD

Automatic emergency braking (AEB) is a safety technology designed to mitigate or prevent collisions without driver intervention. This technology was introduced nearly 10 years ago in heavy commercial vehicles and has evolved rapidly to include improved technology and additional features. While many fleets report reductions in the number and severity of crashes after adopting AEB, voluntary adoption across the industry as a whole has been slow. Until recently, the technology was included in less than 50 percent of new class 8 truck sales, and the current stock of heavy vehicles equipped with AEB remains a small portion of the total U.S. fleet. In the medium-duty classes, voluntary adoption has lagged behind heavy-duty significantly, and the technology is not available on some vehicles. The purpose of this report is to explore technical and market barriers to the voluntary adoption of AEB and to identify strategies that the Federal Motor Carrier Safety Administration (FMCSA) can implement to increase adoption of the technology to encompass 90 percent of new truck sales.

The technical barriers and market barriers identified in this report may be of interest to a wide variety of stakeholders in the trucking industry. Many of the strategies identified will require coordination with multiple stakeholders, and accelerating adoption may ultimately depend on several organizations prioritizing that goal. The report may be of interest to other agencies that wish to understand the adoption mechanisms of new technologies in the complex environment of commercial trucking, and may also be useful in understanding the adoption of future safety technologies.

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16. Abstract

This report describes barriers to truck fleets' voluntary adoption of automatic emergency braking (AEB), and actions that may mitigate or eliminate these barriers. The report recommends approaches that the Federal Motor Carrier Safety Administration (FMCSA) could take to accelerate voluntary adoption of AEB technologies. It rates these approaches based on potential resource and time requirements, potential impacts on voluntary AEB adoption, and potential for a recommended action to fail. It also outlines one potential core strategy for reaching 90 percent adoption for new heavy-duty vehicles, though other strategies may also be feasible depending on FMCSA resources and priorities. While there does not appear to be a feasible roadmap to achieving 90 percent voluntary adoption for medium-duty vehicles, the strategies for the heavy-duty segment may still be viable for some medium-duty applications. Once some of the technical barriers with medium-duty vehicles are resolved, these market strategies may boost voluntary adoption within certain medium-duty market segments, though it remains unclear whether a 90-percent take rate is achievable. This report will help industry stakeholders understand the issues fleets have experienced during AEB adoption and what tools fleets require to see AEB as an economically attractive option for their new vehicle purchases.

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SI* (MODERN METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
In	inches	25.4	millimeters	mm
Ft	feet	0.305	meters	m
Yd	yards	0.914	meters	m
Mi	miles	1.61	kilometers	km
		Area		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	Acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		Volume (volumes greater than 1,000L shall be shown in m³)		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
		Mass		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		Temperature (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		Force and Pressure or Stress		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		Area		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
Ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		Volume		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		Mass		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		Temperature (exact degrees)		
°C	Celsius	1.8c+32	Fahrenheit	°F
		Illumination		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		Force and Pressure or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009.)

TABLE OF CONTENTS

EXECUTIVE SUMMARY IX

1. LITERATURE REVIEW 1

1.1 REVIEW OF CURRENT AUTOMATIC EMERGENCY BRAKING (AEB) TECHNOLOGIES 1

1.1.1 Older AEB Technologies 1

1.1.2 Always-Active AEB 1

1.2 MARKET PENETRATION OF AEB 3

1.2.1 Class 7 and 8 Trucks 3

1.2.2 Class 4–6 Trucks 3

1.3 POTENTIAL BENEFITS OF AEB 4

1.4 POTENTIAL BARRIERS TO VOLUNTARY ADOPTION 5

1.4.1 Cost Barriers 5

1.4.2 Performance Barriers 6

1.4.3 Perception Barriers 6

1.5 EFFORTS TO PROMOTE VOLUNTARY ADOPTION OF AEB 7

1.5.1 Light Vehicle Efforts in the United States 7

1.5.2 Heavy Vehicle Efforts in the United States 7

1.5.3 Heavy Vehicle Efforts in Europe 10

1.6 SUMMARY 10

2. HEAVY-DUTY TECHNICAL BARRIERS 11

2.1 GENERAL AEB TECHNICAL BARRIERS 11

2.1.1 AEB Performance Barriers 11

2.1.2 Audio/Visual Alert Performance Barriers 12

2.1.3 Human-Machine Interface Barriers 14

2.1.4 Retrofit Barriers 14

2.2 TECHNICAL BARRIERS FROM MULTIPLE GENERATIONS OF AEB 15

2.3 TECHNICAL BARRIERS FROM MULTIPLE BRANDS OF AEB 17

2.4 TECHNICAL BARRIERS TO INTEGRATING AEB DATA 17

3. MEDIUM-DUTY TECHNICAL BARRIERS 19

4. APPROACHES FOR MITIGATING TECHNICAL BARRIERS 23

5. HEAVY-DUTY MARKET BARRIERS 25

5.1 RISK EXPOSURE AND TOLERANCE 26

5.2 RETURN ON INVESTMENT 28
5.2.1 Calculating ROI 28
5.2.2 Initial Cost.................... 31
5.2.3 Payback Period.................... 32
5.2.4 Incentives 32
5.2.5 Training and Data Utilization 34
5.2.6 Resale Value 35
5.3 DRIVER ACCEPTANCE 35
5.3.1 System Differences 36
5.3.2 Human-Machine Interface 36
5.3.3 Configurability.................... 38
6. MEDIUM-DUTY MARKET BARRIERS....................39
6.1 RETURN ON INVESTMENT 39
6.2 INTERMEDIATE BUILDERS 39
7. RECOMMENDATIONS....................41
7.1 ACTIONS FOR ACCELERATING AEB ADOPTION 41
7.2 CORE STRATEGY 46
REFERENCES....................51

LIST OF FIGURES

Figure 1. Timeline. AEB product releases and updates since 2008..15
Figure 2. Screen capture. Image of VTTI's ROI tool allowing input of equipment costs............30
Figure 3. Screen capture. Image of VTTI's ROI tool showing cost/benefit output......................31

LIST OF TABLES

Table 1. Stakeholder Groups Supporting AEB Voluntary Adoption. 8
Table 2. New class 8 truck sales, estimated take rates, and estimates of AEB sold by year. 26
Table 3. Classifications and definitions for recommendations to accelerate AEB voluntary adoption. 42
Table 4. Recommendations related to OEM engagement or OEM policies. 42
Table 5. Recommendations related to fleet engagement or fleet decision-making. 43
Table 6. Recommendations related to industry engagement and guidance. 44
Table 7. Recommendations related to CSA framework. 44
Table 8. Recommendations related to the medium-duty truck market segment...........................45
Table 9. Recommendations that were not rated high resources, high time to implement, or low feasibility. 47

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym	Definition
AAA	American Automobile Association
ADAS	advanced driver assistance system
ABS	antilock brake systems
ACC	adaptive cruise control
ACB	active cruise with braking
AEB	automatic emergency braking
ATA	American Trucking Associations
CSA	Compliance, Safety, Accountability
CVSA	Commercial Vehicle Safety Alliance
ELD	electronic logging device
ESC	electronic stability control
EU	European Union
FAIR Score	Forward Assessment of Indexed Risk Score
FCW	forward collision warning
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
HMI	human-machine interface
IIHS	Insurance Institute for Highway Safety
ISO	International Organization for Standardization
LDW	lane departure warning
MCMIS	Motor Carrier Management Information System
NAS	National Academy of Sciences
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board

OEM	original equipment manufacturer
OOIDA	Owner-Operator Independent Driver Association
ROI	return on investment
RP	Recommended Practice
SAE	Society of Automotive Engineers
TAG	Technical Advisory Group
TCO	total cost of operations
TMC	Technology Maintenance Council
VIN	vehicle identification number
VORAD	Vehicle Onboard Radar
VTTI	Virginia Tech Transportation Institute

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EXECUTIVE SUMMARY

PURPOSE

This study sought to identify technical and market barriers to the voluntary adoption of automatic emergency braking (AEB) technology on commercial motor vehicles and to identify strategies that may increase voluntary adoption to 90 percent of new truck sales.

PROCESS

This study explored AEB voluntary adoption through three major steps. First, a literature review was conducted to collect known information about adoption rates, product updates, fleet opinions, and safety benefits. Second, AEB suppliers and heavy vehicle manufacturers were consulted to identify technical barriers to adoption. This step explored system performance, underlying technical requirements for AEB installation, and differences in how suppliers design systems and manufacturers integrate systems. Third, AEB suppliers, heavy vehicle manufacturers, fleets, and insurance representatives were consulted to identify market barriers to adoption. This step explored driver acceptance, gaps in fleet information, fleet risk tolerance, and secondary costs that AEB adoption can entail.

RATIONALE AND BACKGROUND

AEB is a safety technology that applies braking force in response to input from radar or other sensors. AEB has been available on heavy vehicles for over a decade, but adoption of the technology has been slow. This is despite fleets that use the technology reporting that they are seeing reductions in both the number and severity of crashes, and a resulting positive return on investment (ROI). Because commercial vehicles often have a long useful life, each new vehicle purchased without AEB could remain in use for a long time. Retrofitting a vehicle with AEB is possible, but it is currently a specialized process and not necessarily cheaper than including AEB on a new vehicle. Thus, accelerating AEB voluntary adoption on new vehicle purchases presents the best opportunity to increase the share of vehicles equipped with the technology and reduce the number of crashes and fatalities involving commercial vehicles.

STUDY FINDINGS

Technical Barriers

In heavy-duty truck classes, there are moderate technical barriers that may be impeding AEB voluntary adoption. Past generations of AEB suffered from false activations in both physical braking and audio/visual alerts. While newer generations of the technology may reduce these issues, negative perceptions of AEB still remain, resulting in the market barrier of resistance to new truck purchases with AEB. For technical reasons, AEB retrofits are difficult to apply broadly, generically, or cheaply. There are also technical barriers stemming from how AEBs are designed with audio/visual components. These audio/visual alerts raise barriers to driver acceptance and fleet training; however, for technical reasons, these components cannot be separated from AEB.

In medium-duty classes, there are significant technical barriers to voluntary adoption. Supporting technologies like stability control are not available for many makes and models of medium-duty trucks, and AEB suppliers do not currently offer AEB without underlying stability control. Because stability control is not standard, medium-duty fleets must decide whether to purchase stability control at added cost—a likely market barrier. Additionally, when AEB is offered for medium-duty vehicles, it lags at least one generation behind the product offered in heavy-duty vehicles. Therefore, medium-duty systems may not offer the same technical improvements to reduce false activations and may lack new features.

The technical barriers for medium-duty fleets are significant and difficult to overcome. Even so, it may be possible to focus on segments of the medium-duty market where AEB provides the greatest benefits and attempt to accelerate voluntary adoption within those segments. While technical barriers may be impeding voluntary adoption in heavy-duty trucks, market barriers appear to pose a more significant problem.

Market Barriers

For heavy-duty vehicles, several major market barriers appear to be impeding voluntary adoption. First, fleets typically cycle new vehicles into their fleets slowly over the course of several years. Fleets who champion AEB technology require 5, 7, or even 10 years to equip all their vehicles. This is also why current market penetration of AEB is estimated to be less than 15 percent of current trucks based on market information available in 2017. This slow adoption also leads to multiple generations of the technology existing concurrently within a fleet, which can create problems. Drivers may be confused or biased by older, less mature generations of the technology, reducing acceptance. Second, confusion arises when a fleet contains different makes of truck with different brands of AEB. Systems from the various AEB providers work slightly differently and may be integrated differently by each OEM. Third, fleets that are considering AEBs may not have the information or tools they need to make ROI calculations and justify adoption. Finally, the positive ROIs that fleets can expect could take several years to realize. Insurance discounts are a possible source of cost savings, but insurers typically wait for downstream reductions in liability before offering reductions in premiums.

RECOMMENDATIONS

There are several actions the Federal Motor Carrier Safety Administration (FMCSA) could take to improve AEB adoption. The recommended actions vary both in how much support they will require from outside FMCSA and how much they are likely to increase AEB adoption. The identified actions have been rated based on resource requirements, time requirements, potential for failure, and potential to accelerate voluntary adoption. The report identifies a core strategy of four actions which are expected to provide near-term increases in AEB voluntary adoption. Actions outside this core strategy, which could also reduce risks and improve results, can be considered based on FMCSA’s priorities and on interest levels from industry stakeholders.

1. LITERATURE REVIEW

1.1 REVIEW OF CURRENT AUTOMATIC EMERGENCY BRAKING (AEB) TECHNOLOGIES

1.1.1 Older AEB Technologies

While significant changes have been made to the newest versions of AEB products, it is important to consider the history of AEB technologies for two key reasons. First, many drivers and fleets tested or adopted previous versions of the technology, and these experiences influence their perceptions of the newest technologies. Second, AEB applications emerged from a suite of sensors that originally provided only alerts to drivers. AEB products still integrate these alert systems, which could influence fleets' willingness to adopt AEB technologies.

The sensors currently used for AEB applications first became available for heavy commercial vehicles through the Eaton Vehicle Onboard Radar (VORAD) system in the 1990s.[(1)] Originally, VORAD was an aftermarket product that could be installed to record data related to a crash. In 1999, the EVT-300 Collision Warning System was introduced with an updated radar and a driver display that could provide alerts if it detected a potential hazard. The EVT-300 included forward collision warning (FCW) based on forward-facing radar, adaptive cruise control (ACC) based on forward-facing radar, and blind spot warnings based on side-facing radar. VORAD was the first ACC product available for trucks and the first such product that many fleets and drivers experienced.[(2)] These experiences varied, and some fleets chose not to adopt the product or discontinued adoption based on testing or feedback from drivers.[(3)] Negative personal experiences and subsequent word-of-mouth accounts may continue to influence AEB perceptions today.

The first versions of AEB for commercial vehicles were introduced by Meritor WABCO and Bendix Commercial Vehicle Systems. Meritor WABCO developed their OnGuard product in 2007. In 2009, Bendix Commercial Vehicle Systems acquired the VORAD technology from Eaton and developed the Wingman Adaptive Cruise with Braking (ACB) product. OnGuard was designed to keep AEB available at all times, while Wingman only made AEB available when cruise control was engaged. Both systems could apply approximately one-third foundation braking capacity (achieving roughly 0.35g deceleration) automatically if the forward-facing radar detected an imminent collision. These systems retained the FCW and blind spot alerts from previous generations, which could be active even when cruise control was not engaged. By the end of 2010, these systems could be factory-installed on most brands and models of class 8 trucks.[(4 5)] No data could be found on the real-world effectiveness of this generation of AEB products, and any effects would be limited to driving conditions in which the driver chose to use cruise control. Research by Woodrooffe et al. (2012) found in simulations that AEB availability during cruise control could have potential safety benefits and that these benefits could be increased by making AEB available when cruise control was not in use.[(6)]

1.1.2 Always-Active AEB

In 2012, Meritor WABCO and Bendix introduced new versions of their products; thus, all three makers had an AEB that was "always available." Meritor WABCO continued to use the

OnGuard product branding, while Bendix called its new system Wingman Advanced. These systems increased AEB force to approximately two-thirds of the vehicle's braking capacity (for approximately 0.6g deceleration). This generation of AEB would automatically engage braking if the forward-looking radar detected an imminent collision and the vehicle was above a minimum speed (about 10 mi/h), regardless of whether cruise control was active. The marketing narrative accompanying these products was that they could buy additional time for a driver to respond to a situation and help direct a driver's attention to the forward roadway. By being "always available," the systems could help respond to most front-to-rear collision scenarios that drivers might face. This generation continued packaging AEB with FCW and blind spot alerts, while adding a new camera-based lane departure warning (LDW) system.

While few data were available for the previous generation of AEB, the potential benefits of the newer generation drew increased attention. From 2013 to 2016, the National Highway Traffic Safety Administration (NHTSA) sponsored a naturalistic study with the Virginia Tech Transportation Institute (VTTI) in which 150 trucks equipped with OnGuard or Wingman Advanced products drove their normal, revenue-producing routes with VTTI's data collection equipment installed.[7] The results found that AEB generally activated when appropriate, and there were no front-to-rear collisions in over 2.5 million miles of recorded driving.

But the study also noted false activations of AEB. Scrutiny of false AEB activations showed that they were typically shorter in duration than valid AEB activations, resulting in less braking force and speed reduction. These false AEB activations raised questions about system performance, particularly in adverse environmental conditions. The study also collected data about FCW and LDW, finding that drivers may have received FCW and LDW feedback frequently and in situations that were not necessarily safety-critical. This frequent feedback could be a source of annoyance, and could lead to mistrust about whether the system would engage AEB appropriately in a safety-critical situation.

Beginning in 2014, new developments occurred in the AEB market. Daimler developed its own AEB, called Detroit Assurance 2.0, for use on Freightliner trucks. While the features of this system were similar to those of OnGuard and Wingman Advanced, Detroit Assurance was not commercially available when data collection started for the above-described NHTSA project. Therefore, data on its performance are limited.

In 2015, Bendix announced a new product called the Wingman Fusion, which used a window-mounted camera to supplement the forward-looking radar with object detection and classification.[8] The Wingman Fusion allows AEB to have 100 percent braking authority to slow or stop the vehicle. Wingman Fusion also provides AEB in response to stationary objects, a new feature for this generation of AEB product.

Also in 2015, Meritor WABCO introduced an upgrade to OnGuard called OnGuardACTIVE, which introduced partial braking in response to stationary objects.[9] Meritor WABCO announced another upgrade in 2016 to its OnGuard system called OnGuardMAX, which supplements the forward-looking radar with a window-mounted camera.[10] The OnGuardMAX (available in 2019) will allow AEB to have 100-percent braking authority and the ability to activate in response to stationary objects.

In 2017, Daimler released the Detroit Assurance 4.0, which also allows 100 percent braking authority for both moving and stationary objects, but does not include a camera system for detection of objects in front of the truck.[11]

These developments represent a maturation and expansion of AEB capability. Additional sensors, improvements to detection algorithms, and the ability to brake in additional scenarios have the potential to improve safety more than previous generations of the technology. However, the amount of data available on these technologies in real-world operation remains limited due to their recent development. NHTSA has sponsored a second naturalistic study with VTTI to explore the real-world performance of the newest AEB products, with data collection underway starting in mid-2018.

