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Cost and Weight Analysis of Heavy Vehicle Forward Collision Warning (FCW) and Automatic Emergency Braking (AEB) Systems for Heavy Trucks

from:

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1.0 ABSTRACT

The US Department of Transportation (US DOT), National Highway Traffic Safety Administration (NHTSA), is developing a regulatory framework that encourages the safe development, testing and deployment of advanced driver assist systems (ADAS) and automated vehicle technology for both passenger and commercial vehicles[1]. Key features of these technologies relative to heavy vehicles include forward collision warning (FCW) and automatic emergency braking (AEB) systems that help prevent rear-end crashes or reduce their severity by applying the brakes for the driver[2].

On 16 October 2015, the National Highway Traffic Safety Administration (NHTSA) issued a grant of petition for rulemaking relative to forward collision avoidance and mitigation technology on heavy vehicles, including FCW and AEB systems. This grant of petition allows NHTSA to determine whether to issue a rule in accordance with statutory criteria.[3] Subsequent research has included evaluation of heavy-vehicle crash warning interfaces (DOT HS 812 191), automatic emergency braking test track evaluations (DOT HS 812 166), and truck tractor braking

[1] Chao, E.L., Introductory Message, Automated Driving System 2.0, A Vision for Safety, U.S. Department of Transportation, National Highway Traffic Safety Administration, 6 September 2017, https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf

[2] National Highway Traffic Safety Administration, U.S. Department of Transportation, Driver Assist Technologies, Available Technologies, Automatic Emergency Braking Systems and Forward Collision Warning, https://www.nhtsa.gov/equipment/driver-assistance-technologies

[3] Federal Register, the Daily Journal of the United States Government, Federal Motor Vehicles Safety Standard, Automatic Emergency Braking, A Rule by the National Highway Traffic Safety Administration, 80FR62487, 49CFR571, Docket Number NHTSA-2015-0099, Document Number 2015-26294, October 16, 2015, https://www.federalregister.gov/documents/2015/10/16/2015-26294/federal-motor-vehicle-safety-standard-automatic-emergency-braking

performance improvement (DOT HS 809 753 and DOT HS 809 700).[4] Field tests of heavy-vehicle crash avoidance systems were completed during 2016 and produced the conclusion that the overall systems work as intended.[5] In 2015, the National Transportation Safety Board (NTSB) recommended that manufacturers install forward collision avoidance systems as standard features on all newly manufactured passenger and commercial motor vehicles.[6] The purpose of the current study is to determine the product piece, total system cost, incremental consumer price, and weight of FCW/AEB systems on medium duty and heavy duty trucks to provide insight into the safety and efficiency benefits of using the systems for crash avoidance.

Currently available collision avoidance system (CAS) technologies employ a number of sensors and warnings intended to inform the driver, assist in maintaining safe distances, and intervene if the driver does not respond to a potential conflict. These features include AEB, FCW alerts, lane departure warnings (LDWs), adaptive cruise control (ACC), impact alerts (IAs), following distance alerts (FDAs) and stationary object alerts (SOA) which indicate urgency of the potential conflict. Appropriate and timely activations could reduce distraction, modify driver behaviour, identify conflicts before they unfold, and enable improved vehicle control[7]. During the current study, cost and weight estimates were developed for FCW/AEB systems as employed on heavy duty trucks with gross vehicle weight ratings (GVWR) exceeding 10,000 lbs.[8] This included four commercially available baseline systems (Bendix® Wingman® Fusion™, Meritor WABCO OnGuardACTIVE®, Detroit Assurance®, and Delphi AdvanceTrac®) as implemented on five vehicles (Ford F-Series Super Duty®, Freightliner M2, International LT™, Volvo VNL, and Freightliner Cascadia®). These systems first entered the market in 2013. Components unique to the FCW/AEB systems include a forward-facing camera, heads up/dedicated display, front radar sensor, connectors, wire harnesses, and associated processors.[9]

Criteria used for selecting the subject vehicles and FCW/AEB components included 1) at least two of the systems were to include crash imminent braking (CIB) and at least one system without CIB, 2) at least one vehicle in GVWR Class 4-6, 3) at least one vehicle in GVWR Class 7, 4) at

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[4] National Highway Traffic Safety Administration, Heavy Vehicle Safety Research, Crash Avoidance, https://one.nhtsa.gov/Research/Crash%20Avoidance/Heavy-Vehicle-Safety-Research

[5] Grove, K., *et. al.*, Field Study of Heavy-Vehicle Crash Avoidance Systems, National Highway Traffic Safety Administration, Report Number DOT HS 812 280, June 2016.

[6] National Transportation Safety Board. 2015. The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes. Special Investigation Report NTSB/SIR-15-01. Washington, DC, 19 May 2015, https://www.ntsb.gov/safety/safety-studies/Documents/SIR1501.pdf

[7] Grove, K., *et. al.*, Field Study of Heavy-Vehicle Crash Avoidance Systems, Background, National Highway Traffic Safety Administration, Report Number DOT HS 812 280, June 2016, page xiv.

[8] National Highway Traffic Safety Administration, Contract DTNH2216D00037/DTNH2217F00147, cost and Weight Analysis of Heavy Vehicle Forward Collision Warning (FCW) and Automatic Emergency Braking (AEB) Systems for Heavy Trucks, Sections C.2 (Background), C.3 (Purpose), and C.4 (Objective), 29 September 2017.

[9] Not all vehicles include all of the identified components; for example, some systems are integrated with existing control units and do not include a separate processor.

least two systems equipped with dynamic brake support (DBS), 5) at least two vehicles with hydraulic brake systems, and 6) at least two vehicles with air brake systems. The study of the FCW/AEB systems included A) identification of parts unique to the FCW/AEB functions, and B) teardown and evaluation of FCW/AEB components to determine manufacturing methods and costs and component weights.

Ricardo Strategic Consulting (RSC) and NHTSA have selected FCW/AEB systems and studied the cost and weight impact on medium and heavy duty vehicles (GVWR greater than 10,000 lbs). Because the components that were added for FCW/AEB over the baseline vehicle functionality vary significantly in number and function, the five selected vehicles were divided into four categories with average incremental manufacturing costs and associated incremental weights determined for each category. The four categories were: 1) addition of FCW only - applies to Ford F-Series Super Duty® and Freightliner Cascadia® LT, 2) addition of FCW and dash display - applies to Freightliner M2 106, 3) addition of FCW, camera, dash display and side radar - applies to Volvo VNL, and 4) addition of FCW, camera, electronic control unit, and dash display - applies to International LT™. The average incremental manufacturing costs and weights were: for category 1: $44.23 and 0.46 kg; for category 2: $96.43 and 3.23 kg; for category 3: $164.12 and 2.38 kg; and for category 4: $197.51 and 3.10 kg.

2.0 SUMMARY OF FINDINGS

Ricardo worked with NHTSA to define the FCW/AEB study scope, baseline equipment, study assumptions, and costing methodology for medium duty and heavy duty vehicles. The process began with three key procedures: 1) vehicle research, 2) vehicle segregation, and 3) vehicle selection. The Ford F-Series Super Duty®, Freightliner M2 106, Freightliner Cascadia®, Volvo VNL, and International LT™ were selected for teardown analysis, which included cost and weight determination for each FCW/AEB system component. The average annual sales for these vehicles for the years 2015-2018 (model year 2018 sales are projected) were[10]: Ford F-Series Super Duty®: 67,044; Freightliner M2 106: 35,518; Freightliner Cascadia®: 86,542; International LT™: 24,284; and Volvo VNL: 38,541.

FCW/AEB components could include:

1. Sensors (radar mounted at front bumper and, in some cases, camera located at top, inside portion of windshield)
2. Control units (electronic control unit)
3. Display (in some cases integrated with existing dash cluster, in other cases, a separate display)
4. Associated wiring harnesses
5. Mounting hardware specific to FCW/AEB system
6. Other materials and scrap (for electronic parts, this category includes labels, soldering materials, flux, and fasteners)

[10] *The Rhein Report*, Truck Sales 2016, January 2017, pages 1-8, and HIS Markit, Registrations and Vehicles in Operation, 2018.

Owner's manuals, service manuals, OEM parts descriptions, and interviews with service technicians were employed to identify subassemblies, components, and parts associated with the FCW/AEB systems. Detailed evaluations, including identification of sensors, displays, printed circuit board (PCB) pin assemblies, associated wire systems, and mounting hardware, ensured that only those items related to the FCW/AEB system were included in the cost and weight determinations. The identified parts were then purchased through local dealers.

Ricardo engaged automotive system and vehicle integration experts, cost modeling teams, and procurement professionals to support the cost and weight analysis. In researching the bill of materials and following acquisition of the parts from dealers, analyses were performed to determine which subassemblies, components, and parts were uniquely associated with the five vehicle FCW/AEB systems and were incremental to baseline components already offered on the vehicles. The parts were then disassembled ("tear-down" procedure), catalogued, evaluated to determine manufacturing processes and determine materials used, weighed, and analyzed using manufacturing cost software. The cost and weight teardown analysis was performed by MeC using their proprietary software

The complete results of the cost and weight analysis, including bills of materials, are included in the appendix of this report. Because the added FCW/AEB components vary significantly in number and function, the five vehicles were divided into four categories with average incremental manufacturing costs and associated incremental weights determined for each category. The four categories were:

1) addition of FCW only - applies to Ford F-Series Super Duty® and Cascadia® LT
2) addition of FCW and dash display - applies to Freightliner M2 106
3) addition of FW, camera, dash display and side radar - applies to Volvo VNL
4) addition of FCW, camera, electronic control unit, and dash display - applies to International LT™.

The average incremental FCW/AEB manufacturing costs for these four categories vary from $44.23 to $197.51 as shown in Figure 1.

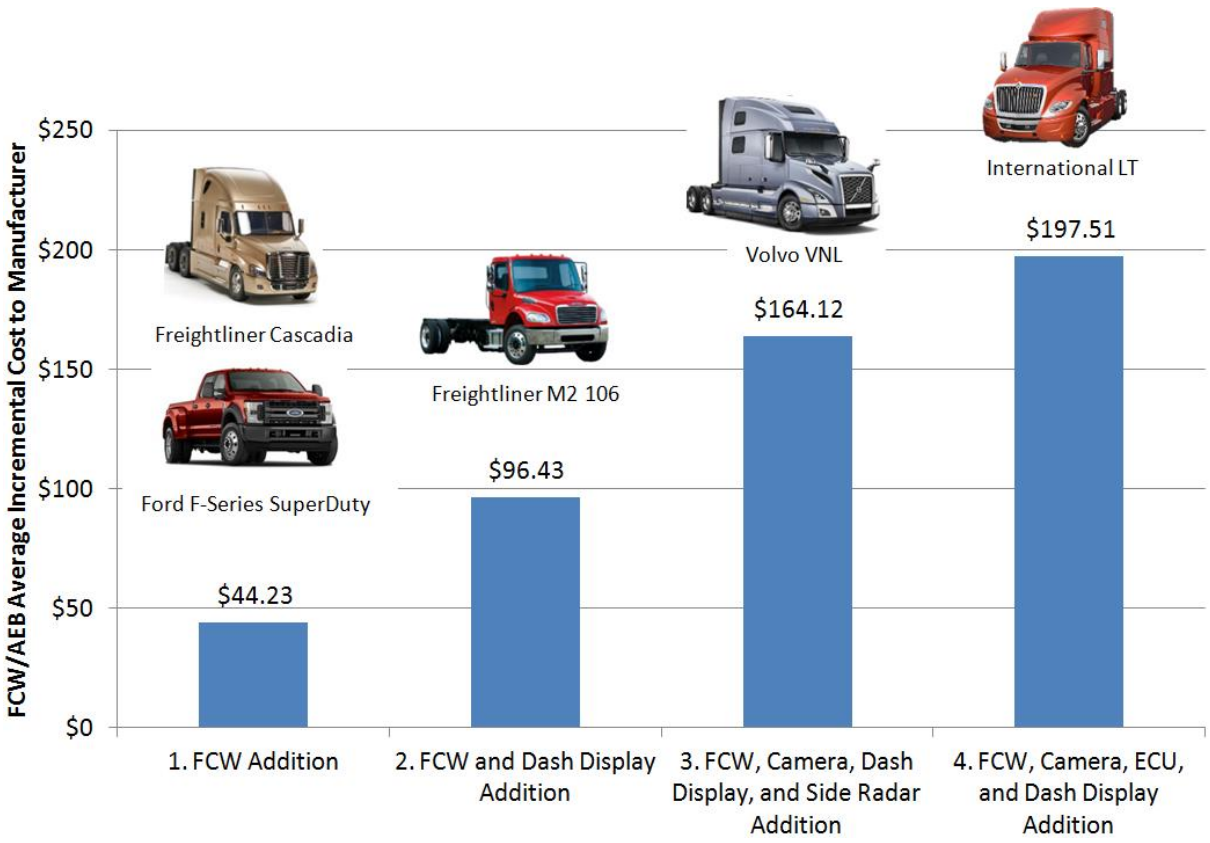

Figure 1: Average Incremental Cost to Manufacturers for FCW/AEB Systems

The average incremental weights of these FCW/AEB systems vary from 0.46 kg to 3.23 kg as shown in Figure 2.

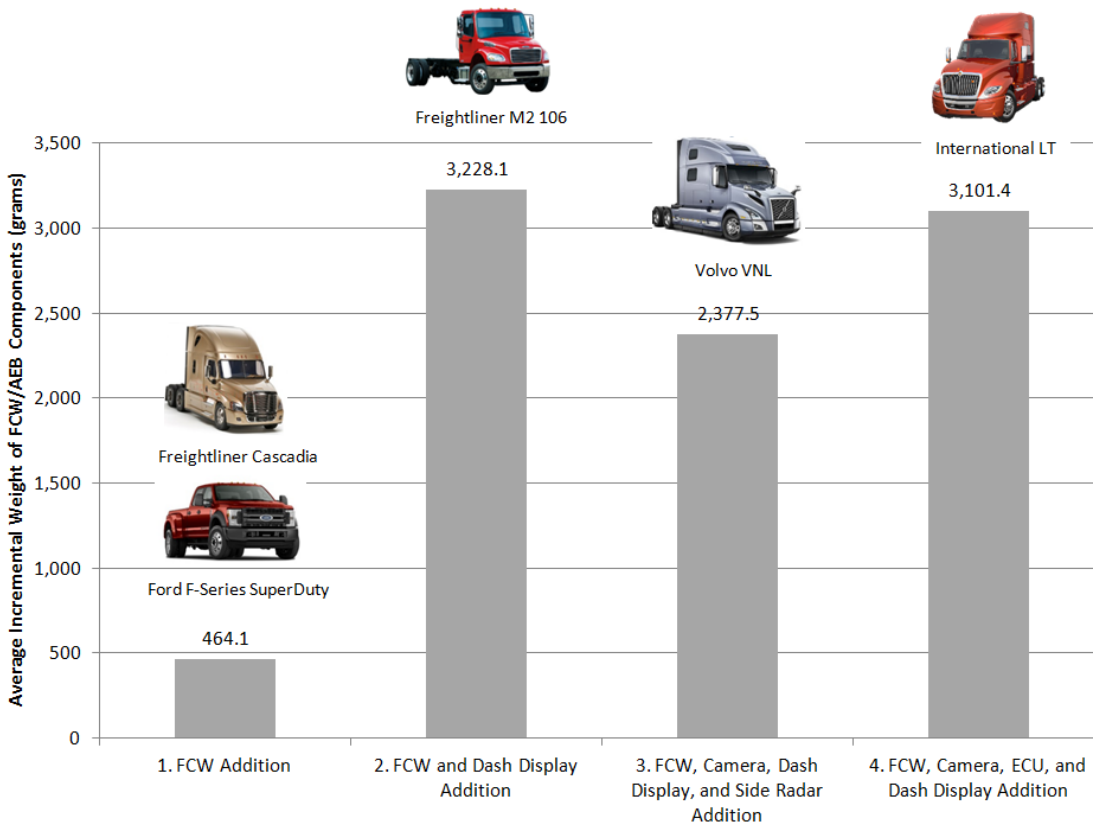

Figure 2: Average Incremental Weight Associated with FCW/AEB Systems

The average manufacturing costs are further characterized by four elemental cost components of labor, material, variable and fixed costs, as described in Section 3.0. These manufacturing cost components are shown in Table 1.

	FCW/AEB Category	Corresponding Vehicles					Average Incremental Manufacturing Costs					
		Ford F-Series SuperDuty MD	Freightliner M2 106 MD	Freightliner Cascadia Class 8	Volvo VNL Class 8	International LT Class 8	Labor	Material	Other Variable	Fixed	Variable Costs (Labor + Material + Other Variable)	Total Cost to Manufacture per Unit
1	*FCW Addition*	X		X			$ 1.51	$ 37.83	$ 2.40	$ 2.49	$ 41.73	$ 44.23
2	*FCW and Dash Display Addition*		X				$ 3.18	$ 81.97	$ 7.07	$ 4.21	$ 92.22	$ 96.43
3	*FCW, Camera, Dash Display, and Side Radar Addition*				X		$ 12.01	$ 137.95	$ 8.00	$ 6.16	$ 157.96	$ 164.12
4	*FCW, Camera, ECU, and Dash Display*					X	$ 10.14	$ 166.59	$ 13.20	$ 7.58	$ 189.93	$ 197.51

Table 1: Average Incremental Manufacturing Cost Elements for FCW/AEB Systems

Overhead burdens, characterized by fixed percentage markups for SG&A, profit, transportation & warranty; as well as dealer costs and markup, are applied to the total manufacturing costs to determine the end-user price increase. These additional price increments for the FCW/AEB systems range from $70.80 to $316.18 as shown in the graph of Figure 3.

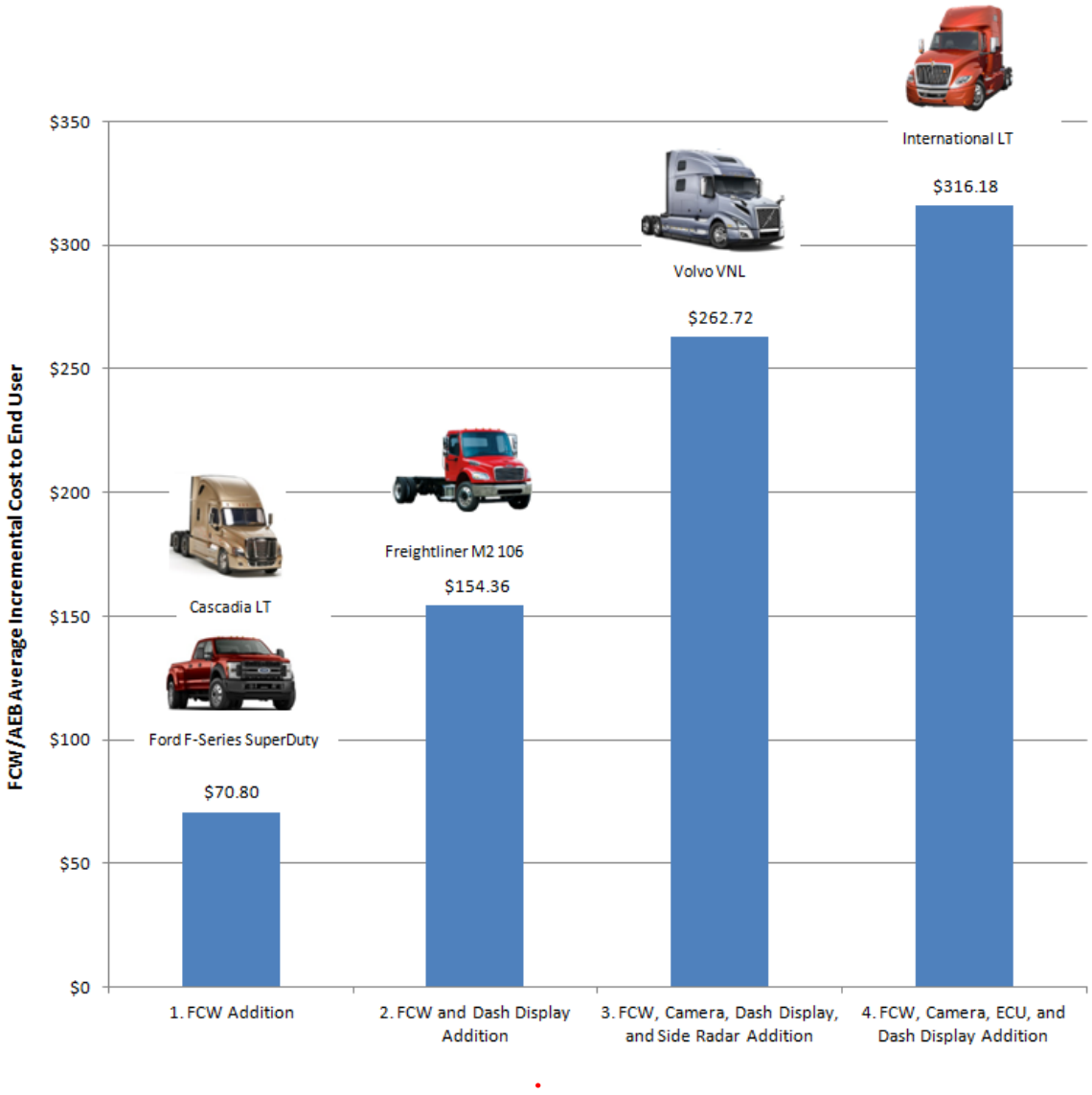

Figure 3: Average Incremental Price to End User for FCW/AEB Systems

3.0 ENGINEERING ANALYSIS

Heavy vehicle Forward Collision Warning (FCW) and Automatic Emergency Braking (AEB) Systems help prevent rear-end crashes or reduce their severity by applying the brakes for the driver. The systems use on-vehicle, forward-looking sensors such as radar, cameras or lasers to detect an imminent crash, warn the driver and apply the brakes if the driver does not take sufficient action quickly. AEB systems work with or without driver intervention, by combining

inputs from radar and/or camera sensors and driver inputs to determine if a rear-end crash with the vehicle ahead is likely to happen and warn the driver to apply the brakes and, depending on the type of system, apply the brakes if sufficient braking is not applied to mitigate a collision. Specifically, AEB technology includes two systems—crash imminent braking (CIB), which applies the brakes in cases where a rear-end crash is imminent and the driver is not taking sufficient action to avoid the crash, and dynamic brake support (DBS), which supplements the driver's braking input if the driver is not applying sufficient braking to avoid a rear-end crash.[11]

Automatic braking technology and stability control systems have been offered on large trucks since at least 2006.[12] Many large fleets and truck leasing companies such as Penske and Ryder have recently accelerated implementation of advanced safety features as prices of these systems continue to decline. The American Transportation Research Institute estimates the payback period for onboard safety systems is now 12 to 14 months.[13]

Forward collision warning systems are onboard, electronic systems that monitor the roadway ahead of the host vehicle and provide warnings to the driver when a potential collision risk exits. These systems have been commercially available since 1994[14]. Currently available FCW systems employ radar sensors, and in some cases both radar and visual camera-based sensors, to determine distance, azimuth, and relative speed between the host vehicle and the vehicle or object ahead of it. Warnings are issued to the driver when the vehicle or object are within a closing time threshold. FCW systems can be integrated with AEB to slow the vehicle and avoid or mitigate crashes.[15]

Automatic Emergency Braking (AEB) is a technology that combines sensors with computer algorithms to warn drivers of certain types of impending forward collisions. This technology was initially incorporated into heavy vehicles (defined as those with a gross vehicle weight greater than 10,000 lbs) during 2009. The system automatically engages vehicle braking if the driver doesn't, and supplements a driver's braking if it is deemed insufficient.[16]

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[11] National Highway Traffic Safety Administration, Contract DTNH221D00037/DTNH2217F00147, Cost and Weight Analysis of Heavy Vehicle Forward Collision Warning (FCW) and Automatic Emergency Braking (AEB) Systems for Heavy Trucks, Section C – Description/Specifications/Statement of Work, Part C.2, Background, 29 September 2017.

[12] Gillan, J., Automatic Emergency Braking – Prime Time for Regulation, *Trucks*, 23 June 2016, https://www.trucks.com/2016/06/23/automatic-emergency-braking-ready/

[13] Schaffner, C., Trucking Fleets Get Closer to Automation, Add Advanced Safety Features, *Trucks*, 20 January 2017, https://www.trucks.com/2017/01/20/trucking-companies-automated-safety-features/

[14] Tidwell, S., Blanco, M., Trimble, T., Atwood, J., & Morgan, J. F. (2015, September). Evaluation of heavy-vehicle crash warning interfaces. (Report No. DOT HS 812 191). Washington, DC: National Highway Traffic Safety Administration.

[15] University of Michigan Transportation Research Institute, Forward Collision Warning Systems, http://www.umtri.umich.edu/our-focus/forward-collision-warning-systems

[16] Glassbrenner, D., *et. al.*, A Target Population for Automatic Emergency Braking in Heavy Vehicles, Mathematical Analysis Division, National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Report DOT HS 812 390, July 2017.

During February 2015, the Truck Safety Coalition, the Center for Auto Safety, Advocates for Highway and Auto Safety, and Road Safe America collectively submitted a petition to NHTSA. Their petition requested that the agency initiate rulemaking to establish a new Federal motor vehicle safety standard to require vehicle manufacturers to install forward collision avoidance and mitigation (FCAM) systems on all vehicles with a gross vehicle weight rating (GVWR) of 10,000 pounds or more. The petitioners claimed that FCAM systems have the potential to provide significant safety, economic, and societal benefits. On 16 October 2015, NHTSA granted the petition for rulemaking to establish a safety standard to require automatic forward collision avoidance and mitigation systems on certain heavy vehicles. NHTSA also agreed to continue research on forward collision avoidance and mitigation technology on heavy vehicles, including forward collision warning and automatic emergency braking systems, including evaluation of real-world performance of these systems through track testing and field operational testing. NHTSA will then determine whether to issue a rule in the course of the rulemaking process, in accordance with statutory criteria.[17] The purpose of the current analysis is to perform and establish reliable cost and weight estimates for FCW/AEB as currently offered on heavy trucks with a gross vehicle weight rating (GVWR) exceeding 10,000 lbs. This includes dismantling the FCW/AEB systems to determine the incremental costs and weights as well to support insight into the efficiency benefits of using the systems for crash avoidance.

Technology

Original equipment manufacturers have steadily been improving FCW systems by adding capabilities such as collision mitigating braking (CMB), engine braking, and integrated radar and camera sensors. While solving some of the deficiencies of early-generation systems (e.g., high false alarm rate, stationary object detection), these advancements have also produced new challenges, including lack of standardized driver interaction and crash warning interfaces (CWIs). Current FCW systems are available as original equipment manufacturer (OEM) options and aftermarket retrofit kits.[18]

Although FCW/AEB system features and components vary between manufacturers, they all perform a cascading system of actions as shown in Figure 4. Two key components of the systems are:

1. Driver Alert: this may be audible, visual, haptic, or a combination of these warning modes and are referred to as FCW, collision warning system (CWS), CWI, driving safety support system (DSSS), stationary object alerts (SOA), and following distance alert (FDA).

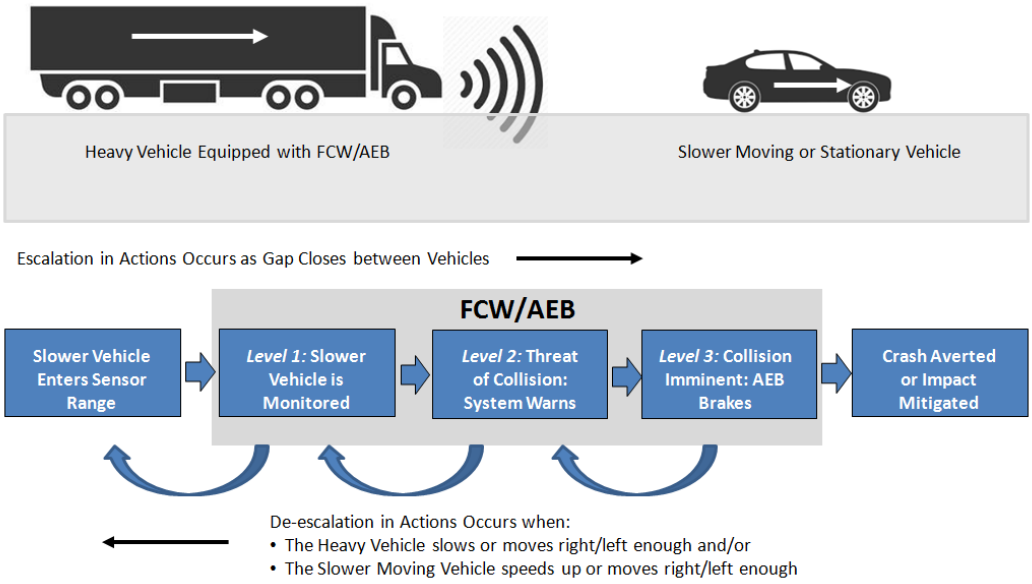
[17] US Federal Register, Federal Motor Vehicle Safety Standard; Automatic Emergency Braking, A Rule by the National Highway Traffic Safety Administration, Document 80 FR 6287, Pages 62487-62488, 49 CFR 571, Document Number 2015-26294, October 16, 2015.

[18] Tidwell, S., Blanco, M., Trimble, T., Atwood, J., & Morgan, J. F. (2015, September). Evaluation of heavy-vehicle crash warning interfaces. (Report No. DOT HS 812 191). Washington, DC: National Highway Traffic Safety Administration.

2. Brake Engagement: this involves application of the vehicle brake system independent of the driver and is referred to as AEB, CMB, CIB, or forward collision avoidance and mitigation (FCAM).

Not all frontal crashes would be mitigated by the technology. For instance, the current systems do not act in crashes under 10-15 mph, nor do they act in crashes into walls, trees, and other fixed non-vehicular objects.[19] It is also noted that the AEB, CMB, and CIB systems are categorized as crash mitigation systems as opposed to crash avoidance systems[20].

The radar sensor and, for some currently available FCW systems, camera monitor the roadway in front of the vehicle and warn the driver when a potential collision risk exists. Electronic signals from the radar and camera are processed using specially-developed algorithms to determine distance, orientation (azimuth), and relative speed between the host vehicle with CWS and vehicles or objects ahead of it. As the time interval to the vehicle or object ahead decreases, the FCW system issues a progressively more urgent warning. As an object gets closer to the front of the host vehicle, corresponding to decreasing range or time interval, the system issues different types of alarms. These progressive thresholds are illustrated in Figure 5.



[19] Glassbrenner, D., *et. al.*, A Target Population for Automatic Emergency Braking in Heavy Vehicles, National Highway Traffic Safety Administration, Report DOT HS 812 390, July 2017, Section 1b, Introduction to AEB, pages 2-3.

[20] Stocksdale, J., AAA Shows that not all auto-braking systems are created equal, *Autoblog*, 24 August 2016, https://www.autoblog.com/2016/08/24/automatic-braking-safety-system-effectiveness-study/

Figure 4: FCW/AEB Actions in a Collision Threat[21]

As noted above, there are currently no US Federal regulations for FCW systems. During 2005, the Federal Motor Carrier Safety Administration issued voluntary operational requirements for these systems, which include 1) functional (basic system functions and operation), 2) data collection and processing, 3) hardware and software, 4) driver vehicle interface (DVI) definition, and 5) maintenance and support functions.[22] Many of these voluntary requirements dictate the hardware and functions of the FCW systems, such as:

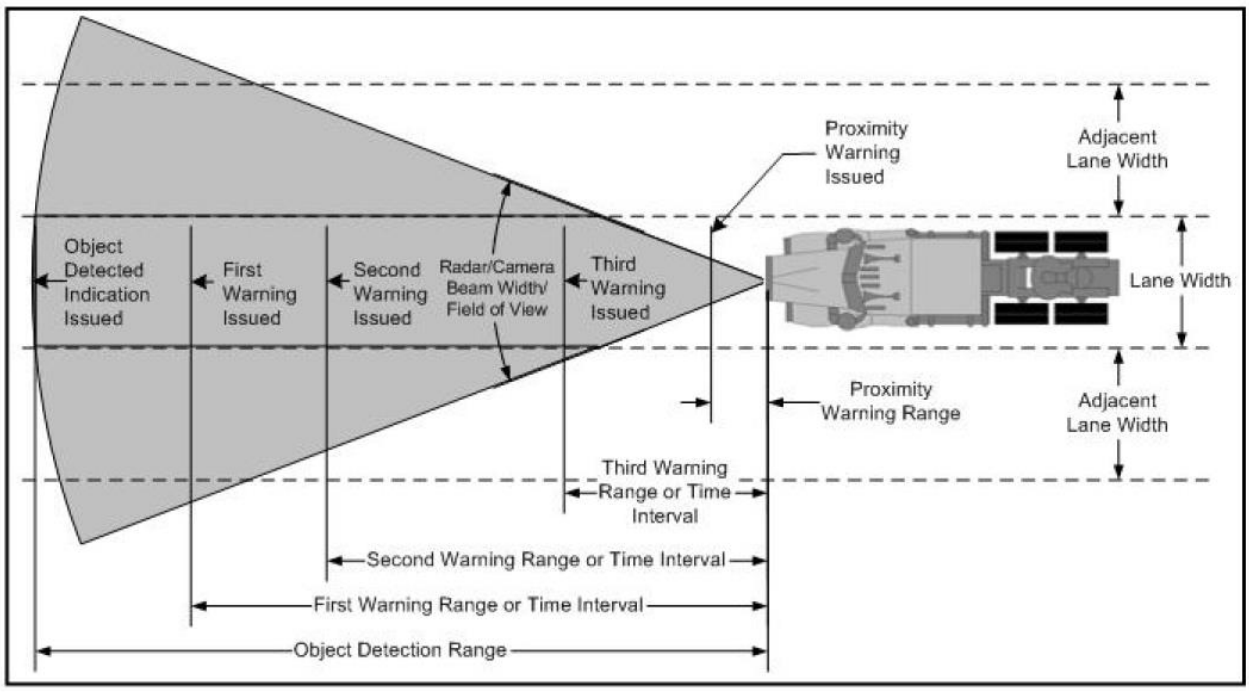


Figure 5: FCW Object Detection Ranges and Collision Warning Thresholds (from Houser, *et. al.*, 2005)[23]

Functional Requirements include:

- self-test upon starting vehicle
- detection, tracking and issuance of warnings for defined pre-collision conditions

[21] Woodrooffe, J., Blower, D., Bao, S., Bogard, S., Flannagan, C., Green, P. E., et al. (2012). Performance Characterization and Safety Effectiveness Estimates of Forward Collision Avoidance and Mitigation Systems for Medium/Heavy Commercial Vehicles. Ann Arbor, MI: University of Michigan Transportation Research Institute.

[22] Houser, A., Pierowicz, J., and McClellan, R., Concept of Operations and Voluntary Operational Requirements for Automated Cruise Control/Collision Warning Systems (ACC/CWS) On-Board Commercial Motor Vehicles, Federal Motor Carrier Safety Administration (FMCSA), Report No. FMCSA-MCRR-05-007, July 2005.