1.2 MARKET PENETRATION OF AEB

1.2.1 Class 7 and 8 Trucks

Limited publicly available data suggest that the voluntary adoption of AEB has been slow but steady. In 2013, the National Transportation Safety Board (NTSB) received an industry estimate that 8–10 percent of trucks were equipped with AEB.[12] Adoption is typically tied to the timing of new truck purchases and the life cycle of a fleet's existing trucks. Con-way, a large trucking fleet that operates throughout the United States, provided data to the NTSB, reporting that it began installing OnGuard on all new trucks in 2010.[13] Because of truck life cycles and the timing of new truck purchases, Con-way projected that half its fleet would be equipped by 2015.

Data on current adoption rates is scarce. Public statements by Daimler indicate that AEB is being voluntarily purchased on over 50 percent of their new vehicle sales, while public statements by Meritor WABCO indicate that their OnGuard product is being purchased on 15 percent of compatible new trucks.[14,15] There have been public statements from AEB suppliers regarding the development of retrofit kits, but there is no information on when they would be available, what their cost would be, or how their effectiveness would compare to factory-installed options on new trucks.[16] Given incomplete information available on market penetration, the best information currently available will be used to estimate market penetration in Chapter 5. Chapter 5's method will use a combination of publicly available sales totals and take-rate data to estimate the current number of vehicles on the road equipped with AEB and how take rates have changed over time to reach the current state.

One important technical note is that suppliers of AEB systems recommend also installing electronic stability control (ESC) systems, which AEB relies on during braking activations. ESC technology has recently been mandated for class 7 and class 8 tractors. ESC is not mandated in class 4-6 vehicles, which introduces a potential technical barrier that is not present in heavy-duty classes.[17]

1.2.2 Class 4–6 Trucks

AEB products have typically not been available on class 4–6 medium-duty trucks, while successive generations of AEB products have been introduced in class 7–8 vehicles. One major reason for this is that ESC is a recommended companion technology, as mentioned above. ESC in heavy trucking was first developed for class 7 and 8 trucks and was available at least as early as 2004.[18] ESC did not become available in medium-duty trucks until around 2009.[19] As a result, ESC has not had as much time to penetrate the medium-duty market compared to the heavy-duty market. In 2017, Ford announced that ESC would become standard on F-650 and F-750 models, which could open the door for AEB development and adoption on those platforms.[20] In 2016, Kenworth announced that that the Wingman Advanced product would become available for the T270 and T370 trucks.[21] These developments are important for achieving greater market penetration in the future, but based on how slowly trucks cycle out of use, it could take years for AEB to be available on a majority of medium-duty trucks. On the policy side, there is not yet a mandate for ESC on medium-duty trucks, which means adoption of ESC could be relatively slow.

1.3 POTENTIAL BENEFITS OF AEB

Few studies have empirically evaluated the potential safety benefits of AEB. A search of the peer-reviewed literature found only six studies (see references 22, 23, 24, 25, 26, and 27). Of these studies, three estimated the potential effectiveness of AEB by filtering national crash datasets based on hypothetical relevant crash scenarios without real-world effectiveness data. In 2011, Kuehn, Hummel, and Bende estimated that AEB could prevent 52.3 percent of all heavy vehicle front-to-rear crashes in Germany.[28] In 2012, Jermakian estimated that AEB could prevent 31–37 percent of heavy vehicle front-to-rear crashes, resulting in 26,000–31,000 fewer crashes, 2,000–3,000 fewer injuries, and 98–115 fewer fatalities.[29] Recently, NHTSA estimated that large-truck AEB could prevent a maximum of 11,499 crashes, 7,703 injury crashes, and 173 fatal crashes each year, assuming 100-percent market penetration and 100-percent effectiveness.[30]

Three studies used real-world data to estimate the effectiveness of AEB. In 2012, Woodrooffe et al. evaluated the performance of large-truck AEB on a test track and used computer simulations to estimate the number of crashes that AEB may prevent given 100-percent market penetration.[31] Woodrooffe et al. found that:

- AEB braking at 0.35g (moving objects only, no stationary object braking) could prevent 16 percent of heavy vehicle front-to-rear crashes.
- AEB braking at 0.3g for fixed objects and 0.6g for recently stopped/moving vehicles could prevent 28 percent of heavy vehicle front-to-rear crashes.
- AEB braking at 0.6g for fixed and moving objects/vehicles could prevent 40 percent of all heavy vehicle front-to-rear crashes.

Similarly, Hickman et al. found that heavy vehicles with AEB were involved in 20.7 percent fewer front-to-rear crashes compared to heavy vehicles without AEB.[32] Finally, Grove et al. suggested how naturalistic data collected from NHTSA-sponsored research could be used to update safety benefit models. Real-world data on headways, AEB activation timing, AEB activation brake force, and driver brake response times from vehicles equipped with commercial systems could refine models to provide more realistic benefit estimates.[33]

Camden et al. recently completed a societal cost-benefit analysis for AEB in the United States.[34] This study estimated that voluntary adoption of large truck AEB has the potential to prevent a maximum of 12,732 property-damage-only crashes, 6,010 injury crashes, and 165 fatal crashes. Further, based on the effectiveness rates from Woodrooffe et al. (16–28 percent reduction in front-to-rear crashes), Camden et al. estimated that AEB could prevent 2,037–3,565 property-damage-only crashes, 962–1,683 injury crashes, and 26–46 fatal crashes. Eliminating these crashes would prevent 31–55 fatalities, 130–228 serious injuries, 430–753 minor injuries, and 947–1,657 possible injuries each year.[35] Because the new generation of AEB offers improved braking ability, Camden et al.'s estimates are likely the minimum number of crashes prevented. Finally, Camden et al. found that the societal benefits of installing AEB on all new heavy vehicles outweighed the societal costs, assuming a 28-percent effectiveness rate and a $2,500 purchase price.

1.4 POTENTIAL BARRIERS TO VOLUNTARY ADOPTION

There are many potential barriers to the voluntary adoption of AEB in the trucking industry. Some of these barriers may be related, such as the different costs of AEB voluntary adoption, the performance levels of different features within the systems, or the perceptions of drivers, maintenance, and management in fleets. This report organizes the current literature on voluntary adoption barriers by the categories of cost, performance, and perception. It is possible that barriers within these categories have related root causes, or that multiple barriers within these categories could be addressed by similar actions. Further data from fleets and industry will be necessary to identify how these barriers might be similar, but the current framework helped drive discussions about the most effective actions that could be taken. The categories and general framework were updated as necessary throughout the project to reflect information learned from the industry.

1.4.1 Cost Barriers

The various costs of AEB are one potential set of barriers. Based on the data AEB provides, these costs may include some or all of the following: initial purchase price, maintenance or out-of-service time due to issues with the technology, training costs, and program management costs. In particular, many fleets are unsure whether the crash avoidance benefits realized in revenue-producing runs will justify the large up-front cost.[36] In order to make these judgements, fleets need data and tools that will help them estimate life-cycle costs and calculate the return on investment (ROI).

Another potential barrier is that fleets may not be taking a total cost of operations (TCO) view of their business or understand how to incorporate AEB and other safety systems into TCO models.[37] Some data also suggest that fleets consider the initial cost expensive.[38] This could deter smaller fleets in particular, which are less capable of absorbing up-front equipment costs. Market research found that AEB priced at $2,750 per vehicle could increase adoption rates.[39] Data also suggest that smaller fleets may not consider downstream cost reductions after adopting AEB.[40] Potential benefits, such as reduced maintenance costs, litigation savings, reduced vehicle and driver downtime, and environmental savings are all based around uncertain events and more difficult to quantify than the up-front cost.

One final cost barrier may be related to difficulty accessing or using the data that come from AEB. While AEB may be able to mitigate or prevent a collision as a stand-alone system, the full safety benefits are tied to integrating the data from AEB into fleet operations. This could include monitoring system activations, driver training on how systems work, or safety interventions based on patterns of activations. Unfortunately, many AEB technologies cannot be integrated with other safety technologies. Fleets need different dashboards or interfaces to view data from AEB, driver monitoring systems, electronic logging systems, or other fleet management technologies. Fleet managers have reported the desire to have one safety system that combines multiple capabilities, such as AEB, video-based driver monitoring, LDW, etc.(41) The effort involved in using data from AEB alongside a fleet's other data sources adds time and cost and may therefore be a barrier to voluntary adoption.

1.4.2 Performance Barriers

Data on performance are limited. Still, given current information, there are two main potential performance barriers. The first is the performance of AEB itself. Drivers report that AEB overreacts or brakes too hard in some scenarios. Over-braking may cause following vehicles to rear-end the truck or may cause the trailer to jackknife.(42) The trend of increasing the braking authority of AEB could contribute to these concerns. Drivers also report that weather conditions and dirt or mud build-up on radar sensors can cause AEB to turn off.(43) Drivers may need to manually clean the radar or turn off the truck to reboot the radar, which can cause delays.(44) Finally, the effective performance of AEB relies on well-maintained brakes, which means existing issues can compromise AEB's effectiveness. Results from the most recent Commercial Vehicle Safety Alliance (CVSA) Brake Safety Day showed that 14 percent of all inspected vehicles were placed out of service for brake-related violations.(45) If a fleet does not have a reliable program of brake maintenance, it may not realize the full benefits of AEB.

The second main potential performance barrier is associated with the suite of safety systems included with AEB. As mentioned above, weather, dirt, or debris can cause the radar to become blocked and AEB to become unavailable. The cruise controls on trucks equipped with AEB are also tied into the radar sensors to provide ACC functionality. These trucks are typically not capable of operating in "traditional" cruise control modes and must be operated in ACC modes. If the radar sensor is compromised, the system prevents any cruise control operation. This limitation may annoy drivers who often drive in adverse environmental conditions.

There are also performance concerns related to the audio/visual alerts provided by AEB. The naturalistic study conducted by VTTI found that drivers received, on average, dozens of low-level FCW alerts per hour. These alerts were heavily influenced by traffic conditions, with drivers tending to receive more alerts in heavier traffic. There was also evidence of drivers misusing the button that disables LDW. Some drivers were observed disabling the alerts repeatedly for long durations, even when lane markings appeared to be clear and consistent. While participants were not interviewed about this behavior, it could be due to annoyance at the amount or type of audible feedback that the drivers received.

1.4.3 Perception Barriers

Beyond the actual performance of AEB and other safety technologies included with AEB, another barrier to voluntary adoption is the perceived performance. As mentioned above, previous generations of AEB had a reputation for false activations. Some of this reputation may be justified; the OnGuard and Wingman Advanced were both observed in naturalistic data to produce some false activations. Investigations of these false activations showed that they generally did not result in substantial slowing of the truck, but they may still have an impact on driver and fleet acceptance. These false alarms caused drivers and fleets to consider AEB or the related suite of safety systems ineffective and a nuisance.(46) It is possible that many fleets remember these early experiences and assume that the current generation of AEB is still more a nuisance than an effective safety system.

A general mistrust of automation systems among the general public may also contribute to the perception of AEB. A new public poll found that a majority of respondents were concerned about sharing the road with automated vehicles, did not support exemptions for Federal Motor Vehicle Safety Standards (FMVSS), and wanted additional safety standards for driverless cars.(47) This mistrust is present in the trucking industry as well, because heavy vehicle drivers often do not trust a vehicle's safety technology; simulator studies of platooning in heavy vehicles have found that driver trust and acceptance for partial automation (longitudinal automation with manual steering) and full automation (automated longitudinal and lateral control) were lower than for traditional cruise control.(48)

1.5 EFFORTS TO PROMOTE VOLUNTARY ADOPTION OF AEB

1.5.1 Light Vehicle Efforts in the United States

Efforts to promote AEB in the light vehicle domain have resulted in a voluntary agreement among over 20 automakers to make AEB a standard technology by 2022.(49) This agreement was a joint effort by NHTSA and the Insurance Institute for Highway Safety (IIHS). The model of building a voluntary coalition among automakers originates from previous efforts by IIHS to promote safety, such as the voluntary adoption of side impact safety measures.(50) IIHS has favored these approaches in the past due to the long rulemaking process that is required for regulation. With AEB, it remains to be seen to what degree automakers will comply with the agreement, and what forms AEB will take. For example, to comply with the agreement some automakers may choose a modular approach in which AEB can be installed without other audio-visual alerts. It is also too early to tell whether car manufacturers will meet the deadline and whether the voluntary process will result in faster deployment than a regulatory approach would have.

1.5.2 Heavy Vehicle Efforts in the United States

At the present time, there is a number of renowned stakeholder groups who support the voluntary adoption of AEBs in heavy-duty trucks. These stakeholders cover private highway safety advocates, a large trucking industry organization, a large private motor carrier and public agencies. These stakeholders are shown in Table 1 below along with the source reference documenting their support and a terse summary of how they support AEB voluntary adoption

Table 1. Stakeholder groups supporting AEB voluntary adoption.

Stakeholder	Source	Comment
American Automobile Association Traffic Safety Foundation	"Leveraging Large-Truck Technology and Engineering to Realize Safety Gains" https://aaafoundation.org/wp-content/uploads/2017/09/Truck-Safety-4Report-Fact-Sheet.pdf	ADAS is cost-beneficial.
American Trucking Associations	"Update 2018 Strategic Policy & Advocacy Issues"	Advocates adoption of ADAS.
Insurance Institute for Highway Safety (IIHS)	"Large Trucks to Benefit from Technology Designed to Help Prevent Crashes" IIHS Status Report, Vol. 45, No. 5	Urges adoption of ADAS.
NHTSA	"Field Study of Heavy-Vehicle Crash Avoidance Systems" Report No. DOT HS 812 280	Says all six fleets would recommend the technology despite some false alarms, which are being reduced by OEMs using better sensors and improved software.
National Safety Council (NSC)	"Road to Zero Vision" Final Report https://www.nsc.org/Portals/0/Documents/DistractedDrivingDocuments/Driver-Tech/Road%20to%20Zero/The-Report.pdf?ver=2018-04-17-111652-263	States ADAS must be one of three core strategies to reach Vision Zero.
National Transportation Safety Board (NTSB)	"2019 Most Wanted List" https://www.ntsb.gov/safety/mwl/Pages/default.aspx	Recommends ADAS to reduce crashes.
Schneider	NTSB "Roundtable: ADAS– Strategies for Increasing Commercial Vehicle Adoption." https://www.ntsb.gov/news/events/Pages/2017-adas-rt.aspx.	Experienced 69% fewer crashes due to ADAS.

Proposed efforts to increase voluntary adoption of AEB in heavy vehicles in the United States have focused mainly on three areas:(51)

- Educating truck drivers, owner-operators, fleet managers, and fleet executives on the functionality, effectiveness, and benefits of AEB.
- Incentivizing the voluntary adoption of AEB through State and Federal tax incentives, safety ratings, insurance discounts, and preferential hiring and pricing for fleets with AEB.
- Federal regulation.

Educational efforts have thus far focused on industry events such as the Fleet Safety Conference and the Brake Safety Symposium.(52 53) The approach has been to present high-level, qualitative information about how AEB and other advanced driver assistance systems work in the real world, the types of crashes the systems are designed to prevent, and how fleets can adopt the technologies. Insurers have sponsored some additional work to help the trucking industry understand the societal costs and benefits for voluntary adoption of AEB and other safety technologies.[54 55 56 57] Research has also documented best practices for adopting advanced safety technologies.[58] As described earlier, there may be performance or trust issues among drivers, so outreach to drivers may an effective way to change perceptions or disseminate new performance information to fleets. These education efforts are not focused on assisting fleets with making cost or benefit estimates specific to their operations.

Incentives to adopt AEB could help drive deployment in a profit-oriented environment like trucking. Insurance companies do not currently offer discounts and would have difficulty pricing them appropriately in the absence of better information about AEB's benefits. The benefits may also vary from fleet to fleet depending on driver buy-in, how fleets use data collected by AEB systems, and other factors. Therefore, heavy vehicle insurers may prefer to customer premiums after the results of voluntary adoption take shape.

Preferential hiring and pricing would be a powerful motivator, but customers who contract with fleets may not understand the benefits AEB offers to them. As described above, AEB could reduce the risk of crashes and the resulting downtime, but these benefits are abstract and difficult for a customer to quantify.

State or Federal tax incentives could also be a powerful motivator of voluntary adoption, but these would likely be phased out over time, as happened with tax incentives for electric vehicles. It is also unclear how to ensure that the incentives go to fleets that have not yet adopted AEB rather than fleets that already have. In short, incentives are a powerful motivator, but any incentives would have to be carefully designed to ensure that they have the desired effect and no unintended consequences.

Given the uncertainty of insurance discounts and Federal or State tax incentives, it may be helpful to provide fleets with detailed ROI information. VTTI has a current project to develop a calculator to estimate the expected ROI of implementing AEB and other technologies. This calculator will use data from Camden et al.[59 60 61] and allow fleets to enter data specific to their operations (e.g., mileage, number of trucks, number of rear-end crashes, number of injuries and fatalities, installation cost, etc.). Calculations based on this detailed information will allow fleet executives and managers to see the financial benefits they could realize through voluntary adoption of AEB and other safety technologies. Once finalized, this calculator will be freely available, and VTTI researchers will conduct industry outreach and educational activities to disseminate it.

Though NHTSA has adopted a voluntary approach for AEB on light vehicles that is predicted to be successful, there are some who advocate a Federal mandate.[62 63] A mandate would involve rulemaking for an FMVSS to include minimum safety requirements.[64] One factor that could reduce the likelihood of voluntary adoption is the smaller number of truck manufacturers compared to car manufacturers. In the voluntary agreement between car manufacturers, IIHS and NHTSA added more OEMs to the process as momentum built, and there was pressure not to be left out. In trucking, which has far fewer OEMs, it may be less likely that one or more parties agreeing to make AEB standard would pressure others to do so. Competition for customers who do not desire AEB may also encourage OEMs to keep the feature optional.

1.5.3 Heavy Vehicle Efforts in Europe

In 2009, the European Parliament moved to mandate “advanced emergency braking systems” on commercial vehicles.(65) Per this regulation, all new commercial vehicles sold in the European Union (EU) after November 1, 2015, are equipped with AEB.(66) A similar U.S. requirement in the form of an FMVSS would be a strong driver of adoption, but rulemaking can be a lengthy process because significant effort would be required to establish guidelines, safety standards, testing protocols, and other work in support of the mandate. Additionally, the EU mandate (and any potential U.S. mandate) applies only to new commercial vehicles sold. Given the typical lifecycle of trucks in Europe or the United States, it could take a decade or longer to achieve 90 percent or greater market penetration.