[23] Houser, A., Pierowicz, J., and McClellan, R., Concept of Operations and Voluntary Operational Requirements for Automated Cruise Control/Collision Warning Systems (ACC/CWS) On-Board Commercial Motor Vehicles, Federal Motor Carrier Safety Administration (FMCSA), Report No. FMCSA-MCRR-05-007, July 2005.

- detection distances on straight and curved roads
- differentiation between on-coming traffic and vehicles in the travel lane
- operation during potential adverse weather conditions
- differentiation between stationary roadside objects and moving or stationary vehicles
- brake light activation

Data requirements include:

- compliance with Society of Automotive Engineers (SAE) standards J1587 and J1939 relative to in-vehicle data communication in heavy trucks
- recommendation that FCW suppliers adopt a common set of warnings and messages

Hardware and software requirements include:

- requirements for forward-looking sensor(s) or detector(s) and detection specifications
- electronic control unit (ECU) performance
- definition of driver vehicle interface
- environmental operating conditions
- electrical requirements, including power supply, SAE electrical standards, and power surge protection
- mounting and installation
- embedded software that controls the FCW systems

Driver-Vehicle interface requirements include:

- audible tones for warnings
- visual indicator when no vehicles are in lane
- visual indicator of system operational status
- visual or audible indicator when system failure or malfunction occurs
- system indicators to be discernible in direct sunlight or at night

Maintenance and support requirements include:

- definition of periodic system service requirements
- training manual
- definition of minimum speed at which FCW systems are in operation
- availability of product support for users and fleets

NTSB is supporting NHTSA's rulemaking process along with associated standards definition and is recommending regulations that require collision warning systems and adoptive cruise control on all commercial vehicles.[24]

FCW/AEB Components

Information flows among the various CAS modules, from the sensing systems (i.e.: FCW, Side Collision Warning - SCW, vision, and onboard vehicle), to a processing module (existing ECU or specialized collision warning processing module), and eventually the Driver-Vehicle Interface (DVI) which provides the appropriate warning cues to the driver. Each of the sensing systems receives information about the host vehicle states (such as: yaw rate, vehicle speed, etc.) and sends appropriate parameters/information (such as: lane path, detected vehicle speed and range, etc.) relative to the host vehicle. The collision warning processing module will combine the information from the active sensing systems (i.e.: vision, radar, etc.) and passive sensors (i.e.: on-board sensors used to determine host vehicle states) in order to accomplish object detection, target tracking, in-path target identification, and threat assessment. If the identified detected target is assessed as being a potential hazard to the host vehicle, then appropriate warning cues will be initiated and provided to the driver in the form of visual, auditory or tactile (haptic) cues. This is illustrated in Figure 6 below.[25]

[24] Morrison, J., Forward Collision Warning Systems, National Transportation Safety Board, Office of Highway Safety, 2016 Fleet Safety Conference, Shaumberg, Illinois, 18-20 July 2016, https://www.ntsb.gov/news/events/Documents/miami_ok-FCWS_Presentation.pdf

[25] Zador, P.L., Krawchuk, S.A., and Voas, R.B., Final Report – Automotive Collision Avoidance (ACAS) Program, National Highway Traffic Safety Administration, Report No. DOT HS 809 080, August 2000.

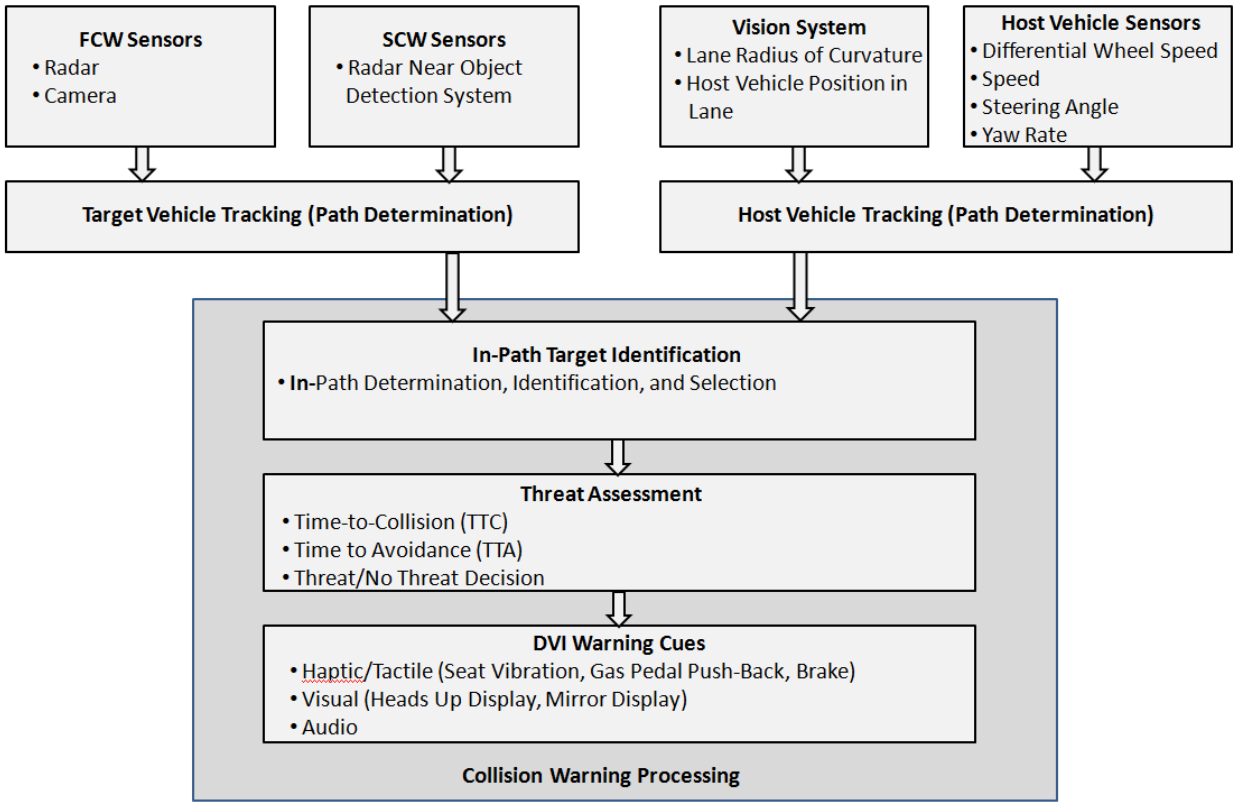


Figure 6: : Example Architecture for Collision Warning System (FCW, SCW) (after NHTSA)

FCW/AEB systems include some or all of the following key components:

Radar Sensor: The forward looking radar (FLR) sensor is typically mounted at the front bumper of the host vehicle. It is used to determine whether moving or stationary objects occupy the lane in which the host vehicles is traveling. It is noted that not all lane occupying objects are detected by the radar system, such as an animal entering the road, vehicles passing on the right or left, or rapidly-moving cross traffic. Some FCW systems employ only a radar sensor to detect relative speed and position and some use visual camera signals as a secondary validation of objects sensed by the radar and/or to identify whether objects are licensed vehicles[26] in the evaluation of forward collision threats.

Camera: The Bendix Wingman Fusion includes a visual camera as part of the FCW system. The camera is located inside the cab at the top, center section of the windshield. Signals from the camera as included in the forward collision threat evaluation algorithms.

ECU: Signals from the radar and camera (if included in the FCW system) are processed within an electronic control unit. In some cases, a separate ECU specific to the FCW system is included.

[26] Bendix Wingman Fusion, I thought, can use the camera to identify the license plate thereby tagging the object as a motor vehicle.

In others, signals are processed within an existing ECU. The ECU provides input to the DVI and, if the vehicle is equipped with AEB, to the brake controls.

Wiring and Connectors: Ricardo analyzed the wiring harnesses and connectors (including active connector pins) to determine which portions were uniquely associated with the FCW/AEB systems.

Mounting Hardware, including Brackets: This includes the brackets and hardware for the radar sensor, camera (if part of system), wire harnesses, and ECU (if part of system).

These key FCW/AEB system key components are illustrated in Figure 7.

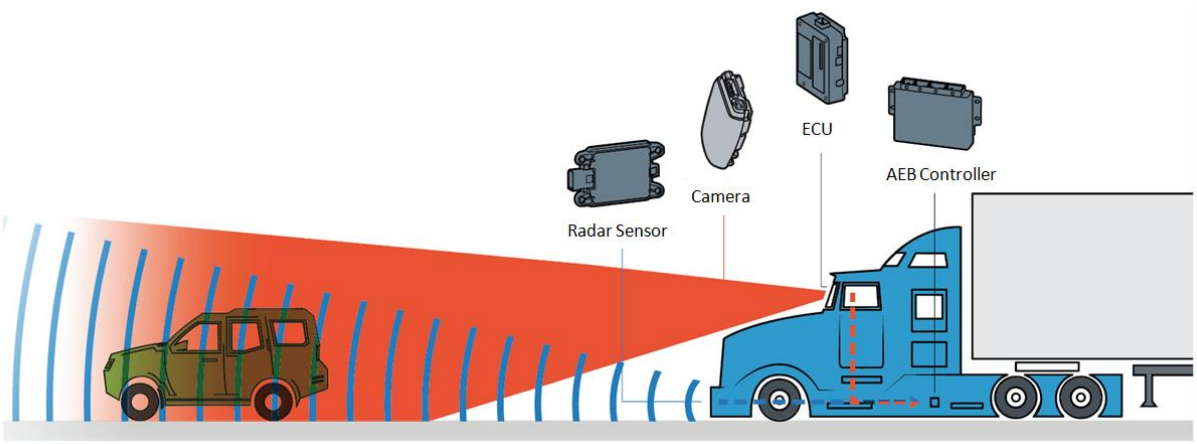


Figure 7: Key FCW/AEB System Components (based on Bendix information[27])

Selection of Vehicles

Ricardo worked with NHTSA to define the study scope, baseline equipment, study assumptions, and costing methodology. The vehicle identification and selection methodology is summarized in Figure 8 and Figure 9. The process began with three key procedures: 1) vehicle research, 2) vehicle segregation, and 3) vehicle selection. NHTSA approved the evaluation of five (5) FCW/AEB systems that were to be selected according to the following criteria:

- The samples may include but are not limited to at least two AEB systems with CIB
- The samples may include but are not limited to at least one AEB system without CIB
- The samples may include but are not limited to at least two AEB systems with DBS
- System manufacturers should include the Heavy Vehicle (HV) market (e.g., Freightliner, Volvo, International, Hino, Mercedes, Ford, RAM etc.)

[27] Bendix® Wingman® Fusion™, The Integration of Camera, Radar, and Brakes, Bendix Commercial Vehicles Systems, LLC, September 2015, http://www.bendix.com/media/documents/products_1/wingman_fusion/BW3025_Fusion_Brochure.pdf

- System manufacturers may include but are not limited to Bendix, Meritor WABCO, Daimler Trucks, etc.
- The samples may include at least 2 hydraulic-braked systems and at least 2 air-braked systems. Vehicles under 26,000 GVWR have a mixed use of air and hydraulic brakes.
- Electronic Stability Control (ESC) costs need to be considered for medium duty vehicles (10-26k lbs GVWR). The chart in Table 2 shows component needs:[28]

Heavy Vehicle Category	Current Brake System		Available AEB System	ESC System	Teardown and Cost Analysis
Medium Duty (GVWR: 10,000 to 26,000 lbs) Note: ESC is not Required for a FMVSS	Have both air brakes and hydraulic brakes for this category	If Equipped with Air Brakes	Candidate: Meritor WABCO's OnGuard Active	Not Required	Include AEB and ESC
			Candidate: Bendix Wingman Fusion		
		If Equipped with Hydraulic Brakes	Candidate: Ford Commercial Trucks F350 with ABS and ESC	ESC is a Standard Feature	
			Candidate: Freightliner Sprinter Equipped with ABS/ESC.FCW/DBS		
			Candidate: RAM Commercial Trucks Chassis Cab 4500 or 5500 Series with ABS/EsC		
Heavy Duty (greater than 26,000 lbs) Note: ESC is required by the FMVSS ESC.	Almost all trucks in this category are equipped with air brakes	If Equipped with Air Brakes	Candidate: Meritor WABCO's OnGuard Active	Not Required	AEB Only
			Candidate: Bendix Wingman Fusion		
		If Equipped with Hydraulic Brakes	Note: Based on marker Research, NHTSA is not aware of any heavy vehicles (with a GVWR greater than 26,000 lbs) equipped with hydraulic brakes.		

Table 2: Specified FCW/AEB Component Selection Targets

For the current study, the weights and costs for the FCW systems are included as separate line items since this could be a separate regulatory option for NHTSA. In addition, since NHTSA is not requiring ESC for medium trucks, the ESC cost is included as part of the AEB system for medium trucks (because AEB requires ESC functionalities).

The vehicle selection process included current model year offerings from key HD vehicle OEMs such as Daimler (Freightliner, Western Star), Volvo, International, PACCAR (Kenworth, Peterbilt), Mack, Hino, Freightliner, Ford, General Motors, RAM, and Fuso. FCW and AEB systems that were evaluated as candidates include Delphi Technologies (includes Electronically

[28] National Highway Traffic Safety Administration, Contract Number DTNH2216D00037/DTNH2217F00147, Cost and Weight Analysis of Heavy Vehicle Forward Collision Warning (FCW) and Automatic Emergency Braking (AEB) Systems for Heavy Trucks, 29 September 2017.

Scanning Radar, ESR), Meritor WABCO OnGuardACTIVE™ (includes 77GHz radar sensor), Bendix® Wingman® Fusion™ (integrated radar and camera sensors), and Detroit Assurance Division Safety Systems: Video Radar Decision Unit (VRDU), which includes both radar and camera sensors as well as Active Brake Assist (ABA).

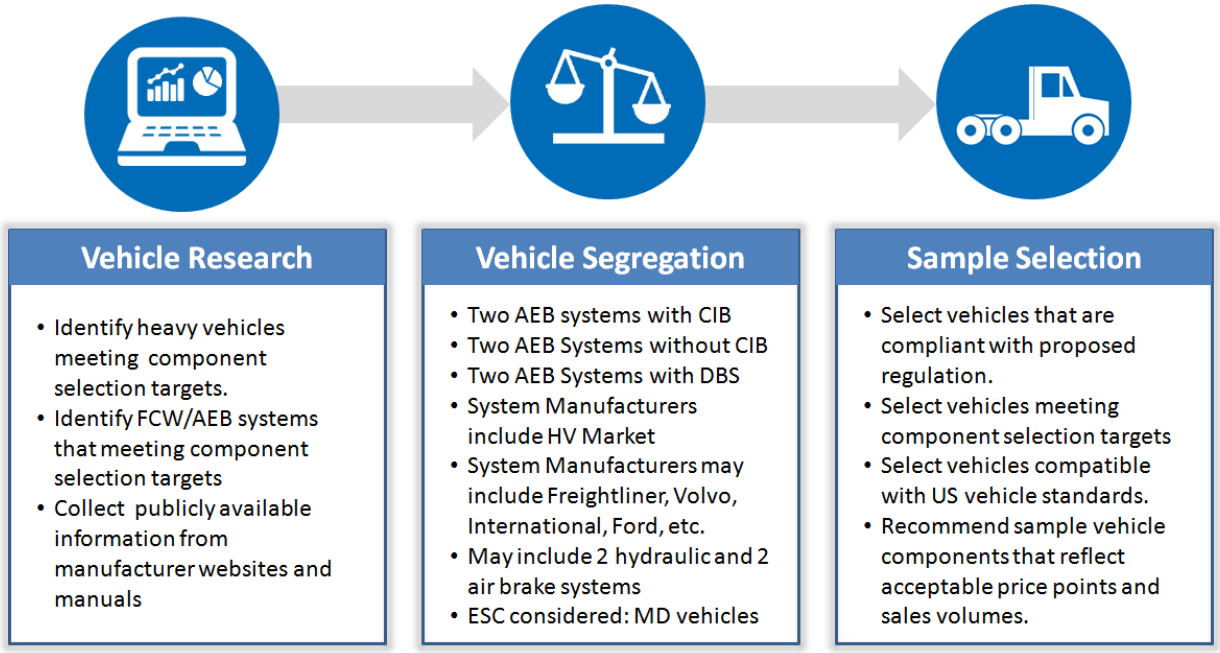


Figure 8: Vehicle Identification/Selection Methodology

Additional vehicle selection criteria included:

- Availability of information on vehicle FCW/AEB systems
- Availability of FCW/AEB system parts for purchase
- Annual sales volumes
- Focus on systems developed by major suppliers of FCW/AEB technology
- To be representative of high-volume, mainstream systems offered by key global suppliers

During the sample selection process, Ricardo compiled information from a variety of sources, including vehicle tear-down and costing data suppliers, company brochures and specification sheets, users manuals, parts suppliers, supplier and manufacturer representatives, Ricardo technical experts, and technical papers available in the literature.

The five vehicles selected for detailed evaluation include:

1. Ford Super Duty® F-Series Trucks (GVW Class 4-7)
2. Freightliner M2 106 (GVW Class 7)
3. International LT™ (GVW Class 8)
4. Volvo VNL (GVW Class 8)
5. Freightliner Cascadia® (GVW Class 8)

Comparisons of the selected vehicles relative to the target criteria are included in Figure 9.

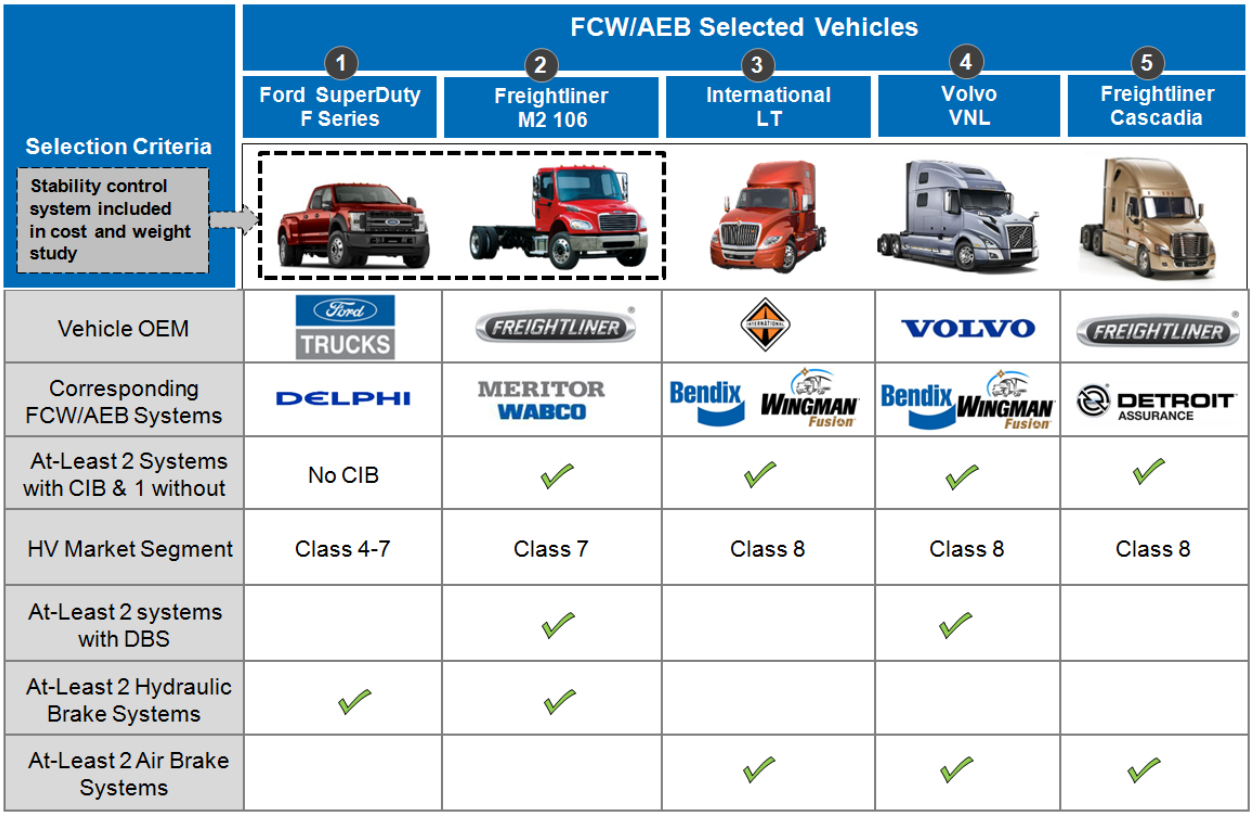


Figure 9: Selected Vehicles and Selection Criteria

Annual Sales Volumes for Selected Vehicles: Sales volumes for the selected vehicles are shown in the graph of Figure 10. Actual sales are presented for the years 2015 and 2016.[29] Projected sales for 2018 are also shown, based on month-to-date data.[30] To meet the goal of defining costs and weights representative of high-volume, mainstream systems offered by key global suppliers, identified FCW and AEB component costs were evaluated based on the assumption of production volumes of 200,000 vehicles per year because, as will be shown below, many of the components such as the radar sensor are common between truck manufacturers and therefore a share a common supply base with economies of scale.

FCW/AEB System Descriptions for Selected Vehicles

Descriptions were obtained from manufacturer literature, independent product descriptions, vehicle owners manuals, maintenance manuals, and interviews with industry experts.

Ford Super Duty® F-Series: FCW is offered on Ford Super Duty® trucks, but CIB (AEB) is not an available option. The Ford Collision Warning and Brake Support System is part of an Adoptive Cruise Control option available on the following trim variants for the Ford Super

[29] *The Rhein Report*, Truck Sales 2016, January 2017, pages 1-8.

[30] IHS Markit, Registrations and Vehicles in Operation, 2018

Duty® F-Series: Lariat, King Ranch, and Platinum[31]. The Brake Support System pre-charges the brakes for full responsiveness if the driver does not initially react to the FCW alerts while continuing to get closer to the vehicles ahead in the same lane, but does not automatically apply the brakes. The system is active at vehicle speeds greater than 5 mph and can be disengaged by the driver. The system becomes unavailable if the driver disables the electronic stability control.[32]

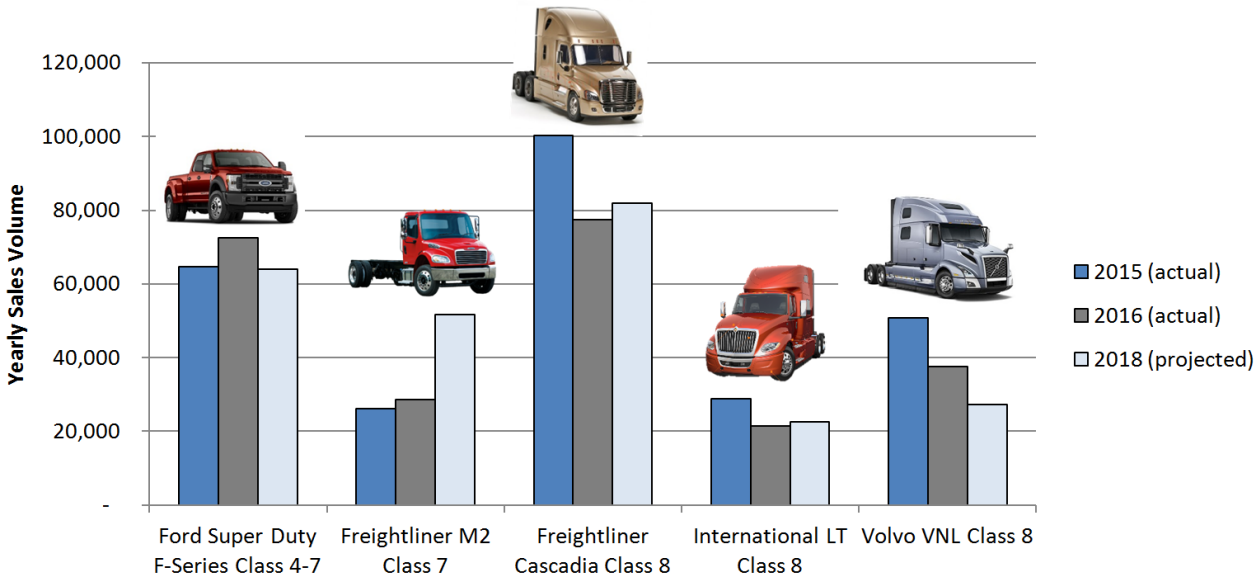


Figure 10: Yearly Sales for Selected Vehicles

A head up display (HUD) is activated when the vehicle enters the forward collision warning zone[33] as illustrated in Figure 11. If the risk of collision further increases after the warning light illuminates, the brake support prepares the brake system for rapid braking. The system does not automatically activate the brakes, but if the brake pedal is pressed, full force braking applies, even if the brake pedal is lightly pressed. The collision warning system's sensitivity can be adjusted to any one of three possible settings (high, medium, or low) if warnings are perceived to be too frequent or disturbing to the driver.

The Ford system includes a single radar sensor located behind a fascia cover near the driver side of the lower grille as shown in Figure 12. The 2018 Super Duty® Owner's Manual cautions that the sensors will not function properly if they are blocked by objects such as front mounted snow plows or if the surface of the radar in the grille is dirty or swirling water, snow, fog, or ice

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[31] *Automotive Fleet*, Ford F-150 Super Duty® Driver Assist Features, https://www.automotive-fleet.com/144261/2015-ford-f-150-driver-assist-features?photo=178219

[32] Ford Motor Company, 2018 F-350 Super Duty® Owners Manual, Driving Aids, Collision Warning System, Principle of Operation, http://www.fordservicecontent.com/Ford_Content/vdirsnet/OwnerManual/Home/Content?bookCode=O38134&languageCode=en&marketCode=US&viewTech=IE&chapterTitleSelected=G1803376&subTitleSelected=G1853281&topicHRef=G1679765&div=f&vFilteringEnabled=False&userMarket=USA

[33] Ford Motor Company, 2018 F-350 Super Duty® Service Manual, http://www.fordservicecontent.com/Ford_Content/

interfere with the radar signal. The Manual lists the following instances where vehicles do not provide a collision warning.

- Stationary vehicles or vehicles moving below 6 mph (10 km/h).
- Pedestrians or objects in the roadway.
- Oncoming vehicles in the same lane.
- Severe weather conditions.
- Debris build-up on the grille near the headlamps.
- Small distance to vehicle ahead.
- Steering wheel and pedal movements are large.

Figure 11: Ford FCW Zone, Brake Support Zone and Head Up Display (Reference: Ford 350 Super Duty® Owner's Manual)

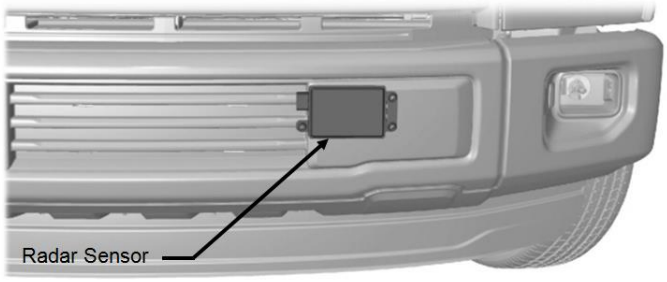

Figure 12: Location of Ford Radar Sensor at Lower Front Grille (Reference: Ford Super Duty® Owner's Manual)

Ford Super Duty® trucks offer AdvanceTrac® Roll Stability Control (RSC®), which includes an Antilock Braking System (ABS) and ESC to help maintain stability of both the vehicle and a trailer in-tow. Also included is a load adaptive response system which senses load levels using engine torque and acceleration signals. The FCW employs a radar system with integrated electronics that is supplied by Delphi Delco. The RSC® feature shares its components with ABS/ATC modules; RSC® requires only one additional valve for operation, which is not included in the FCW cost and weight analysis.[34]

Key components for the Ford Super Duty® FCW system are illustrated in Figure 13. It is noted that the radar and wire harness are unique to the FCW system, while the ECU supports several of the AdvanceTrac® components. Since the ECU is not unique to the FCW system, it was not included in the cost and weight analysis. A list of hardware associated with the AdvanceTrac® systems is shown in Table 3. AEB is not currently available on Ford heavy commercial vehicles. Ford says it will offer auto emergency braking as an option for its heavier commercial trucks by 2020[35].

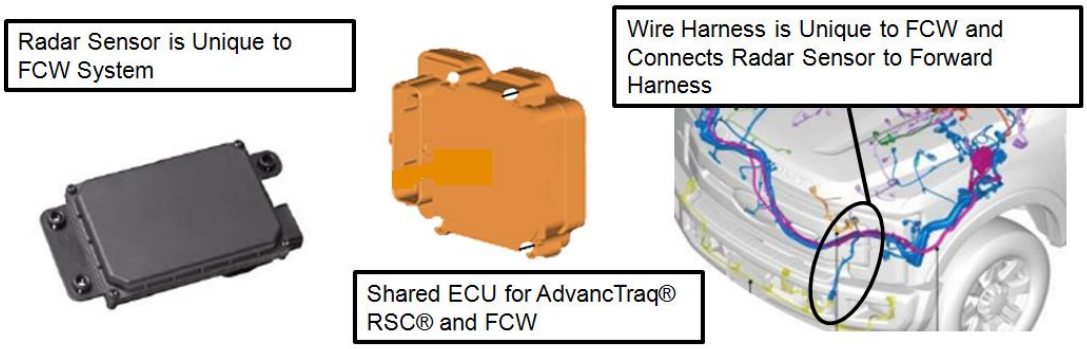

Figure 13: Ford AdvanceTrac® FCW Components[36]

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[34] *Autobytel*, Ford AdvanceTrac® Roll Stability Control (RSC®), https://www.autobytel.com/car-ownership/technology/ford-advancetrac-with-roll-stability-control-rsc-104185/

[35] Meier, F., Safety Standard: Ford to Include Auto Braking, Other Tech Lineup—Wide, *Cars.com*, 16 March 2018, https://www.cars.com/articles/safety-standard-ford-to-include-auto-braking-other-tech-lineup-wide-1420699431396/

[36] Ford Super Duty® F-350 Maintenance Manual 2017.

The system architecture for the AdvanceTrac® system, including the functional relationships between the FCW components and those for RSC®, is illustrated in Figure 14.[37]

A table of specific parts included in the tear-down and cost/weight analysis of the Ford Super Duty® F-Series FCW system is included in the Appendix of this report, along with photos of the parts, a bill of materials, and detailed costs & weights of each assembly, subsystem, and component.

	Ford SuperDuty AdvanceTrac® RSC and FCW Hardware List
FCW	Integrated Radar Module
FCW	Wiring Harness
AdvanceTrac	Shared ECU
AdvanceTrac / RSC	Lateral Acceleration Sensor
AdvanceTrac / RSC	Wheel Speed Sensor
AdvanceTrac / RSC	Drivetrain Speed sensor
AdvanceTrac / RSC	Steering Angle Sensor
AdvanceTrac	Yaw Rate Sensor
AdvanceTrac	ABS module
AdvanceTrac	ATC module

Components highlighted in blue are associated with FCW functions

Table 3: Hardware list for components associated with Ford AdvanceTrac® Systems

[37] Ricardo analysis based on component inspection and evaluation of Ford Super Duty® F-350 Maintenance Manual wiring diagrams.

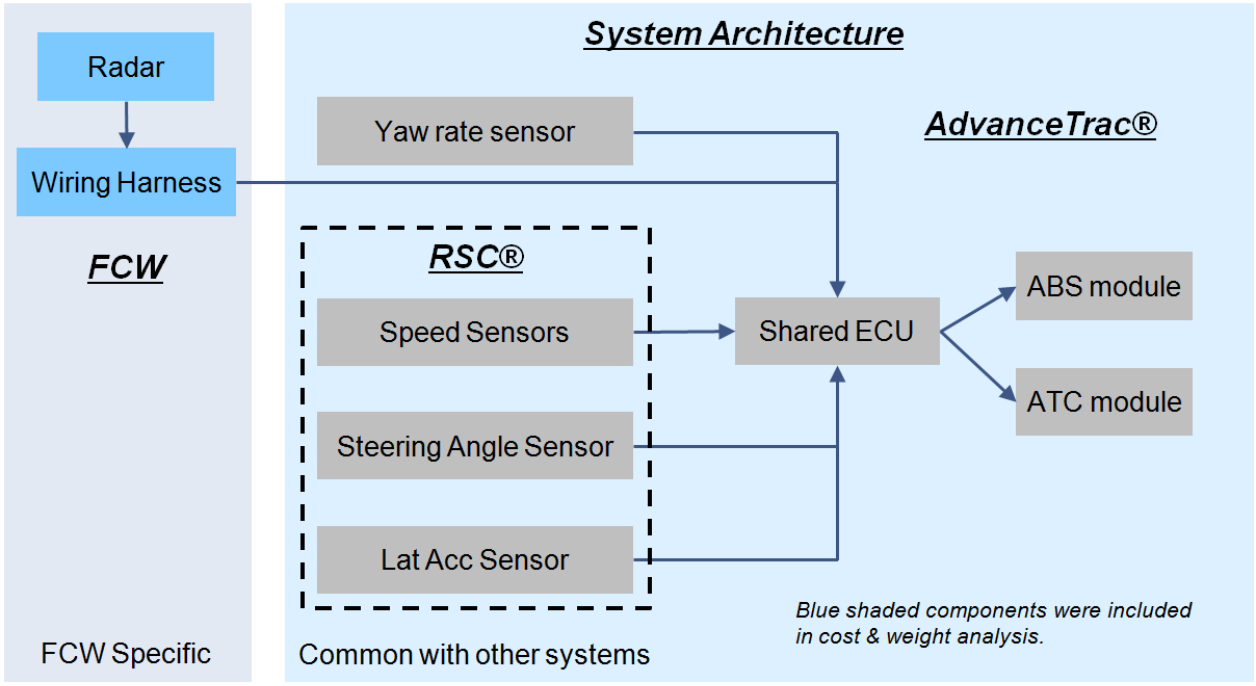

Figure 14: System Architecture of Ford AdvanceTrac® System including FCW-Specific Components

Freightliner M2 106: Freightliner employs the Meritor Wabco OnGuardActive® Collision Mitigation System on the M2 106 Class 7 Series of trucks. The system includes both FCW and AEB capabilities. In addition, the OnGuardActive® system includes adaptive cruise control. The system maintains the set cruising speed when the lane ahead is clear, and automatically adjusts the speed to maintain a set time interval between the host vehicle and the vehicle ahead.[38]

Published functions of the Meritor Wabco OnGuardActive® system include[39]

Collision Mitigation

- Audible & visual warnings and active braking on stationary vehicles that could be a possible obstruction in their lane.
- Vehicle collision audible & visual warnings that alert drivers to developing rear-end collisions
- Haptic warning provides short brake pulse which causes drivers to respond faster to imminent rear-end collisions

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[38] *The BRAKE Report*, Freightliner M2 106 Model Now Available with Meritor WABCO's OnGuard Collision Mitigation System, 21 August 2015, https://thebrakereport.com/freightliner-m2-106-model-now-available-with-meritor-wabcos-onguard-collision-mitigation-system/

[39] WABCO OnGuardACTIVE® Collision Mitigation System, Overview, Features & Benefits, http://www.meritorwabco.com/Product,2,15,2,OnGuard%E2%84%A2-Collision-Safety-Systems-.aspx

- "Always on" at speeds above 15 mph even when cruise control is not set
- Applies up to 50% of the vehicle's braking power to help avoid or mitigate an impending collision

Adaptive Cruise w/Active Braking

- Assists in maintaining a 3.6 seconds interval between driver's vehicle and the vehicle ahead
- Augments cruise control functions in various traffic conditions
- Reduces driver fatigue in congested traffic

Key OnGuardActive® system functions are illustrated in Figure 15. The FCW system employs both narrow angle, far range and wide angle near range radar to detect moving vehicles, stopped vehicles, or stationary objects at distances up to 650 feet. Mitigation includes:

- Three levels of warnings: audible, visual, and haptic
- Active braking: the engine is automatically de-throttled and foundation brakes may be applied up to 50% of available braking power.

The system is active at vehicles speeds between 15 mph and 77 mph. Key components: the WABCO OnGuardActive® system consists of a radar, a radar cover (fascia), a video display unit, and associated wiring that connects the two components and links the display to the vehicle controller area network (CAN). WABCO additionally offers SmartTrac™ stability control system that integrates with other active safety systems, such as FCW and AEB. The SmartTrac™ system includes ABS, automatic traction control (ATC), Electronic Stability Control and Roll Stability Control features. It is also noted that the OnGuardActive® system has been upgraded from the 2013 version to include detection of stationary vehicles[40]. The WABCO OnGuard Max system also integrates lane departure warning system (LDWS) functionality using a camera. It is noted that only the FCW and AEB system components are included in the cost and weight analysis.[41]

[40] Meritor WABCO, OnGuardACTIVE® Operations Manual, Meritor WABCO Vehicle Control Systems, 2016, http://www.meritorwabco.com/MeritorWABCO_document/OM-16108%20OnGuardACTIVE%20Operations%20Manual%20Final.pdf

[41] WABCO Global, WABCO Introduces OnGuardMAX™ Advanced Emergency Braking System; Innovative Technology Adds Full Braking on Stationary Vehicles Ahead; Further Enables Automated Driving for Commercial Vehicles, 2016, https://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/

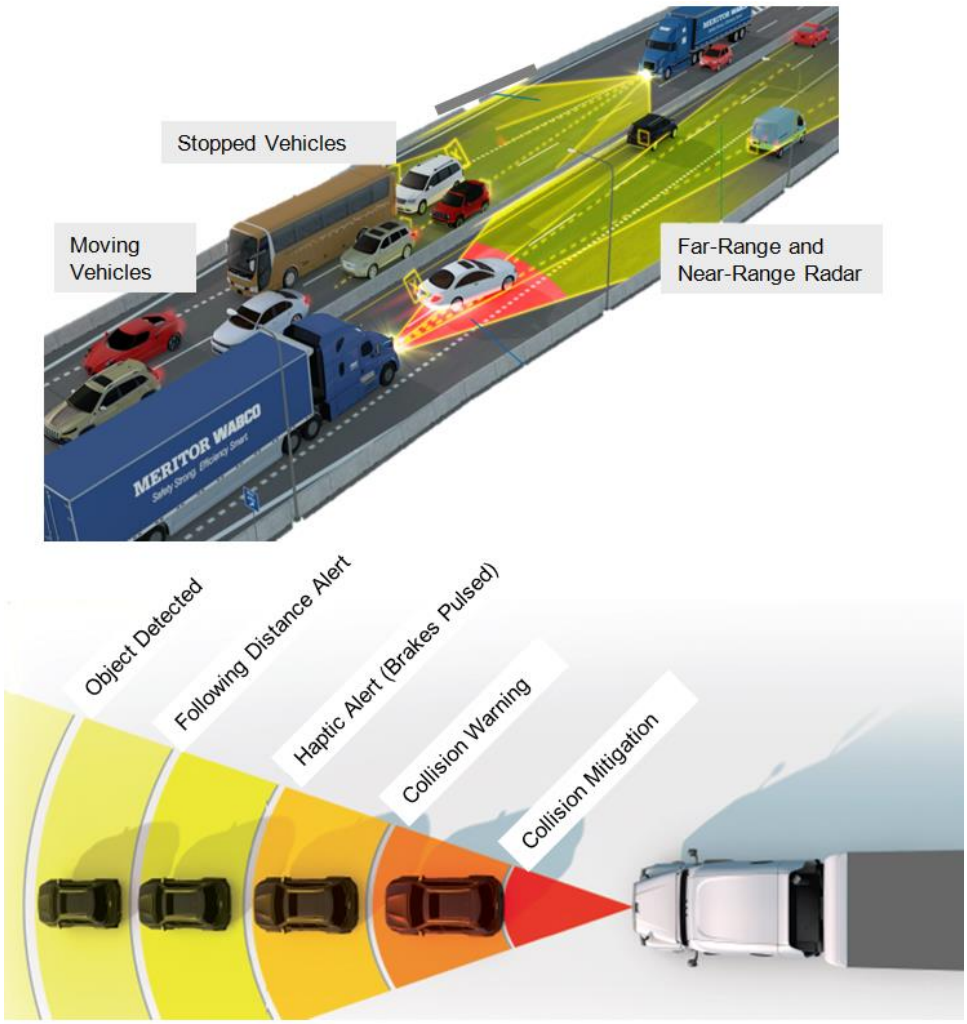

Figure 15: Key Meritor Wabco OnGuardActive® FCW and AEB System Functions[42]

The OnGuardACTIVE® system is provided as a retrofit kit for the Freightliner M2 106. The key components are illustrated in Figure 16.

[42] Meritor Wabco OnGuardACTIVE® Collision Mitigation System, Brochure, June 2015, http://www.meritorwabco.com/MeritorWABCO_document/SP-15135%20OnGuardACTIVE%20Brochure%20102315.pdf

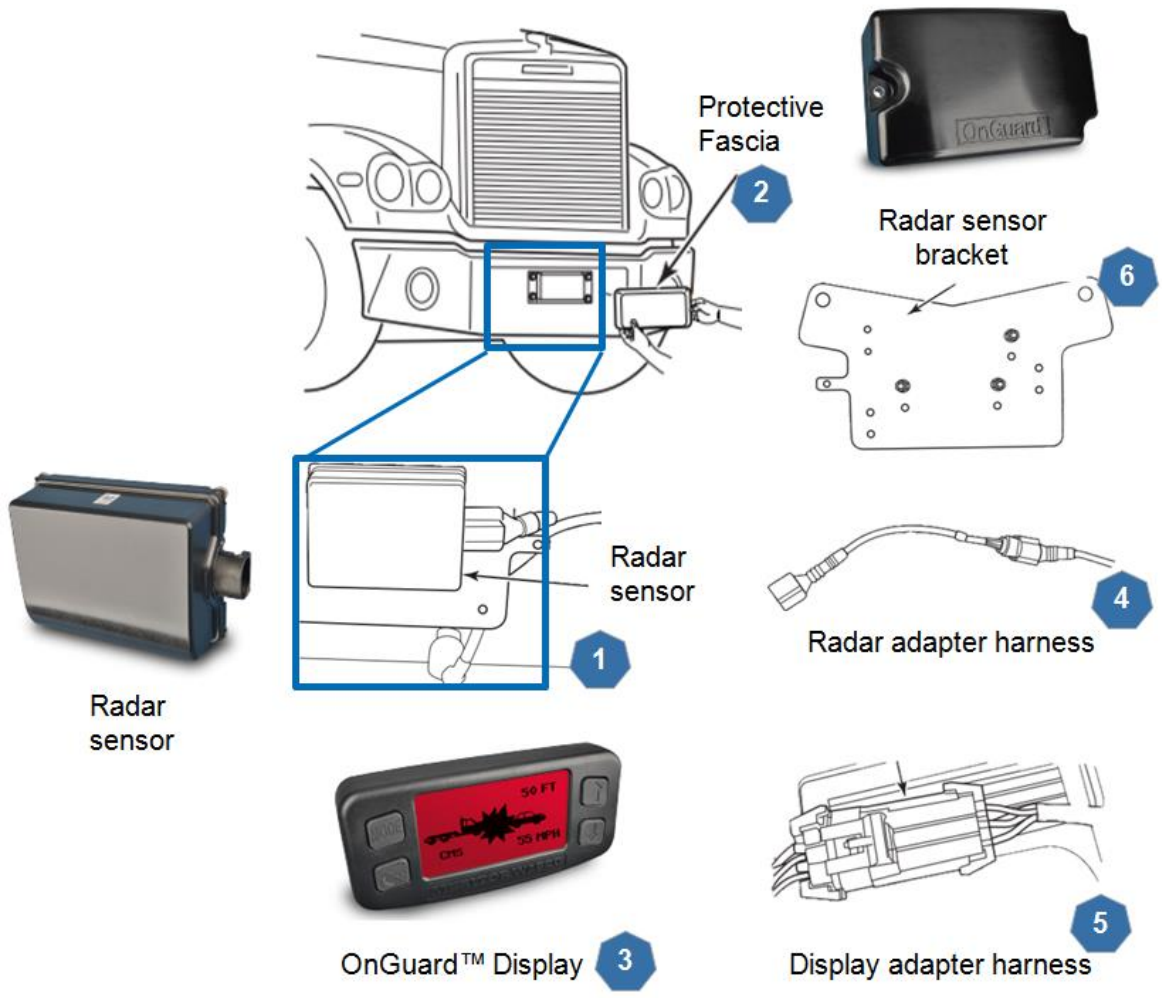

Figure 16: Key Components of Meritor Wabco OnGuardACTIVE® FCW and AEB Systems[43]

It is noted that the radar, display & radar wire harnesses, fascia, bracket, and associated mounting hardware are unique to the FCW and AEB systems, while the ECU supports several of the OnGuardACTIVE® components. Since the ECU is not unique to the FCW system, it was not included in the cost and weight analysis. Since radar unit communicates with ECU via CAN, specific components cannot be identified on the ECU that are dedicated to FCW functionality. A list of incremental hardware associated with the OnGuardACTIVE® FCW and AEB systems is shown in blue in Table 4 and components that interact with it but are not incremental to FCW and AEB system functionality are shown in grey.

The system architecture for the OnGuardACTIVE® system, including the functional relationships between the FCW and AEB components and those for ABS and ATC, are illustrated in Figure 17.

[43] Meritor WABCO, Maintenance Manual MM-1306, OnGuard™ Collision Mitigation System, Revised 02-16, http://www.meritorwabco.com/MeritorWABCO_document/MM-1306.pdf

A table of specific parts included in the tear-down and cost/weight analysis of the Freightliner M2 106 FCW and AEB systems is included in the Appendix of this report, along with photos of the parts, a bill of materials, and detailed costs & weights of each assembly, subsystem, and component.

	FCW/AEB Components of Meritor WABCO OnGuardACTIVE® System Kit Hardware List
OnGuard™	Radar
	Fascia
	Video Display Unit
SmartTrac™	ABS Module
	Lateral Acceleration & Yaw Rate Sensor
	Steering Angle Sensor
	Wheel Speed Sensor
	Drivetrain Speed sensor
	Shared Control Unit
	ATC Module

Components highlighted in blue are associated with FCW/AEB functions

Table 4: Hardware list for components associated with Meritor WABCO OnGuardACTIVE® Systems

Freightliner Cascadia®: Freightliner Division of Daimler Trucks North America LLC offers the Daimler Detroit Assurance® Suite of Safety Systems as options for the Cascadia® Class 8 tractor. The Detroit Assurance® sensors and controls integrate into any Freightliner Cascadia® model equipped with a Detroit™ engine and DT12™ or manual transmission. With bumper-mounted radar and optional windshield-mounted camera, Detroit Assurance® communicates information to the truck's brakes, engine and transmission in real time to help mitigate collisions and enhance driver safety.[44] The system includes FCW and AEB (in the form of Active Brake Assist, which includes CIB functionality). The Assurance® radar has the capacity to track up to 40 objects simultaneously and has a maximum range of 825 feet.[45]

[44] Freightliner, Detroit Assurance® Suite of Safety Systems, Daimler Trucks North America, LLC, https://freightliner.com/demand-detroit/detroit-assurance-suite-of-safety-systems/

[45] Detroit Assurance® Radar System and Active Brake Assist, Detroit Diesel Corporation, https://demanddetroit.com/technology/safety/radar-system/

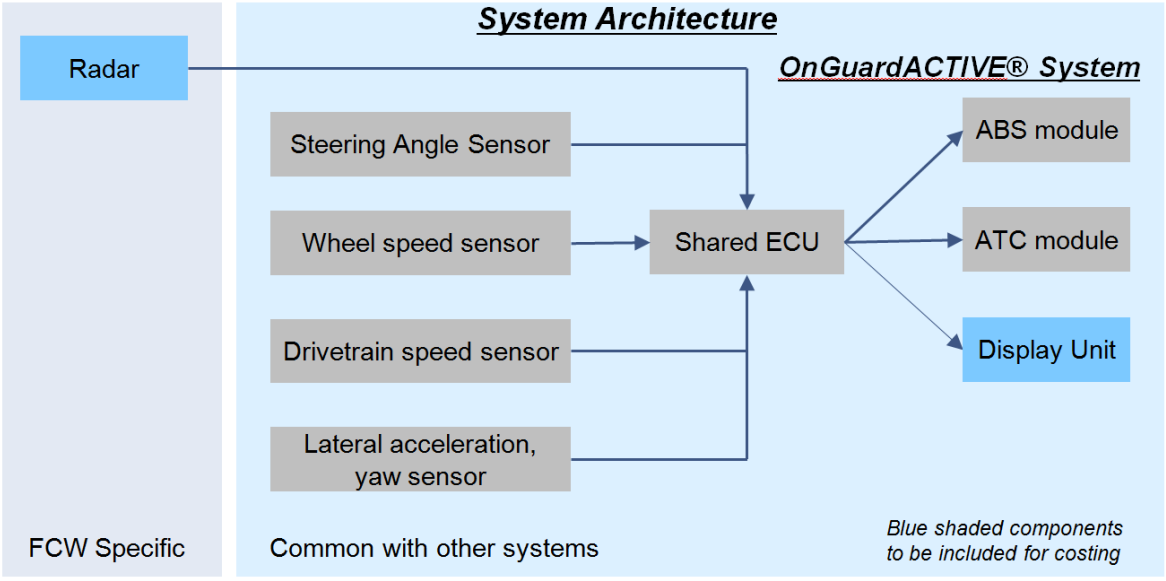

Figure 17: System Architecture of WABCO OnGuardACTIVE® System including FCW/AEB-Specific Components

The Detroit Assurance® system includes two sensors: 1) a radar (both short and long range) mounted at the front bumper, and 2) a camera located at the top, center section of the windshield. It can identify the top six vehicles by level of threat. The video radar decision unit (VRDU) refreshes the speed, distance, and time calculations 200 times/second. The active brake assist system is always on and tracks the distance from the radar sensor to other vehicles occupying its lane. When the closing distance decreases, the following warnings are initiated in order:[46]

Sequence	Warning Type	Comment
1	Audio with Visual Warning	The driver receives a simultaneous visual and dash alert and pulsating warning tone
2	Haptic Warning	If the driver does not respond, the system will send a visual dash alert and solid warning tone while pulsing the brakes simultaneously.
3	Active Braking	If there is still no driver input, the system will send a visual dash alert, solid warning tone, and slow the truck using the transmission, engine brake, and service brake.

Table 5: Detroit Assurance® FCW and AEB Warning and Action Sequence

Other features of the system include:[47]

[46] Detroit Assurance® Suite of Safety Systems, Technical Specifications, Detroit Diesel Corporation, Subsidiary of Daimler Trucks North America, LLC, https://detroitads.azureedge.net/assurance_4_product_overview_guide.pdf

[47] Detroit Assurance® Suite of Safety Systems, Technical Specifications, Detroit Diesel Corporation, Subsidiary of Daimler Trucks North America, LLC, https://detroitads.azureedge.net/assurance_4_product_overview_guide.pdf

Full braking on stationary objects: With Active Brake Assist (ABA), the radar constantly tracks stationary objects and has the capacity to engage full braking on these objects, such as a vehicle parked and unloading or stopped traffic in the truck's path that has not moved as the truck approaches. Active Brake Assist is integrated with the existing antilock braking system (ABS) module, so no separate dedicated hardware is required for the ABA functionality.

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

Adaptive Cruise Control (ACC): automatically adjusts the truck's cruising speed to maintain a set following distance from other vehicles in its path, allowing the truck to remain in cruise control longer. With the optional headway control in the new interactive dash display, distance can be adjusted between 2.4 and 3.6 seconds.

Tailgate Warning: Independent of the Active Brake Assist and Adaptive Cruise Control features, Tailgate Warning will activate according to a truck's speed and the following distance.

- If a driver remains at the following speeds for 10 seconds or longer, a visual dash alert will trigger:
  - Greater than 45 mph, following within 2.7 or fewer seconds
  - At speeds between 35 and 45 mph, following at a ramp-up distance between 1.8 and 2.7 seconds
  - Between 25 and 35 mph, following within 1.8 seconds or less
- Once activated, Tailgate Warning will deactivate only at speeds less than 20 miles per hour.
- By remaining in any Tailgate Warning mode for 10 seconds or longer, the event will become reportable via J1939 CAN to the selected telematics system.

Camera System (Optional): this system performs two primary functions:

- Lane Departure Warning (LDW)
  - Tracks the truck's position and sounds a warning if the truck veers out of its lane.
  - A windshield-mounted, forward-facing Bendix AutoVue camera detects the reflective paint and raised reflectors in lane markers. If the truck crosses those markers without using a turn signal, the radio is muted and an audible warning is sent through the corresponding speaker on the side of the truck that crosses the lane marker.
- Video Capture: the camera system is part of the existing lane departure and automatic traction control and ACC functions, so no additional dedicated hardware is required for the AEB functions other than the radar and associated wire harness and connectors.

- The camera on the windshield continuously records video of the truck's activity on the road to capture any severe collision mitigation events.
- A total of 20-30 seconds of recording – along with other driver performance data – is transmitted to the SafetyDirect® web portal for fleet operators and safety personnel to download and analyze.

No separate display is required for the Detroit Assurance® system. Instead, it shares the existing flexible dash display. This is illustrated in Figure 18.

Figure 18: The Detroit Assurance® System utilizes the existing Cascadia® dashboard display (photo credit: Detroit Assurance® Brochure)

In addition, the Detroit Assurance® system shares the existing ECU with the ABS and ATC modules. Since the ECU is not unique to the FCW system, it was not included in the cost and weight analysis. Since radar unit communicates with ECU via CAN, specific components cannot be identified on the ECU that are dedicated to FCW functionality.

It is noted that the radar and radar wire harnesses are the only components unique to the FCW system. These were included in the component cost and weight analysis and are illustrated in Figure 19. The list of hardware associated with the Detroit Assurance® FCW system (AEB utilizes existing ABS and ATC systems) is shown in Table 6.

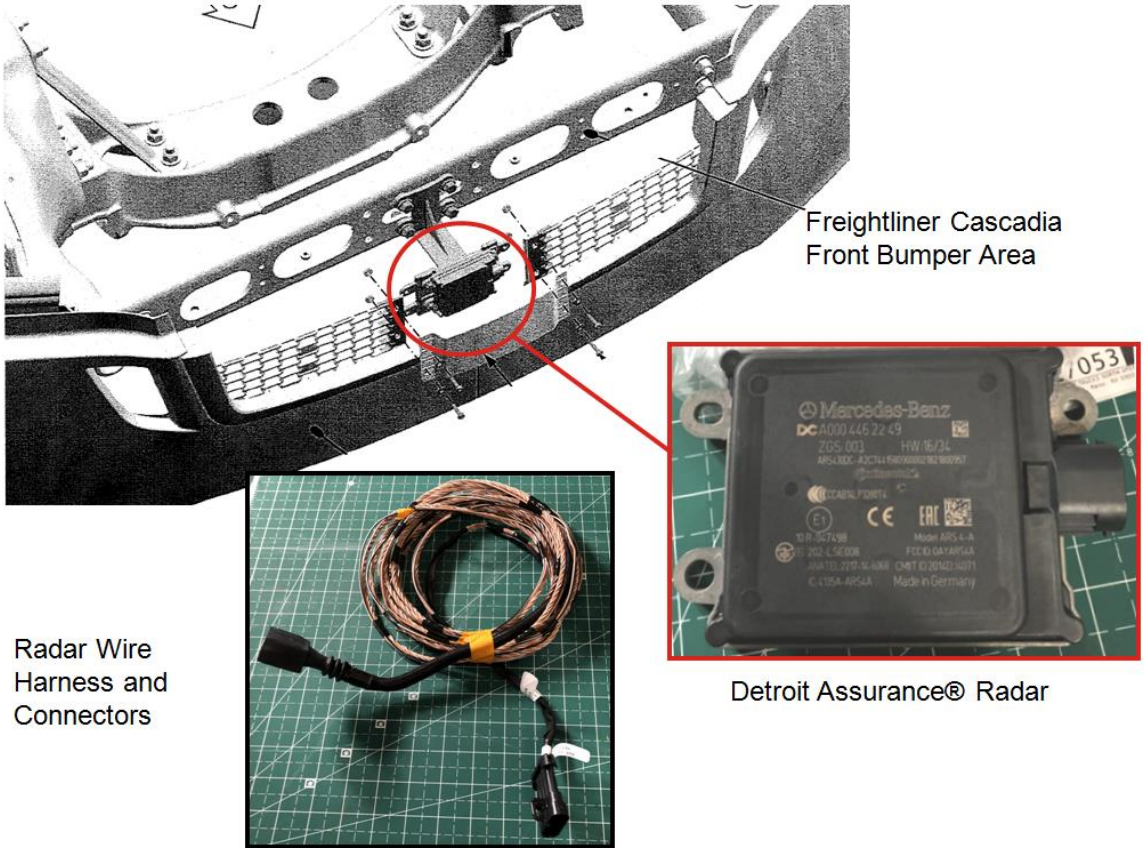

Figure 19: Detroit Assurance® FCW System Components (Photo Credits: MeC S.r.l)

	Detroit Assurance® FCW Hardware List
FCW	Radar Unit
Included with ESC	Shared ECU
	ABS module
	Lateral Acceleration & Yaw Rate Sensor
	Steering Angle Sensor
	Wheel Speed Sensor
	Drivetrain Speed sensor
	ATC module

Components highlighted in blue are incrementally required for FCW/AEB functions

Table 6: Detroit Assurance® FCW System Components for Freightliner Cascadia®

The system architecture for the Detroit Assurance® system, including the functional relationships between the FCW and AEB components and those for ABS and ATC, are illustrated in Figure 20.

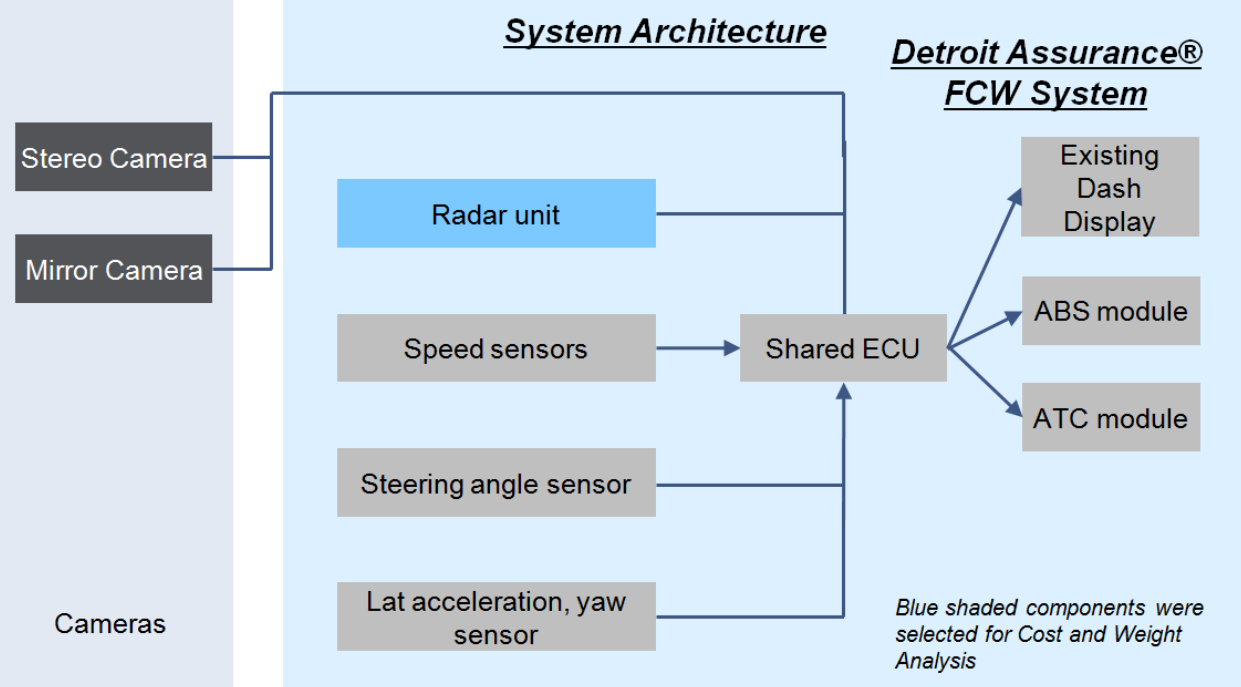

Figure 20: System Architecture of Detroit Assurance® System including FCW/AEB-Specific Components

A table of specific parts included in the tear-down and cost/weight analysis of the Freightliner Cascadia® Detroit Assurance® FCW and AEB systems is included in the Appendix of this report, along with photos of the parts, a bill of materials, and detailed costs & weights of each assembly, subsystem, and component.

Volvo VNL: Volvo Trucks North America Inc offers the Bendix® Wingman® Fusion™ FCW/AEB system as a standard feature for the VNL Class 8 tractor. The Bendix system is part of Volvo's Active Driver Assist feature.[48] The Bendix® Wingman® Fusion™ collision mitigation system integrates signals from both a radar and a camera to provide FCW warnings and AEB interventions to mitigate rear-end collisions, rollovers, and loss-of-control situations.[49]

The full Bendix® Wingman® Fusion™ system includes:

- Bendix® ESP® Electronic Stability Program full-stability system
- Bendix® Wingman® Advanced™ – A Collision Mitigation Technology
- AutoVue® Lane Departure Warning System from Bendix Commercial Vehicle Systems (CVS).

[48] Volvo Trucks North America, Inc., Build Your Volvo, Safety, Volvo Active Driver Assist, https://www.volvotrucks.us/trucks/build/configurator/safety

[49] *Heavy Duty Trucking*, Truckinginfo, Bendix-Based Safety System Standard on Volvo VNL and VNR Models, 20 July 2017, https://www.truckinginfo.com/141368/bendix-based-safety-system-standard-on-volvo-vnl-and-vnr-models

Volvo has integrated some of the Bendix equipment into its Active Driver Assist System. This includes the windshield-mounted camera, radar sensor, heads up display, side radar sensors, and associated wire harnesses and connectors. Volvo does not utilize the Wingman® Fusion® ECU or instrument panel display system. Instead, the Volvo Active Driver Assist System ECU and existing Volvo dash display are utilized.

Key features of the Bendix® Wingman® Fusion™ system include:[50]

Stationary Vehicle Braking (SVB): includes vehicle-ahead verification using signals from both radar and camera. This system is activated at speeds greater than 15 mph. When a large, stationary, metallic object in a vehicle's lane of travel is definitively identified as a licensed motorized vehicle, the driver is notified up to 3.5 seconds before impact. If the driver does not take action to address the potential impact that caused the alert, Wingman Fusion can automatically engage the brakes to assist the driver in reducing the severity of or potentially avoiding a collision with the stationary vehicle. If the system cannot definitively identify the stationary object as a licensed motorized vehicle, the driver will get up to 3.0 seconds of alert to address the situation ahead; no automatic braking will be applied.

Overspeed Alert & Action: uses Wingman® Fusion's camera to read most roadside speed limit signs. On the road, when traveling above 20 mph, the system compares the posted speed limit with the vehicle's speed and provides two levels of alert and/or intervention to assist the driver.

For a Level One intervention – initially set at +5 mph – the system provides an audible warning to the driver notifying them to slow down. If the vehicle is traveling at 10 mph or more over the speed limit – known as a Level Two intervention – the system provides an alert and then a 1-second dethrottle of the engine to get the driver's attention. In addition, for Level Two, a severe event notification is sent wirelessly through SafetyDirect® – if the fleet is a subscriber[51] – to be analyzed by a fleet's back office for possible training. Both Level One and Level Two speed thresholds are customizable by the fleet using Bendix® ACom® diagnostics.

Enhanced Collision Mitigation: When triggered by a slower-moving or stationary vehicle ahead, Bendix® Wingman® Fusion™ will reduce vehicle speed nearly twice as much as previous versions of the system. In addition, a backup plan is in place if the camera becomes inoperable due to damage or an active Diagnostic Trouble Code (DTC). If that happens, Wingman Fusion reverts to Wingman Advanced functionality, including collision mitigation.

Alert Prioritization: The most-recent version of the Wingman® Fusion™ system includes methods to minimize false alerts. A new feature, termed "alert prioritization" has been incorporated. In the event that multiple system alerts are needed simultaneously, such as lane departure warning and impact alert, Wingman Fusion will arrange them in order of importance

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[50] Bendix Commercial Vehicles Systems, LLC, Bendix® Wingman® Fusion™ Integration of Camera, Radar, and Brakes, Driver Assistance System, 2015, Brochure BW3025.

[51] SafetyDirect® is a subscription service offered to fleets by Bendix to collect information on vehicles, drivers, and routes. It collects data from the vehicle, transforms it into actionable information and reports it wirelessly to the specified fleet contacts. The information includes video feed from the windshield-mounted camera. The SafetyDirect brochure can be reviewed at http://www.bendix.com/media/documents/products_1/safetydirect/BW2879.pdf

and deliver only the most crucial alert to the driver to minimize potential distraction, as shown in Figure 21.

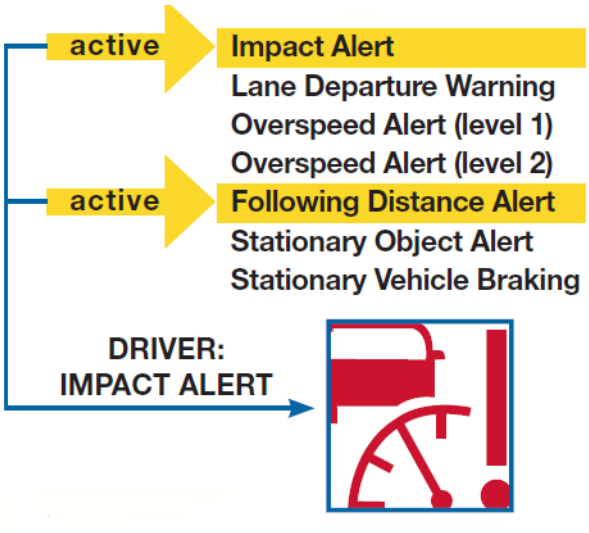


Figure 21: Bendix® Wingman® Fusion™ Alert Priority Ranking (graphic credit: Bendix Operator's Manual)

Following Distance Alerts (FDA) and Lane Departure Warning (LDW): Both features alert the driver to potentially hazardous situations. When driving too close to the forward vehicle, the system will sound an alert and display visual graphics to alert the driver to back off. When the gap with the forward vehicle is growing, the FDA is silent. The FDA is customizable by the fleet to allow for varying fleet operating environments. In addition, if the vehicle unintentionally departs the lane without the turn signal activated, the system will also sound a lane departure warning. This can be particularly valuable to help the driver mitigate run-off-road accidents usually caused in part by distraction or drowsiness.

Key components for the Bendix® Wingman® Fusion™ system as implemented on the Volvo VNL are illustrated in Figure 22. As noted above, the ECU is shared with other Fusion™ systems, so has not been included in the cost and weight analysis for the FCW and AEB components. The components unique to the FCW and AEB systems include the camera, head up display, front radar sensor, side radar sensors, and associated wire harnesses. The connectors and wire harness for the side sensors are integrated with the sensor, so no separate harness components are required. The camera wire harness is assumed to be identical to the camera harness for the International LT™, which also utilizes the Bendix® Wingman® Fusion™ system for FCW and AEB functions.

Camera: The camera is located at the top, center location of the windshield, inside the cab. This is illustrated in Figure 23. The camera, wire harness, and connectors are attached to the inside of the cab soffit. The camera field of view is 42 degrees on either side of the camera centerline.

Head Up Display: The head up display is located at the top of the dash immediately forward of the driver. It projects warning messages onto the windshield if immediate driver action is required and also provides warning messages on the existing dashboard display. The head up display is illustrated in Figure 24.

Figure 22: Key FCW/AEB components for the Volvo VNL (Bendix® Wingman® Fusion™ System)

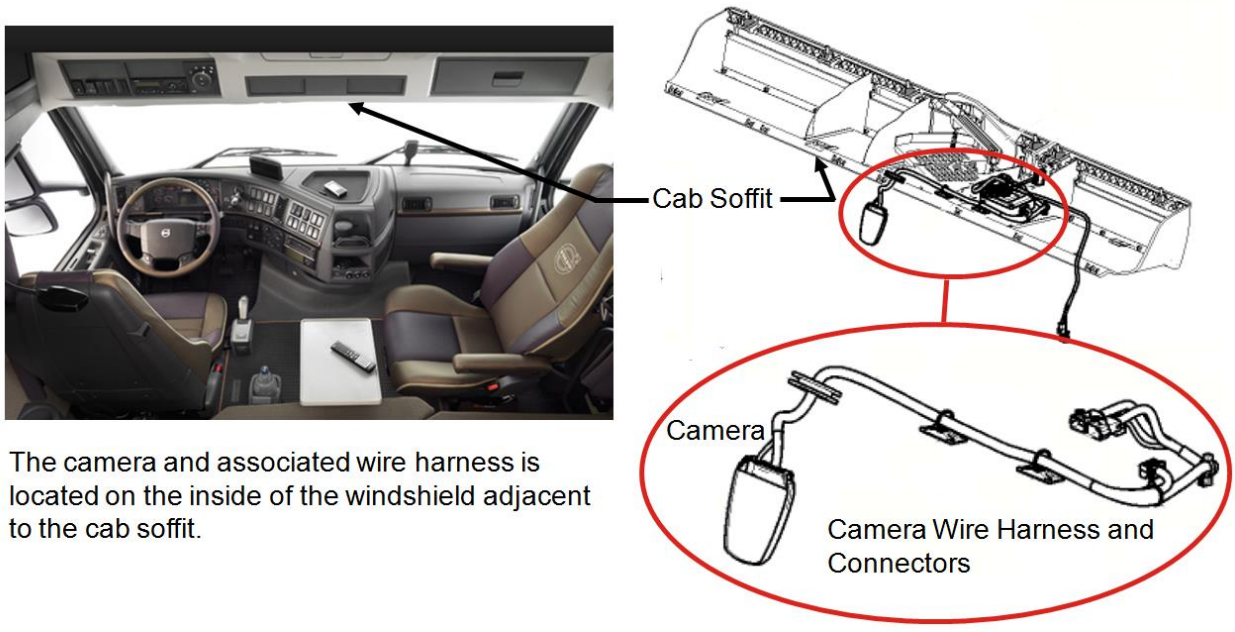


Figure 23: Volvo VNL (Bendix® Wingman® Fusion™) camera and associated wire harness

Volvo Active Driver Assist sends visual alerts to head-up display and dashboard

Head-up display: A red warning light flashes in the heads-up display to alert the driver if the vehicle sensors detect slower or stationary objects ahead

Dash Cluster: When a potential collision is detected, a visual warning displayed on instrument cluster; but the cluster warning is used for other functions so it is not an incremental part for the Volvo VNL FCW/AEB system.