1.6 SUMMARY

Despite AEB technologies being commercially available for a decade, data on precisely how and why fleets decide whether to adopt the technology are limited. Information on general industry concerns and how recent generations of AEB perform in the real world suggests a few possible barriers, but the ways fleets have attempted to deal with these or other barriers are not known. The take rates of AEB products seem to indicate that fleets continue to buy the systems and have had some success adopting them. To facilitate voluntary adoption, it would be valuable to understand exactly how fleets have adopted AEB, what barriers they have encountered, and what strategies they have enacted to address these barriers. Sharing this knowledge would allow other fleets to identify potential barriers early and learn best practices from the experiences of early adopters. This information would also give other industry stakeholders such as OEMs, AEB developers, and insurers the ability to help address barriers to voluntary adoption.

Several powerful forces could accelerate AEB voluntary adoption based on similar efforts with light vehicles, but these may not be feasible in the heavy vehicle domain. A voluntary agreement by the OEMs to make AEB standard would put the onus on fleets to “reject” the technology when purchasing vehicles, but OEMs may resist this approach because they compete for business from fleets that do not desire AEB or rather use the money that could be spent on AEBs on something else on a truck. Discounts can be a powerful motivator, but the OEM pricing mechanics are complicated and the details are considered proprietary between the OEM and their customers. Insurers may have difficulty pricing discounts if the majority of safety benefits are tied to fleet-dependent supporting activities such as training or monitoring. Government discounts would need to be applied in a way that is fair to existing or continuing adopters.

However, the fundamental issue for AEB voluntary adoption needs to be addressed: fleets may lack the tools to delineate and calculate what costs they should expect, decide which strategies to use, and understand what benefits will ultimately result. Such tools would either make AEB an attractive option or provide a clearer picture to industry of how AEB costs/benefits need to change to become attractive.

2. HEAVY-DUTY TECHNICAL BARRIERS

This report identified several technical issues following the literature review, interviews with industry stakeholders, and interviews with fleets. Discussion of these issues is organized under four topics: individual technical barriers, barriers due to multiple generations of AEB, barriers due to multiple brands of AEB, and barriers to integrating AEB data.

2.1 GENERAL AEB TECHNICAL BARRIERS

2.1.1 AEB Performance Barriers

The first barrier to the voluntary adoption of AEB is system performance. How the system performs at preventing or mitigating crashes is what helps establish an ROI, which in turn makes product voluntary adoption desirable. The performance of AEB has not been widely established, but there are several key data points that indicate it may have a safety benefit and positive ROI for fleets.

The first study investigating AEB effectiveness, sponsored by NHTSA, was published in 2013. It estimated the number of crashes AEB adoption could prevent by combining test track data on AEB performance with naturalistic data from trucks that were not equipped with AEB.(67) This method did not use real-world data on system effectiveness; it used a novel method of establishing possible AEB impacts. Based on the data and AEB performance specifications available at the time, the study estimated that AEB could prevent 16 percent of rear-end crashes. Importantly, the technology tested did not include braking for stationary objects. The study estimated that future technology developments that allow stationary object braking could prevent 28 percent of rear-end crashes. Since these estimates were made, the technology has developed in ways that were not modeled, including an increase in AEB braking power. Additionally, real-world AEB performance data were not available at the time of the study. Driver behaviors and real-world conditions could affect the effectiveness of AEB both positively and negatively.

While the efficacy numbers estimated in the aforementioned NHTSA study could be enough to make the products attractive to many fleets, there is reason to believe that individual fleets could achieve even better results. At a roundtable discussion on fleet safety hosted by the National Safety Council and NTSB, Schneider National, a large U.S. trucking fleet with more than 10,000 power units, indicated that it has seen a 69-percent reduction in number and a 95-percent reduction in severity of collisions since it began adopting AEB.(68) At the same event, AEB suppliers Bendix and WABCO indicated that these numbers are not outliers and that customers typically report reductions of about 70 percent in crash numbers and severity. While Schneider National is a large fleet compared to most of the trucking industry, its results suggest that other fleets could achieve efficacy above the 28-percent reduction estimated just a few years prior.

In 2016, the American Automobile Association (AAA) Foundation for Traffic Safety sponsored a study to estimate the societal benefits and costs of AEB using the performance estimates described above.(69) With a 28-percent efficacy rate, the societal benefits of AEB outweighed its costs even when equipping only new large trucks. As mentioned above, many carriers and manufacturers believe AEB has an efficacy rate much higher than 28 percent. Thus performance in terms of ability to provide societal benefits does not appear to be a technical barrier. This result suggests the potential ROI at a carrier-level has a greater impact on voluntary adoption rates of AEB. Even focusing solely on carriers' ROI, though, the potential for individual fleets to exceed a 28 percent efficacy seems to indicate that most fleets would have a positive ROI from AEB. This suggests that performance aspects other than efficacy may be a barrier to voluntary adoption.

Another potential barrier related to the technology's performance could be false or annoying system-generated alerts. From 2013 to 2016, NHTSA sponsored a large collection of field data to try to understand how AEB and related audio-visual activations performed in the real world.(70) The study covered 150 trucks, 169 drivers, and approximately 2.5 million driven miles of data from across the United States. The study was not aimed at calculating safety benefits, but instead focused on observing AEB operation and documenting it for other modeling efforts. The study did not observe any rear-end crashes on AEB-equipped trucks. A total of 264 AEB activations were observed, and through examination several false activations were identified. Additionally, some AEB activations occurred in non-critical situations. The timing of these false activations was relatively short, leading to less braking and less speed reduction compared to valid AEB activations. The brevity of these activations should mitigate some concerns. While the sample of AEB activations was small, these experiences throughout fleets may have negative impacts on driver or fleet perceptions of the technology. These negative perceptions may affect voluntary adoption in smaller fleets.

Another potential barrier is rooted in a difference between how large and small fleets measure their crash risk. AEB suppliers have observed that some small fleets recognize AEB's efficacy in preventing or mitigating crashes but are hesitant to adopt the technology because of a perceived low exposure to crash risk, which reduces the net advantages of purchasing AEB. While a fleet's exposure to crashes may be lower due to a relatively small number of trucks, each individual truck is exposed to the same crash risk as any other truck based on its miles traveled and other factors. Large fleets may enjoy some economies of scale from having dedicated safety departments to integrate fleet management technology with data from AEB systems, but the basic ROI proposition for an individual truck being equipped does not appear to be significantly different for large and small fleets. This may be a sign of a significant market barrier rather than a technical barrier, and it will be investigated further for discussion in Chapter 5 (Heavy-duty Market Barriers). A related consideration is how fleets pay for their liability. Larger fleets that are partly self-insured can see an immediate ROI, while fleets that are insured by an outside company may need to wait for one or more policy renewals to see the benefit. This also points to a potential market barrier that will be discussed further in Chapter 5.

Overall, there do not appear to be major technical barriers related to individual system performance. False alerts are a valid concern, but from the limited field data available, they appear to be rare events resulting in less vehicle deceleration than a typical AEB activation. The issues with individual performance may instead be issues with awareness of the systems' effectiveness, of how false activations actually affect the vehicle, and awareness of exposure to high risk of scenarios requiring sudden stopping that should be weighed against performance.

2.1.2 Audio/Visual Alert Performance Barriers

Another potential technical barrier is the performance of AEB audio/visual alerts. As discussed in the literature review, AEB has evolved in parallel with audio/visual alert systems that use the same sensor technologies. When AEB began to reach the market approximately 10 years ago, existing audio/visual alert packages were included with AEB. These audio/visual alert packages are still included with AEB and, to date, cannot be separated from AEB products. The performance of these audio/visual alerts may influence driver or fleet perception of AEB performance. However, as with AEB performance, there is little real-world alert performance data available from which to draw conclusions.

Like AEB performance, the main source of data on audio/visual alert performance is from the NHTSA study conducted from 2013 to 2016.[(71)] The study sampled audio/visual alerts to evaluate performance, and found several concerns. First, the most severe type of audio/visual alert, called Impact Alert, was observed to have some false activations. Second, Stationary Object Alerts (which did not include braking) were observed to be mostly false activations triggered by overpasses, overhead signs, and guardrails. Finally, Lower Level alerts for following distance or lane departures were accurate but occurred with high frequency, potentially annoying drivers. These issues with audio/visual alerts cannot be separated from AEB performance, because the alert systems are included with AEB products. Because alerts occur with greater frequency than AEB activations, drivers typically experience many audio/visual alerts before experiencing an AEB activation. Dislike of these alerts can spill over to damage users' perception of the entire system, potentially reducing AEB voluntary adoption rates.

These issues can be approached from the user side through education, training, or incentives. These approaches will be discussed in Chapter 5. The market approaches focus more on changing perceptions of existing performance or establishing the benefits of existing performance levels. Another approach is to make technical improvements to reduce false AEB activations and the frequency of low-level alerts. The NHTSA data on audio/visual alert performance reflect the "previous" generation of AEB. New systems, which have become available since 2016, may already be addressing these concerns. The Wingman Fusion AEB product from Bendix, for instance, has added camera integration, which may improve object detection and reduce false activations. Other brands such as OnGuard and Detroit Assurance have updated their radar algorithms in ways that may reduce false alerts without additional camera integration. For now, though, no data are publicly available to confirm whether these updates have improved alert performance. Additionally, it is unclear whether updates to reduce the frequency of low-level alerts have been made.

At the time the NHTSA study was conducted, AEB system manufacturers offered only limited options for customizing how AEB activations and audio/visual alerts were generated. The Bendix Wingman Advanced product offers 10 different alert profile configurations. These are factory set and typically are not changed by a fleet after delivery. Some fleets that were interviewed were not aware that these configuration options existed and accepted the "default" configuration when ordering new trucks. Making these configurations easier to adjust, or even adjustable by the driver, could help address some market barriers related to perception and desirability. On the other hand, greater customization leaves open the possibility of reduced safety benefits if the system parameters are changed from the default settings. The potential trade-offs will be investigated further and discussed in Chapter 5.

2.1.3 Human-Machine Interface Barriers

Another potential technical barrier is the method that individual systems use to alert drivers, either during AEB activations or during audio/visual alerts. The audio, visual, or physical feedback mechanisms could be affecting overall perception or acceptance of the systems. If the method of alerting drivers is annoying or distracting, it could also have an impact on voluntary adoption of AEB in general. For example, all current brands of AEB include audio-based LDW. Often LDWs attempt to mimic “rumble strip sounds” when drivers cross a lane marking. While these alerts were relatively accurate in the field data, they are designed for the worst-case scenario.[72] They produce loud, directional noises that could urgently alert a drowsy or distracted driver. Depending on the frequency of these alerts, drivers may become annoyed at receiving loud noises in non-emergency situations. To reduce the annoyance factor, these sounds could be replaced with gentler sounds, or the systems could be redesigned to incorporate other alert methods. In the light vehicle domain, OEMs have begun to use haptic steering wheel feedback to alert drivers to lane departures. There appear to be no technical barriers to doing the same in the heavy vehicle domain, aside from cost barriers. This, along with other potential cost barriers to making product changes, will be discussed further in Chapter 5.

Some systems have already incorporated haptic feedback, but drivers may object to the specific method. The WABCO OnGuard systems use brake pulses to generate haptic feedback just before AEB is engaged as a “last warning” before automatically braking. As with AEB itself, drivers may be concerned about what to do when the brakes are pulsing. If a driver is operating under poor roadway conditions or attempting to turn or swerve during the brake pulses, new control conflicts could arise. Because AEB is integrated with stability control systems, this is less a technical than a perception barrier. Because drivers do not experience AEB often and do not have the opportunity to test the systems in different conditions, they may not be sure how AEB will behave in those different conditions. However, it may be possible to remove any concerns related to pulsing the brakes by choosing a different location for haptic alerts, such as the seat or steering wheel. Again, these present new cost barriers, the pros and cons of which must be weighed by designers and integrators.

2.1.4 Retrofit Barriers

One final topic is the technical limitations of retrofitting AEB on unequipped trucks. Most fleets adopting AEB cycle in AEB-equipped vehicles as older vehicles are cycled out. This makes AEB adoption a multi-year process even for fleets that are committed to the technology. While retrofitting AEB is theoretically possible, it is not a standardized process and is more expensive than factory installation of systems. Given that cost is already a potential barrier to voluntary adoption, retrofitting is likely feasible only to large fleets at this time. This may be a viable option in combination with other incentives to help “fill out” large fleets more quickly. There may also be a trickle-down effect. If retrofitting becomes more common in large fleets, the increased experience could allow AEB suppliers to perform installations more cheaply, thereby making retrofitting feasible for medium or small fleets. Currently, the technical barrier is the vehicles themselves, because different make/model configurations present unique challenges to retrofitting. Incentivizing retrofit activity could help jump start a “virtuous cycle” where more retrofitting technical experience is gained more quickly, driving down costs and creating demand for even more retrofits. Potential incentives that could drive this process will be discussed in Chapter 5, but likely candidates for providing incentives are insurers, the Government, or AEB suppliers themselves (accepting upfront cost to raise demand in exchange for long-term customer loyalty).

Retrofits may not offer benefits identical to those of new systems. Even if incentives were in place to drive the retrofit model, the actual performance of retrofit systems is not well understood. Older vehicles can have diminished braking capabilities, leading to degraded AEB performance. Other service procedures could become a standard part of a retrofit to ensure brake integrity, but this adds cost and reduces feasibility for smaller fleets.

2.2 TECHNICAL BARRIERS FROM MULTIPLE GENERATIONS OF AEB

AEB has changed rapidly over the last decade, with several iterations of the technology being developed by each supplier. Figure 1 shows a timeline of when each supplier released or made significant updates to their systems between 2008 and 2019.

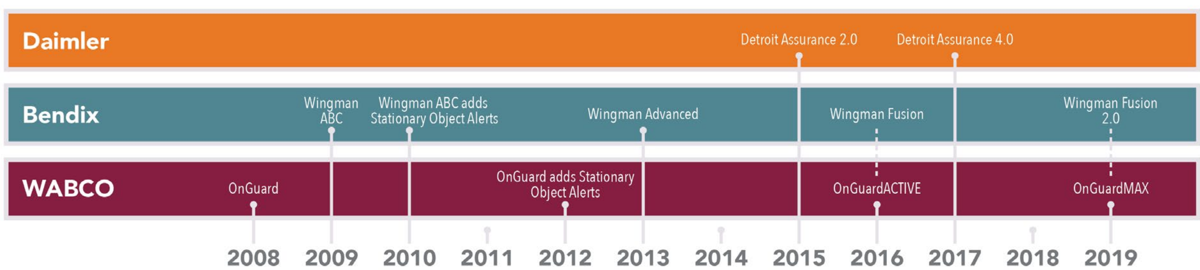

Figure 1. Timeline. AEB product releases and updates since 2008.

This rapid development has left fleets with multiple generations of AEB technology spread across their vehicles, which may make it difficult for fleets and drivers to discern the capabilities or benefits of any given version. The pace of development may also complicate purchasing decisions because some OEMs now offer multiple generations in a tiered approach. To illustrate, suppose a fleet purchases new vehicles and keeps them for 3 years before selling, which corresponds to the warranties most OEMs provide on engines. That fleet would have trucks from 2015 to 2018 (as of the date of this report), an interval which spans two generations of AEB from all three suppliers. If a fleet was on a 5-year replacement cycle, which corresponds to warranties OEMs provide on most non-engine components, the issue could become more pronounced. If the fleet bought Bendix or WABCO products, then they would still likely have two generations, but a larger proportion of their fleet would be an older generation of product. The differences between the generations may make it more difficult for fleets to estimate ROI and result in confusion among their drivers about performance. Finally, if a fleet was on a 7-year replacement cycle, corresponding to the length of time before major component maintenance is usually performed, it would likely have three generations of the technology on trucks from 2011 to 2018.

The staggered availability of OEM AEB and third-party AEB adds another degree of complexity. Suppose a fleet began purchasing Freightliner Cascadia trucks before 2014. Because the Detroit Assurance system was not available on Freightliner trucks prior to 2014, the fleet could have multiple brands of AEB as they buy newer trucks from the same OEM but retain older trucks with third-party systems. In the 7-year scenario described above, the fleet could be using two generations of Detroit Assurance in addition to two generations of older WABCO and Bendix products.

These generational differences in AEB products within fleets could cause confusion over performance. If fleets are confused over performance, they could struggle to estimate ROI on the technology in general or to decide which version of AEB to adopt. Confusion over performance could also lead to lower safety outcomes with drivers, further reducing the ROI potential of the technology. As discussed earlier, manufacturers have updated their products with hardware changes, software changes, or both in attempts to make improvements. For example, the Bendix Wingman Advanced product applies up to two-thirds braking authority on the truck, while the Bendix Wingman Fusion product applies up to 100-percent braking authority. The Wingman Advanced provides only audio/visual alerts in response to stationary objects, while the Fusion provides stationary object automatic braking. The Fusion's camera system also adds speeding alerts based on the camera's reading of speed limit signs. These are examples from just one product; WABCO and Daimler have made similar updates to their OnGuard and Detroit Assurance systems in recent years. At the driver level, this can lead to confusion about when the vehicle will brake, how hard the vehicle will brake, and what kinds of targets it will brake for. At the fleet level, management may not understand the incremental ROI of adding additional braking power, or the ROI of braking for additional objects.

While generational system differences are mostly a market barrier, there are some technical actions that could help address them. Retrofitting could upgrade the existing AEB on a given truck to the latest product and make the technologies on a fleet more homogenous. In some cases, this could be done via software update, such as updating an OnGuard system to OnGuardACTIVE. In other cases, it could require a hardware update, as with Wingman Advanced to Wingman Fusion. However, as discussed earlier, retrofits involving hardware are not standardized, are highly dependent on fleet composition, and are more expensive than factory-installed systems. Again, there is the possibility of incentivizing the jump-start of the technical knowledge acquisition required to upgrade AEB via retrofit, but it is unclear how to perform the ROI calculations for this kind of activity. Additionally, the safety benefits from focusing efforts on retrofitting non-equipped vehicles could exceed those from attempting to upgrade systems on already-equipped vehicles.