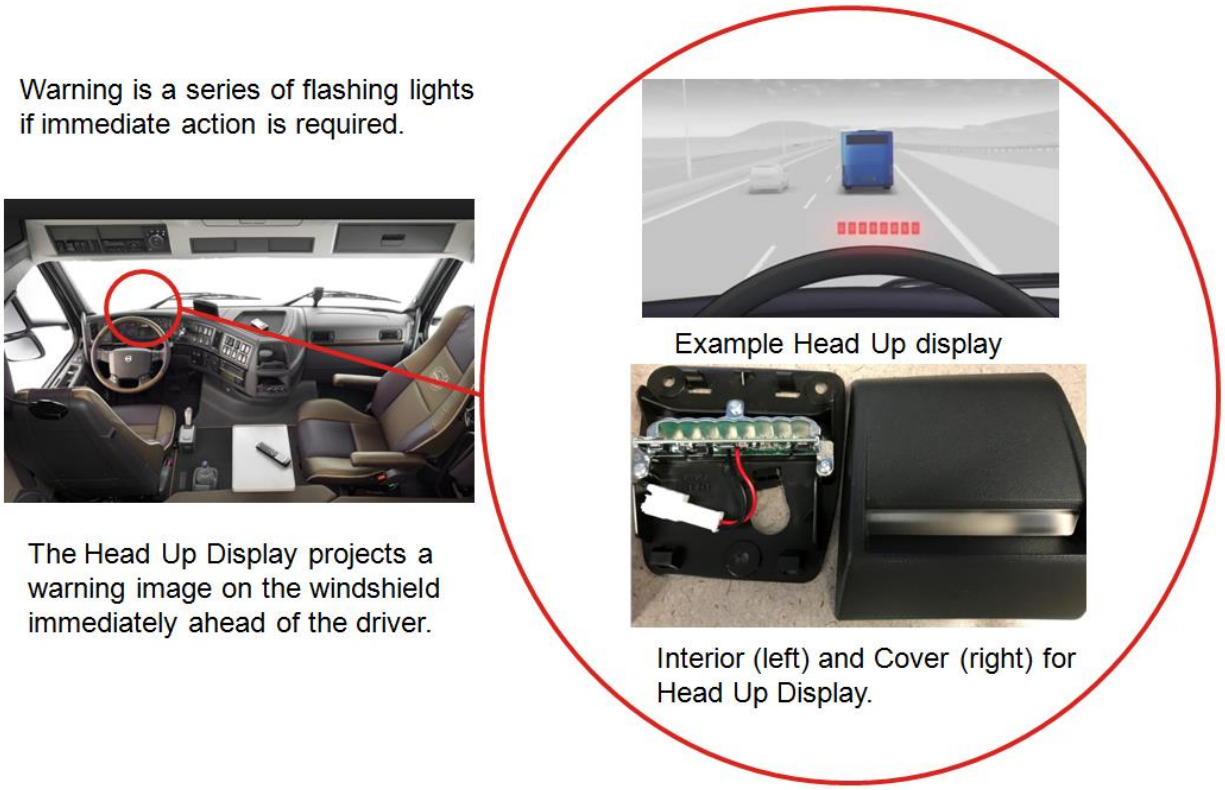


Figure 24: Volvo VNL (Bendix® Wingman® Fusion™) head up warning display (photo credit: Bendix Operator's Manual and Ricardo)

The instrument cluster display is illustrated in Figure 25.

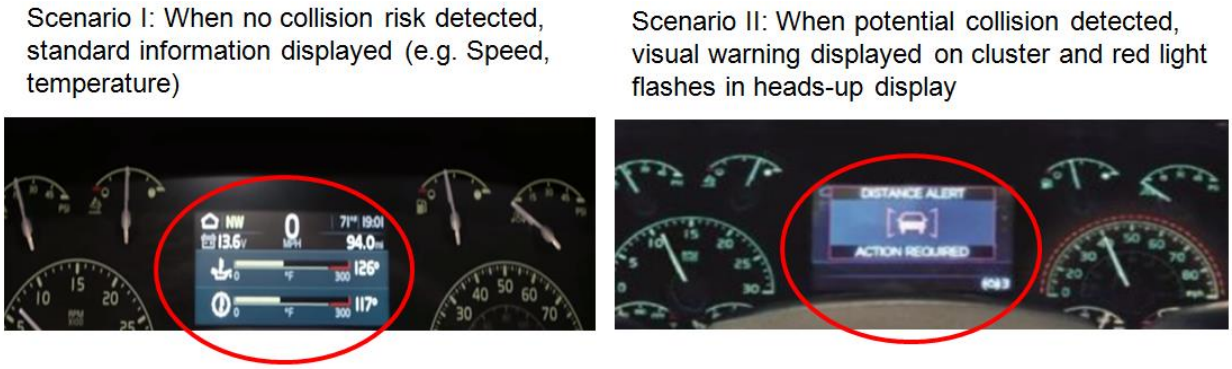


Figure 25: Volvo VNL (Bendix® Wingman® Fusion™) instrument cluster warning display (photo credit: Bendix Operator's Manual)

Front Radar Sensor: The front radar is located at the lower front bumper, as illustrated in Figure 26.

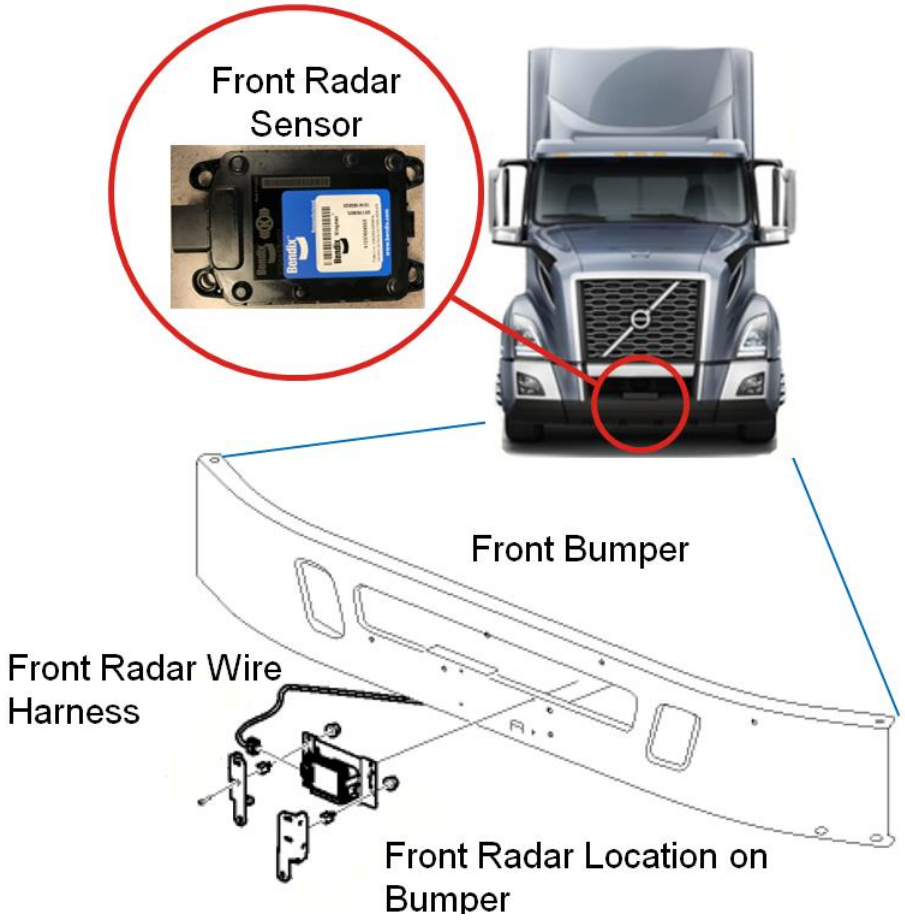


Figure 26: Volvo VNL (Bendix® Wingman® Fusion™) front radar location (photo credit: Volvo Maintenance Manual)

The wiring harness connects front sensor and main forebody harness and includes all wires and connectors. The detection range for the front radar is 22 degrees on each side of the vehicle longitudinal centerline and up to 500 feet in front of the vehicle.

Side Radar Sensor: The Bendix® Wingman® Fusion™ components, as integrated into the Volvo VNL Active Driver Assist System, include two side object detection systems that provide drivers with warnings if vehicles are occupying adjacent lanes in the blind spot of the side view mirrors. The side object detection system is based on side-facing radar that is located just aft of the cab doors as shown in Figure 27.[52]

[52] *Manuals Directory*, Bendix Commercial Vehicle Systems, Bendix BlindSpotter SD User Manual, http://www.manualsdir.com/manuals/583544/bendix-commercial-vehicle-systems-bendix-blindspotter-sd.html?page=16

The side radar sensors are able to detect metallic objects that are within an area that is approximately 15 long (along direction of vehicle centerline) and 10 feet wide (measured perpendicular to the side of the vehicle). This detection zone is illustrated in Figure 28.[53]

Figure 27: Typical Location of Bendix® Wingman® Fusion™ Side Radar Sensor (photo credit: Bendix Operator's Manual)

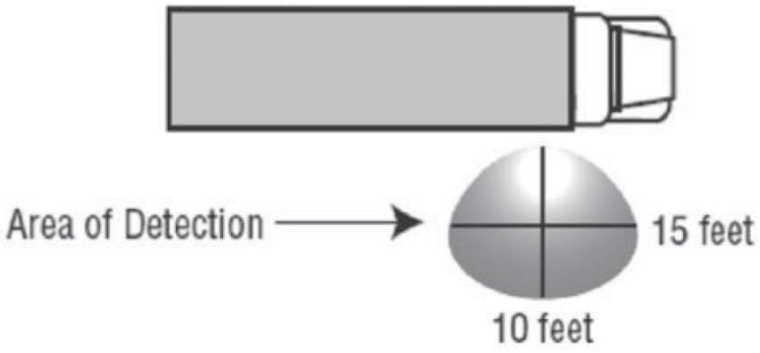


Figure 28: Bendix® Wingman® Fusion™ Side Radar Sensor Detection Zone (graphic credit: Bendix)

Bendix recommends that the side radar sensors be regularly inspected and that any mud, snow, or debris that many interfere with sensor operation should be removed.

The side radar systems include integrated wire harnesses. These wire harnesses connect to the cab body wire harness as shown in Figure 29.

Since the ECU is not unique to the FCW/AEB system, it was not included in the cost and weight analysis. Since radar units and camera communicates with ECU via CAN, specific components cannot be identified on the shared ECU that are dedicated to FCW/AEB functionality.

It is noted that the components unique to the Volvo VNL FCW and AEB systems include the camera, head up display, front sensor, side sensor, and associated wire harness and connectors. These were included in the component cost and weight analysis and are illustrated in Figure 30.

[53] Bendix Commercial Vehicle Systems LLC, *Driver Instructions, Bendix Blind Spotter Side Object Detection,* May 2010, https://comnet2.newmarcorp.com/instance1env99newmar/html/images/BENDIXVS400INSTRUCT.pdf

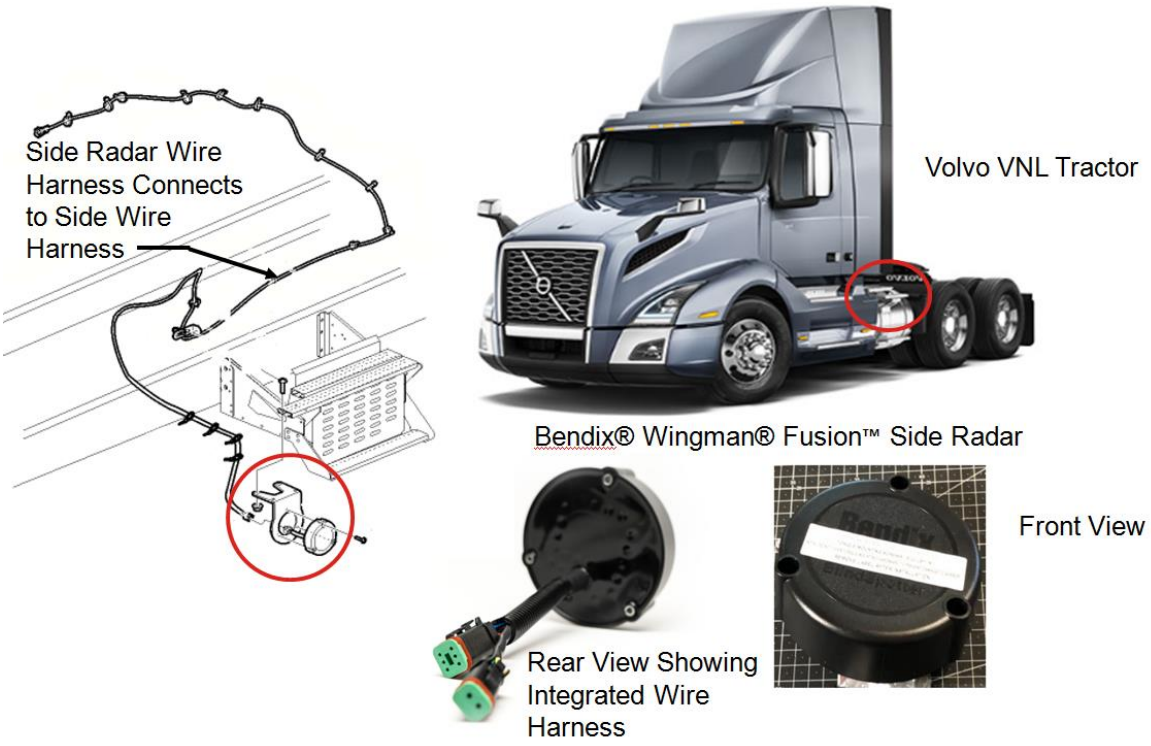


Figure 29: Bendix® Wingman® Fusion™ Side Radar Sensor Location and Wire Harness Connection (photo and graphics credits: Volvo Maintenance Manual, Ricardo, and MeC S.r.l.)

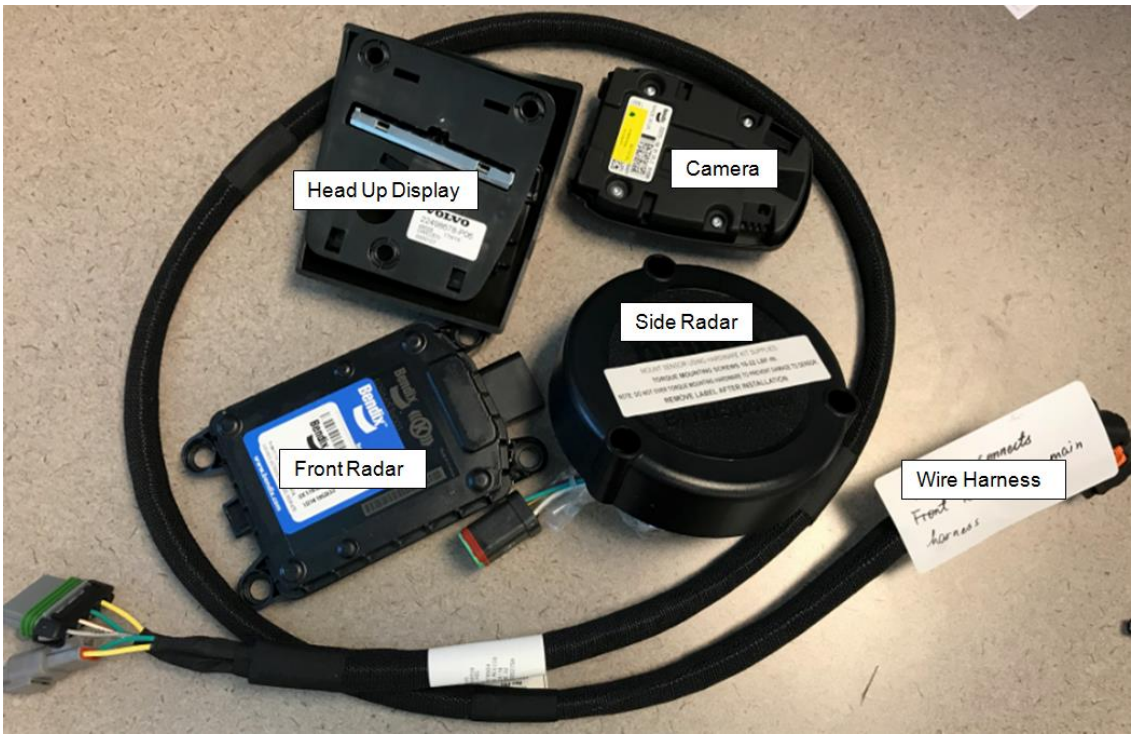


Figure 30: Bendix® Wingman® Fusion™ Key Components as Implemented on Volvo VNL (photo credit: Ricardo)

It is noted that the Bendix® Wingman® Fusion™ camera wire harness for the Volvo VNL was ordered but did not arrive prior to completion of this report. Because the camera wire harnesses for the Volvo VNL and International LT™ are identical, the International camera wire harness teardown and cost analysis was employed as a surrogate for the Volvo camera wire harness.

The identified features of the Bendix® Wingman® Fusion™ system were evaluated relative to their support of the FCW and AEB functions in an effort to determine which components would be included in the cost and weight analysis. The result of this assessment is summarized in Table 7.

Bendix® Wingman® Fusion™ Supported Features	Included in Cost & Weight Analysis
Stationary Vehicle Braking	Yes (part of FCW/AEB)
Following Distance Alert	
Active Cruise with Braking	
Stationary Object Alerts	
Overspeed Alert and Action	Not required feature of FCW and AEB
Alert Prioritization	Yes (part of FCW/AEB)

Table 7: Volvo VNL (Bendix® Wingman® Fusion™) supported features relative to FCW/AEB

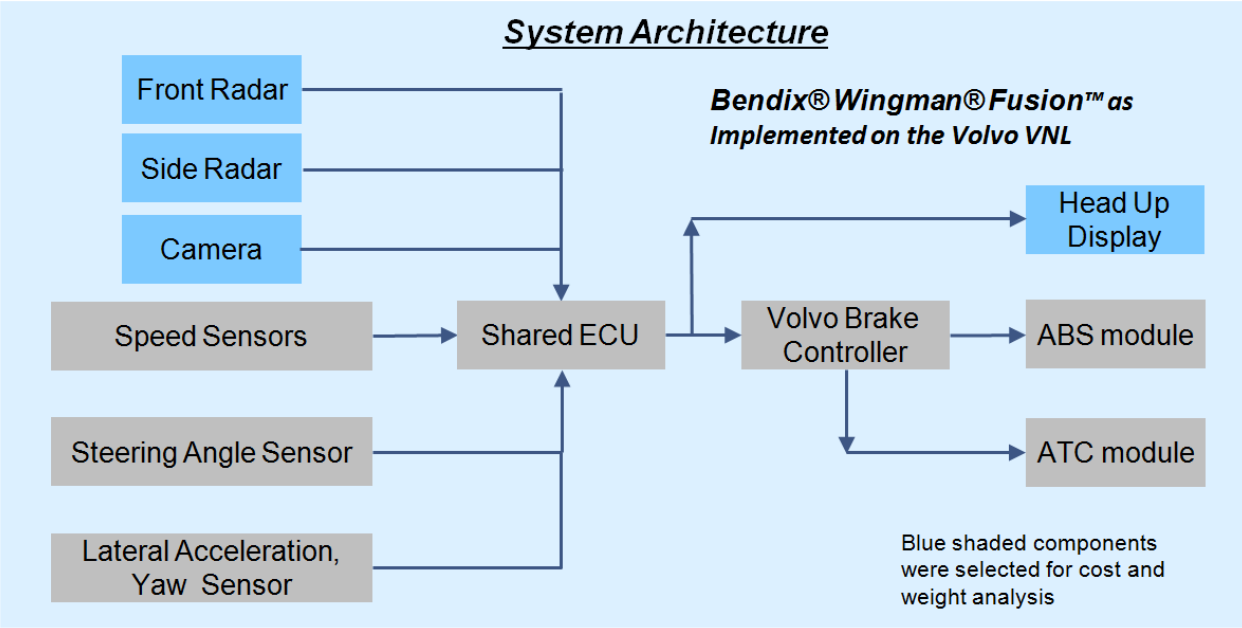
The list of hardware associated with the Bendix® Wingman® Fusion™ key components as implemented on Volvo VNL is shown in Table 8.

	Bendix® Wingman® Fusion™ Hardware List: Volvo VNL
Fusion specific	Camera
	Head Up Display
	Front Radar Sensor
	Side Radar Sensor
Included with ESC	Shared ECU
	Lateral Acceleration & Yaw Rate Sensor
	Steering Angle Sensor
	Wheel Speed Sensor
	Drivetrain Speed sensor
	ATC module

Components highlighted in blue are associated with FCW/AEB functions

Table 8: Volvo VNL (Bendix® Wingman® Fusion™) components unique to FCW/AEB system

The system architecture for the Bendix® Wingman® Fusion™ system, as implemented on the Volvo VNL, including the functional relationships between the FCW and AEB components and those for ABS and ATC, are illustrated in Figure 31.



Note – Volvo uses a customized version of the Bendix system which includes application of the engine compression brake and downshifts are applied prior to engaging foundation brakes.

Figure 31: System Architecture of Bendix® Wingman® Fusion™ System including FCW/AEB-Specific Components for the Volvo VNL.

A table of specific parts included in the tear-down and cost/weight analysis of the Volvo VNL FCW and AEB systems is included in the Appendix of this report, along with photos of the parts, a bill of materials, and detailed costs & weights of each assembly, subsystem, and component.

International LT™: The International Truck Division of Navistar offers the Bendix® Wingman® Fusion™ FCW/AEB collision mitigation system as a standard feature for the VNL Series of Class 8 tractors. The Bendix system integrates signals from both a radar and a camera to provide FCW warnings and AEB interventions to mitigate rear-end collisions, rollovers, and loss-of-control situations.[54] This is the same Bendix® Wingman® Fusion™ system utilized for the Volvo VNL as described in the previous section of this report, except for the variations identified in Table 9. Four of the components are the same for the two vehicles, including the front radar sensor, camera, radar harness, and camera harness. Comparisons of the camera and radar sensor are shown in Figure 32 and Figure 33, respectively.

[54]Bendix Commercial Vehicle Systems, LLC, International Truck is First Manufacturer to make Collision Mitigation Standard, News Release, 3 October 2016, http://www.bendix.com/media/documents/press_releases/2016/NavistarLT_WMA_FINAL_1016.pdf

ID	Volvo Part Number	International Part Number	Part Name	Quantity on Vehicle	Comparison of Components
1	2326552	2516066C2	Camera	1	Same for both vehicles
2		2516071C3	Processor (Safety Direct)	1	Not used on Volvo (integrated with existing processor)
3	85150484	2516065C2	Front Radar Sensor	1	Same for both vehicles
4	22498678		Head Up Display	1	Not used on International
5		BXK120829N002	Bendix Display	1	Volvo employs head up display and existing dash display
6		BXK073215	Radar bracket and Standoffs	1	Integrated into Volvo Structure
7		2515172C91	Camera bracket	1	
8	21585145		Side Radar Sensor	2	Not included for International
9		6127277C91	Cable (connects camera and Safety Direct processor)	1	Bendix processor not employed by Volvo
10	22564558	6128868F94	4-wire Harness (from radar sensor)	1	Same for both vehicles
11		6128955F94	2-wire Harness (connects radar sensor and main harness)	1	Unique to International
12	222554809	6127439C93	Camera and Safety Direct Processor Harness (connects camera, processor and roof harness)	1	Same for both vehicles

Table 9: Comparison of Bendix® Wingman® Fusion™ FCW/AEB as employed by Volvo and International

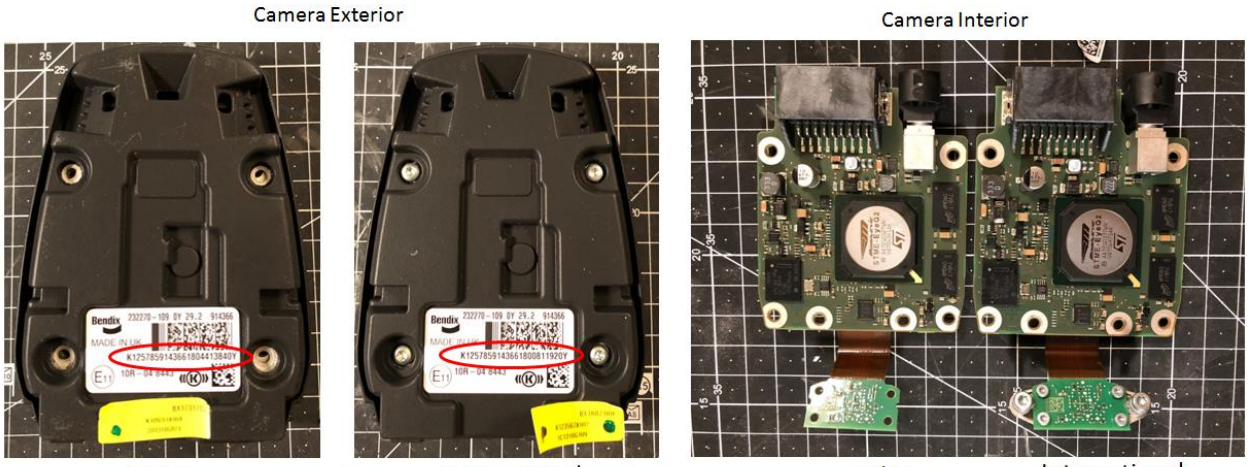


Figure 32: Comparison of Bendix® Wingman® Fusion™ Camera as employed by Volvo and International (photo credit: MeC S.r.l.)

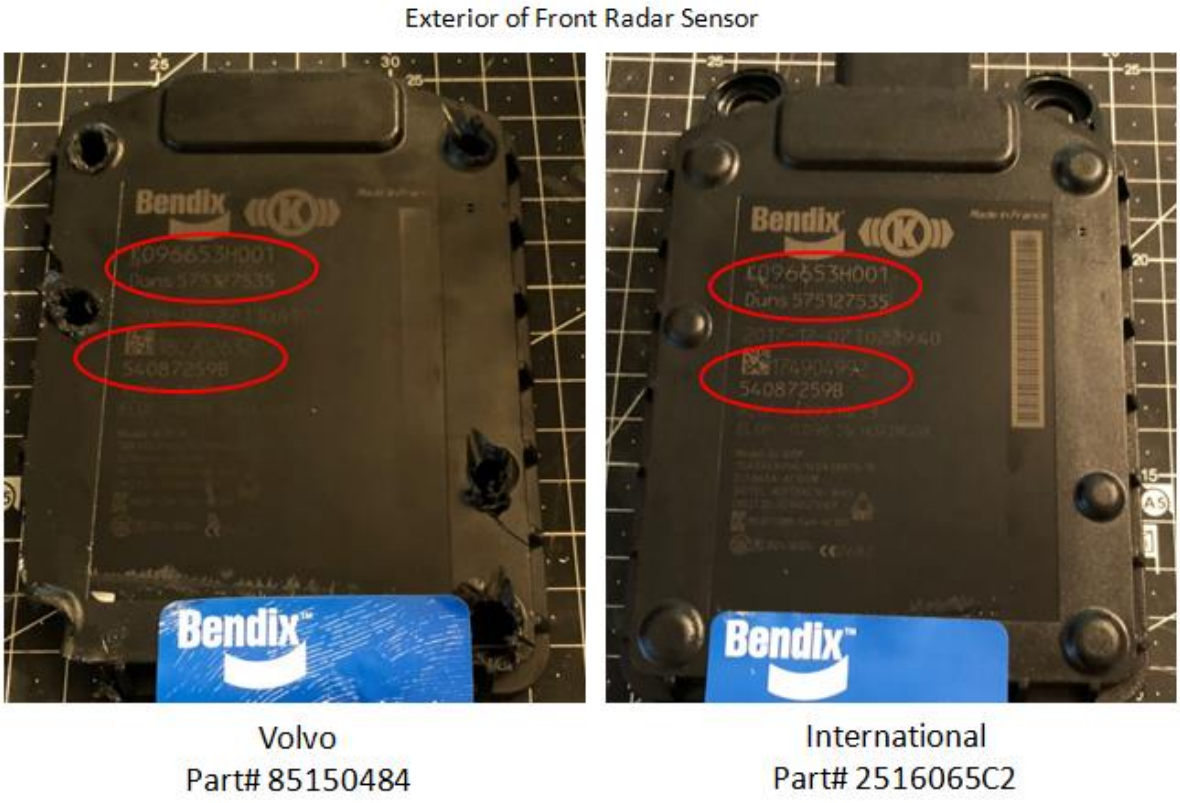


Figure 33: Comparison of Bendix® Wingman® Fusion™ Front Radar Sensor as employed by Volvo and International (photo credit: MeC S.r.l.)

Since the Volvo and International versions of the Bendix® Wingman® Fusion™ camera and front radar sensors and their associated functions are identical and have been described in the previous section of this report, this section will focus on the two Bendix components employed on the International LT™ but not on the Volvo VNL: 1) SafetyDirect® Processor, and 2) Bendix display.

SafetyDirect® Processor: A schematic of the Bendix® Wingman® Fusion™ components and associated wiring connections is shown in Figure 34. The SafetyDirect® Processor and Bendix display are indicted by the blue boxes. SafetyDirect® includes a web portal and collects complex safety data from the vehicle, transforms it into actionable information and reports it to designated fleet contacts wirelessly. The camera enables fleet contacts to view video of any severe events.[55] The SafetyDirect® processor also has connections to the camera, radar, warning systems (audio, visual, haptic), and vehicle CAN (J1939). As implemented on the International LT™ truck, the Bendix collision mitigation system offers the following features.[56]

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[55] Bendix Commercial Vehicle Systems LLC, SafetyDirect® by Bendix CVS, 2012, http://www.bendix.com/media/documents/products_1/safetydirect/BW2879.pdf

[56] Bendix Commercial Vehicle Systems LLC, Bendix® Wingman® Collision Mitigation Technology, Document BW28551, September 2011, http://www.bendix.com/en/servicessupport/documentlibrary/doclib_1.jsp

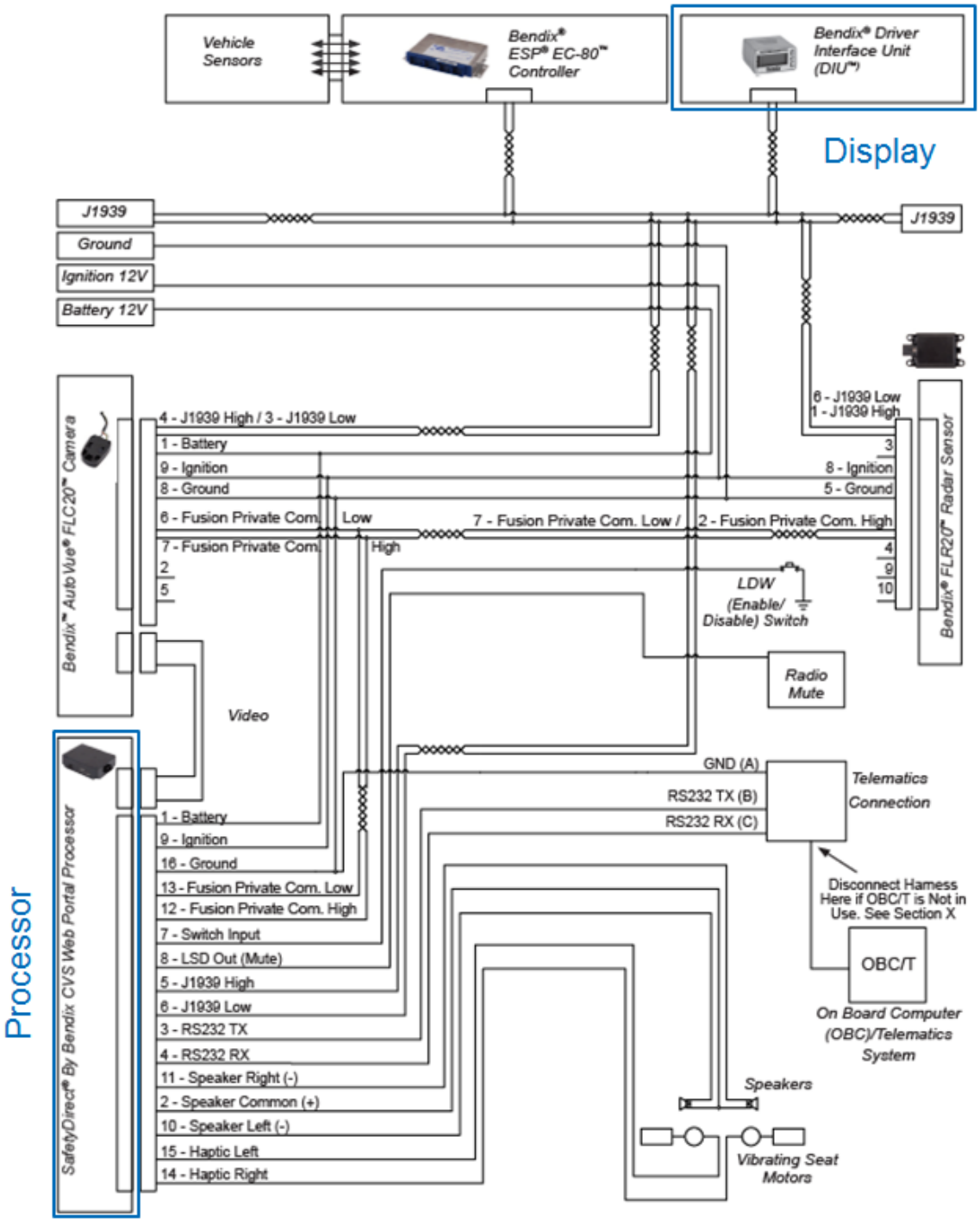

Figure 34: Bendix® Wingman® Fusion™ Component and Wiring Schematic[57] (graphic credit: Bendix® Wingman® Fusion™ Service Data SD-61-4963)

[57] Bendix Commercial Vehicle Systems, LLC, Bendix® Wingman® Fusion™, *Service Data*, SD-61-4963, Rev 2, 07/2016.