In general, it may be difficult to justify the cost of upgrading systems via hardware retrofit. There is potential to address concerns about false activations or annoyance alerts through software updates, but this could also have downsides. The ability to update could lead to more frequent updates, and if trucks are not on scheduled maintenance programs, this could create even more differentiation between products in a fleet. The final result would be many smaller differences instead of a few large differences.

Ultimately, the need for improvements must be balanced with user expectations and realistic schedules for updating trucks. Providing clear and easy updates on the technical side would need to be accompanied by training and education updates on the market barriers side. This joint activity would help ensure that products are designed to meet a driver's needs, and that a driver's expectations match their vehicle's functionality.

2.3 TECHNICAL BARRIERS FROM MULTIPLE BRANDS OF AEB

There are many differences between AEB brands. As discussed in the previous section, many early AEB adopter fleets are also relatively large. These larger fleets typically have a mix of vehicle makes and models, and in turn a mix of AEB products. While AEB brands are not exclusive on most truck models, certain brands are factory integrated by certain OEMs and are therefore more common. Just as different generations of product could lead to issues and barriers to voluntary adoption, so too could brand differences within the same fleet. In addition to design differences, there may also be performance differences. In the NHTSA field study of AEB products, the two evaluated brands seemed to have different approaches to alerting for and activating AEB. One brand showed a higher rate of false activations but relatively few "advisory" activations in non-critical situations. The other brand showed a low false activation rate but a relatively higher rate of "advisory" activations in non-critical situations. This difference extended into Impact Alerts, the most severe type of audio/visual alert that the systems produced. Based on this limited amount of field data, it seems that drivers using different brands of AEB could have different experiences. If a driver switches truck brands, either within a fleet or between fleets, there may be issues with expectations and acceptance. The technical means of dealing with these issues are limited, but there are a few approaches that may be feasible. First, the ability to change settings could help mitigate these issues by allowing drivers to customize how their AEB systems behave. Second, AEB suppliers could decide to standardize some aspects of their operations.

Some consistency in how AEB and the supporting alerts work could ultimately have safety benefits by speeding voluntary adoption and improving driver reactions to activations. At the American Trucking Associations (ATA) Technology & Maintenance Council's 2018 Annual Meeting, Fred Andersky, Director of Customer Solutions–Controls for Bendix, discussed these topics at a high level, suggesting that greater consistency between designs could lead to better safety outcomes.(73) He used the example of air brake control modules in trucks, which have a high degree of visual consistency but are integrated differently in each vehicle. But despite acknowledgement of the issue, there are no indications that suppliers or OEMs are actually moving toward greater consistency, perhaps due to concerns over competitive advantages. Additionally, the pace of product development has been rapid in AEBs, and suppliers may worry that customization or standardization could stifle new developments. Customization adds a new level of interaction that designers must plan for, while standardization could limit how new features are implemented. There are also costs to adding customization or changing operation to meet self-imposed standards, and the benefits to individual suppliers for doing so are unclear. This is an opportunity for technical organizations such as the Technology & Maintenance Council or SAE to lead efforts to develop standards. AEB suppliers and OEMs are already involved in these organizations, and their ability to engage in development of standards will be explored further in Chapter 5.

2.4 TECHNICAL BARRIERS TO INTEGRATING AEB DATA

One key source of value from AEB is the visibility of the data it produces. Some products can integrate with a fleet's management software, allowing tracking of AEB activations or other alerts. Some AEB systems integrate with driver monitoring systems, allowing generation of training events based on AEB activations. Some AEB suppliers also provide trainable events to safety managers as a paid service. While these activities can provide additional value to fleets, subscribing to the service and acting on the data can require additional fleet resources. Larger fleets are better able to take advantage of this feature because they have more sophisticated management systems, full-time safety personnel to review data, and financial resources to pay for subscriptions.

Smaller fleets may have difficulty accessing the data from AEB, filtering the data from AEB to find actionable information, and effectively acting on that information. The first two issues are potential technical barriers, while effective action is more of a market barrier and will be discussed in Chapter 5. With the mandate for electronic logging devices (ELDs), there is a new avenue for management to interact with drivers based on AEB feedback. For example, some ELDs can alert management when AEB messages are detected over the vehicle network or help organize AEB data by driver logs for management review.

3. MEDIUM-DUTY TECHNICAL BARRIERS

While AEB can be purchased on most models of heavy-duty trucks, its availability is more limited in medium-duty trucks, including classes 4, 5, and 6. The main technical reason for this may be the availability of stability control. Stability control is mandated for heavy-duty trucks but not for medium-duty trucks. Most OEMs and AEB suppliers consider stability control a required technology for AEB, and currently do not sell AEB on medium-duty trucks unless stability control is installed. AEB developers also make the stability control systems, and essentially pair their stability control and AEB systems.

Stability control systems are developed based on specific brake technologies. Both WABCO and Bendix have developed their stability control technologies based on air brakes, and neither offers systems compatible with hydraulic brakes. For economic reasons, Bendix does not appear to be developing a stability control system compatible with hydraulic brakes, while WABCO may be developing one in the near future. Based on this information, hydraulic brakes could continue to be a technical barrier for the near future, and potentially in the long term, unless the economic viability of developing stability control for medium-duty hydraulic brakes changes.

Another important consideration is the different body types and vocational applications of medium-duty trucks. Many medium-duty trucks are manufactured in a two-step process, with OEMs producing the chassis and a third party installing a body. The benefits of stability control depend on the body type and application of the particular truck. Examples at the ends of the medium-duty spectrum are rear discharge concrete mixers, which may have stability issues due to the rotating drum on the back, and dump trucks, which are relatively stable. There may be an opportunity to increase AEB voluntary adoption if OEMs had chassis specifications for different applications (e.g., a discrete “concrete mixer” specification), which could help increase voluntary adoption in vocations where it might have the highest impact. But this solution depends on OEMs knowing what application a chassis will be used for. Frequently, they may not. Similarly, if the end user deals only with the body manufacturer, the user may not know that the manufacturer offers AEB.

Ultimately, different body types appear to be more of a market barrier than a technical barrier. While different body types can significantly affect characteristics such as mass or center of gravity, this is also true of class 8 vehicles, where different trailer types or loads can affect vehicle dynamics. Different loads are not a technical barrier in class 8, and likewise would not be a technical barrier in medium-duty if stability control were also included. This is evidenced by the number of medium-duty models for which AEB (including supporting technologies of air brakes and stability control) is currently available. Models include medium-duty vehicles manufactured by Navistar, Peterbilt, and Kenworth (see references 74, 75, 76, and 77). During discussion, Navistar and PACCAR mentioned that some additional technical barriers needed to be overcome, such as wiring limitations, vehicle network limitations, and vehicle dynamics questions. Both OEMs agreed that these barriers can be solved with application of resources.

The main issue that seems to be causing voluntary adoption to lag is not a technical barrier, but cost. There are several factors associated with medium-duty trucks that make AEB less attractive from an ROI perspective. First, medium-duty vehicles often cost less than class 8 vehicles, but AEB technologies generally cost the same. As discussed above, cost is a known issue limiting voluntary adoption in class 8 vehicles, and the relative costs of medium-duty vehicles magnify this issue. Further, the majority of medium-duty fleets are small, and voluntary adoption of AEB among small fleets lags behind the voluntary adoption rates of large fleets. The vocational differences described above also affect attractiveness; fleets may know that certain vehicles are relatively stable or spend little time in environments where AEB could be beneficial. Reduced exposure to conditions where stability control or AEB could prevent collisions may, in turn, reduce the potential benefits. Finally, some vocations for medium-duty trucks may involve more time operating in environments that are prone to damaging sensors. The potential for sensor damage, misalignment, or out-of-service time to remedy issues increases the total costs of operating trucks with AEB in hazardous environments. Together, these issues may be significant market barriers to AEB voluntary adoption in medium-duty trucks, even if stability control and AEB were available on all models. Chapter 6 (Medium-duty Market Barriers), will address these issues further, along with ways industry sees these costs being mitigated.

Another important note is that even where available, medium-duty AEB technology is a generation behind heavy-duty AEB. For example, Navistar and Kenworth offer the Bendix Wingman Advanced product on their medium-duty trucks rather than the more robust and up-to-date Wingman Fusion product available on class 8 vehicles. This can be both beneficial and detrimental to voluntary adoption. Based on discussions with suppliers, fleets that are mixed between medium-duty and heavy-duty have a higher voluntary adoption rate than purely medium-duty fleets. This could partly be due to familiarity with the product; the products available for medium-duty vehicles have been available on their heavy-duty counterparts for several years. At the same time, these generational differences could contribute to the issues of confusion or mistrust described earlier. Additionally, if fleets prefer the latest versions of the technology, they may wait to adopt AEB on medium-duty trucks until the latest versions also become available there. As noted earlier, hardware retrofits are expensive and infeasible for all but the largest fleets.

Another technical barrier is the potential for third-party modifications. In general, OEMs manufacturing medium-duty vehicles do not know what applications the vehicles will be used for. As mentioned earlier, the type of body may not be a technical barrier by itself, but it does lead to more complexity in this segment of the market. While OEMs may be able to update their designs to allow for AEB, they may not know what kinds of modifications are required for specific applications. These modifications may affect the wiring, vehicle network, or other physical aspects of the vehicle (like an attached snowplow) that impact sensors. The result is a disconnect between OEMs and AEB developers. The two groups are not in a position to anticipate the exact impacts of these modifications, let alone come up with solutions to address problems.

This disconnect appears to be primarily a market barrier; it arises from how customers specify and purchase vehicles rather than from how the technology itself works. Currently there are no data available on the performance of AEB on medium-duty trucks, though discussions with suppliers have indicated that they do not expect a performance difference between systems installed on heavy-duty and medium-duty classes. Suppliers have also indicated that medium-duty fleets do not seem concerned about safety performance. Like the small heavy-duty fleets, medium-duty fleets may believe their exposure to rear-end crashes does not justify the cost of AEB. As discussed above, this may actually be true, and there are not yet sufficient tools for understanding how AEB benefits could change based on different environments. If such data were available, it might be possible to demonstrate the ROI for specific applications and improve voluntary adoption in some segments of the medium-duty vehicle market. At present, there is no clear method of obtaining this data, or evidence suggesting which segments should be targeted for voluntary adoption.

The technical barriers to AEB in medium-duty trucks due to hydraulic brakes will be difficult to overcome. The developers are currently split on the economic viability of developing stability control systems compatible with hydraulic brakes, and even if they believe the systems may be viable, it is unclear whether they will follow through with any products. Extending the requirement in FMVSS 49 CFR. § 571.136 for stability control on heavy-duty trucks to cover medium-duty trucks could address this problem, but the process may not allow for accelerated voluntary adoption, and the industry may be resistant to the change. Pushing for air disc brakes—or the improved stopping distances associated with air disc brakes—could also help solve the technical barriers but may face similar issues of timing or resistance. Identifying the body types or vocations that are most likely to benefit from stability control or AEB and promoting the technology in these sectors could help push OEMs and developers to ease voluntary adoption. However, medium-duty is generally a smaller market segment for manufacturers, meaning there is less demand-driven incentive.

The technical barriers in medium-duty trucks may need broader, longer-term solutions to drive voluntary adoption, because the complexity, costs, and low existing voluntary adoption in this segment could reduce the impact of smaller efforts. As will be discussed in Chapter 6, there may be some market barriers and mitigating actions within specific vocations, but the technical barriers may still limit the success of any efforts to promote the technology at the fleet level.

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4. APPROACHES FOR MITIGATING TECHNICAL BARRIERS

Based on the available literature and discussions with industry, there do not appear to be major technical barriers to voluntary adoption in class 8 vehicles. The limited available evidence points toward the technology being effective and to fleets understanding its effectiveness. The major barrier appears to be on the fleet side, and to be grounded in the difficulty of calculating ROI or its constituent factors, such as crash risk. Industry believes that mitigating these barriers would have the largest impact on AEB voluntary adoption. Potential actions will be explored in Chapter 5.

Still, there are technical aspects that could increase voluntary adoption. Desirable improvements include making AEB operation more consistent among brands and generations of products, developing improved interfaces for alerting drivers, and integrating AEB more smoothly with other technologies. Based on conversations with industry and fleets, it is unclear whether these issues are actually affecting voluntary adoption, but they are still factors that could impact safety benefits in the real world. Based on conversations with industry, a technical committee such as one of the Technology & Maintenance Council task forces could be the most appropriate avenue for addressing these concerns.

Overall safety benefits may also be suffering from misunderstandings or insufficient training in technical operation. These issues will ultimately need to be addressed through fleets, but there may be an opportunity for the Federal Motor Carrier Safety Administration (FMCSA) to provide tools to help address these issues. Chapter 5 will explore the needs of fleets more closely and examine how drivers become misinformed or develop negative attitudes toward AEB products.

Finally, there are technical barriers to AEB voluntary adoption in medium-duty trucks that will need to be addressed before voluntary adoption can improve. Having ESC as a standard technology, either through OEM action or a regulatory requirement, would eliminate one barrier to making the technology more widely available. The benefits of AEB are hard to predict for medium-duty vehicles; due to varying operating environments, medium-duty vehicles may be exposed to varying levels of rear-end crash risk, and these levels may be significantly different from those for heavy-duty vehicles. As in the heavy-duty market, there may be issues with the perception of risk rather than the perception of effectiveness. It may be possible to create operational profiles specific to lower-speed or off-highway conditions, which would address perception barriers related to effectiveness. However, as in the heavy-duty classes, this barrier may be better addressed through market mechanisms or tools to help fleets understand their risk. Solutions must also contend with the reality that the market for medium-duty is smaller than that for heavy-duty, and technical solutions in medium-duty classes may not be a priority for OEMs or suppliers with limited resources.

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5. HEAVY-DUTY MARKET BARRIERS

Several market issues were identified that may affect the voluntary adoption of AEB in heavy-duty vehicles. The issues described in this report come from the literature review, interviews with industry stakeholders, interviews with fleets, and a roundtable discussion of AEB voluntary adoption issues conducted with member fleets of the ATA's Technical Advisory Group (TAG) on July 10, 2018. ATA's TAG consists of approximately 30 fleets and provides guidance on many industry issues related to commercial motor vehicle technology and engineering. More in-depth surveys were conducted with three members of ATA's TAG to gain further information about their AEB decision-making and experiences. Discussion of the identified market barriers is organized into the three following sections: fleets' risk exposure and tolerance, ROI, and driver acceptance.

Before addressing barriers and interventions, it is worth discussing the current market penetration of AEB into the U.S. fleet. AEB suppliers have published snapshots of their sales, which can be used to build rough estimates of total units in the market. In March 2017, WABCO announced that total sales had reached 130,000 units.(78) Also in March 2017, Bendix announced that over 200,000 vehicles were equipped with collision avoidance technology.(79) Based on conversations with Bendix, about half of these were older systems without always-active AEB and may not be appropriate to include in estimations. In July 2017, Daimler published that its New Cascadia (equipped with Detroit Assurance 4.0) was seeing a take rate of 59 percent, compared to a 25-percent take rate on the older Cascadia (Detroit Assurance 2.0).(80) Given that retrofitting was not available or was a negligible part of voluntary adoption, it can be assumed that all of these sales were on new vehicles.

Information from WABCO, Bendix, and Daimler can be used to estimate how voluntary adoption has changed over time and what portion of the U.S. fleet is currently equipped with AEB. Table 2 shows the number of new class 8 trucks sold by year since 2009,(81 82 83) an estimate of how the take rates have changed over time, and an estimate of how many AEB units were sold in each given year. The estimated take rates extrapolate backward from 2017 through approximate take rates during the introduction of the technology around 2009. The extrapolated take rates are rough estimates meant to help visualize how the industry may have reached the currently known sales data and take rates described above.

Based on these estimates, approximately 352,973 AEBs have been sold to date. The most recently available data for the size of the U.S. class 8 fleet was 2,752,043 trucks in 2016.(84) Assuming that this number did not change significantly from 2016 to 2017 (since new vehicle sales did not change significantly), this would give an estimate that 352,973 of 2,752,043, or 12.8 percent, of class 8 trucks in the United States were equipped with AEB in 2017. Note that this estimate does not consider any AEB-equipped vehicles that may have left the U.S. fleet due to attrition. AEB is a fairly new technology and most voluntary adoption has taken place within the last 7 years, so most AEB-equipped vehicles are likely still in use, though not necessarily with their original owners. Fleets purchasing used AEB-equipped trucks may also disable the systems, which is not accounted for in this estimate.

Table 2. New class 8 truck sales, estimated take rates, and estimates of AEB sold by year.

Year	New Class 8 Truck Sales	Estimated Take Rate	Estimated AEB Sold	Estimated Cumulative AEB Sales
2009	94,790	1%	948	948
2010	107,140	3%	3,214	4,162
2011	171,350	5%	8,568	12,730
2012	194,710	10%	19,471	32,201
2013	193,010	15%	28,952	61,152
2014	220,340	20%	44,068	105,220
2015	248,730	30%	74,619	179,839
2016	192,520	40%	77,008	256,847
2017	192,252	50%	96,126	352,973

Given an estimated 12.8 percent of current class 8 trucks equipped with AEB and improving take rates, it is clear that the long useful lives of these vehicles has slowed penetration. This longevity is why a swift increase in the percentage of AEB-equipped trucks on the road depends on a high take rate for new trucks. New trucks that are purchased now without AEB could continue to operate for many years without the benefits of the technology.

5.1 RISK EXPOSURE AND TOLERANCE

One market barrier that appears to be affecting AEB voluntary adoption in heavy vehicles is the difficulty of calculating crash risk and its potential impact on a fleet. A key argument for AEB being a worthwhile investment is that it can reduce the probability of a vehicle being involved in a rear-end crash or mitigate the severity of a rear-end crash. In Chapter 2 (Heavy-duty Technical Barriers), it was noted that several fleets have reported reductions in both number and severity of rear-end crashes due to voluntary adoption of AEB. These fleets have a large number of trucks and therefore a visible, readily quantifiable exposure. A smaller fleet operating fewer vehicles is likely to experience fewer crashes and have less data to work from in calculating future crash risk and costs. Even so, a smaller fleet's per-truck risk may be similar to that of larger fleets. A crash may also have more serious consequences for a small fleet's business than it would for a large fleet's business. High-profile crashes could lead to loss of clients, loss of revenue-producing vehicles, or protracted litigation that drains company resources that a small fleet is less able to spare. Each of these situations could affect a small fleet more than a large fleet, especially if it is a dedicated carrier or specialized in their operations. A small fleet's exposure to crash risk may be similar, but its financial or business risk may be greater.