- Alerts (are always available whether cruise control is engaged or not)
    - Following Distance Alerts - audible and visual alerts which let driver know when getting too close to forward vehicle
    - Impact Alerts – audible and visual alerts warning the driver that a collision with the forward vehicle is likely and that they should address the situation immediately
    - Stationary Object Alerts - audible and visual alerts that provide the driver up to a 3.0 second alert when a metallic object(s) may be blocking lane of travel
- Adaptive Cruise Control with Braking (functions when cruise control is on and speed is set); interfaces with existing International LT™ cruise and brake system controls.
    - Reduces throttle to help the driver maintain a set following distance behind a forward vehicle
    - Engages engine retarder to help the driver maintain a set following distance behind a forward vehicle
    - Applies foundation brakes to help the driver maintain a set following distance behind a forward vehicle
- Electronic Stability System
    - Bendix® ESP® full stability system to help drivers mitigate rollovers and loss-of-control situations on wet and dry roadways
- Collision Mitigation (functions whether or not cruise control is on and speed is set)
    - Provides audible and visual alerts to the driver and applies the brakes when the system determines a collision with forward vehicle is imminent

A photo of the Bendix SafetyDirect® Processor is shown in Figure 35.[58]

Figure 35: Bendix® Wingman® Fusion™ SafetyDirect® Web Portal Processor (photo credit: Bendix® Wingman® Fusion™ Service Data SD-61-4963)

[58] Bendix Commercial Vehicle Systems, Service Data, Bendix® Wingman® Fusion™ Driver Assistance System, Document SD-61-4963, Rev 002, July, 2016.

Bendix Display: The FCW/AEB display is part of the Bendix® Driver Interface Unit (DIU). A photo of the display unit is shown in Figure 36. Example display warnings are shown in Figure 37.[59]

Figure 36: Bendix® Wingman® Fusion™ Driver Interface Unit Display (photo credit: Ricardo)

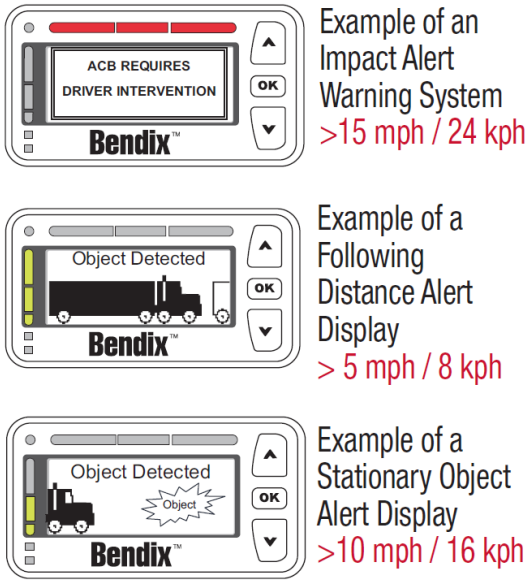

Figure 37: Example warning messages for Bendix® Wingman® Fusion™ Driver Interface Unit Display (graphic credit Bendix® Wingman® Fusion™ Operator's Manual)

[59] Bendix Commercial Vehicle Systems LLC, Bendix® Wingman® Fusion™, Reference Guide, March 2017, http://www.bendix.com/en/servicessupport/documentlibrary/doclib_1.jsp

Components unique to the Bendix® Wingman® Fusion™ FCW/AEB system as implemented on the International LT™ Class 8 tractor are shown in the photo of Figure 38.

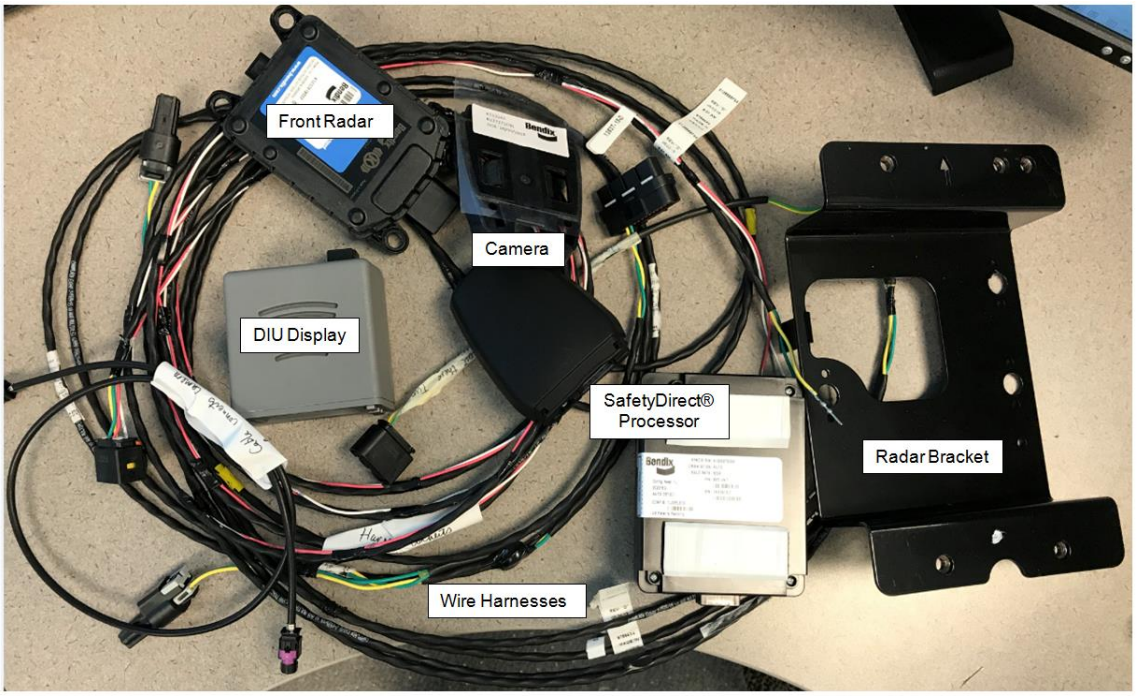

Figure 38: Bendix® Wingman® Fusion™ Components Unique to International LT™ Class 8 Tractor (photo by Ricardo)

The list of hardware associated with the Bendix® Wingman® Fusion™ key components as implemented on International LT™ is shown in Table 10.

	Bendix® Wingman® Fusion™ Hardware List for International LT
Wingman Fusion Specific	Front Radar Sensor
	Radar Bracket
	Camera
	Data Processing Unit (SafetyDirect®)
	Bendix Display (Driver Interface Unit)
Included with ESC	ABS Controller
	Lateral Acceleration & Yaw Rate Sensor
	Steering Angle Sensor
	Wheel Speed Sensor
	Drivetrain Speed sensor
	ATC module

Components highlighted in blue are incremental FCW/AEB functions

Table 10: International LNT (Bendix® Wingman® Fusion™) components unique to FCW/AEB system

The system architecture for the Bendix® Wingman® Fusion™ system, as implemented on the International LT™, including the functional relationships between the FCW and AEB components and those for ABS and ATC, are illustrated in Figure 39

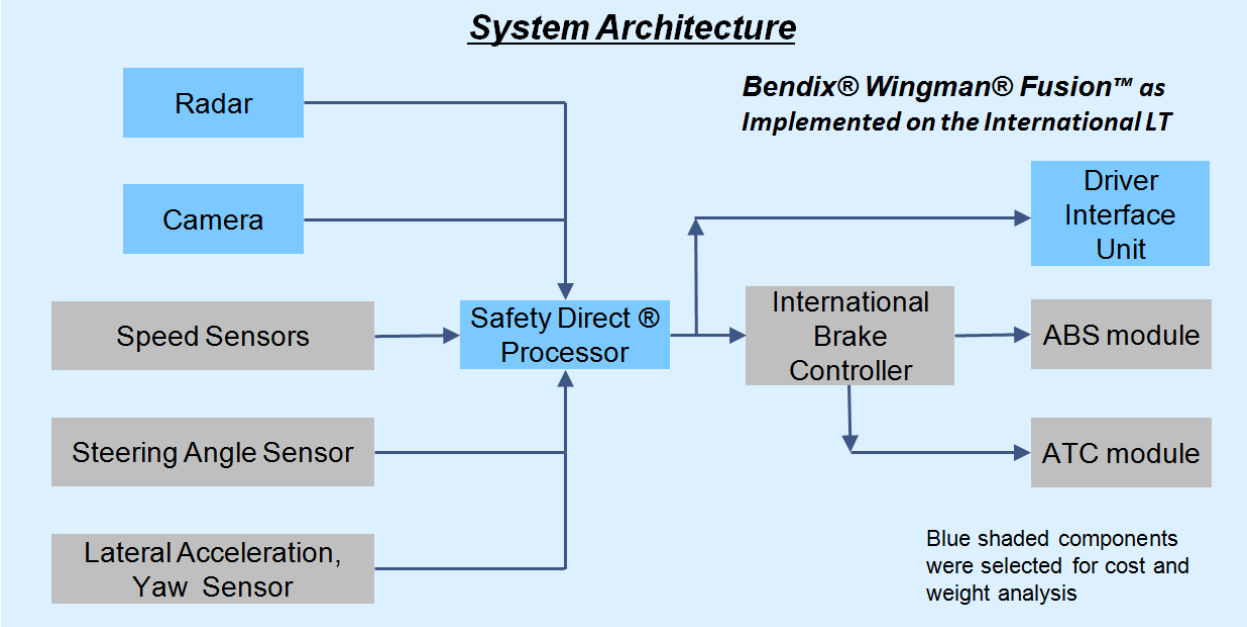

Figure 39: System Architecture of Bendix® Wingman® Fusion™ System including FCW/AEB-Specific Components for the International LT™

A table of specific parts included in the tear-down and cost/weight analysis of the International LT™ FCW and AEB systems is included in the Appendix of this report, along with photos of the parts, a bill of materials, and detailed costs & weights of each assembly, subsystem, and component.

Component Procurement and Disassembly

Key tasks for the cost and weight analysis include the procurement of FCW/AEB parts associated with the five selected MD and HD vehicles, disassembly of these parts/components, identification of materials and processes used to produce the components, and measurement of the weights of the subassemblies, components, and parts. Specific FCW/AEB components included in the analysis include:

1. Front Radar Sensor, including fascia, wire harness, brackets and hardware
2. Integrated Dash Display
3. Separate Dash Display, including display wire harness
4. Camera, including camera wire harness, brackets and hardware
5. Side Radar Sensor
6. Integrated with Existing ECU
7. Separate ECU (processor; it is noted that some FCW/AEB systems share existing ECUs), including wire harnesses that connect the radar and camera to the separate ECU

8. Other materials and scrap (for electronic parts, this category includes labels, soldering materials, flux, and fasteners)

The five selected vehicles included a range of FCW/AEB components, with none containing the same components as any of the others. The identified components for each of the five vehicles are shown in Table 11.

Component Name	Vehicle				
	Ford F-Series Super Duty	Freightliner M2 106	Freightliner Cascadia	Volvo VNL	International LT
	Corresponding FCW/AEB Supplier				
	Delphi AdvanceTrac®	Meritor WABCO OnGuardACTIVE®	Detroit Assurance®	Bendix® Wingman® Fusion™	
Front Radar Sensor	✓	✓	✓	✓	✓
Fascia		✓			
Wire Harness	✓	✓	✓	✓	✓
Bracket and Hardware		✓			✓
Integrated Dash Display	✓		✓		
Separate Dash Display		✓		✓	✓
Display Wire Harness		✓			✓
Camera				✓	✓
Camera Wire Harness				✓	✓
Bracket and Hardware					✓
Side Radar Sensor				✓	
Integrated with Existing ECU	✓	✓	✓	✓	
Separate ECU (Processor)					✓
Radar, Camera ECU Wire Harness					✓

Table 11: FCW/AEB System Components for the Five Selected Vehicles

Owner's manuals, service manuals, OEM parts designations, and interviews with service technicians were employed to identify subassemblies, components and parts associated with the FCW/AEB systems. Detailed evaluations, including identification of sensors, cameras, PCBs, connectors, pin assemblies, associated wire harness systems, and mounting hardware, ensured that only those items related to the FCW/AEB systems were included in the cost and weight determinations. The identified parts were then purchased through local dealers.

Cost and Weight Analysis Approach

Ricardo engaged automotive system and vehicle integration experts, cost modeling teams, and procurement professionals to support the cost and weight analysis. Following acquisition of the parts from dealers, analyses were performed to determine which subassemblies, components, and parts were uniquely associated with the five selected vehicles and the corresponding FCW/AEB systems. The parts were then disassembled ("tear-down" procedure), catalogued, evaluated to determine manufacturing process, evaluated to determine materials used, weighed, and analyzed using proprietary manufacturing cost software by Ricardo's subcontractor MeC, Inc.

Figure 40: Weighing of Bendix® Wingman® Fusion™ Display Housing (photo credit: MeC S.r.l.)

The analysis software facilitates organization of the disassembly process including a precise, systematic cataloguing system. Notes and measurements are included with the annotated photos. Computational, experience-base, and heuristic procedures are followed in order to define the process, process times, and materials costs. The results are summarized on standard cost and weight data forms.

Costing Approach and Assumptions

The identified FCW/AEB components were torn down for cost and weight analysis of each individual elemental part and assembly costs were developed for each manufacturing step. Components that went through a series of production operations had the costs associated with those operations captured in the component costs. Standard parts such as fasteners were accounted for as procured parts in the analysis. Detailed manufacturing process operation worksheets are provided in the appendix for each of the analyzed components that illustrate how variable manufacturing costs, fixed burden, and weights are accumulated. These are then reconciled, each part to its subassembly, and from subassembly to the total incremental system.

An Asset Center Costing (ACC) methodology was used to identify cost drivers in terms of:

- Direct labor minutes per cycle
- Direct material costs per cycle
- Machine occupancy or station times per cycle
- Machinery, equipment, and tooling utilized and allocated per cycle.

The total manufacturing cost was built up from the following elements:

- Direct labor cost per unit (based on US rates for appropriate trades by manufacturing process)

- Direct material costs including scrap allowance and inbound freight per unit
- Variable burden/overhead costs, including indirect labor, energy, and other costs that vary with production volume
    - Indirect plant staff
    - Material handlers
    - 1st line supervision
    - Tool & equipment maintenance
    - Facilities maintenance
    - Non-production plant supplies
    - Energy
    - Process fluids & gases
    - Fringe on Direct labor
- Fixed burden / overhead per unit, including capital depreciation and other fixed costs
    - Capital equipment requiring investment and amortized at the stated annual sales volumes including property, plant machinery, equipment and primary tooling
        - Capital depreciation schedules for property, plant, and equipment
        - Special tooling depreciation schedules
    - Floor space for manufacturing and offices
    - Taxes – local and property
    - Insurance – property and liability

The following assumptions were utilized in applying the ACC methodology to the systems and components analyzed:

- Annual vehicle production volume of 200,000 units
- Burdened labor rate: labor rates were determined for specific manufacturing processes and applied to the cost analyses. For example, the labor rate associated with injection molding operations located in the Midwest was assumed to be $33.66/hour.
- Capital equipment depreciation schedule of 12 years straight line with no residual value consistent with IRS depreciation schedules
- Special tooling depreciation schedule of 5 years straight line with no residual value consistent with IRS depreciation schedules
- Scrap rate of 1% of direct material cost based on an average for the automotive industry

In addition, overhead burdens for an automotive supplier and an automotive manufacturer were applied to get a more complete estimate of the contribution margin. The following corporate overhead rates were used as being typical for in-house made components by an original

equipment manufacturer (OEM) in the light-duty automotive industry after reviewing Spinney et al[60], Rogozhin et al[61], National Academy of Sciences (NAS)[62], and Vyas et al[63]:

- SG&A of 8% applied to total manufacturing costs, including
  - Sales
  - Research & Development
  - General administration
  - Human resources
  - Supplier quality
  - Senior plant management
- Profit of 5% applied to total manufacturing cost
- Transportation and warranty costs of 10% applied to total manufacturing cost.

For outsourced components made by a Tier 1 supplier, however, the NAS found that outsourced components had a markup factor of only 75% that for in-house components as their Table 3.5 shows[64].

TABLE 3.5 Comparison of Markup Factors

Markup Factor for	ANL	Borroni-Bird	EEA
In-house components	2.00	2.05	2.14
Outsourced components	1.50	1.56	1.56

SOURCE: Vyas et al. (2000).

Therefore, the following corporate overhead rates for outsourced components, at 75% of the OEM in-house component rates, were used:

- SG&A of 6% applied to total manufacturing costs
- Profit of 3.75% applied to total manufacturing cost
- Transportation and warranty costs of 7.5% applied to total manufacturing cost.

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[60] Spinney, B.C., Faigin, B., Bowie, N., & St. Kratzke. 1999, Advanced Air Bag Systems Cost, Weight, and Lead Time analysis Summary Report, Contract NO. DTNH22-96-0-12003, Task Orders – 001, 003, and 005. Washington, D.C., U.S. Department of Transportation

[61] Rogozhin, A., Gallaher, M., & McManus, W. 2009, Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers. Report by RTI International to Office of Transportation Air Quality. U.S. Environmental Protection Agency, RTI Project Number 0211577.002.004, February, Research Triangle Park, N.C.

[62] National Academy of Sciences, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," The National Academies Press, Washington D.C., 2011

[63] Vyas, A., Santini, D., And Cuenca, R., "Comparison of Indirect Cost Multipliers for Vehicle Manufacturing," Technical Memorandum of the Center for Transportation Research, Argonne National Laboratory, April 2000

[64] See p. 33 of National Academy of Sciences, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," The National Academies Press, Washington D.C., 2011

These overhead burdens, along with the fixed burden and the variable manufacturing cost equate to a wholesale price from the manufacturer. Dealer costs and markup were estimated to be 11% of the wholesale price, consistent with Spinney et al, to arrive at a final end-user cost.

4.0 COST AND WEIGHT ANALYSIS

Components related specifically to the heavy vehicle FCW/AEB systems were identified as described in the System Descriptions for Selected Vehicles Section of 3.0 Engineering Analysis. To meet the goal of defining costs and weights representative of high-volume, mainstream systems offered by key global suppliers, identified FCW/AEB component costs were evaluated based on the assumption of production volumes greater than 200,000 vehicles per year.

Cost and Weight Results

The components were disassembled to individual parts. The parts were analyzed, photographed, weighed and evaluated to determine manufacturing costs as per the approach outlined in Costing Approach and Assumptions Section 3.0. Photos of all key components for each vehicle are included in the Appendix of this report. The following pages describe the key components associated with the five selected heavy vehicle FCW/AEB systems. A summary of these components is listed in Table 11 above.

Ford F-Series Super Duty® MD Trucks

The key components of the FCW system for the Ford F-Series Super Duty® Trucks include:

1. Adaptive Speed Control Radar Sensor
2. Radar Wiring Harness

The complete results of the cost and weight analysis are included in the appendix, along with photos of the individual FCW system components. Table 12 provides a summary for the key subsystems as well as the full FCW system.

Ford F-Series SuperDuty FCW/AEB Manufacturing Costs										
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1	**Ford FCW system**	**$ 48.67**	**1**	**$ 48.67**	**$ 1.78**	**$ 40.83**	**$ 2.66**	**$ 3.39**	**541.6**	**541.6**
1.1	Adaptive Speed Control Radar Sensor	$ 46.12	1	$ 46.12	$ 1.15	$ 39.40	$ 2.20	$ 3.38	468.1	468.1
1.2	Radar Wiring Harness	$ 2.54	1	$ 2.54	$ 0.64	$ 1.43	$ 0.46	$ 0.02	73.5	73.5

Table 12: Manufacturing Costs and Weights Summary for Ford F-Series Super Duty® Truck FCW System

The calculated incremental cost of the Ford F-Series Super Duty® FCW system is estimated to be $48.67, with the front radar system accounting for 95% of the total. The total manufacturing costs are summarized by cost element as shown in Figure 41. The addition of the FCW components increases the vehicle weight by 0.54 kg.

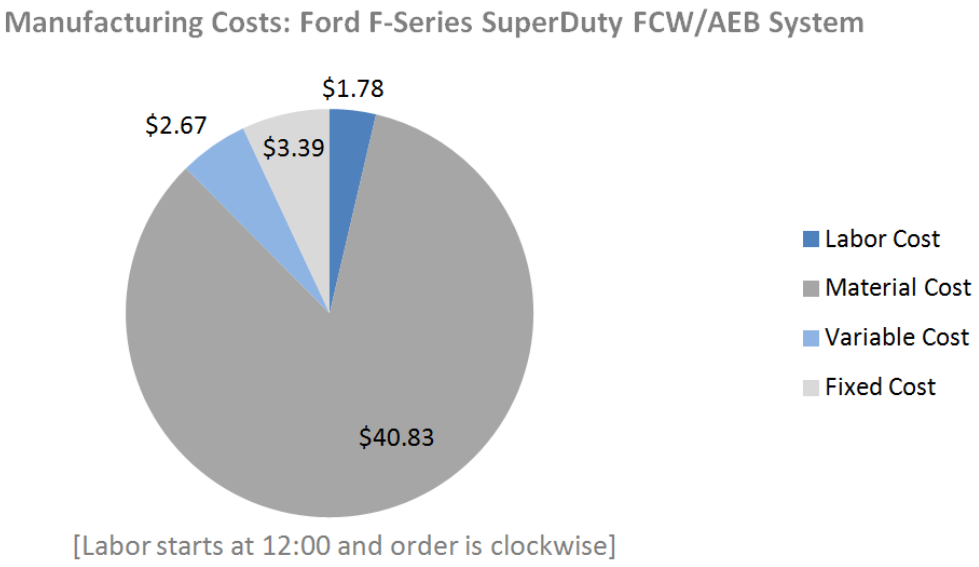


Figure 41: Ford F-Series Super Duty® Truck FCW System Cost Build-Up

The manufacturing cost increase of the Ford FCW system is shown in Table 13.

Ford F-Series SuperDuty FCW/AEB System Cost Analysis			
Category	**Cost**	**Variable Manufacturing Cost**	**Total Manufacturing Cost**
Labor Cost	$1.78	**$45.27**	**$48.67**
Material Cost	$40.83		
Variable Cost	$2.67		
Fixed Cost	$3.39		

Table 13: Estimated Incremental Manufacturing Cost Analysis of Ford F-Series Super Duty® FCW System

Freightliner M2 106 MD Truck

The key components of the FCW/AEB system for the Freightliner M2 106 MD truck include:

1. Front Radar Sensor
2. Display
3. Radar Adapter Wire Harness
4. Display Adapter Wire Harness
5. Radar Sensor Bracket
6. Radar Bracket Mounting Bolts
7. Nuts for Radar Bracket Mounting
8. Fascia (Radar)
9. Fascia Bolts

The complete results of the cost and weight analysis are included in the appendix, along with photos of the individual FCW/AEB system components. Table 14 provides a summary for the key subsystems as well as the full FCW/AEB system.

Freightliner M2 106 MD Truck, FCW/AEB System Manufacturing Costs										
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1	**Freightliner M2 106 FCW/AEB System**	**$ 96.43**	**1**	**$ 96.43**	**$ 3.182**	**$ 81.972**	**$ 7.065**	**$ 4.207**	**3228.1**	**3228.1**
1.1	Front Radar Sensor	$ 66.13	1	$ 66.13	$ 1.374	$ 58.367	$ 3.846	$ 2.540	379.1	379.1
1.2	Display	$ 21.34	1	$ 21.34	$ 0.448	$ 17.175	$ 2.288	$ 1.430	114.4	114.4
1.3	Radar Adapter Wire Harness	$ 3.56	1	$ 3.56	$ 0.770	$ 2.270	$ 0.490	$ 0.027	168.0	168.0
1.4	Display AdapterWire Harness	$ 1.98	1	$ 1.98	$ 0.368	$ 1.204	$ 0.340	$ 0.070	74.0	74.0
1.5	Radar Sensor Bracket	$ 1.19	1	$ 1.19	$ 0.090	$ 1.060	$ 0.021	$ 0.020	2090.0	2090.0
1.6	Radar Bracket Mounting Bolts	$ 0.80	2	$ 0.40	-	$ 0.400	-	-	51.3	102.6
1.7	Nuts for Radar Bracket Mounting	$ 0.45	3	$ 0.15	-	$ 0.15	-	-	13.5	40.5
1.8	Fascia (Radar)	$ 0.79	1	$ 0.79	$ 0.132	$ 0.461	$ 0.080	$ 0.120	230.0	230.0
1.9	Fascia Bolts	$ 0.19	3	$ 0.06	-	$ 0.06	-	-	9.8	29.5

Table 14: Manufacturing Costs and Weights Summary for Freightliner M2 106 Truck FCW/AEB System

The calculated incremental cost of the Freightliner M2 106 MD Truck FCW/AEB system is estimated to be $96.43, with the front radar system accounting for 69% of the increment and the display accounting for 22% of the increment. The total manufacturing costs are summarized by cost element as shown in Figure 42. The addition of the FCW and AEB components increases the vehicle weight by 3.23 kg.

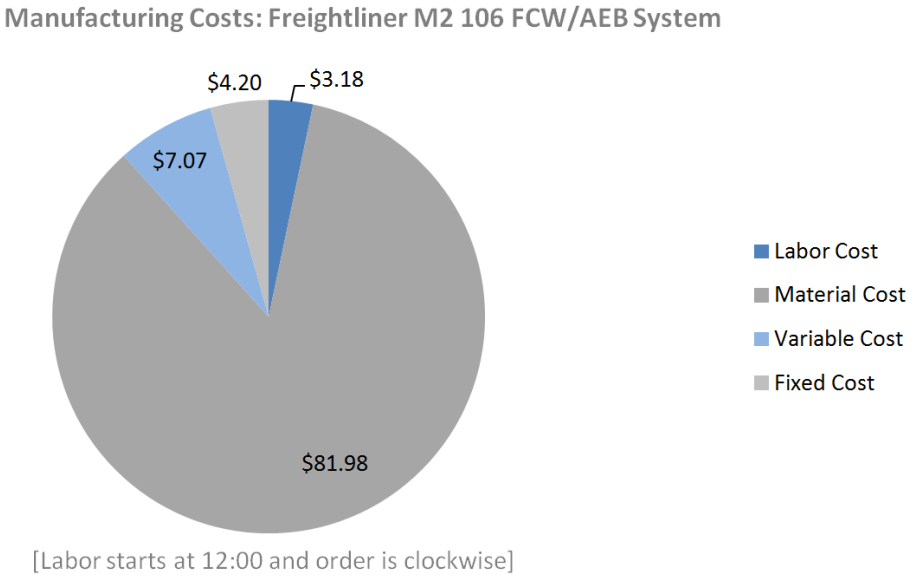


Figure 42: Freightliner M2 106 MD Truck FCW/AEB System Cost Build-Up

The manufacturing cost increase of the Freightliner M2 106 MD Truck FCW/AEB system is shown in Table 15.

Freightliner M2 106 FCW/AEB System Cost Analysis			
Category	**Cost**	**Variable Manufacturing Cost**	**Total Manufacturing Cost**
Labor Cost	$3.18	**$92.23**	**$96.43**
Material Cost	$81.98		
Variable Cost	$7.07		
Fixed Cost	$4.20		

Table 15: Estimated Incremental Manufacturing Cost Analysis of Freightliner M2 106 FCW/AEB System

Freightliner Cascadia® Class 8 HD Truck

The key components of the FCW/AEB system for the Freightliner Cascadia® HD truck include:

1. Front Radar Sensor
2. Front Radar Sensor Wire Harness

The complete results of the cost and weight analysis are included in the appendix, along with photos of the individual FCW/AEB system components. Table 16 provides a summary for the key subsystems as well as the full FCW/AEB system.

Freightliner Cascadia HD Truck, FCW/AEB System Manufacturing Costs										
Item	**Description**	**Total Manufact-uring Cost**	**Quantity per Vehicle**	**Cost to Manu-facture per Unit**	**Labor**	**Material**	**Variable**	**Fixed**	**Unit Weight [g]**	**Total Weight per Vehicle [g]**
1	**Freightliner M2 106 FCW/AEB System**	**$ 39.79**	**1**	**$ 39.79**	**$1.232**	**$ 34.827**	**$ 2.134**	**$ 1.597**	**386.5**	**386.5**
1.1	Front Radar Sensor	$ 32.00	1	$ 32.00	$0.344	$ 28.603	$ 1.482	$ 1.576	288.0	288.0
1.2	Front Radar Sensor Wire Harness	$ 7.79	1	$ 7.79	$0.889	$ 6.224	$ 0.652	$ 0.021	98.5	98.5

Table 16: Manufacturing Costs and Weights Summary for Freightliner Cascadia® FCW/AEB System

The calculated incremental cost of the Freightliner Cascadia® FCW/AEB system is estimated to be $39.79, with the front radar system accounting for 80% of the increment. The total manufacturing costs are summarized by cost element as shown in Figure 43. The addition of the FCW and AEB components increases the vehicle weight by 0.39 kg.

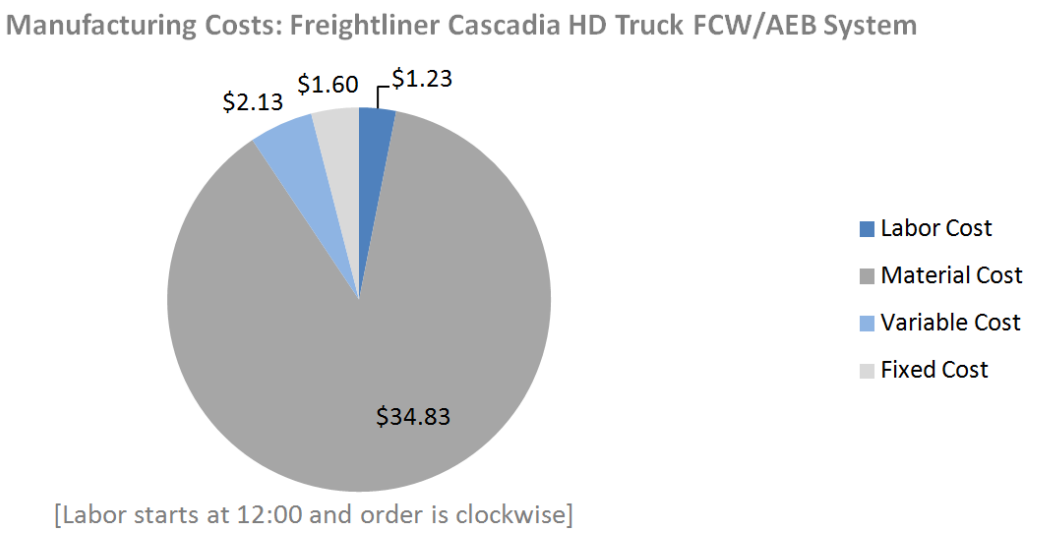


Figure 43: Freightliner Cascadia® HD Truck FCW/AEB System Cost Build-Up

The manufacturing cost increase of the Freightliner Cascadia® HD Truck FCW/AEB system is shown in Table 17.

Freightliner Cascadia HD Truck FCW/AEB System Cost Analysis			
Category	**Cost**	**Variable**	**Total**
Labor Cost	$1.23	**$38.19**	**$39.79**
Material Cost	$34.83		
Variable Cost	$2.13		
Fixed Cost	$1.60		

Table 17: Estimated Incremental Manufacturing Cost Analysis of Freightliner Cascadia® FCW/AEB System

Volvo VNL Class 8 HD Truck

The key components of the FCW/AEB system for the Volvo VNL HD truck include:

1. Front Radar Sensor
2. Radar Wiring Harness
3. Camera
4. Side Sensor
5. Head Up Display
6. Camera Wire Harness

The complete results of the cost and weight analysis are included in the appendix, along with photos of the individual FCW/AEB system components. Table 18 provides a summary for the key subsystems as well as the full FCW/AEB system.

Volvo VNL HD Truck, FCW/AEB System Manufacturing Costs										
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1	**Volvo VNL FCW/AEB System**	**$ 164.12**	**1**	**$ 164.12**	**$ 10.305**	**$ 111.889**	**$ 7.411**	**$ 5.546**	**2377.5**	**2377.5**
1.1	Front Radar Sensor	$ 31.77	1	$ 31.77	$ 0.622	$ 27.884	$ 1.455	$ 1.807	311.3	311.3
1.2	Radar Wiring Harness	$ 8.09	1	$ 8.09	$ 1.483	$ 6.444	$ 0.125	$ 0.041	255.7	255.7
1.3	Camera	$ 43.04	1	$ 43.04	$ 0.563	$ 36.954	$ 3.140	$ 2.379	128.0	128.0
1.4	Side Sensor	$ 57.93	2	$ 28.97	$ 1.707	$ 26.059	$ 0.584	$ 0.616	662.7	1325.4
1.5	Head Up Display	$ 4.65	1	$ 4.65	$ 0.810	$ 2.978	$ 0.416	$ 0.444	118.2	118.2
1.6	Camera Wire Harness	$ 18.64	1	$ 18.64	$ 5.120	$ 11.570	$ 1.690	$ 0.260	238.9	238.9

Table 18: Manufacturing Costs and Weights Summary for Volvo VNL HD Truck FCW/AEB System

The calculated incremental cost of the Volvo VNL FCW/AEB system is estimated to be $164.12, with the front radar system accounting for 19% of the increment, the two side radar sensors accounting for 35% of the increment, and the camera accounting for 26% of the increment. The total manufacturing costs are summarized by cost element as shown in Figure 44. The addition of the FCW and AEB components increases the vehicle weight by 2.38 kg.

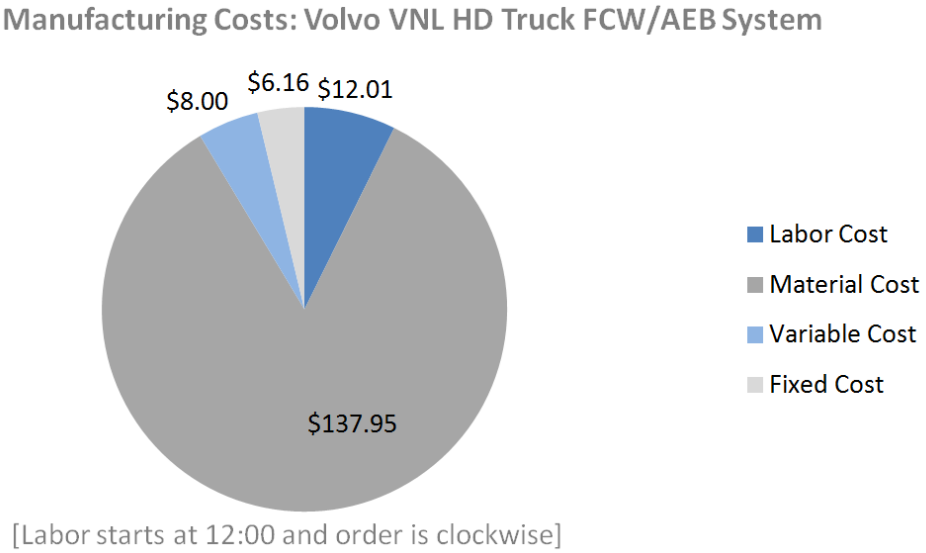


Figure 44: Volvo VNL HD Truck FCW/AEB System Cost Build-Up

The manufacturing cost increase of the Freightliner Cascadia® HD Truck FCW/AEB system is shown in Table 19.