One other important consideration is that crash risk and liability risk may not coincide. Crash risk (the potential for a collision and the potential human and property consequences of that collision) may differ from a fleet's exposure to liability (the chances of being liable and the amount for which it is liable). Liability can vary based on crash severity, but it can also vary based on the size of the fleet involved in the crash, actions of the driver (even if they do not directly contribute to the crash), or the environmental conditions in which a crash takes place.[(85)] A fleet's reduction in crash risk does not necessarily correspond to a meaningful reduction in its liability. For example, a fleet that is involved in a severe injury crash rather than a fatality crash may still be liable for enough damages to put the business at risk. Therefore, the decision to install AEB that could mitigate a fatality crash down to an injury crash may not meaningfully reduce liability exposure—even though it reduces crash risk. Conversely, proactively adopting AEB or other safety technologies may reduce liability due to negligence by encouraging a proactive, positive safety culture within the fleet. At present, there does not appear to be any clear information available to fleets on whether and to what degree AEB technologies could affect liability.

To illustrate the difficulty in estimating liability risk, consider a recent crash involving a heavy vehicle and a large judgments against a fleet. In 2018, Werner Enterprises was successfully sued for almost $90 million when a student truck driver in Texas was involved in a crash in which the other involved vehicle lost control in icy conditions and crossed the median into the path of the truck.[86] The plaintiff's lawyers successfully argued that 1) the fleet had not communicated a National Weather Service warning for icy conditions, 2) the fleet had assigned the student driver a just-in-time load that encouraged driving too fast through icy conditions, and 3) the driver did not follow State commercial driver's license manual procedures to slow down and pull over during such conditions. The plaintiff's lawyers further argued that had the truck driver slowed down and pulled over, the crash would not have occurred. It does not appear, from the description of the events, that this was a situation AEB is designed to mitigate. Even if AEB had been activated and mitigated the situation, there likely still would have been a judgment against Werner based on the reasons listed above. Cases like this illustrate why AEB might not lead directly to liability reduction, making the potential benefits less clear.

Another potential liability risk was discussed at ATA's TAG meeting. Several fleets believed that the data available from AEB could open a fleet to liability if the data were collected but not actively used. For example, if a driver had a history of AEB activations and was involved in a collision, AEB data could be used against a fleet in litigation to argue that the fleet was negligent. In other words, a plaintiff could argue that the fleet did not do its due diligence to address the driver's AEB activations. This could be extended to other types of activations provided by other integrated safety systems, such as lane-departure warnings or following-distance alerts. Fleets may be concerned that they will need to invest significant resources in safety programs to use data from AEB if they choose to adopt the technology.

Fleets may benefit from more information on best practices regarding data usage that could reduce liability risk. Insurers who have a broader knowledge of collisions and liability may be good candidates for identifying data use practices and conducting outreach, helping clients understand whether and how voluntary adoption could impact liability. The issue could also be approached by engaging with industry groups to develop data use guidelines or best practices. Developing some standard practices for using data from AEB, such that fleets can point to compliance with these best practice standards, may reduce perceptions of liability risk. If the guidance comes from well-established industry organizations, it may also reduce actual risk by becoming industry standard. There may be similar concerns regarding driver training and liability for improper training, outdated training, or inconsistent training. Partnership with industry groups may provide a path to engagement to develop guidance that can reduce liability risk through industry-accepted best practices.

The logistics behind crash risk and liability risk are complex and difficult to address. Rather than attempting to realign crash risk and liability risk, it may be more feasible to attempt to understand the performance of AEB in terms of liability risk and then better communicate this benefit to fleets. While crash risk is still valuable information that can help policy makers and researchers, liability risk may be the language that speaks to the realities of the trucking industry. One potential avenue for this is to investigate AEB performance in conjunction with driver monitoring technologies. Camera-based driver monitoring technologies typically offer a reduction in liability risk, and until recently did not include active safety systems. Cameras capture driver behaviors to demonstrate that a fleet is not liable, or to reduce legal costs when it is liable. Traditional camera monitoring systems do not typically warn drivers or physically intervene to avoid a crash. Newer systems may be able to do both, either by integrating driver monitoring and AEB into a single product or by sharing data to allow AEB events to trigger recordings. This combination of technologies has the potential to further reduce liability and may be an effective avenue for increasing voluntary adoption.

5.2 RETURN ON INVESTMENT

A key factor for all technology purchasing decisions in the trucking industry is the potential ROI. ROI was repeatedly mentioned in every interview with OEMs, industry stakeholders, and fleets as the main barrier limiting voluntary adoption of AEB. There are several factors that influence ROI, each of which is discussed below.

5.2.1 Calculating ROI

Before discussing specific factors that may affect ROI, it is worth reviewing what information fleets should incorporate into ROI calculations, what information is particularly challenging to calculate and incorporate, and how tools may be able to assist in the calculation. ROI calculations involve several sets of costs, including:

- Equipment costs:
  - Unit cost of system.
  - Number of trucks equipped.
  - Financing of system (years to be financed, annual interest rate).
  - Depreciation schedule.
- Driver and management costs:
  - Driver pay.
  - Manager pay.
  - Fringe benefits.
  - Training hours.
  - Overhead.
- Maintenance costs:
  - Technician labor.
  - Out-of-service time.

- Replacement parts.

These costs could relate not only to AEB systems themselves but to activities such as driver monitoring, driver training, and incentives programs related to AEB. As discussed below, some of these costs are difficult to quantify, or may relate to activities that have uncertain benefits. To measure offsets to these costs, the ROI calculation should account for several factors, including:

- Crash risk:
  - Crash rate per vehicle miles traveled.
  - Crash severity.
  - Crash type.
  - Crash costs.
  - Value of cargo.
- Insurance costs:
  - Self-insurance versus outside insurer.
  - Deductibles.
- Litigation costs.

Several of these benefits and costs, such as training costs, litigation costs, and insurance costs, are difficult to quantify. For example, fleets that have adopted AEB and have seen benefits in their crash risk may not see changes to their insurance premiums for several more years. There may also be difficulties estimating the potential reductions in number and severity of crashes. It may be difficult to quantify exposure to rear-end crashes, estimate reductions in number or severity of crashes separately, or quantify the benefits of a mitigated crash. In VTTI's follow-up survey with three members of ATA's TAG, all three fleets indicated that training costs were very important in their decision-making. But none quantified the costs of the training, or they considered the costs as negligible because the supplier provided the materials. The three fleets did not report safety benefits in terms of absolute reductions in crashes. Finally, one fleet did not report a purchase cost, while the second fleet quoted a price that was 50 percent higher than the third. These potential information gaps highlight the value of tools to assist fleets in calculating their own costs and providing information where general industry data are difficult to obtain.

As the following sections will illustrate, the complexities of calculating ROI for AEB may be an important barrier to voluntary adoption. The barrier may be especially significant for small fleets. The creation and dissemination of ROI tools to help fleets structure their thoughts about AEB and quantify abstract factors could benefit small fleets and help reduce barriers to voluntary adoption.

VTTI has already developed a tool to help fleets calculate the ROI on advanced safety technologies as part of its work with industry in the National Surface Transportation Safety Center for Excellence. This ROI tool is a customizable calculator that allows fleets to enter information about their own operations or, if they are unsure about their own data, use national averages (Figure 2). This enables fleets to understand the ROI that different technologies may have within a specified timeframe (Figure 3). The tool is also able to estimate the payback period and cost/benefit ratio for comparison to other technologies. This tool will be available to the public once VTTI's internal review is completed. The development, marketing, and distribution of tools such as VTTI's ROI calculator could help fleets understand the potential ROI of safety technologies and help them compare safety technologies to other investments.

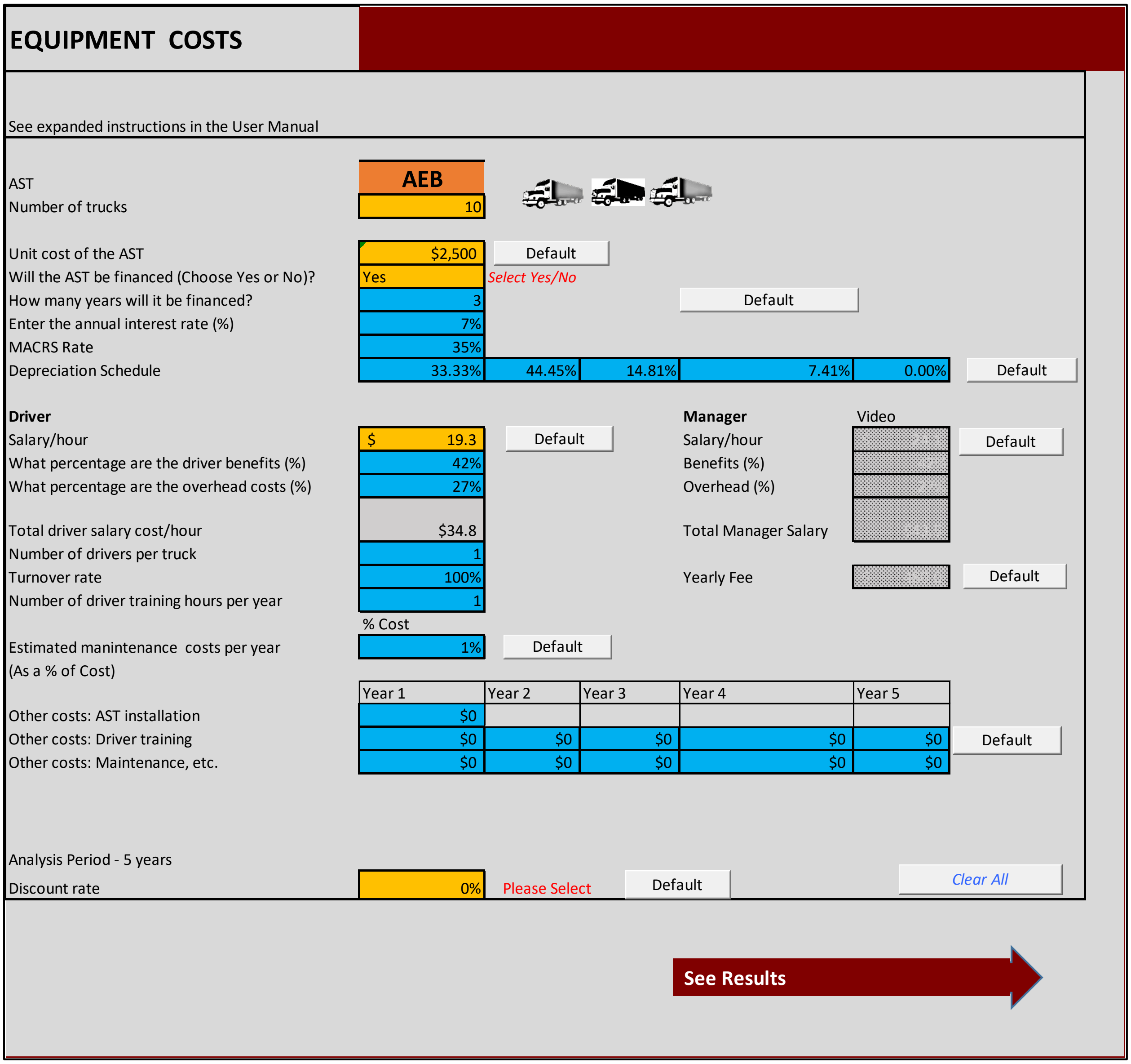

Figure 2. Screen capture. Image of VTTI's ROI tool allowing input of equipment costs.

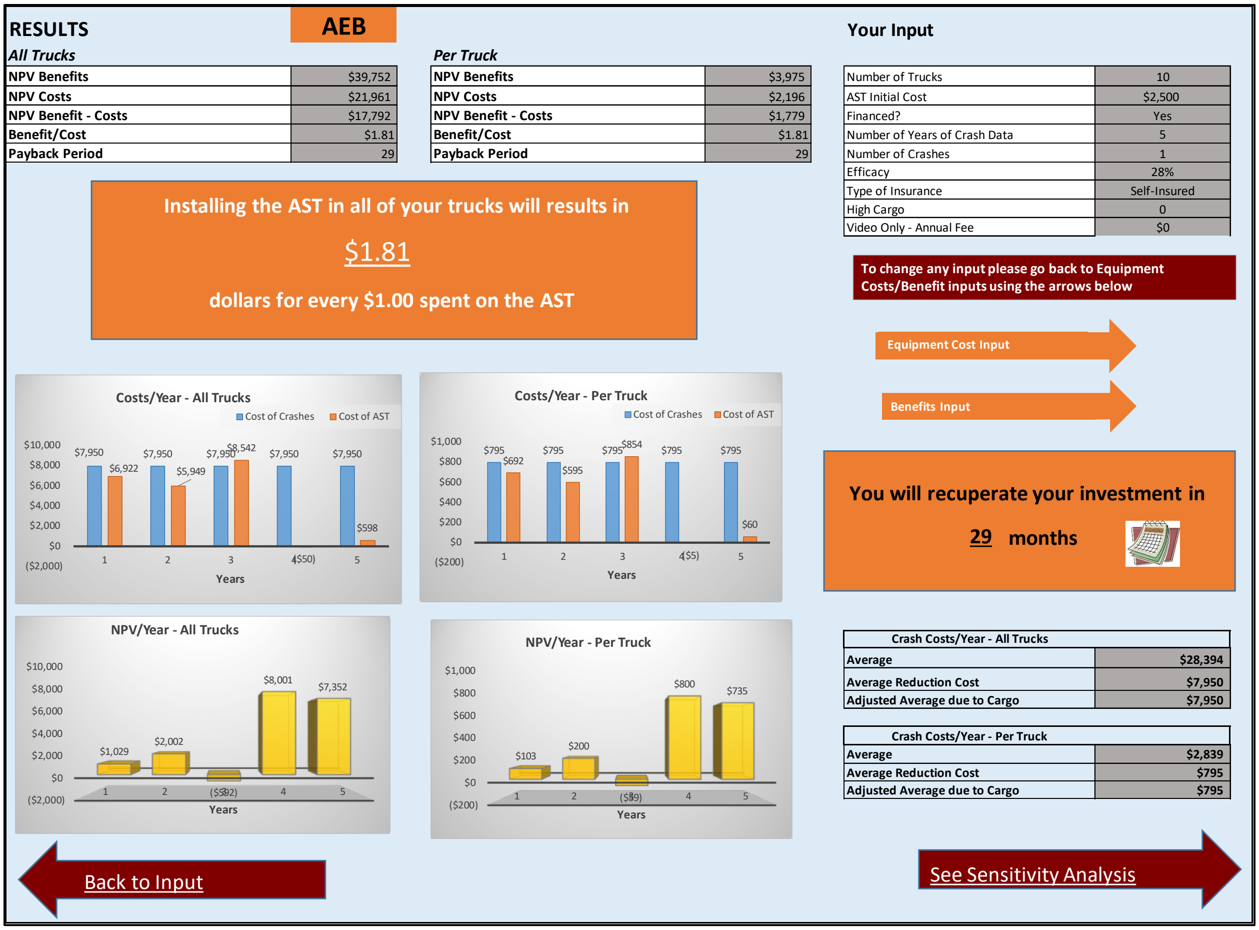

Figure 3. Screen capture. Image of VTTI's ROI tool showing cost/benefit output.

5.2.2 Initial Cost

One of the most important factors in establishing ROI is the initial cost of an AEB system. The initial cost is one of the few well-defined and predictable elements of the ROI calculation for AEB, and as such may be the most important market barrier to voluntary adoption—to fleets, it is the single most visible and best-known cost. Depending on the type of system being installed and the negotiating power of the fleet, integrated safety systems with AEB can cost up to $5,000 per truck. While this may not seem significant for vehicles that cost over $100,000, fleets often operate on tight margins. A reliable, positive ROI is crucial to justifying voluntary adoption.

As noted in Chapter 2, AEB suppliers are beginning to offer retrofits of AEB on a limited basis. Currently, retrofits are specific to makes and models of vehicles and require coordination between the AEB supplier and fleet. They are not widely available as standalone products without other alert systems, and because of the additional work, are not necessarily cheaper than adding AEB to a new truck. When discussing retrofitting AEB with ATA's TAG, fleets did not believe this was a viable path for improving voluntary adoption. They believed retrofitting would not be the preferred method of voluntary adoption unless it could be offered with the latest features, because most fleets choosing to adopt the technology would prefer the newest, most capable version.

Recently, heavy vehicle manufacturers have voluntarily made AEB "standard" on many new models of truck (see references 87, 88, 89, and 90). These voluntary efforts by OEMs should result in an increase in voluntary adoption of AEB. However, OEMs are also offering deletion credits to customers who choose to remove AEB, meaning they are not truly standard. The value of deletion credits varies for each OEM, and may vary between customers depending on the negotiating power of the fleet. These deletion credits offer customers incentives to remove AEB, negatively impacting voluntary adoption of the technology.

The negative impact of deletion credits on voluntary adoption rates could be reduced if OEMs were encouraged to reduce the value of deletion credits and therefore customers' incentive to remove AEB. Because AEB's status as a "standard" technology on heavy vehicles is relatively new, it is not yet known what portion of fleets will ultimately choose to delete AEB or what value of deletion credit is necessary to sway decisions. It is also possible that a fleet choosing to delete a standard safety technology could result in liability concerns similar to those discussed in Section 5.1 if the truck is involved in a collision. A better understanding of how deletion credits motivate a fleet's decision may help shed light on this topic and allow OEMs to optimize deletion credit values to incentivize voluntary adoption without harming vehicle sales.

5.2.3 Payback Period

In addition to needing a positive expected ROI from the voluntary adoption of AEB, fleets may desire to realize their expected ROI quickly. Costs in the trucking industry are often tied to external factors outside an individual fleet's control, such as fuel prices, economic conditions, and labor supply. The unpredictability of these external factors could make investments in safety systems less viable as part of future vehicle purchases.

In the case of AEB, fleets purchase the technology for a defined, up-front cost with the potential to prevent or mitigate rare but costly collisions in the future. Some fleets may be looking for a quick ROI that corresponds to relatively short ownership life cycles. This means fleets may be looking at their crash or liability risk only over this short period of time. Over the same period, AEB purchases may be competing with other investments for a limited pool of resources. Secondary AEB costs, such as training, may also make the technology less appealing over a short timeframe because these costs typically require more up-front spending. Training may not be a critical factor, though; fleets reported little training associated with AEB, and reported the added training cost as negligible.

As mentioned above, one possible method of addressing uncertain payback periods and expected ROIs is the development and dissemination of tools that can help fleets calculate the ROI for AEB within the context of their particular operations. Crucially, these tools could also help fleets understand the payback periods for AEB relative to other technologies, which may encourage voluntary adoption.

5.2.4 Incentives

Other potential drivers of AEB voluntary adoption are market incentives that supplement the expected reductions to risk. These incentives could take several different forms, such as up-front discounts on an insurance policy, benefits to a fleet's safety score (which some customers may use in awarding contracts), AEB price discounts for fleets that want to try the technology, etc.

The key is that these incentives are forward-looking; they provide the incentive at the point of purchase or early in the process of adopting AEB. These kinds of incentives can have two adoption benefits. First, incentives may encourage a fleet to try AEB for the first time, if only on a small scale or trial basis. Second, incentives may facilitate wider voluntary adoption within a fleet by pushing the ROI forward, closer to the point of purchase. In other words, forward-looking incentives offset what most fleets consider the largest barrier to AEB voluntary adoption: the large up-front cost.

To date, few incentives have been offered for adopting AEB. The prices of AEB are negotiable, and large fleets with more leverage may be able to negotiate incentivized pricing for voluntary adoption. For small to medium fleets, this option may be unavailable. In fact, as mentioned above, deletion credits may incentivize some fleets not to adopt AEB. If OEMs continue to offer deletion credits, incentives to encourage voluntary adoption may need to overcome concerns about ROI and payback and also address the initial cost benefits of not installing AEB.

Another candidate for forward-looking AEB incentives is insurance discounts. Insurance companies generally prefer to look at results after a safety technology's voluntary adoption to determine whether and to what degree a fleet's premiums should change. There are several reasons for this approach. First, the precise effectiveness of AEB is not well understood due to a lack of scientific, publicly available research on AEB effectiveness. As discussed in Chapter 2, estimates of crash reduction rates have ranged from 16 percent to 52.2 percent, and these estimates are not necessarily based on real-world performance data.[91] Some fleets have reported up to 75 percent effectiveness, which may lead insurers to conclude that performance relies on the context of particular fleets.[92] At ATA's TAG meeting, fleets did not specify exact values for effectiveness, but generally agreed that they were seeing results in line with the 75-percent figure.

Second, the effectiveness of AEB in the real-world may depend on additional factors. This could include fleet safety culture, driver training, fleet exposure to certain driving conditions, or fleet maintenance on brake components. Without more precise information on effectiveness, insurance companies are unlikely to offer broad discounts based on the presence of AEB.

Third, AEB is evolving rapidly and its effectiveness may do the same. As Chapter 2 noted, fleets often have different generations of AEB in operation as they gradually turn over their fleets with new trucks. If effectiveness differs by generation of AEB, it may be necessary to track the details of AEB deployment to assess safety benefits or liability adjustments for the purposes of discounts.

Despite these factors and the current absence of AEB-based insurance discounts, there are some insurance industry tools that promote technology-related discounts. One example is ATG Risk Solutions, a clearinghouse for telematics data in the insurance industry. ATG Risk Solutions has developed a tool called the Forward Assessment of Indexed Risk (FAIR) Score to help insurance providers determine pricing. The FAIR Score is a numerical value similar to a credit score. It is designed to be easy for fleets to understand so they can take actions that improve their scores and reduce their premiums.[93] ATG's FAIR Score combines usage-based data (telematics, ELD, etc.) with contextual data about a fleet's operations, including safety technologies that are installed on their vehicles. ATG has confirmed that AEB is one of the technologies that will improve a fleet's FAIR Score.

Tools like the FAIR Score have a direct impact on fleets' insurance premiums. Promoting efforts like this could be an effective means of increasing voluntary adoption, though ATG's ability to offer the FAIR Score may be unique due to its access to telematics data. Framing the FAIR Score like a credit score makes it easy to understand how the score is measured and how insurers use the score. Systems like this can also drive voluntary adoption of other safety-oriented technologies or activities by providing transparency about impacts.

Another potential incentive for voluntary adoption is AEB's potential to affect metrics FMCSA uses in its Compliance, Safety, Accountability (CSA) methodology. In June 2018, FMCSA released its response to the National Academy of Sciences' (NAS) report, "Improving Motor Carrier Safety Measurement."[94] The response detailed FMCSA's plans to use the recommendations provided by NAS when updating the CSA program. There are three areas where FMCSA's response could help promote the voluntary adoption of AEB.

In the response to NAS's second recommendation, FMCSA stated that it will improve registration data and consider incorporating self-reported data into the Motor Carrier Management Information System (MCMIS). Most AEB systems are factory-installed on newly purchased trucks, and including this information in vehicle registrations may be the easiest way to begin tracking which vehicles are equipped with AEB, via their vehicle identification number (VIN). To cover existing vehicles equipped with AEB (and account for emerging retrofit capabilities), FMCSA could allow fleets to self-report AEB equipment on their vehicles by VIN. These two measures would provide a relatively comprehensive picture of which vehicles are equipped, and allow for further research on AEB benefits. Exposure and crash data are already recorded in MCMIS; capturing AEB data in the same system would facilitate future analysis.

In response to NAS's third recommendation, FMCSA stated that it will confirm the benefits of additional information that can be used to enhance safety assessments. Vehicle-level information on AEB status, along with fleet-level information on AEB voluntary adoption, AEB-related compensation, and AEB training, could improve cost-benefit analyses. As stated above, these factors may enhance or detract from real-world AEB safety benefits, and their inclusion as additional information (if appropriate) could motivate voluntary adoption.

Finally, as part of NAS's sixth recommendation, NAS noted that relative metrics of safety performance can encourage the voluntary adoption of new technologies over time. As trucks are equipped with additional technology and become safer, absolute metrics could require new thresholds or benchmarks to continue motivating voluntary adoption of new safety technologies. The inclusion of relative metrics could be a motivator for voluntary adoption of AEB. Importantly, the visibility of AEB status in publicly available data could help show whether fleets adopting AEB are performing better, communicating to fleets whether AEB would benefit their metrics.

5.2.5 Training and Data Utilization

The outcomes of adopting AEB may depend on whether and how drivers are trained, both before and after voluntary adoption. The training aspect of AEB performance adds uncertainty to the costs and benefits associated with voluntary adoption. Fleets have a wide variety of training methods available to them, each requiring different levels of resources. Fleets can provide in-vehicle training, classroom instruction, instructional videos, or other forms of training. There is little guidance on the effectiveness of various types of training. AEB suppliers do work with fleets on some training issues, but this is on a case-by-case basis and is not widely available to fleets interested in the technology. This uncertainty around training may compound the issue of realizing a well-defined, timely ROI.

There may also be uncertainty surrounding the costs and effectiveness of using data from an installed AEB system. Effective use of data from AEB may provide additional benefits, but as with initial training efforts, it may be unclear to fleets how costly these options will be and what kind of benefits to expect. It is possible to use data from AEB in a variety of safety applications. These could include driver monitoring activities, where AEB data provide additional information on safety performance and opportunities to train drivers. Products such as SmartDrive currently offer this capability in their driver monitoring systems, but it is not yet known whether this combination of technologies is more or less effective than separate implementations.

Data from false activations may also negatively impact metrics, though driver monitoring tools could mitigate the problem. As mentioned in Chapter 2, false activations have been observed in recent generations of AEB that are still in service. Drivers may be worried that false activations will have a negative impact on their metrics and be resistant to using data from their AEB systems. It may also be difficult to train drivers using data from AEB activations without corresponding video to provide the context of the event. Exactly which behaviors drivers need to be trained on remain unclear. Many driver-monitoring tools are able to use data from AEB and can focus fleet resources on trainable situations with video context for conditions.

5.2.6 Resale Value

AEB often makes a negligible contribution to the resale value of a truck, reducing ROI. If AEB does not contribute to the resale value, the desired ROI can be more difficult to achieve, especially if fleets are selling trucks after a short period of time. AEB's contribution to resale value will depend on increased fleet demand for AEB on used vehicles. ROI tools for fleets purchasing new vehicles could be made applicable to fleets purchasing used vehicles as well. In theory, since AEB has little impact on resale value, it may actually be easier to realize desired ROI for used vehicles since the added cost of AEB is lower (or non-existent) for used vehicles compared to new vehicles. This may be particularly important for smaller fleets that currently have low voluntary adoption rates and are more likely to purchase used vehicles. There may be additional unknown costs to realign or maintain components, but it appears that the used vehicle market may be an effective venue for promoting AEB voluntary adoption. If the ROI can be demonstrated as higher and more reliable in the used vehicle market, it may drive demand for the systems, providing additional resale value and incentives for fleets to add the technology to new truck purchases upstream.

5.3 DRIVER ACCEPTANCE

One general market barrier to AEB voluntary adoption is a lack of acceptance by drivers. As noted in Chapter 2, several issues with driver acceptance may be due to inconsistencies in how systems operate, the human-machine interfaces (HMIs) that provide drivers with information, or a lack of control over how the system operates. These issues have some technical aspects but are more readily addressed on the market side through broader industry agreement on how to maximize safety outcomes.

5.3.1 System Differences

As noted in Chapter 2, there may be significant variations in how different AEB products alert drivers and engage AEB. These differences could arise from brand-specific approaches to developing AEB, multiple generations of products with different capabilities, or even performance differences due to vehicle wear. These variations may cause confusion or among drivers who are not aware of the differences. At ATA's TAG meeting, multiple representatives agreed that this was an issue in their fleets. They said that fleets typically provide training when they hire drivers or when they receive a new vehicle, but that there are operational difficulties related to training drivers to use a different vehicle. Typically, if a driver needs to use a different vehicle, the reasons behind the change are unexpected and do not allow time for training on different types or generations of AEB. Fleets themselves may be confused by variations between products when deciding whether to purchase AEB and at which price points.

One industry-driven approach to mitigating this barrier is through consensus standard organizations, such as the Technology Maintenance Council (TMC), SAE International, and the International Organization for Standardization (ISO). These organizations could take the lead in identifying and defining consistent methods of operation. This is a difficult approach because the technology is evolving rapidly, and new features and capabilities can be important differentiators between brands and products. Even so, it may be possible for the industry to define some guidance on how well established features operate. For example, industry may be able to define operational thresholds where different types of activations take place. Currently, different systems have different thresholds at which automatic braking, impact alerts, following distance alerts, and other features trigger. Defining standard thresholds for these triggers could help drivers understand the technology and improve acceptance as the technology continues to evolve.

5.3.2 Human-Machine Interface

The different ways in which AEB communicates with drivers may be a source of confusion or resistance. At ATA's TAG meeting, fleet representatives identified driver acceptance as the biggest barrier to AEB voluntary adoption, indicating that larger fleets have more resources to assist with driver retention, but that small and medium fleets cannot afford to lose drivers over issues such as AEB. Increasing driver understanding may therefore be critical to accelerating voluntary adoption, and increased understanding depends on improving the consistency and acceptance of HMIs. There are many different HMIs across the various AEB products on the market. WABCO and Bendix both provide an HMI that sits on the dashboard, while other OEMs have begun integrating AEB products with proprietary HMIs of their own. At the Cab and Controls study group session of TMC's Spring 2018 meeting, this issue was discussed by Fred Andersky, Director of Customer Solutions & Marketing–Controls at Bendix Commercial Vehicle Systems.(95) There are currently several HMI features and alerts that are not standardized among AEB systems, including the following:

- Colors associated with different types of activation.
- Sounds associated with different types of activation.
- Icons associated with different types of activation.
- Haptic feedback associated with different types of activation.
- Locations of information provided by the systems (e.g., dash, instrument cluster, etc.).
- Orientation of information provided by the systems (e.g., horizontal light strip, circular light strip, etc.).

There are also examples of HMI capabilities not being aligned with operational capabilities. When Bendix Wingman Fusion was released, the HMI being integrated by some OEMs was not capable of displaying newly added alert types. These vehicles contained two HMIs, one integrated by the OEM and one installed aftermarket by the AEB supplier, which combined to provide alerts to the driver. This HMI solution was not ideal, and may have reduced the speed at which drivers processed the meaning of alerts, degrading the effectiveness of the system.

Effectiveness may also be reduced if drivers are confused by what the HMI is trying to tell them. Inconsistencies can lead to driver mistrust or inaction, as the systems are designed to supplement driver reactions. Again, industry organizations may be able to take the lead in specifying HMI principles, which could improve consistency across products and thus improve overall driver experiences, and thus, systems' acceptance. Specific design principles may also reduce driver resistance, facilitating voluntary adoption of AEB.

In addition to consistency, there is also the possibility of improvements to the overall HMI to improve driver experiences and reduce driver resistance. Improvements could include some standardization of the location of visual warnings related to AEB, the types of alerts (audio, visual, haptic, or combinations) based on which are most appropriate for different levels of activation, and visual designs that clearly and effectively communicate feedback to the driver. Overall improvements were discussed at TMC's Spring 2018 meeting during the roundtable on AEB issues, with audience members commenting that there were differences between HMIs and that some displayed clearer messages during or immediately prior to an AEB activation.(11)

HMI and operational guidance could come from two possible directions. First, NHTSA could provide guidance through the FMVSSs, most likely FMVSS 101: Controls and Displays. NHTSA is currently conducting research to understand how the FMVSSs and associated test procedures may need to be translated to address vehicle designs associated with automated driving systems (Contract Number: DTNH2214D00328L, Task Order DTNH2217F00177). This research is an ongoing effort to review existing standards, which do not cover AEB or other advanced driver-assistance systems. The research is expected to end in March 2021 if all phases are approved. This timeframe may not accelerate voluntary adoption of AEB in the near term even if AEB were addressed in changes to the FMVSSs. Second, industry consensus standards organizations such as TMC and SAE could address these issues. Based on AEB supplier and integrator participation at TMC and other venues, industry seems interested in working together to take on issues related to HMIs. Efforts may require some initial momentum to get started but could result in meaningful improvements in HMIs that improve driver acceptance of AEB.

5.3.3 Configurability

Industry agreement could also address issues related to customization and operational configuration by drivers. Some products offer a degree of driver configuration via a stalk in the steering column or through digital menus. There are concerns that this customization may allow drivers to adjust the settings to significantly reduce the system alerts. This leads to a potential trade-off between acceptance and effectiveness. Industry organizations such as TMC and SAE may be in a good position to address this issue. As a group, industry may need to decide whether and to what degree driver control is appropriate. This industry guidance may also be useful to fleets to provide more effective training on the technology, such as which settings are appropriate for which conditions.

One concern that drivers often express is how AEB will react in adverse weather conditions such as rain, snow, or ice. AEB suppliers continue to include disclaimers about using their products in adverse weather, but drivers have no way to control the sensitivity of AEB or audio/visual alerts in the newer generations of the technology. Providing drivers some control over the system based on the environmental conditions could potentially build trust in the product. However, liability concerns over allowing a driver to deactivate a safety product may be difficult to overcome. While performance may suffer in adverse conditions, AEB is integrated with a vehicle's stability control system and should not cause loss of control.

At ATA's TAG meeting, most fleets expressed concern over giving drivers control of AEB parameters. The TAG participants believed that another layer of monitoring to verify how drivers control AEB could be necessary, or training on which modes are appropriate for which conditions. In general, driver control over system parameters did not seem to be a desirable feature for the participating fleets. However, one fleet at TAG was pilot testing a program that allowed drivers to control the alert parameters in a specific metropolitan area. Congestion in this city was causing a large number of nuisance alerts, and the fleet was allowing drivers to reduce the alert thresholds within this geographic area during times of heavy traffic. The pilot test was still relatively new, so the fleet did not have any data on changes in alert rates, changes in driver acceptance, or compliance with their rules. The issue of driver control over AEB is complex, and while offering more control may build trust in the systems from the drivers' perspectives, the benefits of allowing driver configuration control may be offset by increased crash risk or liability exposure.

6. MEDIUM-DUTY MARKET BARRIERS

6.1 RETURN ON INVESTMENT

Many of the cost barriers discussed in Chapter 5 also apply to medium-duty vehicles, and the supporting technologies required for AEB add additional costs. Stability control and air brakes are not standard on medium-duty vehicles and can add substantial up-front costs. This reduces the ROI, particularly over the short term.

Other important considerations are the truck's body type and its vocation or application. For example, dump trucks are relatively stable, making AEB-supporting technologies like stability control less popular, while concrete mixers are relatively unstable, making stability control more common. As mentioned in Chapter 2, all currently available AEB systems require these supporting technologies. AEB suppliers are considering offering medium-duty systems without requiring supporting technologies in the future, which presents two possibilities for increasing voluntary adoption in medium-duty vehicles. One possibility is for OEM suppliers to continue investigating the feasibility of stand-alone AEB that does not require stability control or air brakes. FMCSA would not have an active role in this development process, but could promote the voluntary adoption of stand-alone AEB if and when such systems are commercially available.

The other possibility accounts for how various vehicle vocations have different exposure to rear-end crashes due to different environments, operating speeds, and traffic conditions. While the typical minimum speed for AEB is 15 mi/h, its primary use case is highway driving. Many medium-duty vehicles operate off-highway or have limited exposure to highway driving. Fleets operating in vocations with a greater exposure to rear-end collisions, such as heavy stop-and-go driving cycles, may not be aware that AEBs will operate at lower speeds, and are therefore unaware of AEB systems' potential for improved ROI. There could be other specialized market segments of medium-duty vehicles where AEB is particularly effective. Identifying these market segments and performing outreach to fleets about AEB's potential ROI could increase voluntary adoption in medium-duty vehicles.