Volvo VNL HD Truck FCW/AEB System Cost Analysis			
Category	**Cost**	**Variable Manufacturing Cost**	**Total Manufacturing Cost**
Labor Cost	$12.01	**$157.96**	**$164.12**
Material Cost	$137.95		
Variable Cost	$8.00		
Fixed Cost	$6.16		

Table 19: Estimated Incremental Manufacturing Cost Analysis of Volvo VNL FCW/AEB System

International LT™ Class 8 HD Truck

The key components of the FCW/AEB system for the International LT™ HD truck include:

1. Front Radar Sensor
2. Radar Bracket and Standoff
3. 4-Wire Front Radar Sensor Harness
4. 2-Wire Front Radar Sensor Harness
5. Camera
6. Camera Bracket
7. ECU, Processor
8. Camera to Processor Harness
9. Separate Dash Display
10. Camera & ECU Harness to Roof Harness

The complete results of the cost and weight analysis are included in the appendix, along with photos of the individual FCW/AEB system components. Table 20 provides a summary for the key subsystems as well as the full FCW/AEB system.

International LT HD Truck, FCW/AEB System Manufacturing Costs										
Item	**Description**	**Total Manufact-uring Cost**	**Quantity per Vehicle**	**Cost to Manu-facture per Unit**	**Labor**	**Material**	**Variable**	**Fixed**	**Unit Weight [g]**	**Total Weight per Vehicle [g]**
1	**International LT FCW/AEB System**	**$ 197.51**	**1**	**$ 197.51**	**$ 10.138**	**$ 166.594**	**$ 13.197**	**$ 7.583**	**3101.4**	**3101.4**
1.1	Front Radar Sensor	$ 31.77	1	$ 31.77	$ 0.622	$ 27.884	$ 1.455	$ 1.807	311.3	311.3
1.2	Radar Bracket and Standoff	$ 2.42	1	$ 2.42	$ 0.219	$ 1.663	$ 0.123	$ 0.416	1201.4	1201.4
1.3	4-Wire Front Radar Sensor Harness	$ 1.76	1	$ 1.76	$ 0.726	$ 0.957	$ 0.061	$ 0.020	238.9	238.9
1.4	2-Wire Front Radar Sensor Harness	$ 1.92	1	$ 1.92	$ 0.846	$ 0.417	$ 0.625	$ 0.037	213	213
1.5	Camera	$ 43.04	1	$ 43.04	$ 0.563	$ 36.954	$ 3.140	$ 2.379	128	128
1.6	Camera Bracket	$ 1.08	1	$ 1.08	$ 0.016	$ 1.033	$ 0.010	$ 0.017	47.6	47.6
1.7	ECU, Processor	$ 60.01	1	$ 60.01	$ 0.588	$ 54.714	$ 3.526	$ 1.180	248.2	248.2
1.8	Camera to Processor Harness	$ 1.28	1	$ 1.28	$ 0.361	$ 0.865	$ 0.041	$ 0.010	238.9	238.9
1.9	Separate Dash Display	$ 35.61	1	$ 35.61	$ 1.082	$ 30.544	$ 2.526	$ 1.455	235.2	235.2
1.10	Camera & ECU Harness to Roof Harness	$ 18.63	1	$ 18.63	$ 5.116	$ 11.563	$ 1.689	$ 0.262	238.9	238.9

Table 20: Manufacturing Costs and Weights Summary for International LT™ HD Truck FCW/AEB System

The calculated incremental cost of the International LT™ FCW/AEB system is estimated to be $197.51, with the front radar system accounting for 16% of the increment, the ECU processor accounting for 30% of the increment, the separate dash display accounting for 18% of the increment, and the camera accounting for 22% of the increment. The total manufacturing costs are summarized by cost element as shown in Figure 45. The addition of the FCW and AEB components increases the vehicle weight by 3.10 kg.

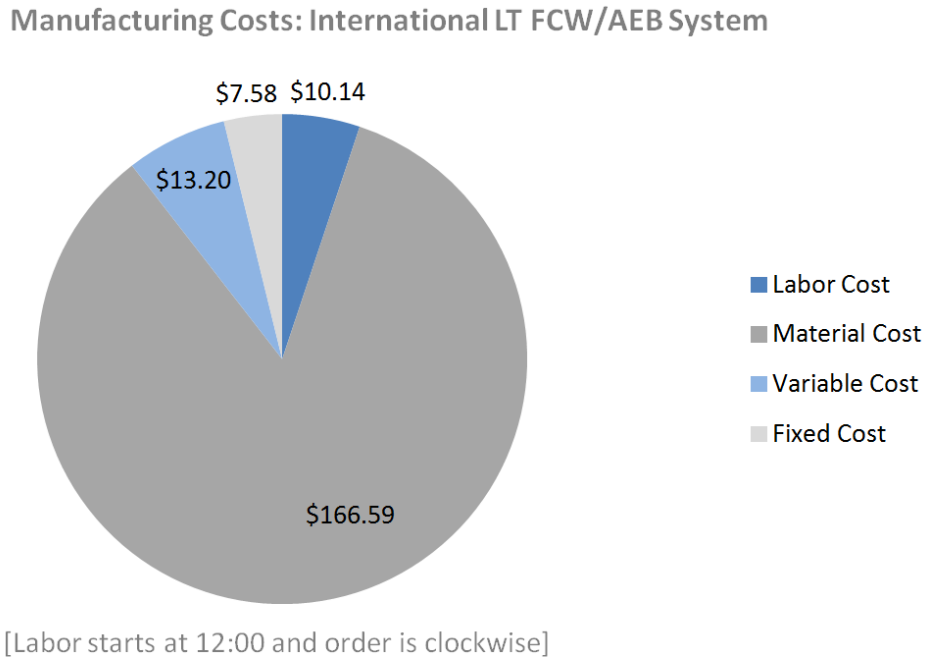


Figure 45: International LT™ HD Truck FCW/AEB System Cost Build-Up

The manufacturing cost increase of the International LT™ HD Truck FCW/AEB system is shown in Table 21.

International LT FCW/AEB System Cost Analysis			
Category	**Cost**	**Variable Manufacturing Cost**	**Total Manufacturing Cost**
Labor Cost	$10.14	**$189.93**	**$197.51**
Material Cost	$166.59		
Variable Cost	$13.20		
Fixed Cost	$7.58		

Table 21: Estimated Incremental Manufacturing Cost Analysis of International LT™ FCW/AEB System

Comparison of Evaluated FCW/AEB Systems and Summary

Table 22 shows comparisons of the study results for the five FCW and AEB systems. It is noted that there are significant variations in components and functions for these five systems, which results in corresponding differences in system weights and manufacturing costs.

Manufacturing Cost Comparisons						
Component Name	Vehicle					Average Component Costs
	Ford F-Series Super Duty	Freightliner M2 106	Freightliner Cascadia	Volvo VNL	International LT	
						
	Corresponding FCW/AEB Supplier					
	Delphi AdvanceTrac®	Meritor WABCO OnGuardACTIVE®	Detroit Assurance®	Bendix® Wingman® Fusion™		
Front Radar Sensor	$ 46.13	$ 66.13	$ 32.00	$ 31.77	$ 31.77	$ 41.56
Fascia		$ 0.79				$ 0.79
Wire Harness	$ 2.54	$ 3.56	$ 7.79	$ 8.09	$ 3.68	$ 5.13
Bracket and Hardware		$ 2.63			$ 2.42	$ 2.53
Integrated Dash Display	✓		✓			
Separate Dash Display		$ 21.34		$ 4.65	$ 35.61	$ 20.53
Display Wire Harness		$ 1.98			$ 9.31	$ 5.65
Camera				$ 43.04	$ 43.04	$ 43.04
Camera Wire Harness				$ 18.64	$ 1.28	$ 9.96
Bracket and Hardware					$ 1.08	$ 1.08
Side Radar Sensor				$ 57.93		$ 57.93
Integrated with Existing ECU	✓	✓	✓	✓		
Separate ECU (Processor)					$ 60.01	$ 60.01
Radar, Camera ECU Wire Harness					$ 9.31	$ 9.31
Totals:	**$ 48.67**	**$ 96.43**	**$ 39.79**	**$ 164.12**	**$ 197.51**	

Table 22: Estimated Incremental FCW/AEB Manufacturing Cost Analyses for Five Selected Vehicles

Costs to the manufacturer range from $39.79 to $197.51 and reflect the available functions and degree of integration with existing systems. For example the Freightliner Cascadia® Class 8 truck has the lowest incremental system cost because the driver visual display is integrated with the exiting dash cluster and the system signals are processed with a shared ECU. On the other hand, the International LT™ has the highest incremental cost because it incorporates all of the functions and components associated with the Bendix® Wingman® Fusion™ system, including separate dash display, camera, separate processor (ECU), and associated wire harnesses and brackets/hardware.

The added weight of the five FCW/AEB systems is summarized in Table 23. As with the manufacturing cost analysis, there is a wide range of values due to the variations in included system components, mounting methods, and degree of integration with existing equipment. The system weights range from 0.39 kg for the Freightliner Cascadia® Class 8 tractor, which includes a high degree of integration with the existing Detroit Assurance® OnGuardACTIVE® lane keeping and CIB systems, to 3.23 kg for the Freightliner M2 106, which includes a heavier front radar mounting bracket and associate hardware.

The FCW/AEB systems associated with the five selected vehicles were placed in four categories to aid in comparing added functions (and associated components) to resulting incremental costs and weights. These four categories are summarized in Table 24.

The four FCW/AEB system categories were defined based on implementation of these systems for the five selected vehicles. These categories and their corresponding FCW/AEB functions and components are:

Incremental Weights (grams) of FCW/AEB Components						
Component Name	Vehicle					Average Component Incremental Weights (g)
	Ford F-Series Super Duty	Freightliner M2 106	Freightliner Cascadia	Volvo VNL	International LT	
						
	Corresponding FCW/AEB Supplier					
	Delphi AdvanceTrac®	Meritor WABCO OnGuardACTIVE®	Detroit Assurance®	Bendix® Wingman® Fusion™		
Front Radar Sensor	468.1	379.1	288.0	311.3	311.3	351.6
Fascia		230.0				230.0
Wire Harness	73.5	168.0	98.5	255.7	451.9	209.5
Bracket and Hardware		2262.6			1201.4	1732.0
Integrated Dash Display	✓		✓			
Separate Dash Display		114.4		118.2	235.2	155.9
Display Wire Harness		74.0			119.5	96.7
Camera				128.0	128.0	128.0
Camera Wire Harness				238.9	238.9	238.9
Bracket and Hardware					47.6	47.6
Side Radar Sensor				1325.4		1325.4
Integrated with Existing ECU	✓	✓	✓	✓		
Separate ECU (Processor)					248.2	248.2
Radar, Camera ECU Wire Harness					119.5	119.5
Totals (grams):	**541.6**	**3228.1**	**386.5**	**2377.5**	**3101.4**	

Table 23: Incremental Weights (grams) of FCW/AEB Systems for Five Selected Vehicles

- FCW Addition: this applies to the Ford F-Series Super Duty® MD Trucks and the Cascadia® LT Class 8 truck:
  - No CIB or Integrated with Existing CIB
  - Hydraulic or Air Brakes
  - Integrated with Existing Dash Display
  - No Camera or Utilize Existing Camera
  - No Side Radar Sensors
  - Integrated with Existing ECU
- FCW and Dash Display Addition: this applies to the Freightliner M2 106 MD truck:
  - Integrated with Existing CIB
  - Hydraulic Brakes
  - Utilizes Existing LDWS Camera
  - No Side Radar Sensors

  - Integrated with Existing ECU
- FCW, Camera, Dash Display, and Side Radar Addition: this applies to the Volvo VNL Class 8 truck;
  - Integrated with Existing CIB
  - Air Brakes
  - Camera Added
  - Integrated with Existing ECU
- FCW, Camera, ECU, and Dash Display: this applies to the International LT™ Class 8 truck:
  - Integrated with Existing CIB
  - Air Brakes
  - Camera Added
  - ECU Added
  - No Side Sensors

FCW/AEB Category		Description	Included Components													Corresponding Vehicles					Incremental Costs and Weights	
			Front Radar Sensor	Radar Fascia	Radar Wire Harness	Radar Bracket & Hardware	Integrated Dash Display	Separate Dash Display	Separate Dash Display Wire Harness	Camera	Camera Wire Harness	Camera Bracket & Hardware	Side Radar Sensors	Separate ECU (Processor)	Radar, Camera, ECU Wire Harness	Ford F-Series SuperDuty MD	Freightliner M2 106 MD	Freightliner Cascadia Class 8	Volvo VNL Class 8	International LT Class 8	Average Incremental Manufacturing Cost	Average Incremental Weight Increase (grams)
1	*FCW Addition*	1. No CIB or Integrated with Existing CIB 2. Hydraulic or Air Brakes 3. Integrated with Existing Dash Display 4. No Camera or Utilize Existing Camera 5. No Side Radar Sensors 6. Integrated with Existing ECU	X		X		X									X		X			$ 44.23	464.05
2	*FCW and Dash Display Addition*	1. Integrated with Existing CIB 2. Hydraulic Brakes 3. Utilizes Existing LDWS Camera 4. No Side Radar Sensors 5. Integrated with Existing ECU	X	X	X	X		X	X								X				$ 96.43	3228.1
3	*FCW, Camera, Dash Display, and Side Radar Addition*	1. Integrated with Existing CIB 2. Air Brakes 3. Camera Added 4. Integrated with Existing ECU	X		X			X		X	X		X							X		$ 164.12	2377.5
4	*FCW, Camera, ECU, and Dash Display*	1. Integrated with Existing CIB 2. Air Brakes 3. Camera Added 4. ECU Added 5. No Side Radar Sensors	X		X	X		X	X	X	X	X		X	X						X	$ 197.51	3101.4

Table 24: Incremental Costs & Weights for Four Categories of FCW/AEB System Additions

The average incremental costs for the indicated FCW/AEB functions and associated components to trucks in each of the four categories, including indications of corresponding truck models are plotted in Figure 46. To meet the goal of defining costs and weights representative of high-

volume, mainstream systems offered by key global suppliers, identified FCW/AEB component costs were evaluated based on the assumption of production volumes of 200,000 vehicles per year.

Similarly, the incremental weights of the FCW/AEB component additions for each of the four categories are shown in the graph of Figure 47.

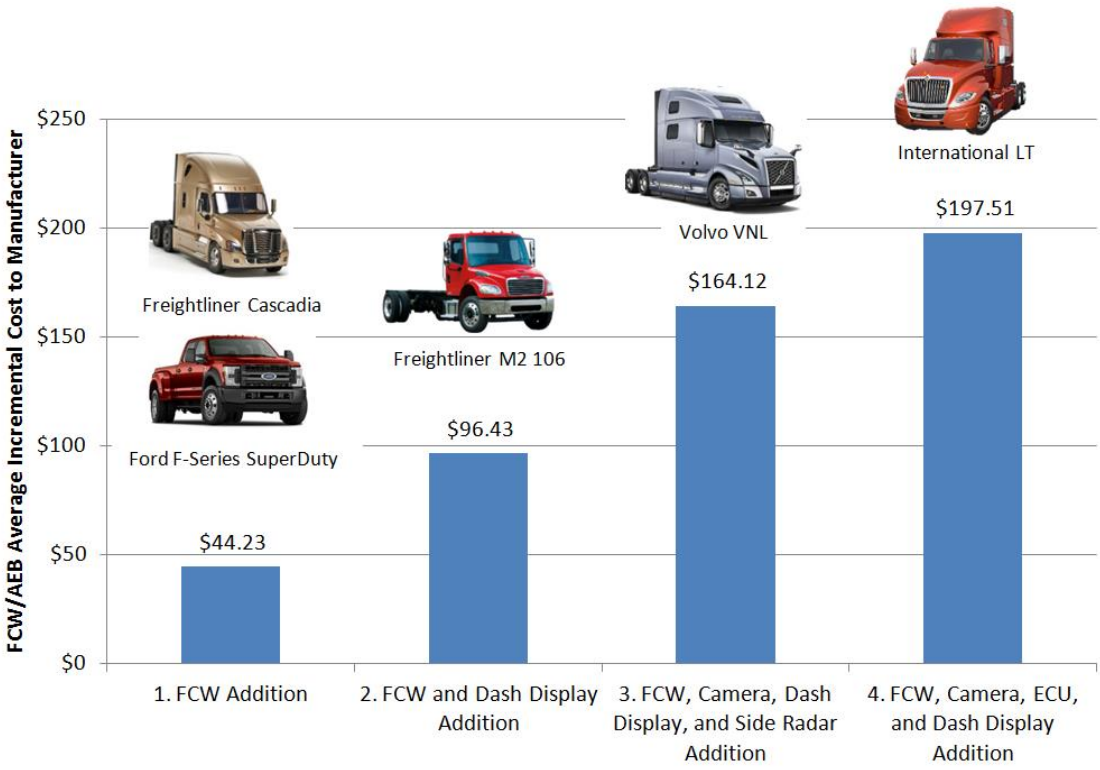


Figure 46: Average Incremental Cost of FCW/AEB Components for Four System Addition Categories

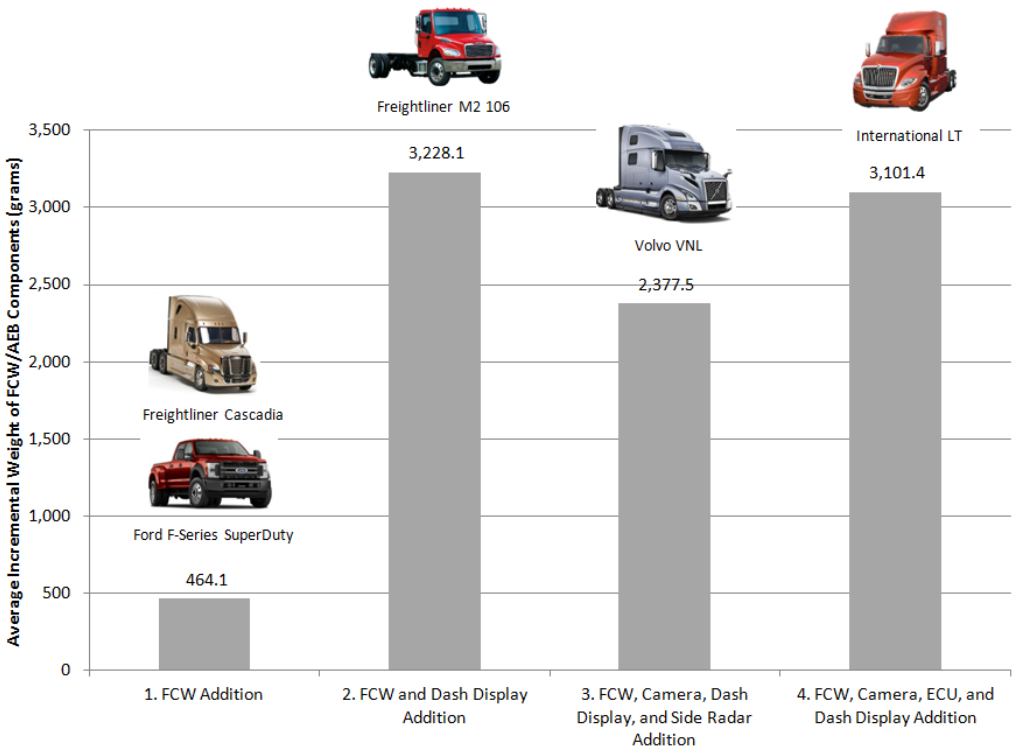


Figure 47: Average Incremental Weight Addition (grams) for FCW/AEB Components in Four Categories

Based on the Costing Approach and Assumptions portion of Section 3 (Engineering Analysis), the calculated manufacturing costs were utilize to estimate the price of the FCW/AEB systems to the end-user for the four defined categories. The costs to the manufacturer, in terms of variable and fixed sources, are shown in Table 25.

FCW/AEB Category		Corresponding Vehicles					Average Incremental Manufacturing Costs					
		Ford F-Series SuperDuty MD	Freightliner M2 106 MD	Freightliner Cascadia Class 8	Volvo VNL Class 8	International LT Class 8	Labor	Material	Other Variable	Fixed	Variable Costs (Labor + Material + Other Variable)	Total Cost to Manu-facture per Unit
1	*FCW Addition*	X		X			$ 1.51	$ 37.83	$ 2.40	$ 2.49	$ 41.73	$ 44.23
2	*FCW and Dash Display Addition*		X				$ 3.18	$ 81.97	$ 7.07	$ 4.21	$ 92.22	$ 96.43
3	*FCW, Camera, Dash Display, and Side Radar Addition*				X		$ 12.01	$ 137.95	$ 8.00	$ 6.16	$ 157.96	$ 164.12
4	*FCW, Camera, ECU, and Dash Display*					X	$ 10.14	$ 166.59	$ 13.20	$ 7.58	$ 189.93	$ 197.51

Table 25: Fixed and Variable Cost Elements for Identified FCW/AEB Categories

These manufacturing costs can then be used to determine the supplier overhead costs as shown in Table 26.

FCW/AEB Category		Corresponding Vehicles					Supplier Overhead			
		Ford F-Series SuperDuty MD	Freightliner M2 106 MD	Freightliner Cascadia Class 8	Volvo VNL Class 8	International LT Class 8	SG&A	Profit	Trans-portation and Warranty	Total, Supplier Over-head
1	*FCW Addition*	X		X			$ 2.65	$ 1.66	$ 3.32	$ 7.63
2	*FCW and Dash Display Addition*		X				$ 5.79	$ 3.62	$ 7.23	$ 16.63
3	*FCW, Camera, Dash Display, and Side Radar Addition*				X		$ 9.85	$ 6.15	$ 12.31	$ 28.31
4	*FCW, Camera, ECU, and Dash Display*					X	$ 11.85	$ 7.41	$ 14.81	$ 34.07

Table 26: Supplier Overhead for Each of the Four Defined FCW/AEB Categories

Similarly, the manufacturer overhead costs can be determined based on the manufacturing costs and the supplier overhead from Table 25 and Table 26. These are shown in Table 27.

FCW/AEB Category		Corresponding Vehicles					Manufacturer Overhead			
		Ford F-Series SuperDuty MD	Freightliner M2 106 MD	Freightliner Cascadia Class 8	Volvo VNL Class 8	International LT Class 8	SG&A	Profit	Trans-portation and Warranty	Total, Manu-facturer Over-head
1	*FCW Addition*	X		X			$ 4.15	$ 2.59	$ 5.19	$ 11.93
2	*FCW and Dash Display Addition*		X				$ 9.04	$ 5.65	$ 11.31	$ 26.00
3	*FCW, Camera, Dash Display, and Side Radar Addition*				X		$ 15.39	$ 9.62	$ 19.24	$ 44.26
4	*FCW, Camera, ECU, and Dash Display*					X	$ 18.53	$ 11.58	$ 23.16	$ 53.26

Table 27: Manufacturer Overhead for Each of the Four Defined FCW/AEB Categories

Finally, the calculated manufacturing costs, supplier and manufacturer overhead, along with the wholesale price increase and dealer costs and markup can be used to calculate the vehicle price increase to the end user for the addition of FCW/AEB components for the four defined categories and these are summarized in Table 28.

FCW/AEB Category		Corresponding Vehicles					Price to End User		
		Ford F-Series SuperDuty MD	Freightliner M2 106 MD	Freightliner Cascadia Class 8	Volvo VNL Class 8	International LT Class 8	Whole-sale Price Increase	Profit	End-User Incre-mental Price Increase
1	*FCW Addition*	X		X			$ 63.78	$ 7.02	$ 70.80
2	*FCW and Dash Display Addition*		X				$ 139.06	$ 15.30	$ 154.36
3	*FCW, Camera, Dash Display, and Side Radar Addition*				X		$ 236.69	$ 26.04	$ 262.72
4	*FCW, Camera, ECU, and Dash Display*					X	$ 284.85	$ 31.33	$ 316.18

Table 28: Estimated Price Increase of FCW/AEB Systems to End User for Four Identified Categories

The price increments to the end user for implementing four categories of FCW/AEB systems on the five selected vehicles are summarized in the bar graph of Figure 48.

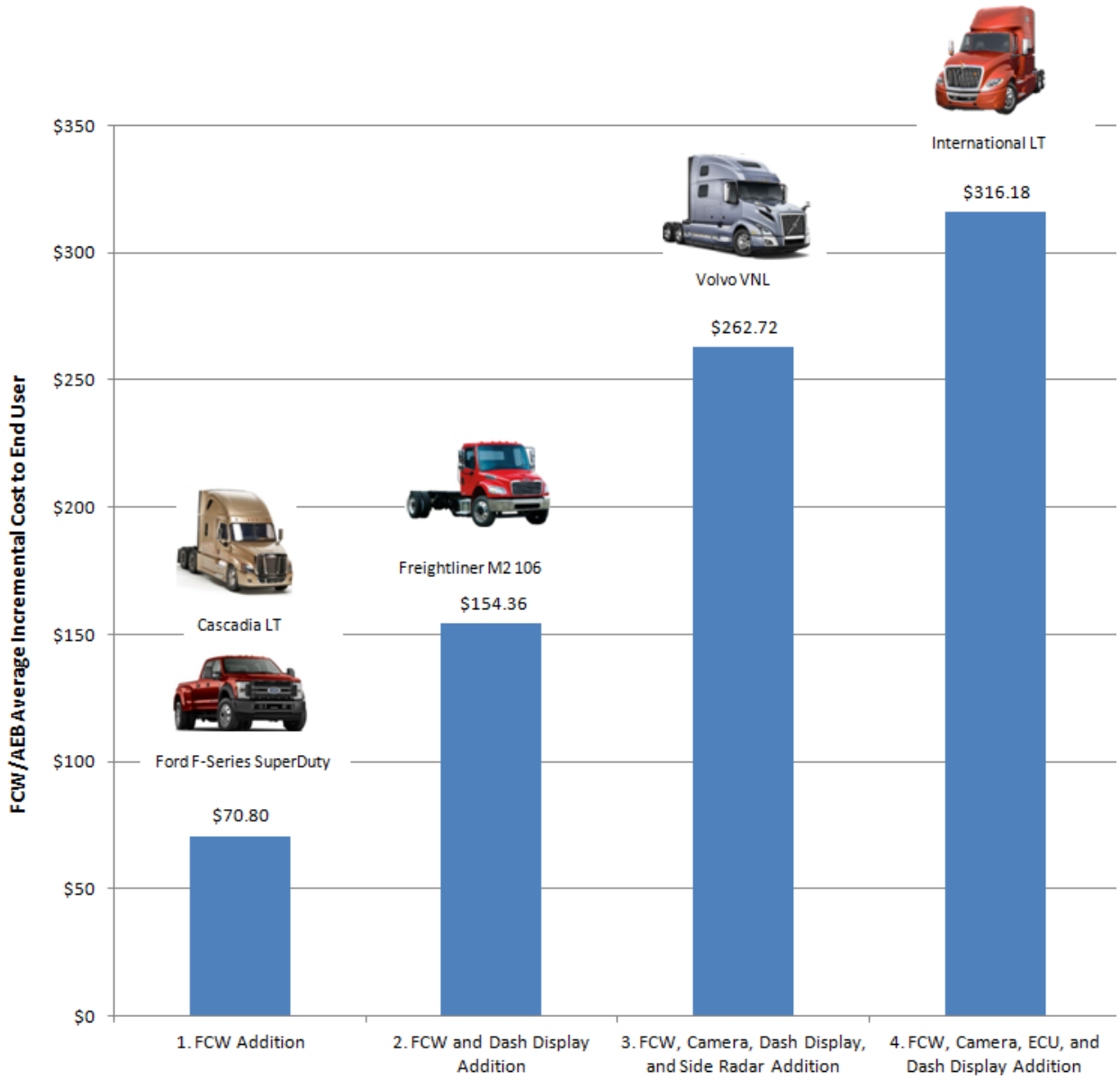


Figure 48: Estimated Price Increase of FCW/AEB Systems to End User for Four Identified Categories

It is interesting to note that these price increases are lower than those projected by The National Transportation Safety Board (NTSB) during 2016. NTSB estimated the price-to-vehicle owner for FCW systems will range between $1,000 and $2,000.[65] The current study indicates there is significant overlap of FCW/AEB functions and components with other key systems. The sharing of sensors, processors, displays, and controls, results in lower incremental costs for the

[65] Morrison, J., Forward Collision Warning Systems, National Transportation Safety Board, Office of Highway Safety, 2016 Fleet Safety Conference, Schaumberg, Illinois, 18-20 July 2016, https://www.ntsb.gov/news/events/Documents/miami_ok-FCWS_Presentation.pdf

FCW/AEB systems because of the reduced number of parts that are not shared with other ADAS functions.

5.0 ACRONYMS

ABS	Anti-lock Braking System
ABA	Active Brake Assist
ACC	Adaptive Cruise Control
ACC	Asset Center Costing
ADAS	Advanced Driver Assist Systems
ADS	Automated Driving Systems
AEB	Autonomous Emergency Braking
ATC	Automatic Traction Control
BOM	Bill of Materials
BRT	Brake Reaction Time
BSD	Blind Spot Detection
BSM	Basic Safety Message
CACC	Cooperative Adaptive Cruise Control
CAN	Controller Area Network
CAS	Collision Avoidance System(s)
CFR	Code of Federal Regulations
CIB	Crash Imminent Braking
CMB	Commercial Motor Vehicle
CO	NHTSA Contracting Officer
COR(TO)	NHTSA Contracting Officer's Representative - Task Order
CRS	Certified Revocation List
CSMA/CA	Carrier-Sense Multiple Access with Collision Avoidance
CV	Connected Vehicle
CVS	Bendix Commercial Vehicle Systems
C-V2X	Cellular-Vehicle-to-Everything
CWS	Collision Warning System
DBS	Dynamic Brake Support
DIC	Cadillac Digital Information Center

DIU	Driver Interface Unit (Bendix)
DOT	U.S. Department of Transportation
DSRC	Dedicated Short Range Communication
DSSS	Driving Safety Support System
DVI	Driver Vehicle Interface
ECU	Electronic Control Unit
ESC	Electronic Stability Control
ESR®	Electronically Scanning Radar
ESP®	Electronic Stability Program
FCAM	Forward Collision Avoidance and Mitigation
FCC	Federal Communications Commission
FCW	Forward Collision Warning
FDA	Following Distance Alert
FLR	Forward Looking Radar
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
GHz	Gigahertz
GPS	Global Positioning System
GVWR	Gross Vehicle Weight Rating
HSM	Hardware Security Module
HD	Heavy Duty
HUD	Head Up Display
HV	Heavy Vehicle
I2V	Infrastructure-to-Vehicle
IA	Impact Alert
IEEE	Institute of Electrical and Electronics Engineers
IIHS	Insurance Institute for Highway Safety
ISO	International Standardization Organization
ITS	Intelligent Transport Systems
ITU-R	Radio Sector of the International Telecommunications Union
LDW	Lane Departure Warning
LTE	ITU-R Long-Term-Evolution Standard for Wireless Communication

MPH	Miles per Hour
MY	Model Year
NCAP	New Car Assessment Program (Europe, Australia, US)
NPRM	Notice of Proposed Rulemaking
NTSB	National Transportation Safety Board
OBE	On-Board Equipment
OFDM	Orthogonal Frequency-Division Multiplexing
OTA	Over-the-Air
PCB	Printed Circuit Board
PE	Precipitating Event
PKI	Public Key Infrastructure
NHTSA	National Highway Traffic Safety Administration
NPRM	Notice of Proposed Rulemaking
RSC	Ricardo Strategic Consulting
RSC®	(Ford) Roll Stability Control
SAE	Society of Automotive Engineers
SCE	Safety-Critical Event
SCW	Side Collision Warning
SOA	Stationary Object Alert
SVB	Stationary Vehicle Braking
TA	Trusted Authority
TDMA	Time-Division Multiple Access
TTA	Time-to-Avoidance
TTC	Time-to-Collision
UHF	Ultra High Frequency
V2I	Vehicle-to-Infrastructure Communications
V2P	Vehicle-to-Pedestrian Communications
V2V	Vehicle-to-Vehicle Communications
V2X	Vehicle-to-Other Systems Communications
VIN	Vehicle Identification Number
VRDU	Video Radar Decision Unit
WAVE	Wireless Access in Vehicular Environments

WSU Wireless Safety Unit

6.0 APPENDICES

The appendices include the following tables which contain information for the components related to the FCS/AEB systems for all five selected vehicles: 1) System parts lists, 2) bills of materials (BOMs), and 3) manufacturing costs and weight for each identified part, component, and subassembly.

Ford Super Duty® F-Series Trucks

The Ford Super Duty® F-Series trucks include two primary components for the FCW System (AEB is not currently offered). The parts subjected to the tear-down and weight analyses are shown in the following table and photos:

Ford FCW System Parts List

ID	Ford Part #	Description	MY	Qty
1	9E731	Adaptive Speed Control Sensor (*The sensor is in the lower front grille, behind a fascia panel*)	2017	1
2	15K867	Electrical Wiring Harness (*Connects sensor to the main harness*)	2017	1

Parts List: Ford Super Duty® F-Series FCW System

Photo of Ford Super Duty® F-Series Adaptive Speed Control (Radar) Sensor (photo credit MeC S.r.l.)

Ford Super Duty® F-Series Radar Sensor Wire Harness (photo credit MeC S.r.l.)

Bills of Materials (BOMs) for Ford Super Duty® F-Series FCW/AEB System

Ford F-Series Super Duty FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Radar Sensor, PCB 1 Components						
Micro-controllers	Analog Devices (Radar front end)	AD8285WBCPZ - 72 pin	1		$ 3.870	$ 3.870
Passive components	Ceramic Capacitor SMD	Average value	77		$ 0.004	$ 0.283
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	14		$ 0.006	$ 0.086
Passive components	Resistor SMD	Various Values 0402-0603-0805-	58		$ 0.001	$ 0.071
Micro-controllers	Customized Integrated circuit	Customized Integrated circuit	3		$ 2.450	$ 7.350
Active components	Transistor/Mos Fet SOT223 --> 'BSP 452	W49 / G1439	5		$ 0.184	$ 0.920
Connectors	Zif per flat Display 30 vie SMD	-	1		$ 0.384	$ 0.384
Various integrated circuits	Quad . Op. Ampl.	LM2902 Operational Amplifier x 4 SO14	1		$ 0.360	$ 0.360
Micro-controllers	STMicroelectronics SOP STM32F030F4P6	STM8 8bit - 48MHz - FLASH 16kB - RAM 4kB - Internal oscillator - 20	1		$ 0.669	$ 0.669
Various integrated circuits	Driver x 7 ch	ULQ2003 Considered ULN2003 Texas	1		$ 0.103	$ 0.103
Passive components	Resistor SMD 1/2 W	Various Values 1810 2,5 x 5 mm	2		$ 0.006	$ 0.012
Various integrated circuits	Driver	VN5016A (M157 x n° 2) PSSO12 HSD 16 mOhm 40A	2		$ 0.491	$ 0.981
Passive components	Quartz SMD 4kHz	4.0000:18 11,4 x 4,83 x 4,3	1		$ 0.147	$ 0.147

Ford F-Series Super Duty FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of**	**Cost Each**	**Cost Total**
Radar Sensor, PCB 2 Components						
Passive components	Electrolytic Capacitor SMD		5		$ 0.101	$ 0.503
Passive components	Electrolytic Capacitor SMD	100uF 25V 8,2x8,2x6,2	3		$ 0.069	$ 0.206
Passive components	Electrolytic Capacitor SMD	100uF 16V 6,2x6,2x6,2	2		$ 0.056	$ 0.113
Passive components	Inductor SMD 5x5,4x5	225K 9022 Vishay	3		$ 0.245	$ 0.736
Passive components	Double Inductor SMD EPCOS	BB2793	1		$ 0.331	$ 0.331
CAN/LIN transceivers	C-CAN Transcevier	A1042/3	2		$ 0.331	$ 0.662
Voltage regulators	Voltage regulator Step Down	7112Q	3		$ 0.445	$ 1.335
External memory IC	Flash 16 Mb (2Mb x8)	S25FL116K0XMFB040 16-SOIC - 108MHz - NOR - [2,7; 3,6] V - SPI quadruplo I/O	1		$ 1.270	$ 1.270
Passive components	Inductor SMD chip		1	1	$ 0.025	$ 0.049
Active components	Transistor/Mos Fet D-PAK	BSP 452 Driver HS	1		$ 0.331	$ 0.331
Active components	Diode SGS (SMB)	Various Values 4x4,2x2,2	2		$ 0.092	$ 0.184
Active components	Transistor/Diode bjt	Various Values	3	8	$ 0.018	$ 0.198
Micro-controllers	Processor	DRA4168IZDU	**1**		$ 9.600	$ 9.600
Various integrated circuits	Real Clock RTC	PCA8565TS Estimation, waiting for NXP	2		$ 0.613	$ 1.227
Various integrated circuits	Double . Op. Ampl.	LM2904 Operational Amplifier x 2 SO8	1		$ 0.130	$ 0.130
Voltage regulators	Low Drop Voltage Tracker TO220/5 SMD	MAX 16974	1		$ 0.497	$ 0.497
Micro-controllers	Microcontroller a 8 bit - MCU 8 Bit MCU 14KB Flash 1KB RAM, 18 I/O	F1829	**1**		$ 0.620	$ 0.620
Micro-controllers	MICROCHIP EEPROM 128k 16KX8 2.5V SER EE EXT	25LC128E	1		$ 0.500	$ 0.500
Active components	Transistor/Diode SOT23	Various Values	1	1	$ 0.018	$ 0.037
Passive components	Ceramic Capacitor SMD	Average value	19	105	$ 0.004	$ 0.456
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	11	2	$ 0.006	$ 0.080
Active components	Diode SMD SOD123	Various Values 1,5x2,8x1,2	5	26	$ 0.009	$ 0.266
Passive components	Resistor SMD	Various Values 0402-0603-0805-	5	38	$ 0.001	$ 0.053
Connectors	2-way SMD	Estimated value	1		$ 0.080	$ 0.080
Passive components	Resistor SMD mini-melf	Various Values		2	$ 0.004	$ 0.007
Passive components	Resistor SMD 1/2 W	Various Values 1810 2,5 x 5 mm		4	$ 0.006	$ 0.025

Ford F-Series Super Duty FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Radar Sensor Wire Harness Components						
Cable	UNIPOLE	T3 - 125°C	4	1.5	$ 0.480	$ 0.188
Blocks		14-18 WAYS	1			$ 0.705
Heat Shrink Tubes	Solded points protection	Simple+Glue	3			$ 0.093
Clips/Strips	clip plastic		2			$ 0.185
Tubes	Tipo B - UNSLIT	Corrugated Tube T3 - 125°C	1	9	$ 0.380	$ 0.055
Tapes	PVC Tape	T3 125 °C	1			$ 0.174

Cost and Weight Summary for Ford Super Duty® F-Series FCW/AEB System

Details of the FCW/AEB cost and weight analysis for the Ford Super Duty® F-Series MD trucks shown in the table below:

Ford F-Series Super Duty FCW/AEB System												
Item	Description	Total Manufacturing Cost	Quantity per Vehicle	Cost to manu-facture per unit	Cycle time [sec]	Man power	Labor	Material	Variable	Fixed	Unit weight [g]	Total weight per vehicle [g]
1	**Ford FCW system**	**$ 48.67**	**1**	**$ 48.67**			**$ 1.78**	**$ 40.83**	**$ 2.66**	**$ 3.39**	**541.6**	**541.6**
1.1	**Adaptive Speed Control Radar**	**$ 46.12**	**1**	**$ 46.12**			**$ 1.15**	**$ 39.40**	**$ 2.20**	**$ 3.38**	**468.1**	**468.1**
1.1.1	Housing	$ 5.92	1	$ 5.92			$ 0.96	$ 1.50	$ 0.52	$ 2.94	349	349
1.1.1.1	External Plastic Cover	$ 0.40	1	$ 0.40	10.08	1	$ 0.06	$ 0.25	$ 0.03	$ 0.07	37.5	37.5
1.1.1.2	External Metal Cover	$ 3.40	1	$ 3.40	30.00	1	$ 0.53	$ 0.80	$ 0.30	$ 1.78	152.1	152.1
1.1.1.3	Internal Housing	$ 2.01	1	$ 2.01	18.00	1	$ 0.34	$ 0.41	$ 0.18	$ 1.08	150	150
1.1.1.4	Internal Frame	$ 0.11	1	$ 0.11	3.00	0.5	$ 0.03	$ 0.05	$ 0.01	$ 0.01	9.4	9.4
1.1.2	Radar PCBs	$ 40.20	1	$ 40.20			$ 0.18	$ 37.90	$ 1.68	$ 0.44	119.1	119.1
1.1.2.1	First PCB	$ 18.50	1	$ 18.50			$ 0.09	$ 17.42	$ 0.79	$ 0.20	71.7	71.7
1.1.2.1.1	PCB Components		1	$ 15.24	-	-	-	$ 15.24	-	-		
1.1.2.1.2	Circuit board		1	$ 1.92	-	-	-	$ 1.92	-	-		
1.1.2.1.3	Other materials/Scrap		1	$ 0.26	-	-	-	$ 0.26		-		
1.1.2.1.3.1	Label		1	$ 0.02	-	-	-	$ 0.02	-	-		
1.1.2.1.3.2	Glue		1	$ 0.06	-	-	-	$ 0.06	-	-		
1.1.2.1.4	Processing		1	$ 1.08			$ 0.09	$ -	$ 0.79	$ 0.20		
1.1.2.1.4.1	SMD component circuits		1	$ 0.80	11.76	2	$ 0.07	-	$ 0.56	$ 0.17		
1.1.2.1.4.2	Circuit testing and programming		1	$ 0.25	11.76	1	$ 0.01	-	$ 0.24	-		
1.1.2.1.4.3	Setup		1	$ 0.03	-	-	-	-	-	$ 0.03		
1.1.2.2	Second PCB	$ 21.70	1	$ 21.70			$ 0.10	$ 20.48	$ 0.89	$ 0.24	47.4	47.4
1.1.2.2.1	PCB Components		1	$ 19.50	-	-	-	$ 19.50	-	-		
1.1.2.2.2	Circuit board		1	$ 0.76	-	-	-	$ 0.76	-	-		
1.1.2.2.3	Other materials/Scrap		1	$ 0.23	-	-	-	$ 0.23	-	-		
1.1.2.2.3.1	Label		1	$ 0.02	-	-	-	$ 0.02	-	-		
1.1.2.2.4	Processing		1	$ 1.22			$ 0.10	$ -	$ 0.89	$ 0.24		
1.1.2.2.4.1	SMD component circuits		1	$ 0.90	13.14	2	$ 0.08	-	$ 0.63	$ 0.19		
1.1.2.2.4.2	Circuit testing and programming		1	$ 0.27	13.14	1	$ 0.01	-	$ 0.26	-		
1.1.2.2.4.3	Setup		1	$ 0.05		-	-	-	-	$ 0.05		
1.2	**Electrical Wiring Harness**	**$ 2.54**	**1**	**$ 2.54**			**$ 0.64**	**$ 1.43**	**$ 0.46**	**$ 0.02**	**73.5**	**73.5**
1.2.1	Wires		1	$ 0.19	-	-	-	$ 0.19	-	-		
1.2.2	Connectors		1	$ 0.71	-	-	-	$ 0.71	-	-		
1.2.3	Heat Shrink Tubes		1	$ 0.09	-	-	-	$ 0.09	-	-		
1.2.4	Clips/Strips		1	$ 0.19	-	-	-	$ 0.19	-	-		
1.2.5	Tubes		1	$ 0.06	-	-	-	$ 0.06	-	-		
1.2.6	Tapes		1	$ 0.17	-	-	-	$ 0.17	-	-		
1.2.7	Other materials/Scrap		1	$ 0.03	-	-	-	$ 0.03	-	-		
1.2.8	Process		1	$ 1.11	187.92	1	$ 0.64	-	$ 0.46	$ 0.02		

Freightliner M2 106 Class 6-7 Truck

The Freightliner M2 106 trucks include nine primary components for the Meritor WABCO OnGuardACTIVE® AEB/FCW System. The parts subjected to the tear-down and weight analyses are shown in the following table and photos:

Parts list for FCW/AEB Components of Meritor WABCO OnGuardACTIVE® System kit			
ID	Part #	Description	Qty
400-871-940-2		OnGuard™ System Retrofit Kit*	1
1	S4008710400	Radar Sensor	1
2	S4008718010	OnGuard™ Display	1
3	S4008782000	Fascia	1
4	S4008770010	Radar Adapter Harness	1
5	S4008778010	Display Adapter Harness	1
6	S4008784110	Radar Sensor Bracket	1
7	S4008780114	Fascia M6 Bolts	3
8	S4008780124	Bracket Mounting Bolts	2
9	S8840144124	Radar M6 Nuts	3

Meritor WABCO OnGuardACTIVE® Radar Sensor (left) and Display (right) (photo credit: WABCO)

Meritor WABCO OnGuardACTIVE® Radar Fascia (left) and Radar Adapter Wire Harness (right) (photo credit MeC S.r.l)

Meritor WABCO OnGuardACTIVE® Display Adapter Harness (left) and Radar Sensor Bracket (right) (photo credit MeC S.r.l)

Bills of Materials (BOMs) for Freightliner M2 106 FCW and AEB Systems

The bills of materials for the assemblies, subassemblies, and parts unique to the FCW/AEB functions for the Freightliner M2 106 are shown in the following tables.

Freightliner M2 106 FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of**	**Cost Each**	**Cost Total**
Radar Sensor, Master PCB Components						
Passive components	Ceramic Capacitor SMD	Various Values	120	90	$ 0.004	$ 0.773
Passive components	Electrolytic Capacitor SMD 10x10x10,5	470uF 25V 10x10x10,5	0	3	$ 0.101	$ 0.302
Passive components	Inductor SMD on ferrite 11x11x8,4	220 1191 Vishay - Estimated Value	2	3	$ 0.613	$ 3.067
Passive components	Inductor SMD	Misc	3	1	$ 0.510	$ 2.040
Passive components	Resistor SMD	Various Values 0402-0603-0805-1206	73	40	$ 0.001	$ 0.139
Passive components	Resistor SMD 1/2 W	0.5% tolerance (green)	1	0	$ 0.010	$ 0.010
Passive components	Resistor SMD	0.25% tolerance (blue)	17	2	$ 0.019	$ 0.361
Active components	Transistor/Diode SOT23	BJT	11	5	$ 0.018	$ 0.294
Active components	Transistor/Mos Fet SOT223	MOSfet	3	0	$ 0.061	$ 0.184
Active components	Diode SGS (SMA)	Various Values 2,6x4,2x2,2	12	13	$ 0.025	$ 0.613
Active components	Transistor/Diode SOT23	Ht 1	4	0	$ 0.084	$ 0.336
Active components	Gate Driver	3NV04P 4F644	0	1	$ 0.256	$ 0.256
Active components	Transistor/Mos Fet D-PAK	A983255	0	2	$ 0.331	$ 0.662
Micro-controllers	PWM Controller	SPC5673LVVZ2	1	0	$ 0.810	$ 0.810
Active components	LDO Voltage Regulators	33KA5 64 63	1	0	$ 0.280	$ 0.280
Active components	Board Mount Temperature Sensors W/ Over Temp Alert	FR6 650A A7 31	1	0	$ 0.923	$ 0.923
Active components	Board Mount Hall Effect/Magnetic Sensors	Ultra-Low Power 1.65V to 5.5V Hall Effect Switch Sensor 3-SOT-23 -40 to 85	1	0	$ 0.169	$ 0.169
External memory IC	Sram 4bit	IC SRAM 4MBIT 10NS 44TSOP	1	0	$ 1.729	$ 1.729
Active components	Latches	Latches Mil Enhanced 16B Transp D-Type Latch	1	0	$ 1.480	$ 1.480
Micro-controllers	MCU	T5CZ9FG-0001	1	0	$ 7.200	$ 7.200
Active components	Digital/Analog converter	Digital to Analog Converters - DAC 10-Bit 210 MSPS	1	0	$ 3.322	$ 3.322
Active components	Digital/Analog converter	Analog to Digital Converters - ADC 10-Bit, 40-MSPS Analog-to-Digital Converter (ADC) - Qualified for Automotive Applications 28-TSSOP -40 to 85	1	0	$ 3.320	$ 3.320
Active components	Analog/Digital converter	Analog to Digital Converters - ADC Nanopower, Dual-Channel, Programmable Sensor Monitor 10-X2QFN -40 to 125	1	0	$ 0.797	$ 0.797
Switches SMD	Switches SMD	SWITCH TACTILE SPST-NO 0.05A 24V	1	0	$ 2.169	$ 2.169
Active components	LDO Voltage Regulators	79633Q 68Z6J3H	1	0	$ 1.220	$ 1.220
Micro-controllers	MCU	SPC5673LVVZ2 ON31E QZM1645K	0	1	$ 8.600	$ 8.600
CAN/LIN transceivers	B-CAN Transcevier	NXP TJA 1043T FK900036 TnD16401	1	0	$ 0.675	$ 0.675
Active components	Transistor/Diode SOT23	SJ 6B	1	0	$ 0.084	$ 0.084
Various integrated circuits	-	6CI7 SSUB	1	0	$ 0.815	$ 0.815
Various integrated circuits	-	ST 4ZEJ 29014 MRC648	1	0	$ 0.477	$ 0.477
Various integrated circuits	-	AEJX	1	0	$ 0.124	$ 0.124
Various integrated circuits	-	HG 1BL 3	1	0	$ 0.313	$ 0.313

Freightliner M2 106 FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Radar Sensor, Slave PCB Components						
Passive components	Resistor SMD	0.25% tolerance (blue)	6	0	$ 0.019	$ 0.114
Passive components	Ceramic Capacitor SMD	Various Values	10	0	$ 0.004	$ 0.037
Passive components	Inductor SMD on ferrite 11x11x8,4	220 1191 Vishay - Estimated Value	2	0	$ 0.613	$ 1.227
Micro-controllers	Customized MCU	CUSTOM	1		$ 2.450	$ 2.450

Freightliner M2 106 FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Display PCB Components						
Passive components	Electrolytic Capacitor SMD	470uF 25V 10x10x10,5	3	0	$ 0.101	$ 0.302
Passive components	Ceramic Capacitor SMD	Various Values	27	33	$ 0.004	$ 0.221
Passive components	Resistor SMD	220 1191 Vishay - Estimated Value	50	48	$ 0.001	$ 0.120
Passive components	Inductor on ferrite	CUSTOM	4	0	$ 0.613	$ 2.453
Active components	Transistor/Diode SOT23	BJT	9	14	$ 0.018	$ 0.423
Active components	Transistor/Diode SOT6 Double		1	3	$ 0.037	$ 0.147
Various Integrated	Real Clock RTC	A120C69	1	0	$ 0.613	$ 0.613
Micro-controllers	Renesas RX621	RF56218BDFP RX6218 TA40437 86220	1	0	$ 4.043	$ 4.043
Various Integrated	Linear Voltage Regulator	IC Positive Adjustable 1 Output 1.2 V ~ 32 V 100mA 8-SOIC	1	0	$ 0.118	$ 0.118
Active components	Transistor/Mos Fet SOT223	Channel P 200V 670 mA (Tc) 2,5 W (Tc) (SMD, SMT) SOT-223-4	1	0	$ 0.061	$ 0.061
Various Integrated	Driver	dhr 6bh57	1	0	$ 0.221	$ 0.221
Various Integrated	CAN Transreceiver	VP234 64M A2HC	0	1	$ 0.810	$ 0.810
Connectors	Zif per flat Display 5 vie SMD		1	0	$ 0.184	$ 0.184
Connectors	Header	8 pin	0	1	$ 0.960	$ 0.960
Switches SMD	Switches SMD		4	0	$ 0.098	$ 0.392

Freightliner M2 106 FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Radar Sensor, Wire Harness Components						
Cable	UNIPOLE	T3 - 125°C	4	2	0.5	$ 0.252
Cable	UNIPOLE	T3 - 125°C	1	2	1.2	$ 0.014
Blocks		4-6 WAYS complex	1			$ 0.577
Blocks		7-9 WAYS complex	1			$ 0.719
Heat Shrink Tubes		Simple+Glue	1			$ 0.140
Bellows		Superseal bellows (1-10 vias)	1			$ 0.037
Tubes	Type B - UNSLIT	TUBO CORRUGATO T3 - 125°C Col. Marcat. Verde	4			$ 0.065
Tapes	PVC Tape	T3 125 °C	1			$ 0.005
Connector	Housing Connector		1			$ 0.422

Freightliner M2 106 FCW/AEB System BOMs						
TYPE	COMPONENT	DESCRIPTION	Quantity	Section (mm)	Length (m)	Cost Total
Display Wire Harness Components						
Cable	UNIPOLE	T3 - 125°C	4	2	0.2	$ 0.101
Blocks		4-6 WAYS complex	1			$ 0.280
Blocks		7-9 WAYS complex	1			$ 0.719
Heat Shrink Tubes		Simple+Glue	1			$ 0.046
Tapes	PVC Tape	T3 125 °C	1			$ 0.040

Cost and Weight Summary for Freightliner M2 106 FCW and AEB Systems

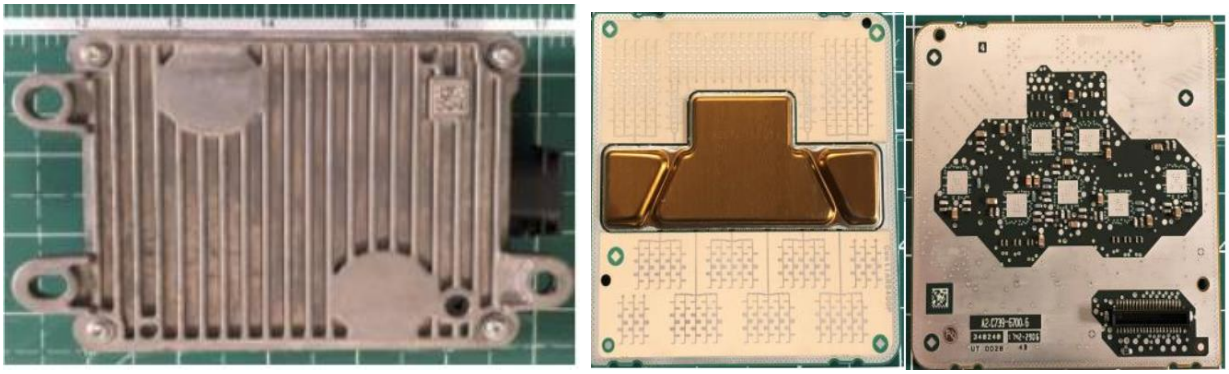
Details of the FCW and AEB systems cost and weight analysis for the Freightliner M2 106 are shown in the table below:

Freightliner M2 106 FCW/AEB System												
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Cycle Time [sec]	Man power	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1	**Freightliner M2 FCW system**	**$ 96.43**	**1**	**$ 96.43**	**428.76**	**$ 3.00**	**$ 3.18**	**$ 81.97**	**$ 7.06**	**$ 4.21**	**3228.10**	**3228.1**
1.1	**Radar Sensor**	**$ 66.13**	**1**	**$ 66.13**			**$ 1.37**	**$ 58.37**	**$ 3.85**	**$ 2.54**	**379.1**	**379.1**
1.1.1	Housing	$ 11.06	1	$ 11.06			$ 0.89	$ 6.74	$ 1.75	$ 1.68	261.3	261.3
1.1.1.1	Internal Housing 1		1	$ 0.43	20.00	1	$ 0.03	$ 0.09	$ 0.02	$ 0.28	13.8	
1.1.1.2	Internal Housing 2		1	$ 0.36	12.00	1	$ 0.01	$ 0.28	$ 0.01	$ 0.06	7.2	
1.1.1.3	Housing Top		1	$ 7.47	48.00	1	$ 0.60	$ 4.97	$ 1.58	$ 0.32	110	
1.1.1.4	Housing Internal		1	$ 1.38	18.00	1	$ 0.12	$ 0.24	$ 0.08	$ 0.94	49.1	
1.1.1.5	Radar Housing		1	$ 1.43	49.62	1	$ 0.13	$ 1.16	$ 0.07	$ 0.08	81.2	
1.1.2	Radar PCBs	$ 55.07	1	$ 55.07			$ 0.49	$ 51.63	$ 2.09	$ 0.86	117.8	117.8
1.1.2.1	Main PCB	$ 48.93	1	$ 48.93			$ 0.32	$ 45.82	$ 1.99	$ 0.80	44.3	44.3
1.1.2.1.1	PCB Components		1	$ 43.54	-	-	-	$ 43.54	-	-		
1.1.2.1.2	Circuit board		1	$ 1.12	-	-	-	$ 1.12	-	-		
1.1.2.1.3	Other materials/Scrap		1	$ 1.15	-	-	-	$ 1.15	-	-		
1.1.2.1.3.1	Connectors		1	$ 0.67	-	-	-	$ 0.67	-	-		
1.1.2.1.4	Processing		1	$ 3.11	-	-	$ 0.32	$ -	$ 1.99	$ 0.80		
1.1.2.1.4.1	SMD component circuits		1	$ 1.89	21.60	2	$ 0.17	-	$ 1.26	$ 0.46		
1.1.2.1.4.2	Wave Soldering		1	$ 0.87	21.60	1	$ 0.13	-	$ 0.49	$ 0.24		
1.1.2.1.4.3	Circuit testing and programming		1	$ 0.26	21.60	1	$ 0.01	-	$ 0.24	-		
1.1.2.1.4.4	Setup		1	$ 0.10	-	-	-	-	-	$ 0.10		
1.1.2.2	Slave PCB	$ 4.53	1	$ 4.53			$ 0.03	$ 4.34	$ 0.10	$ 0.06	3.6	3.6
1.1.2.2.1	PCB Components		1	$ 3.83	-	-	-	$ 3.83	-	-		
1.1.2.2.2	Circuit board		1	$ 0.47	-	-	-	$ 0.47	-	-		
1.1.2.2.3	Other materials/Scrap		1	$ 0.04	-	-	-	$ 0.04	-	-		
1.1.2.2.4	Processing		1	$ 0.19			$ 0.03	$ -	$ 0.10	$ 0.06		
1.1.2.2.4.1	SMD component circuits		1	$ 0.09	1.38	2	$ 0.02	-	$ 0.04	$ 0.02		
1.1.2.2.4.2	Circuit testing and programming		1	$ 0.06	1.38	1	$ 0.00	-	$ 0.06	-		
1.1.2.2.4.3	Setup		1	$ 0.04	-	-	-	-	-	$ 0.04		
1.1.2.3	Motor	$ 1.61	1	$ 1.61			$ 0.14	$ 1.47	-	-	69.9	69.9
1.2	**On Board Display**	**$ 21.34**	**1**	**$ 21.34**			**$ 0.45**	**$ 17.18**	**$ 2.29**	**$ 1.43**	**114.4**	**114.4**
1.2.1	Display Housing	$ 0.64	1	$ 0.64			$ 0.13	$ 0.33	$ 0.07	$ 0.12	86.5	86.5
1.2.1.1	Screen Protector		1	$ 0.33	94.62	0.5	$ 0.05	$ 0.18	$ 0.03	$ 0.07		
1.2.1.2	Front Cover		1	$ 0.08	39.12	0.5	$ 0.02	$ 0.03	$ 0.01	$ 0.01		
1.2.1.3	Rear Cover		1	$ 0.23	67.44	0.5	$ 0.05	$ 0.12	$ 0.03	$ 0.03		
1.2.2	**Display PCB**	**$ 20.70**	**1**	**$ 20.70**			**$ 0.32**	**$ 16.85**	**$ 2.22**	**$ 1.31**	**27.9**	**27.9**
1.2.2.1	PCB Components		1	$ 11.07	-	-	-	$ 11.07	-	-		
1.2.2.2	Circuit board		1	$ 0.15	-	-	-	$ 0.15	-	-		
1.2.2.3	Other materials/Scrap		1	$ 5.63	-	-	-	$ 5.63	-	-		
1.2.2.3.1	Display		1	$ 5.43	-	-	-	$ 5.43	-	-		
1.2.2.4	Processing		1	$ 3.85	-	-	$ 0.32	$ -	$ 2.22	$ 1.31		
1.2.2.4.1	SMD component circuits		1	$ 2.51	6.96	2	$ 0.23	-	$ 1.68	$ 0.61		
1.2.2.4.2	Wave Soldering		1	$ 0.53	6.96	1	$ 0.08	-	$ 0.30	$ 0.15		
1.2.2.4.3	Circuit testing and programming		1	$ 0.26	6.96	1	$ 0.01	-	$ 0.24	-		
1.2.2.4.4	Setup		1	$ 0.55	-	-	-	-	-	$ 0.55		
1.3	**Radar Adapter Harness**	**$ 3.56**	**1**	**$ 3.56**	**217.80**	**1**	**$ 0.77**	**$ 2.27**	**$ 0.49**	**$ 0.03**	**168**	**168**
1.4	**Display Adapter Harness**	**$ 1.98**	**1**	**$ 1.98**	**130.38**	**1**	**$ 0.37**	**$ 1.20**	**$ 0.34**	**$ 0.07**	**74**	**74**
1.5	**Radar Sensor Bracket**	**$ 1.19**	**1**	**$ 1.19**	**4.98**	**0.5**	**$ 0.09**	**$ 1.06**	**$ 0.02**	**$ 0.02**	**2090**	**2090**
1.6	**Radar Bracket Mounting Bolts**	**$ 0.80**	**2**	**$ 0.40**	**-**	**-**	**-**	**$ 0.40**	**-**	**-**	**51.3**	**102.6**
1.7	**Radar M6 Nuts**	**$ 0.45**	**3**	**$ 0.15**	**-**	**-**	**-**	**$ 0.15**	**-**	**-**	**13.5**	**40.5**
1.8	**Fascia**	**$ 0.79**	**1**	**$ 0.79**	**75.6**	**0.5**	**$ 0.13**	**$ 0.46**	**$ 0.08**	**$ 0.12**	**230**	**230**
1.9	**Fascia M6 Bolts**	**$ 0.19**	**3**	**$ 0.06**	**-**	**-**	**-**	**$ 0.06**	**-**	**-**	**9.83**	**29.5**

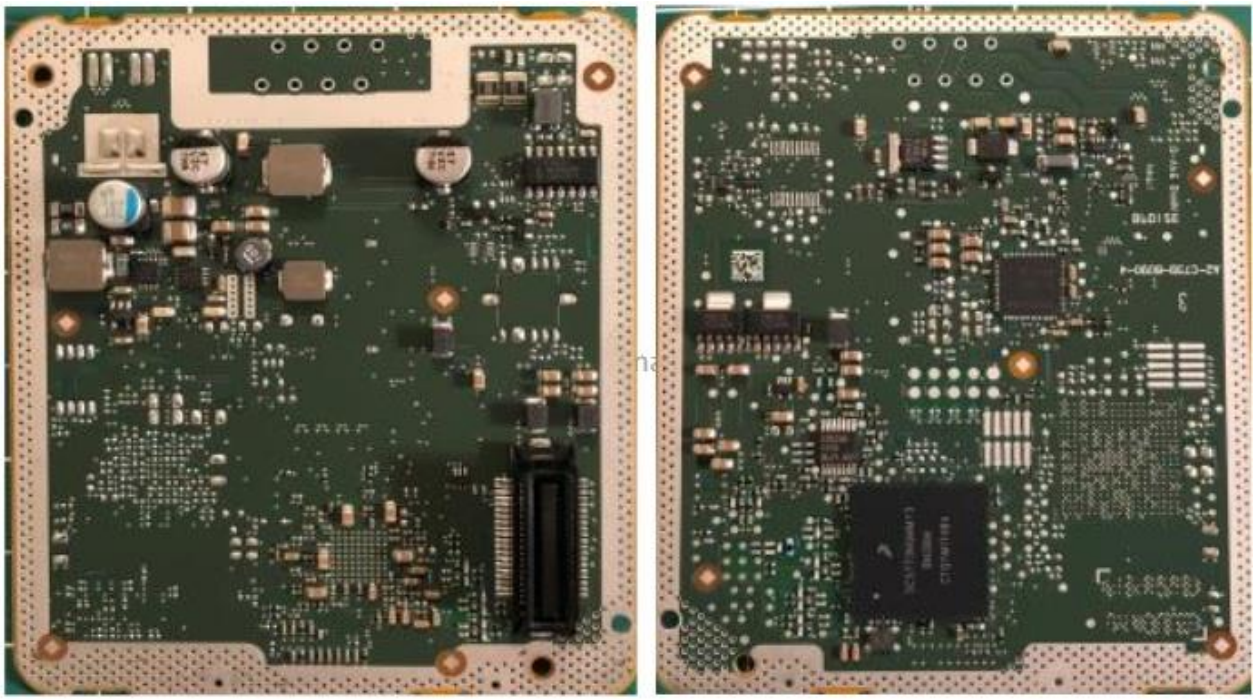
Freightliner Cascadia®: The Freightliner Cascadia® trucks include two primary components for the Detroit Assurance® AEB/FCW System. The parts subjected to the tear-down and weight analyses are shown in the following table and photos:

Freightliner Detroit Assurance® FCW/AEB (Active Braking Assist) system parts list			
ID	Part #	Description	Qty
1	000-446-22-49	RADAR UNIT	1
2	A66-02708-001	HARNESS	1

Freightliner Cascadia® Radar Housing Top (left) and Bottom (right) (photo credit MeC S.r.l)



Freightliner Cascadia® Radar Bottom Cover Heat Sink (left) and Radar Antenna Top and Bottom (right) (photo credit MeC S.r.l)



Freightliner Cascadia® Radar PCB Top (left) and Bottom (right) (photo credit MeC S.r.l)

Freightliner Cascadia® Radar Harness and Connectors (photo credit MeC S.r.l)

Freightliner Cascadia® Detroit Assurance® FCW Radar Sensor (photo credit MeC S.r.l)

Bills of Materials (BOMs) for Freightliner Cascadia® FCW and AEB Systems

The bill of materials for the Freightliner Cascadia® FCW and AEB Systems, which consists of the front radar sensor and associated wire harness, is shown in the following tables.