6.2 INTERMEDIATE BUILDERS

Another potential barrier to voluntary adoption of AEB on medium-duty vehicles is the additional layer that sometimes exists between the OEM and the end user. Some OEM customers purchase vehicles and then have a third-party body builder add specialized bodies to the chassis (e.g., refuse haulers, dump bodies, aerial utility lifts, etc.). Some customers work directly with the body builder to purchase the chassis. The body builder may not be aware of, or promote, advanced safety technology like AEB. Promoting the technology to third-party body builders so that they can inform their customers may increase AEB voluntary adoption.

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7. RECOMMENDATIONS

7.1 ACTIONS FOR ACCELERATING AEB ADOPTION

Based on the barriers identified in previous chapters of this report, this report recommends 10 specific actions FMCSA should take to accelerate the voluntary adoption of AEB technologies. This chapter provides an account of how these possible approaches relate to one another and how they might be combined, prioritized, or assessed. The specific actions are:

1. Conduct outreach to industry to inform fleets about potential liability risks associated with deleting an OEM's standard safety technology from new truck purchases.
2. Develop and disseminate tools to increase awareness of AEB's potential to reduce exposure to risk and liability.
3. Support improvement of methods to calculate and use exposure data.
4. Develop and disseminate tools to assist fleets in calculating the ROI for AEB.
5. Support the development of standards for fleet training and fleet data use related to AEB.
6. Support the development of Recommended Practices (RPs) or guidance on AEB functions and interfaces to improve consistency.
7. Collect vehicle-level data on AEB voluntary adoption for inclusion in CSA methodologies.
8. Examine CSA methodologies for safety metrics based on AEB's relationship to safety benefits.
9. Support a study to identify medium-duty vocations that have higher exposure to collisions AEB can address.
10. Determine how best to motivate OEMs to make AEB standard for certain medium-duty truck/body combinations.

While each of the recommendations may lead to accelerated voluntary adoption of AEB, there are distinct challenges and merits to each approach. Some approaches could have more potential than others to accelerate voluntary adoption, but may require additional resources, additional time to implement, or carry risks that could reduce success. To organize the 11 recommendations and assist in selection of the combination of recommended actions that best fits FMCSA's priorities, each recommended action is classified and rated based on the following: resources required, potential effectiveness in increasing voluntary adoption, estimated time to implement, and risk of failure. For example, a recommended action may rely on coordination with OEMs to achieve its expected results. If an OEM were not inclined to coordinate, perhaps due to competitive considerations, the effort could suffer a delay (due to additional time spent convincing the OEM to join) or reduced effectiveness (due to lack of OEM input or support). These risks and their impacts can be difficult to quantify but can be qualitatively assessed. The definitions of the classifications are presented in Table 3.

Table 3. Classifications and definitions for recommendations to accelerate AEB voluntary adoption.

Categories	Low	Medium	High
Resources Required	<$100,000	$100,000—$300,000	>$300,000
Potential Effectiveness	Increase voluntary adoption by up to 5%	Increase voluntary adoption by 5—10%	Increase voluntary adoption by over 10%
Estimated Time to Implement	Less than 1 year	Between 1 year and 2 years	Over 2 years
Potential for Recommendation to Fail	Low failure potential	Medium failure potential	High failure potential

Recommendations can also be classified based on type of action or involved party. The recommendations are broken down into five groups corresponding to OEM engagement, fleet engagement, industry guidance, CSA changes, and medium-duty barriers. The matrix of classifications and ratings for each recommended action is presented in the following tables.

Table 4. Recommendations related to OEM engagement or OEM policies.

OEM Engagement Recommendation	FMCSA Resources Required	Potential Effectiveness	Time to Implement	Potential for Recommendation to Fail
Recommendation 1: Work with industry to inform fleets about potential liability risks associated with deleting an OEM's standard safety technology from new truck purchases.	Low	Medium	Low	Medium

The first recommendation is that FMCSA should work with OEMs and industry organizations to conduct outreach to inform fleets about potential liability exposure if they choose to delete a standard safety technology from a new truck purchase. The potential for liability is not yet well defined, but industry organizations will be able to use liability concerns experienced by members moving forward to help other members understand the impacts. OEMs would also be valuable partners for communicating any potential liability to their customers.

Table 5. Recommendations related to fleet engagement or fleet decision-making.

Fleet Engagement Recommendations	FMCSA Resources Required	Potential Effectiveness	Time to Implement	Potential for Recommendation to Fail
Recommendation 2: Develop and disseminate tools to increase awareness of AEB's potential to reduce exposure to risk and liability.	Low	Low	High	Low
Recommendation 3: Improve methods to calculate and utilize exposure data.	High	Medium	High	Medium
Recommendation 4: Develop and disseminate tools to assist fleets in calculating the ROI for AEB.	Low	Medium	Low	Low

The second recommendation is for FMCSA to help fleets model how AEB can reduce their exposure to crash and liability risks and to help them quantify the benefits of AEB. AEB suppliers believe that fleets understand how the technology works and understand the types of collisions it is designed to prevent. But calculating the benefits of AEB voluntary adoption depends on knowing the likelihood of being involved in crashes AEB could prevent or mitigate. One approach to address this is to build and disseminate simple tools that help fleets model their general exposure to risks and AEB's potential to affect their operations. ATG's FAIR Score tool translates a fleet's data into a number that insurers use to set rates. This number is easy for a fleet to digest, and changes to the number help the fleet quickly assess costs and benefits related to liability. This approach may appeal to smaller fleets that do not already have extensive specialized knowledge pertaining to crash risk and liability exposure.

The third recommendation shares goals with the third but uses a different approach. FMCSA could provide tools for fleets to calculate actual risk exposure instead of just simplified scores. This method would be attractive to self-insured fleets, which have additional incentive to accurately quantify their exposure to reduce their direct liability. Both this and the previous recommendation may appeal to different fleets, so it may be beneficial to pursue both approaches to maximize impact. Improving the methods for calculating and using exposure data may encourage industry to adopt these tools more widely. The development of these tools may also have long-term benefits beyond AEB voluntary adoption. Advanced driver assistance systems (ADAS) are developing rapidly, and new ADAS may require similar efforts down the road to encourage voluntary adoption. The development and application of these tools now for AEB voluntary adoption may expedite similar future efforts to promote other life-saving technologies.

The fourth recommendation is based on the observation that ROI calculations involving AEB are complex and sometimes counterintuitive. Based on observations, not all fleets are equipped to make these calculations. Even given accurate, real-world data, there is no system in place for fleets to share information and create a more accurate, shared picture of AEB's costs and effects. FMCSA could facilitate the development and dissemination of tools to assist fleets in calculating their ROI on AEB. Such tools would allow fleets to develop business cases for voluntary adoption. To provide useful results, these tools would need access to broad industry information so that knowledge gaps within a specific fleet can be filled in with reasonable estimates.

Table 6. Recommendations related to industry engagement and guidance.

Industry Engagement Recommendations	FMCSA Resources Required	Potential Effectiveness	Time to Implement	Potential for Recommendation to Fail
Recommendation 5: Encourage industry to develop standards for fleet training and fleet data use related to AEB.	Low	Medium	Medium	Low
Recommendation 6: Encourage industry groups to provide RPs or guidance on AEB functions and interfaces to improve consistency.	Low	High	Medium	Medium

The fifth recommendation is that FMCSA work with industry to reduce driver resistance to AEB. This would improve safety outcomes and reduce fleet costs for data monitoring and training. The most effective means for FMCSA to address driver acceptance of AEB is to encourage industry groups to develop and disseminate RPs or guidance to their members. Based on the level of engagement already established within industry associations, this engagement is critical.

The sixth recommendation is that FMCSA encourage additional outreach, effective training, better designs, increased levels of product consistency, and wider dissemination of best practices. This could be done through engagement with industry and a technology champion. FMCSA could support industry organizations dedicated to building consensus-based standards to standardize training or data use related to AEB. Standard practices around AEB may help fleets gain additional value from voluntary adoption and reduce liability concerns.

Table 7. Recommendations related to CSA framework.

CSA Recommendations	FMCSA Resources Required	Potential Effectiveness	Time to Implement	Potential for Recommendation to Fail
Recommendation 7: Collect vehicle-level data on AEB voluntary adoption for inclusion in CSA methodologies.	High	Medium	High	High
Recommendation 8: Examine CSA methodologies for safety metrics based on AEB's relationship to safety benefits.	High	High	High	High

The seventh recommendation is that FMCSA collect vehicle-level data on AEB voluntary adoption and status. This information could be used for subsequent safety analysis or included in updates to the CSA framework. Data collection would likely require some additional effort to document and verify AEB status at the vehicle level. Fleets often adopt AEB in a multi-year process, cycling older non-AEB trucks out in favor of new AEB-equipped trucks that are purchased in batches. This makes it difficult to assign a binary "yes" or "no" status to whether fleets have adopted AEB. If a threshold for voluntary adoption is set at nearly 100 percent of vehicles, it could take several years for a fleet just starting voluntary adoption to reach the threshold and receive credit. Fleets could also purchase the technology but disable it or fail to maintain it afterwards. This could be a conscious action or a low-cost response to bumper damage that affects AEB performance. In either case, some level of verification may be necessary to ensure that fleets maintain AEB systems in working condition. CVSA may be a potential partner for efforts to document or verify AEB status through roadside or periodic inspections. CVSA is not currently structured to inspect optional features unless there is an obvious immediate safety impact (i.e., physical damage that presents an unsafe condition). FMCSA would need to discuss the topic further with CVSA to determine whether and how they could become involved with non-required safety technologies.

The eighth recommendation is that FMCSA use the collected vehicle-level data to offer credits or other incentives within the CSA framework. Carefully designed metrics for safety could encourage voluntary adoption of AEB and other safety technologies. Beyond direct metrics for AEB voluntary adoption, the relationship between AEB voluntary adoption and other metrics related to CSA (e.g., reportable crashes) could be better established. It may be possible to influence AEB voluntary adoption by improving the visibility of connections between AEB and CSA metrics to industry. This way, AEB's impacts on CSA metrics would be clear and easily accessible to fleets considering voluntary adoption.

Table 8. Recommendations related to the medium-duty truck market segment.

Medium-duty Recommendations	FMCSA Resources Required	Potential Effectiveness	Time to Implement	Potential for Recommendation to Fail
Recommendation 9: Identify medium-duty vocations that have higher exposure to collisions AEB can address.	Low	Low	High	Medium
Recommendation 10: Motivate OEMs to make AEB standard for certain medium-duty truck/body combinations.	Medium	Medium	High	High

In medium-duty vehicles, the cost of the enabling technologies (anti-lock brakes and stability control) is a major barrier to AEB adoption. The price is higher relative to vehicle cost, and medium-duty vehicle exposure to rear-end crashes may be limited depending on application. The availability of AEB independent of stability control may improve voluntary adoption, because the ROI on stability control is also heavily affected by exposure. The above-described approaches to help fleets understand their exposure may be helpful, but exposure may be more difficult to estimate without significant context about a given fleet's operations. The vocational variety of medium-duty vehicles also poses a challenge to standard installation of AEB. If there is a way to motivate OEMs to make AEB for particular truck and body combinations standard, then this approach could increase voluntary adoption in medium-duty vehicles.

Industry efforts to develop tools, such as ATG's FAIR Score, may be capable of performing this task via usage-based data, such as telematics, which can provide the necessary context. It is unclear whether ATG has applied the FAIR Score to medium-duty vehicles, but successful applications of the metric in heavy-duty vehicles should motivate similar efforts for medium-duty vehicles.

The ninth recommendation, in light of the limitations described above, is for FMCSA to support a study to identify the segments of the medium-duty industry where exposure to rear-end crashes is highest. FMCSA can then focus medium-duty voluntary adoption efforts accordingly. These segments could be defined by particular vehicle characteristics that make stability control more attractive. If the stability control is already common within a sector, a significant barrier to AEB voluntary adoption has already been reduced. The segments could also be defined by driving environments where rear-end collisions, which AEB is designed to prevent, are more prevalent. The segments could also include mixed heavy-/medium-duty fleets, where management has already adopted AEB on heavy-duty vehicles and already has programs related to AEB (e.g., training, data use, maintenance) in place. These specific medium-duty use cases may be more receptive to increased voluntary adoption, creating a basis from which future voluntary adoption efforts could learn and iterate.

The tenth and final recommendation is for FMCSA to determine how best to motivate third-party truck builders to adopt AEB on medium-duty trucks identified as having the greatest exposure. Neither truck body builders nor OEMs may be aware of the applications for which customers use their trucks. Both body builders and OEMs should be informed of the truck and body combinations identified by the study described in the tenth recommendation. OEMs and body builders can then be encouraged to make AEB standard for these combinations. FMCSA could disseminate information learned about medium-duty applications where AEB has a higher value to identify opportunities for body builders to promote the technology directly to customers.

7.2 CORE STRATEGY

One potential strategy for FMCSA to accelerate voluntary adoption of AEB is to pursue the recommended actions that do not have a “high” resource requirement, “high” time to implement, or “high” potential to fail. This strategy would focus on recommendations that are relatively low cost, quick to enact, and low risk, though not necessarily the most effective. This strategy would enact the four recommendations shown in Table 9.

Table 9. Recommendations that were not rated high resources, high time to implement, or low feasibility.

Recommendation	FMCSA Resources Required	Potential Effectiveness	Time to Implement	Potential for Recommendation to Fail
Recommendation 1: Work with industry to inform fleets about potential liability risks associated with deleting an OEM's standard safety technology from new truck purchases.	Low	Medium	Low	Medium
Recommendation 4: Develop and disseminate tools to assist fleets in calculating ROI of AEB.	Low	Medium	Low	Low
Recommendation 5: Encourage industry to develop standards for fleet training and fleet data use related to AEB.	Low	Medium	Medium	Low
Recommendation 6: Encourage industry groups to provide RPs or guidance on AEB functions and interfaces to improve consistency.	Low	High	Medium	Medium

These four recommendations require relatively low resource commitment from FMCSA, low to medium relative time to implement, and have low to medium potential to fail. They are also medium to high in potential effectiveness, and their combined effectiveness could significantly accelerate voluntary adoption. While this core strategy is only one possible combination of recommendations, it offers a starting point for raising take rates on new vehicles from current levels to 90 percent.

Following these four recommendations will require three separate initiatives. The first initiative would be working with industry organizations on outreach about potential liability related to the deletion of an OEM's standard safety technology. As noted above, there may be liability concerns beyond the types of collisions AEB is designed to mitigate, and industry associations may be in the best position to uncover and disseminate this information.

The second initiative would be developing and disseminating ROI tools to assist fleets. FMCSA has already been involved in the development of some tools, and it may therefore be best to focus on making these existing tools available and accessible to a wide audience. The best way to disseminate these tools would be through a fleet-accessible website. The website should allow fleets to create profiles and store data. This would enable a company to periodically update their analyses of technologies as the characteristics of its fleet or operations change, or to apply their parameters to emerging technologies. This step would require significant security measures, and may work best as a long-term goal to apply lessons from accelerating AEB voluntary adoption to other ADAS. The website would need to be publicized through multiple channels before becoming an effective tool. Winning early buy-in from AEB suppliers, insurers, and industry groups would create the foundation from which the website itself could increase awareness of

AEB. The development and outreach for the website is expected to take 6 months and could begin immediately.

The third initiative would involve working with industry consensus standards organizations to develop guidance for fleet training, for fleet data use, and on AEB system functions and interfaces. The most likely partners for this initiative are TMC and its members within relevant study groups and task forces that usually develop and approve RPs for publication. The initiative would likely need to be broken into three separate topics proposed as new or revised RPs:

1. An RP that describes the types of training that should be provided regarding AEB operation, when the training should be provided, the personnel that should provide the training, and the materials that should be used for training.
2. An RP that describes the data that are typically available from AEB systems, the ways in which the data are available to fleets, the metrics or flags that a fleet should look for in the data, and the actions that should be taken if a metric or flag signals problems (this would also refer to the previous RP).

The fourth initiative would encourage industry fostering of greater interface consistency, such as through an RP that describes the ways in which AEB should alert drivers or intervene in different situations. This would include the types of alerts (visual, audible, haptic, etc.); the locations of the alerts (instrument cluster, center console, heads-up display, etc.); the sounds or tones used in the alerts; the icons, words, or colors used in the alerts; the timing of the alerts; and the ways in which drivers or fleets can change alert parameters.

The process of adding or revising an RP begins with a written request to the technical director or study group chair, or an oral request at the appropriate study group's meeting. This could be done directly, or FMCSA could work with specific OEMs, suppliers, or fleets to encourage them to introduce the RP. The most likely TMC study groups to handle these topics are S4 Cab and Controls, S6 Chassis, and S12 Onboard Vehicle Electronics, but other study groups should be considered as well. The S4 study group has an existing RP 430 on collision avoidance technologies that contains information on AEB, which could be a candidate for modification to include the topics listed above. The third topic—making the interfaces and functions more consistent—is currently within the scope of RP 430, but the necessary updates have not been proposed. FMCSA could champion the necessary updates to accelerate their voluntary adoption or include additional scope such as driver training or fleet data use.

A written request needs to be made at TMC's fall or spring meeting so that the study group can vote on whether to assign the RP to a task force. This request is followed by task force meetings to develop the RP, then public comments and subsequent revisions before the RP is published. The RP process is expected to take at least 6 months but, given support from AEB suppliers, OEMs, and other industry stakeholders, could take less than a year. Without OEM or supplier support, the process could take significantly longer. Because RP 430 currently addresses AEB topics and is scheduled to be updated, adding these topics to the update may be an effective method of achieving results within 12 months. The first two topics (fleet training and data use) are expected to receive significant support from industry, while an RP related to system functions and interfaces could face resistance from OEMs due to proprietary methods of integration. It may be possible to formulate the RP in general enough terms to improve consistency in function and integration without limiting integration methods.

Together, these three initiatives are relatively low cost, could be completed within 1 year, and could accelerate voluntary adoption significantly by raising take rates for new vehicles. There are some risks with the approaches, but coordination with AEB suppliers and OEMs can mitigate these risks. While these recommendations alone may not be sufficient to achieve 90 percent voluntary adoption in the near future, they represent the low but solid ground on which additional recommendations could build. Depending on priorities, there could be other strategies involving other combinations of recommendations which could achieve similar or even better results.

Industry involvement will be crucial to any strategy. Early-adopting fleets appear to be seeing benefits from the technology while recognizing a need for tools and guidance to maximize effectiveness. By working with industry partners, a chosen strategy will help mitigate risk and ensure that fleets have access to the tools, guidance, RPs, and other information likely to drive voluntary adoption.

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REFERENCES

[1] Danaher, D., Buss, T., Ball, J. "Operation of the Eaton VORAD Collision Warning System and Analysis of the Recorded Data." SAE Technical Paper 2009-01-2911. SAE, Warrensburg, PA, 2009. https://doi.org/10.4271/2009-01-2911

[2] "Collision Warning System Adds Smart Cruise Control." *FleetOwner*, July 1, 1998. Retrieved January 19, 2018, from http://www.fleetowner.com/mag/fleet_collision_warning_system

[3] National Transportation Safety Board. "Roundtable: Advanced Driver Assistance Systems – Strategies for Increasing Commercial Vehicle (Heavy-Duty Trucks) Adoption." July 24, 2017. Retrieved January 19, 2018, from https://www.ntsb.gov/news/events/Pages/2017-adas-rt.aspx

[4] Meritor. "Meritor WABCO Introduces OnGuard™, the First Collision Safety System with Active Braking for North American Commercial Vehicles." February 1, 2008. Retrieved January 19, 2018, from https://www.meritor.com/ourcompany/news/Lists/News/DispForm.aspx?ID=333&RootFolder=%2Fourcompany%2Fnews%2FLists%2FNews%2F2008

[5] Bendix Commercial Vehicle Systems LLC. "Bendix® Wingman® ACB – Active Cruise with Braking: Questions and Answers." 2010. Retrieved January 19, 2018, from http://www.bendix.com/media/documents/products_1/acb_1/bw2807bendixwingmanacbfaq.pdf

[6] Woodrooffe, J., Blower, D., Bao, S., Bogard, S., Flannagan, C., Green, P. E., LeBlanc, D. "Final Report: Performance Characterization and Safety Effectiveness Estimates of Forward Collision Avoidance and Mitigation Systems for Medium/Heavy Commercial Vehicles." Docket No. NHTSA-2013-0067. Washington, D.C.: National Highway Traffic Safety Administration, 2012.

[7] Grove, K., Atwood, J., Hill, P., Fitch, G., Blanco, M., Guo, F., ..., Richards, T. "Field Study of Heavy-Vehicle Crash Avoidance Systems. Final Report." Report No. DOT HS 812 280. Washington, DC: National Highway Traffic Safety Administration, June 2016.

[8] Crissey, Jeff. "Bendix Introduces Next-Generation Wingman Fusion Active Safety System, Provides Regulatory Update." *Commercial Carrier Journal*, March 25, 2015. Retrieved January 18, 2018, from https://www.ccjdigital.com/bendix-introduces-next-generation-wingman-fusion-active-safety-system-provides-regulatory-update/

[9] WABCO. "WABCO Introduces OnGuardACTIVE™ Collision Mitigation System to North America." 2015. Retrieved January 19, 2018, from http://ir.wabco-auto.com/releasedetail.cfm?releaseid=903220

[10] WABCO. "WABCO Introduces OnGuardMAX Advanced Emergency Braking System; Innovative Technology Adds Full Braking on Stationary Vehicles Ahead; Further Enables Automated Driving for Commercial Vehicles." 2016. Retrieved January 19, 2018, from http://www.wabco-auto.com/en/media/media-center/press-releases/press-releases-single-view/news-article/wabco-introduces-onguardmax-advanced-emergency-braking-system-innovative-technology-adds-full-braki/

[11] Daimler. "Active Brake Assist on Detroit Assurance® 4.0." 2016. Retrieved January 19, 2018, from https://demanddetroit.com/our-company/community/blog/active-brake-assist-on-detroit-assurance-40

[12] National Transportation Safety Board. "Special Investigation Report: The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes." Report No. NTSB/SIR-15/01 PB2015-104098. Washington, D.C.: National Transportation Safety Board, 2015.

[13] NTSB, 2015.

[14] NTSB, 2017.

[15] Cannon, J. "Next Generation of Driver Assist Technologies – Automatic Emergency Braking." *Commercial Carrier Journal*, December 14, 2017. Retrieved January 19, 2018, from https://www.ccjdigital.com/automatic-emergency-braking-is-the-next-generation-of-driver-assist-technologies/

[16] NTSB, 2017.

[17] Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems for Heavy Vehicles, 49 CFR Part 571.

[18] WABCO. "Electronic Stability Control for Commercial Vehicles." 2004. Retrieved January 19, 2018, from http://www.am.wabco-auto.com/fileadmin/Documents/Media_Center/Press_Releases/ESC.pdf

[19] Bendix Commercial Vehicle Systems. "Commercial Vehicle Market Continues to Choose Full-Stability Technology – Bendix® ESP Continues Growth, Expands Availability to Medium-Duty Tractors." March 24, 2010. Retrieved January 19, 2018, from http://bendix.com/en/_meta/pressreleases/press_detail_2771.jsp

[20] "Ford Upgrades 2018 Medium-Duty Models." *FleetOwner*, May 3, 2017. Retrieved January 19, 2018, from http://www.fleetowner.com/hd-pickup-van/ford-upgrades-2018-medium-duty-models

[21] Kenworth. "Kenworth Adds Bendix Wingman Advanced as Option for Medium Duty T270 and T370." October 1, 2016. Retrieved January 19, 2018, from https://www.kenworth.com/news/news-releases/2016/october/wingman-advanced-md/

[22] Kuehn, M., Hummel, T., Bende, J. "Advanced Driver Assistance Systems for Trucks – Benefit Estimation from Real-life Accidents." In *Proceedings of the 22nd International Technical Conference on Enhanced Safety of Vehicles*, Washington, D.C, 2011.

[23] Jermakian, J. S. "Crash Avoidance Potential of Four Large Truck Technologies." *Accident Analysis and Prevention 49*: 338-346, 2012.

[24] Glassbrenner, D., Morgan, A., Kreeb, R., Svenson, A., Liddell, H., Barickman, F. "A Target Population for Automatic Emergency Braking in Heavy Vehicles." Report No. DOT HS 812 390. Washington, D.C.: National Highway Traffic Safety Administration, 2017.

[25] Woodrooffe, et al., 2012.

[26] Hickman, J. S., Guo, F., Camden, M. C., Medina, A., Hanowski, R. J., Mabry, E. "Onboard Safety System Effectiveness Evaluation Final Report." Report No. FMCSA-RRT-12-012. Washington, D.C.: Federal Motor Carrier Safety Administration, 2013.

[27] Grove, et al., 2016.

[28] Kuehn, et al., 2011.

[29] Jermakian, 2012.

[30] Glassbrenner, et al., 2017.

[31] Woodrooffe, et al., 2012.

[32] Hickman, et al., 2013.

[33] Grove, et al., 2016.

[34] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Automatic Emergency Braking Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[35] Woodrooffe, et al., 2012.

[36] Kilcarr, S. "Bendix: Truck Technology Implementation Is the Real Struggle." *FleetOwner*, September 29, 2017. Retrieved January 17, 2018, from http://www.fleetowner.com/collision-prevention/bendix-truck-technology-implementation-real-struggle

[37] Kilcarr, 2017.

[38] Kilcarr, S. "What Are Fleet Managers Worrying About?" *FleetOwner*, May 23, 2016. Retrieved January 17, 2018, from http://www.fleetowner.com/blog/what-are-fleet-managers-worrying-about

[39] Kilcarr, 2016.

[40] Lockridge, D. "Are We Adopting Advanced Safety Systems Quickly Enough?" *HDT: Heavy Duty Trucking*, November 2017. Retrieved January 17, 2018, from http://www.truckinginfo.com/channel/fleet-management/article/story/2017/11/are-we-adopting-advanced-safety-systems-quickly-enough.aspx

[41] Kilcarr, 2016.

[42] Uvanile-Hesch, S. "Automatic Emergency Braking for Trucks Not Ready for Prime Time." *Trucks.com*, June 2, 2016. Retrieved January 19, 2018, from https://www.trucks.com/2016/06/02/automatic-braking-trucks-not-ready/

[43] Uvanile-Hesch, 2016.

[44] Uvanile-Hesch, 2016.

[45] Commercial Vehicle Safety Alliance. "CVSA Releases Results from Brake Safety Day." November 7, 2017. *Commercial Vehicle Safety Alliance.* Retrieved January 19, 2018, from http://cvsa.org/news-entry/sept-2017-brake-safety-day-results/

[46] Marsh, A. "Collision Mitigation: Require It or Wait?" *FleetOwner,* January 18, 2018. Retrieved January 18, 2018, from http://www.fleetowner.com/technology/collision-mitigation-require-it-or-wait

[47] Advocates for Highway & Auto Safety. "CARAVAN Public Opinion Poll: Driverless Cars." January 12, 2018. Retrieved January 22, 2018, from http://saferoads.org/wp-content/uploads/2018/01/AV-Poll-Report-January-2018-FINAL.pdf

[48] Hjälmdahl, M., Krupenia, S., Thorslund, B. "Driver Behaviour and Driver Experience of Partial and Fully Automated Truck Platooning – A Simulator Study." *European Transport Research Review* 9: 8, March 2017. https://doi.org/10.1007/s12544-017-0222-3

[49] Insurance Institute for Highway Safety. "U.S. DOT and IIHS Announce Historic Commitment of 20 Automakers to Make Automatic Emergency Braking Standard on New Vehicles." *IIHS News*, March 17, 2016. Retrieved January 18, 2018, from http://www.iihs.org/iihs/news/desktopnews/u-s-dot-and-iihs-announce-historic-commitment-of-20-automakers-to-make-automatic-emergency-braking-standard-on-new-vehicles

[50] Insurance Institute for Highway Safety. "Automakers Pledge Series of Steps to Improve Crash Compatibility." *Status Report* 39(1), January 3, 2004. Retrieved January 22, 2018, from http://www.iihs.org/iihs/sr/statusreport/article/39/1/2

[51] Lockridge, 2017.

[52] Fleet Safety Conference. "Full Schedule." 2017. Retrieved January 19, 2018, from http://www.fleetsafetyconference.com/Page/Full-Schedule.aspx

[53] Commercial Vehicle Safety Alliance. (2018). "CVSA Brake Safety Symposium: Schedule." Retrieved January 19, 2018, from http://cvsa.org/eventpage/events/brake-safety-symposium/schedule/

[54] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Automatic Emergency Braking Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[55] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Lane Departure Warning Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[56] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Air Disc Brakes." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[57] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., & Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Video-Based Onboard Safety Monitoring Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[58] Camden, M. C., Hickman, J. S., Hanowski, R. J. (2015). "Effective Use of Commercially Available Onboard Safety Monitoring Technologies: Guidance for Commercial Motor Vehicle Carriers." Report No. 15-UT-032. Blacksburg, VA: National Surface Transportation Safety Center for Excellence, 2015.

[59] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Automatic Emergency Braking Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[60] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Lane Departure Warning Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[61] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., & Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Video-Based Onboard Safety Monitoring Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[62] Lockridge, 2017.

[63] Marsh, 2018.

[64] Gillan, J. "Automatic Emergency Braking – Prime Time for Regulation." Trucks.com, June 23, 2016. Retrieved January 19, 2018, from https://www.trucks.com/2016/06/23/automatic-emergency-braking-ready/

[65] European Parliament. "REGULATION (EC) No 661/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009." Retrieved January 19, 2018 from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009R0661

[66] European Commission. "Safety in the Automotive Sector." Retrieved January 19, 2018, from https://ec.europa.eu/growth/sectors/automotive/safety_en

[67] Woodrooffe, J., Blower, D., Bao, S., Bogard, S., Flannagan, C., Green, P. E., LeBlanc, D. "Final Report: Performance Characterization and Safety Effectiveness Estimates of Forward Collision Avoidance and Mitigation Systems for Medium/Heavy Commercial Vehicles." Docket No. NHTSA-2013-0067. Washington, D.C.: National Highway Traffic Safety Administration, 2012.

[68] NTSB, 2017.

[69] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Automatic Emergency Braking Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[70] Grove, K., Atwood, J., Hill, P., Fitch, G., Blanco, M., Guo, F., ..., Richards, T. "Field Study of Heavy-Vehicle Crash Avoidance Systems. Final Report." Report No. DOT HS 812 280. Washington, DC: National Highway Traffic Safety Administration, June 2016.

[71] Grove, et al., 2016.

[72] Grove, et al., 2016.

[73] Technological Advances in Next Generation Collision Warning Driver Interfaces. Study group session conducted at the ATA's Technology & Maintenance Council 2018 Annual Meeting & Technology Exhibition, Atlanta, GA, March 2018.

[74] Bendix Commercial Vehicle Systems, 2010.

[75] Kenworth. "Kenworth Adds Bendix Wingman Advanced as Option for Medium Duty T270 and T370." October 1, 2016. Retrieved January 19, 2018, from https://www.kenworth.com/news/news-releases/2016/october/wingman-advanced-md/

[76] Peterbilt. "Peterbilt Adds Collision Mitigation to Medium-Duty Models." November 1, 2016. Retrieved June 8, 2018, from http://www.peterbilt.com/about/media/2016/522/

[77] Peterbilt. "OnGuardACTIVE Available on Peterbilt Medium Duty Lineup." March 6, 2018. Retrieved June 8, 2018, from http://www.peterbilt.com/about/media/2018/563/

[78] Huetter, John. "Meritor WABCO Celebrates 10 Years of OnGuard, Says Tech Can Cut Rear-Ending Up to 87%." *Repairer Driven News*, March 8, 2017. Retrieved August 13, 2018, from http://www.repairerdrivennews.com/2017/03/08/meritor-wabco-celebrates-10-years-of-onguard-says-tech-can-cut-rear-ending-by-87/

[79] Bendix Commercial Vehicle Systems. "Growing Adoption of Bendix Wingman Fusion Points to Future of Driver Assistance Systems." *OEM Off-Highway*, March 22, 2017. Retrieved August 13, 2018, from https://www.oemoffhighway.com/electronics/safety/press-release/20855834/bendix-commercial-vehicle-systems-llc-growing-adoption-of-bendix-wingman-fusion-points-to-future-of-driver-assistance-systems

[80] Menzies, James. "New Cascadia Driving Higher Penetration of Proprietary Components." *Truck News*, July 27, 2017. Retrieved August 13, 2018, from https://www.trucknews.com/equipment/new-cascadia-driving-higher-penetration-proprietary-components/1003080105/

[81] Oak Ridge National Laboratories. "2013 Vehicle Technologies Market Report." 2014. Retrieved August 13, 2018, from https://info.ornl.gov/sites/publications/files/Pub48613.pdf

[82] Oak Ridge National Laboratories. "2016 Vehicle Technologies Market Report." May 25, 2017. Retrieved August 13, 2018, from https://cta.ornl.gov/vtmarketreport/pdf/2016_vtmarketreport_full_doc.pdf

[83] Gilroy, Roger. "Class 8 Sales Jump 43% in December to Cap Strong 2017." *Transport Topics*, January 12, 2018. Retrieved August 13, 2018, from https://www.ttnews.com/articles/class-8-sales-jump-43-december-cap-strong-2017

[84] Federal Motor Carrier Safety Administration. "2018 Pocket Guide to Large Truck and Bus Statistics." Washington, D.C.: U.S. Department of Transportation, August 2018.

[85] Neely, Ashley. "Werner Enterprises Slapped with $90 Million Verdict by Texas Jury." *CDL Life News*, May 18, 2018. Retrieved July 11, 2018, from https://cdllife.com/2018/werner-slapped-with-90-million-verdict-by-texas-jury/.[9] Detroit Diesel Corporation. "Daimler Trucks North America Announces Collision Mitigation System, Air Disc Brakes Now Standard on the New Freightliner Cascadia." Detroit, MI: Detroit Diesel Corporation, March 5, 2018. Retrieved July 1, 2018, from https://demanddetroit.com/our-company/media/press-releases/daimler-trucks-north-america-announces-collision-2018-03-05/

[86] Neely, 2018.

[87] PACCAR, Inc. "Kenworth T680 Goes Standard with Bendix Wingman Advanced System." Bellevue, WA: PACCAR, Inc., March 22, 2017. Retrieved July 1, 2018, from https://www.kenworth.com/news/news-releases/2017/march/t680-bendix-wingman/

[88] Peterbilt Motors Company. "Peterbilt Trucks Introduce Bendix Wingman Fusion as Standard." Denton, TX: Peterbilt Motors Company, June 27, 2018. Retrieved July 1, 2018, from https://www.peterbilt.com/about/media/2018/571/

[89] "Bendix-Based Safety System Standard on Volvo VNL and VNR Models." *Trucking Info*, July 20, 2017. Retrieved July 1, 2018, from https://www.truckinginfo.com/141368/bendix-based-safety-system-standard-on-volvo-vnl-and-vnr-models

[90] "Navistar Makes Bendix Safety Systems Standard on International LT Trucks." *Today's Motor Vehicles*, October 5, 2016. Retrieved July 1, 2018, from http://www.todaysmotorvehicles.com/article/bendix-international-navistar-standard-safety-100616/

[91] Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., Hanowski, R. J. "Leveraging Large Truck Technology and Engineering to Realize Safety Gains: Automatic Emergency Braking Systems." Washington, D.C.: AAA Foundation for Traffic Safety, 2017.

[92] NTSB, 2017.

[93] ATG Risk Solutions. The Driving-Risk Scoring Standard for Auto-Insurance [Website]. 2017. Retrieved July 1, 2018, from https://www.atgrisk.com/fair-score

[94] Federal Motor Carrier Safety Administration. "The National Academy of Sciences Correlation Study Corrective Action Plan Report to Congress." Washington, D.C.: Federal Motor Carrier Safety Administration, 2018. Retrieved July 1, 2018, from: https://www.fmcsa.dot.gov/mission/policy/nas-correlation-study-corrective-action-plan-report-congress

[95] Technology & Maintenance Council. The Technical Journal of TMC's 2018 Annual Meeting – March 5-8, 2018. Arlington, VA: American Trucking Associations, 2018.