Freightliner Cascadia FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of**	**Cost Each**	**Cost Total**
Radar Sensor, Master PCB Components						
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	3		$ 0.006	$ 0.018
Passive components	Ceramic Capacitor SMD	Average value	110	116	$ 0.004	$ 0.832
Passive components	Electrolytic Capacitor	7DT-150-6E	1		$ 0.074	$ 0.074
Passive components	Electrolytic Capacitor SMD 8,2x8,2x6,2	47-VZC-7N	2		$ 0.069	$ 0.137
Passive components	Inductor SMD on ferrite 6.5x6.5x3	1750BD - 10uH	1		$ 0.368	$ 0.368
Passive components	Inductor SMD on ferrite 6.5x6.5x3	17488BA -3.3uH	1		$ 0.357	$ 0.357
Passive components	Inductor SMD on ferrite 5.5x5.5x2	1749NG 3.3uH	1		$ 0.325	$ 0.325
Passive components	Inductor SMD 4.5x3.3x3	G7444O2	1		$ 0.387	$ 0.387
Passive components	Inductor SMD 4.5x4.5x2	100	1		$ 0.245	$ 0.245
Passive components	Resistor SMD	Various Values 0402-0603-0805-1206	33	77	$ 0.001	$ 0.135
Passive components	Resistor SMD 1/2 W	Various Values 1810 2,5 x 5 mm	3		$ 0.006	$ 0.018
Active components	Diode SMD SOD123	Various Values 1,5x2,8x1,2	1		$ 0.009	$ 0.009
Active components	Transistor BJT Transistor BJT	SOT23 - Estimated Value	2		$ 0.028	$ 0.056
Connectors	Zif per flat Display 40 vie SMD	-	1		$ 0.491	$ 0.491
Various integrated circuits	Integrated Circuit CAN Interface	TJA1043T	1		$ 0.327	$ 0.327
Various integrated circuits	Integrated Circuit	General Purpose	4	4	$ 0.012	$ 0.099
Various integrated circuits	Integrated circuit	40000 5.7X		1	$ 0.192	$ 0.192
Passive components	Ferrite	Estimated Value		1	$ 0.250	$ 0.250
Various integrated circuits	Transistor MOSFET Transistor MOSFET	QJ431		1	$ 0.380	$ 0.380
Various integrated circuits	Pwr Management IC	TPS65310A		1	$ 1.859	$ 1.859
Various integrated circuits	Rectifier	F2LBY		1	$ 0.106	$ 0.106
Various integrated circuits	Integrated Circuit	BBC		1	$ 0.090	$ 0.090
Various integrated circuits	Amplifier	924IY		1	$ 0.403	$ 0.403
Various integrated circuits	Voltage Regulator	79633Q		2	$ 0.352	$ 0.704
Micro-controllers	MCU	SC5773NQMMY3		1	$ 12.800	$ 12.800

Freightliner Cascadia FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Radar Sensor, Slave PCB Components						
Passive components	Ceramic Capacitor SMD	Average value	97		$ 0.004	$ 0.357
Passive components	Resistor SMD	Various Values 0402-0603-0805-1206	12		$ 0.001	$ 0.015
CAN/LIN transceivers	CAN Transcevier	MC33MR2001VTK		7	$ 0.503	$ 3.521
Connectors	Zif per flat Display 40 vie SMD	-	1		$ 0.491	$ 0.491

Freightliner Cascadia FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Radar Sensor, Wire Harness Components						
Cable	UNIPOLE	T3 - 125°C	6	2	6	$ 4.523
Blocks		4-6 WAYS complex	1			$ 0.577
Blocks		7-9 WAYS complex	1			$ 0.719
Heat Shrink Tubes		Simple+Glue	1	3	0.04	$ 0.018
Heat Shrink Tubes		Simple+Glue	1	10	0.04	$ 0.028
Heat Shrink Tubes	Solded points protection	Simple+Glue	4	20	0.04	$ 0.123
Tapes	PVC Tape	T3 125 °C	1			$ 0.084
Label			1			$ 0.072

Cost and Weight Summary for Freightliner Cascadia® FCW and AEB Systems

Details of the FCW and AEB systems cost and weight analysis for the Freightliner Cascadia® are shown in the table below:

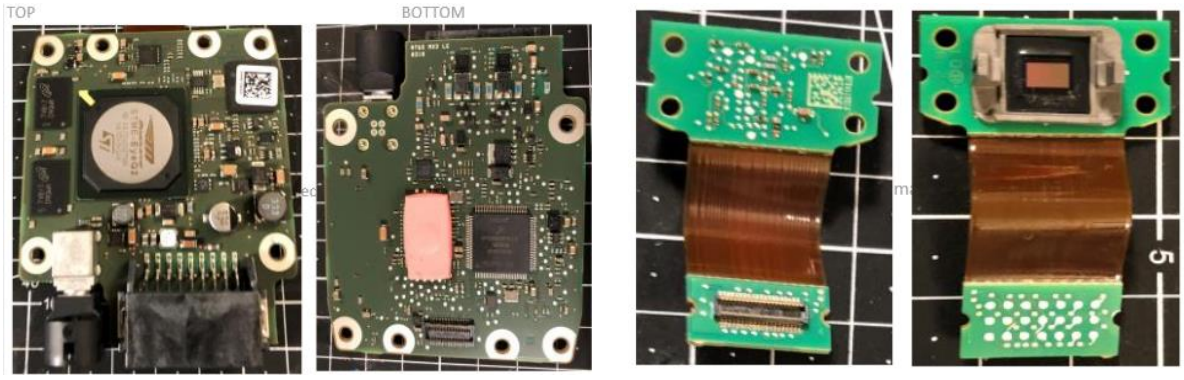
Freightliner Cascadia FCW/AEB System												
Item	**Description**	**Total Manufact-uring Cost**	**Quantity per Vehicle**	**Cost to Manu-facture per Unit**	**Cycle Time [sec]**	**Man power**	**Labor**	**Material**	**Variable**	**Fixed**	**Unit Weight [g]**	**Total Weight per Vehicle [g]**
1	**Freightliner Cascadia FCW system**	**$ 39.79**	**1**	**$ 39.79**			**$ 1.23**	**$ 34.83**	**$ 2.13**	**$ 1.60**	**386.5**	**386.5**
1.1	**Radar Unit**	**$ 32.00**	**1**	**$ 32.00**			**$ 0.34**	**$ 28.60**	**$ 1.48**	**$ 1.58**	**288**	**288**
1.1.1	Housing	$ 2.13	1	$ 2.13			$ 0.12	$ 1.33	$ 0.08	$ 0.61	225.2	225.2
1.1.1.1	Top Housing	$ 0.89	1	$ 0.89	36.40	0.5	$ 0.04	$ 0.78	$ 0.02	$ 0.05	63.6	
1.1.1.2	Bottom Housing	$ 0.90	1	$ 0.90	60.00	1	$ 0.06	$ 0.41	$ 0.04	$ 0.39	111.8	
1.1.1.3	Internal Housing	$ 0.35	1	$ 0.35	48.00	1	$ 0.02	$ 0.13	$ 0.02	$ 0.18	49.8	
1.1.2	Radar PCBs	$ 29.87	1	$ 29.87			$ 0.23	$ 27.28	$ 1.41	$ 0.96	62.8	62.8
1.1.2.1	Master PCB	$ 24.34	1	$ 24.34			$ 0.21	$ 21.94	$ 1.31	$ 0.87	38.2	38.2
1.1.2.1.1	PCB Components		1	$ 20.66	-	-	-	$ 20.66	-	-		
1.1.2.1.2	Circuit board		1	$ 0.90	-	-	-	$ 0.90	-	-		
1.1.2.1.3	Other materials/Scrap		1	$ 0.38	-	-	-	$ 0.38	-	-		
1.1.2.1.3.1	Soldering material		1	$ 0.14	-	-	-	$ 0.14	-	-		
1.1.2.1.4	Processing		1	$ 2.39	-	-	$ 0.21	$ -	$ 1.31	$ 0.87		
1.1.2.1.4.1	SMD component circuits		1	$ 1.64	14.58	2	$ 0.14	-	$ 0.99	$ 0.50		
1.1.2.1.4.2	Wave Soldering		1	$ 0.37	14.40	1	$ 0.06		$ 0.21	$ 0.10		
1.1.2.1.4.3	Circuit testing and programming		1	$ 0.19	14.58	1	$ 0.02	-	$ 0.11	$ 0.06		
1.1.2.1.4.4	Setup		1	$ 0.20	-	-	-	-	-	$ 0.20		
1.1.2.2	Slave PCB	$ 5.54	1	$ 5.54			$ 0.01	$ 5.33	$ 0.09	$ 0.10	24.6	24.6
1.1.2.2.1	PCB Components		1	$ 4.38	-	-	-	$ 4.38	-	-		
1.1.2.2.2	Circuit board		1	$ 0.73	-	-	-	$ 0.73	-	-		
1.1.2.2.3	Other materials/Scrap		1	$ 0.22	-	-	-	$ 0.22	-	-		
1.1.2.2.3.1	Soldering material		1	$ 0.05	-	-	-	$ 0.05	-	-		
1.1.2.2.3.2	Dissipator/Glue		1	$ 0.12	-	-	-	$ 0.12	-	-		
1.1.2.2.4	Processing		1	$ 0.20			$ 0.01	$ -	$ 0.09	$ 0.10		
1.1.2.2.4.1	SMD component circuits		1	$ 0.11	1.24	2	$ 0.01	-	$ 0.07	$ 0.03		
1.1.2.2.4.2	Circuit testing and programming		1	$ 0.04	1.24	1	$ 0.00	-	$ 0.03	$ 0.01		
1.1.2.2.4.3	Setup		1	$ 0.05	-	-	-	-	-	$ 0.05		
1.2	**Harness**	**$ 7.79**	**1**	**$ 7.79**			**$ 0.889**	**$ 6.22**	**$ 0.65**	**$ 0.02**	**98.5**	**98.5**
1.2.1	Wires		1	$ 4.52	-	-	-	$ 4.52	-	-		
1.2.2	Connectors		1	$ 1.30	-	-	-	$ 1.30	-	-		
1.2.3	Heat Shrink Tubes		1	$ 0.17	-	-	-	$ 0.17	-	-		
1.2.4	Tapes		1	$ 0.08	-	-	-	$ 0.08	-	-		
1.2.5	Other materials/Scrap		1	$ 0.15	-	-	-	$ 0.15	-	-		
1.2.6	Process		1	$ 1.56	265.32	1	$ 0.89	-	$ 0.65	$ 0.02		

Volvo VNL Class 8 Truck

The Volvo VNL Class 8 truck includes five primary components for the Bendix® Wingman® Fusion™ AEB/FCW System. The parts subjected to the tear-down and weight analyses are shown in the following table and photos:

Parts for FCW/AEB Components of Bendix® Wingman® Fusion™ System for Volvo VNL			
ID	**Part #**	**Description**	**Qty On Vehicle**
1	23265552	Camera	1
2	22498678	Head Up Display	1
3	85150484	Front Radar Sensor	1
4	21585145	Side Radar Sensor	2
5	22564558	Wiring Harness (connects front sensor to the main body harness)	1
6	22554809	Wiring Harness (connects camera to main body harness)	1

Parts List for FCW/AEB Components for the Volvo VNL Class 8 Truck

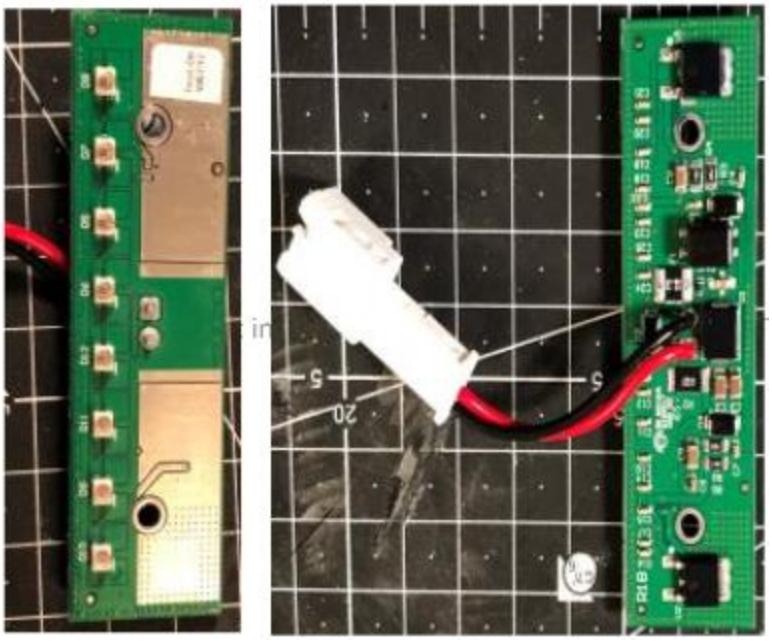


Bendix® Wingman® Fusion™ Camera PCBs: Main Top and Bottom (left) and Slave Top and Bottom (right) (photo credit MeC S.r.l)

Bendix® Wingman® Fusion™ Camera Housing Top (outside, left) and Inside (right) (photo credit MeC S.r.l)

Bendix® Wingman® Fusion™ Camera Housing Bottom (outside, left) and Inside (right) (photo credit MeC S.r.l)

Bendix® Wingman® Fusion™ Head Up Display Housing Bottom (left) and Bezel (right) (photo credit MeC S.r.l)

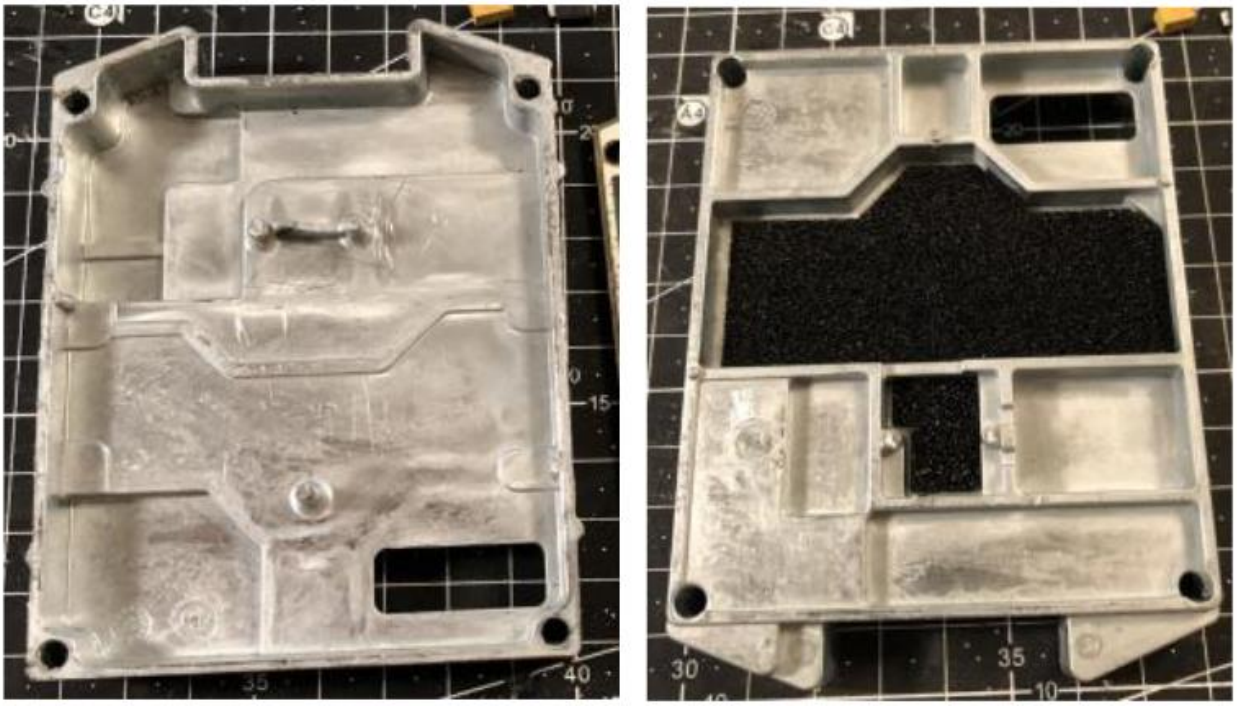


Bendix® Wingman® Fusion™ Head Up Display PCB Top (left) and Bottom (right) (photo credit MeC S.r.l)

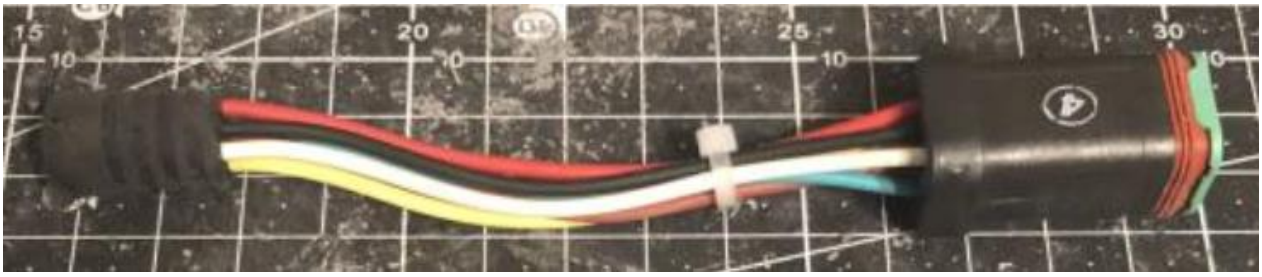
Bendix® Wingman® Fusion™ Head Up Display Housing Top (photo credit MeC S.r.l)

Bendix® Wingman® Fusion™ Head Up Display Front Sensor Housing Top Outside (left) and Inside (right) (photo credit MeC S.r.l)

Bendix® Wingman® Fusion™ Head Up Display Front Sensor Bottom (photo credit MeC S.r.l)



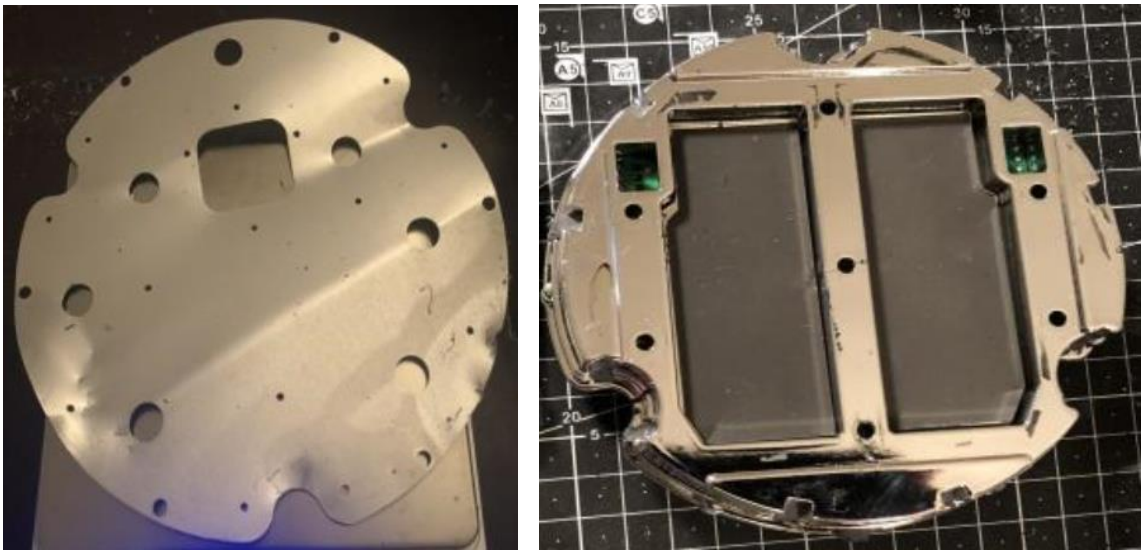
Bendix® Wingman® Fusion™ Head Up Display Front Sensor Internal Housing Side 1 (left) and Side 2 (right) (photo credit MeC S.r.l)



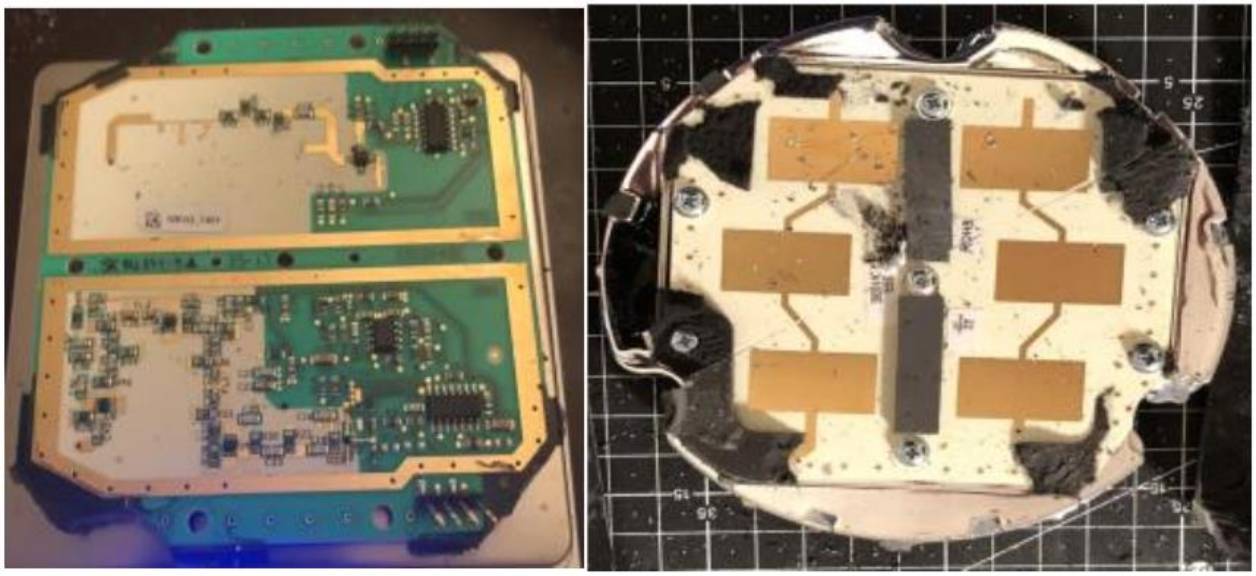
Bendix® Wingman® Fusion™ Head Up Display Side Sensor Wire Harness (photo credit MeC S.r.l)

Bendix® Wingman® Fusion™ Head Up Display Side Sensor Housing Outside (left) and Inside (right) (photo credit MeC S.r.l)

Note: the side sensor PCB was encased in resin and required considerable effort to disassemble.

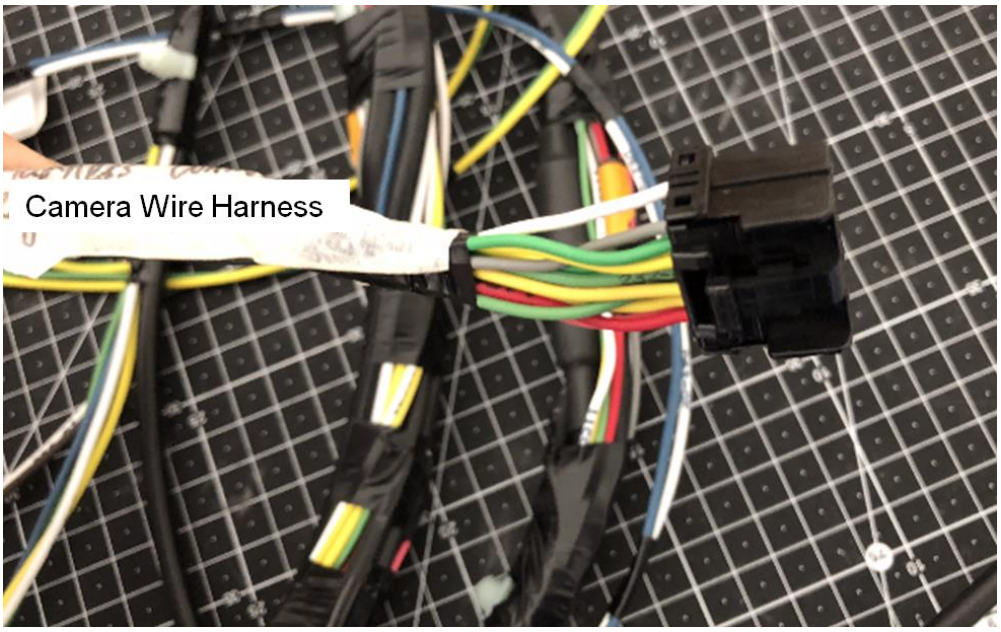


Bendix® Wingman® Fusion™ Head Up Display Side Sensor Internal Cover (left) and Antenna Housing (right) (photo credit MeC S.r.l)



Bendix® Wingman® Fusion™ Head Up Display Side Sensor Antenna PCB (left) and Antenna (right) (photo credit MeC S.r.l)

Bendix® Wingman® Fusion™ Head Up Display Side Sensor Radar Wire Harness (photo credit MeC S.r.l)



Bendix® Wingman® Fusion™ Camera Wire Harness (photo credit MeC S.r.l)

Bills of Materials (BOMs) for Volvo VNL FCW and AEB Systems

The bills of materials for the Volvo VNL FCW/AEB systems are included in the following tables.

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Radar Sensor, Master PCB Components						
Passive components	Fixed Inductors	SMD 47uH 0.59amps	1		$ 0.298	$ 0.298
Passive components	Fixed Inductors	PCC 47uH	2		$ 0.493	$ 0.986
Passive components	Aluminium Electrolytic Capacitors	Low Impedance Electrolytic	1		$ 0.119	$ 0.119
Passive components	Aluminium Electrolytic Capacitors	General Purpose Electrolytic	1		$ 0.079	$ 0.079
Passive components	Tantalum Capacitors	A107C - 503P4	2		$ 0.143	$ 0.286
Passive components	Tantalum Capacitors	22B - 7BB - Z48	1		$ 0.088	$ 0.088
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	19		$ 0.006	$ 0.117
Passive components	Ceramic Capacitor SMD	Evarage Value	69		$ 0.004	$ 0.254
Passive components	Ceramic Capacitor SMD	High Q Multilayer Ceramic Capacitors for General Purpose	29		$ 0.004	$ 0.107
Active components	Diode SMD SOD123	Various Values 1,5x2,8x1,2	66		$ 0.009	$ 0.567
Active components	Diode	T1	1		$ 0.052	$ 0.052
Active components	Diode	ESD Suppressors - RJ49	3		$ 0.136	$ 0.408
Active components	Diode	ESD Suppressors - J35 GFM	4		$ 0.165	$ 0.660
Active components	Transistor/Diode SOT23	General Purpose	4		$ 0.071	$ 0.284
Active components	Transistor	TGHQ	1		$ 0.092	$ 0.092
Passive components	Resistor SMD 1/2 W	Various Values	5		$ 0.006	$ 0.031
Passive components	Resistor SMD	Various Values	1		$ 0.001	$ 0.001
Passive components	Resistor SMD	Various Values	2		$ 0.002	$ 0.004
Various integrated	Integrated Circuit	General Purpouse	1		$ 0.123	$ 0.123
Various integrated	Integrated Circuit	TI7A 0VKQ	1		$ 0.177	$ 0.177
Various integrated	Switching Voltage Regulators	8366EV-27u-61749	1		$ 0.198	$ 0.198
Various integrated	Transistor LDO Voltage Regulators	SG 1801 - 4266 G	2		$ 0.371	$ 0.742
Various integrated circuits	Supervisory Circuits Low Voltage Detector	1H49A8	1		$ 0.189	$ 0.189
Various integrated	Matsushita Sensor	S54GW-792413 EEstimated	1		$ 3.356	$ 3.356
Various integrated	CAN Interface	A51051/3	2		$ 0.336	$ 0.672
Micro-controllers	MCU	SPC5604PVLL6	1		$ 6.756	$ 6.756
Connectors	18 vie SMD		1		$ 0.209	$ 0.209
Active components	FotoDiode SO6	Opto Semiconductor	1		$ 0.221	$ 0.221

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Radar Antenna PCB Components						
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	6		$ 0.006	$ 0.037
Passive components	Ceramic Capacitor SMD	Evarage Value	30		$ 0.004	$ 0.110
Passive components	Ceramic Capacitor SMD	High Q Multilayer Ceramic Capacitors for General Purpose	51		$ 0.004	$ 0.188
Active components	Diode SMD SOD123	Various Values 1,5x2,8x1,2	30		$ 0.009	$ 0.258
Active components	Transistor/Mos Fet SOT223	General Purpose	2		$ 0.061	$ 0.123
Passive components	Resistor SMD	Various Values	1		$ 0.002	$ 0.002
Various integrated circuits	Integrated Operational Amplifiers	V74-A408-730	1		$ 1.875	$ 1.875
Various integrated circuits	Integrated Circuit	General Purpose	1		$ 0.113	$ 0.113
Active components	Transistor	SOT-37	4		$ 0.213	$ 0.852
Various integrated circuits	LDO Voltage Regulators	V8535-180-RHJ	1		$ 0.443	$ 0.443
Various integrated circuits	Operational Amplifiers	33075Y-GZRH737	1		$ 0.251	$ 0.251
Various integrated circuits	Precision Amplifiers	AD-6846-a#746	2		$ 0.710	$ 1.421
Various integrated circuits	Drivers/Receivers	ADW-24003	1		$ 0.786	$ 0.786
Connectors	18 vie SMD		1		$ 0.209	$ 0.209
Various integrated circuits	Real Clock RTC	160077	1		$ 0.613	$ 0.613

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Radar Sensor, Wire Harness Components						
Cable	UNIPOLE	T3 - 125°C	4	2.5	1.6	$ 1.007
Cable	UNIPOLE	T3 - 125°C	2	1.5	1.6	$ 0.314
Blocks		1-3 WAYS complex	1			$ 0.362
Blocks		4-6 WAYS complex	1			$ 0.577
Blocks		7-9 WAYS complex	1			$ 0.719
Heat Shrink Tubes		Simple+Glue	1	3	1.6	$ 2.240
Heat Shrink Tubes	Solded points protection	Simple+Glue	1	10	0.4	$ 0.123
Tapes	PVC Tape	T3 125 °C	1			$ 0.167
Label			1			$ 0.008

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Camera Master PCB Components						
Various integrated circuits	Memory CI SDRAM (FBGA)	MT41K64M16TW-107 (7VBI7)	2		$ 2.320	$ 4.640
Passive components	Electrolytic Capacitors SMD 10x10x10,5	470uF 25V 10x10x10,5	1		$ 0.101	$ 0.101
Passive components	Inductor SMD on ferrite 11x11x8,4	220 1191 Vishay - Estimated Value	1		$ 0.613	$ 0.613
Passive components	Inductor SMD on ferrite 10x10x5	100 8494 Vishay - Estimated Value	1		$ 0.491	$ 0.491
Passive components	Inductor SMD 5x5,4x5	225K 9022 Vishay	1		$ 0.245	$ 0.245
Passive components	Quartz SMD 5kHz	5.00C69 11,4 x 4,83 x 4,3	1	2	$ 0.147	$ 0.442
Passive components	Resistor SMD mini-melf	Various Values	8	6	$ 0.004	$ 0.052
Passive components	Ceramic Capacitor SMD	Evarage Value	45	180	$ 0.004	$ 0.828
Passive components	Ceramic Capacitor SMD array x 4	C Array x 4	7		$ 0.015	$ 0.103
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	11	12	$ 0.006	$ 0.141
Passive components	Resistor SMD	Various Values 0402-0603-0805-1206	30		$ 0.001	$ 0.037
Active components	Diode SGS (SMC)	Various Values 6x7x2,4	2	8	$ 0.184	$ 1.840
Active components	Transistor/Mos Fet D-PAK	BSP 452 Driver HS	1	1	$ 0.331	$ 0.662
Connectors	RCA Jack mono 4 vie		1		$ 0.250	$ 0.250
Connectors	MQS 9 vie	Estimated Value	1		$ 0.200	$ 0.200
Various integrated circuits	Double . Op. Ampl.	LM2904 Operational Amplifier x 2 SO8	5		$ 0.130	$ 0.650
Various integrated circuits	CI	Estimated Value	1	4	$ 0.110	$ 0.550
Various integrated circuits	Driver	VN5016A (M157 x n° 2) PSSO12 HSD 16 mOhm 40A	1		$ 0.491	$ 0.491
Active components	Transistor/Mos Fet SOT223		1		$ 0.061	$ 0.061
Various integrated circuits	Analog Mux/Demux	74HCT4051D 8 Ch Analog Mux/Demux	1		$ 0.081	$ 0.081
Micro-controllers	STMicroelectronics AA721052TWN	Estimated Value	1		$ 8.200	$ 8.200
External memory IC	M29W256GL BGA	Flash memory 256 Mbit	1		$ 4.300	$ 4.300
Active components	FotoDiode SO6	SFH 3201-03	1	1	$ 0.221	$ 0.442
Active components	Diode SGS (SMA)	Various Values 2,6x4,2x2,2		4	$ 0.025	$ 0.098
Active components	Diode SGS (SMC)	Various Values 6x7x2,4		1	$ 0.184	$ 0.184
Connectors	Zif per flat Display 40 vie SMD	-		1	$ 0.491	$ 0.491
Micro-controllers	Microcontroller a 32 bit - MCU	SPC5604PVLL6		1	$ 3.230	$ 3.230
CAN/LIN transceivers	C-CAN Transcevier	TLE6250		2	$ 0.331	$ 0.662
Various integrated circuits	Supervisor Circuit Quad	16001A TE747 BJDO		1	$ 1.520	$ 1.520
Passive components	Double Inductor SMD EPCOS	BB2793		2	$ 0.331	$ 0.662
Active components	Transistor BJT	Estimated Value		4	$ 0.123	$ 0.492

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Camera Slave PCB Components						
Passive components	Ceramic Capacitor SMD	Evarage Value	13		$ 0.004	$ 0.048
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	1		$ 0.006	$ 0.006
Passive components	Resistor SMD	Various Values 0402-0603-0805-1206	8		$ 0.001	$ 0.010
Connectors	Zif per flat Display 40 vie SMD	-	1		$ 0.491	$ 0.491

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Side Sensor Antenna PCB Components						
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	3		$ 0.006	$ 0.018
Passive components	Ceramic Capacitor SMD	Evarage Value	14		$ 0.004	$ 0.052
Passive components	Ceramic Capacitor SMD	High Q Multilayer Ceramic Capacitors for General Purpose	25		$ 0.004	$ 0.092
Passive components	Resistor SMD 1/2 W	Various Values	14		$ 0.006	$ 0.086
Passive components	Resistor SMD	Various Values	15		$ 0.002	$ 0.030
Various integrated circuits	Hex Inverter Gate	0H9AF-74AC04	1		$ 0.096	$ 0.096
Various integrated circuits	Hex Inverter Gate	72AQ18K-C4-AC04	1		$ 0.128	$ 0.128
Various integrated circuits	Integrated Circuit	2262A1-74M-AHHV	1		$ 0.145	$ 0.145
Various integrated circuits	Integrated Circuit	General Purpouse	3		$ 0.123	$ 0.369
Active components	Diode SMD	DIAC Diode	1		$ 0.045	$ 0.045
Active components	Diode	Various Values	3		$ 0.024	$ 0.072
Passive components	Inductor SMD chip	EEstimated Valuete Value	1		$ 0.025	$ 0.025
Connectors	Header connector 4 Pin		2		$ 0.107	$ 0.214

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Side Radar Sensor, Wire Harness Components						
Cable	UNIPOLE	T3 - 125°C	6	2	0.12	$ 0.090
Blocks		4-6 WAYS complex	1			$ 0.577
Co-molded 6 Terminal			1			$ 1.227
Small strip			1			$ 0.013
Socks			1	15		$ 0.859

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Head Up Display PCB Components						
Passive components	Ceramic Capacitor SMD	Evarage Value	21		$ 0.004	$ 0.077
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	4		$ 0.006	$ 0.025
Passive components	Resistor SMD 1/2 W	Various Values 1810 2,5 x 5 mm	4		$ 0.006	$ 0.025
Active components	Diode SMD SOD123	Various Values 1,5x2,8x1,2	3		$ 0.009	$ 0.026
Active components	Diode SGS (SMA)	Various Values 2,6x4,2x2,2	1		$ 0.025	$ 0.025
Active components	Transistor/Mos Fet D-PAK	BSP 452 Driver HS	2		$ 0.331	$ 0.662
Passive components	Resistor a film spesso	R40F - 1W	1		$ 0.280	$ 0.280
SMD LEDs	Orange 605 nm	LOT676 - TLOE1100		8	$ 0.031	$ 0.245
-	Fuse resettable SMD	F100/33X-2	1		$ 0.140	$ 0.140
Various integrated circuits	Quad . Op. Ampl.	LM2902 Operational Amplifier x 4 SO14	1		$ 0.130	$ 0.130

Volvo VNL FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Head Up Display, Wire Harness Components						
Cable	UNIPOLE	T3 - 125°C	6	2	0.45	$ 0.113
Blocks		1-3 WAYS complex	1			$ 0.155
Heat Shrink Tubes		Simple+Glue	1			$ 0.078

Volvo VNL FCW/AEB System BOMs						
TYPE	COMPONENT	DESCRIPTION	Quantity	Section (mm)	Length (m)	Cost Total
Camera Wire Harness Components (connects camera and roof harness)						
Cable	UNIPOLE	T3 - 125°C	1	2	2.45	$ 0.3077
Cable	UNIPOLE	T3 - 125°C	1	2	2.85	$ 0.3581
Cable	UNIPOLE	T3 - 125°C	1	2	2.75	$ 0.3455
Cable	UNIPOLE	T3 - 125°C	1	1.5	3.15	$ 0.3087
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.4	$ 0.0389
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.13	$ 0.0126
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.72	$ 0.0704
Cable	UNIPOLE	T3 - 125°C	1	1.5	2.23	$ 0.2184
Cable	UNIPOLE	T3 - 125°C	1	1.5	2.8	$ 0.2741
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.76	$ 0.0746
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.76	$ 0.0746
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.62	$ 0.0609
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.62	$ 0.0609
Cable	UNIPOLE	T3 - 125°C	1	2	1.6	$ 0.2006
Cable	UNIPOLE	T3 - 125°C	1	2	1.6	$ 0.2006
Cable	UNIPOLE	T3 - 125°C	1	2	1.11	$ 0.1397
Cable	UNIPOLE	T3 - 125°C	1	2	1.11	$ 0.1397
Cable	UNIPOLE	T3 - 125°C	1	1.5	1.11	$ 0.1092
Cable	UNIPOLE	T3 - 125°C	1	1.5	1.11	$ 0.1092
Cable	UNIPOLE	T3 - 125°C	1	2	0.21	$ 0.0263
Cable	UNIPOLE	T3 - 125°C	1	2	0.21	$ 0.0263
Cable	UNIPOLE	T3 - 125°C	1	2	0.92	$ 0.1155
Cable	UNIPOLE	T3 - 125°C	1	2	0.92	$ 0.1155
Cable	UNIPOLE	T3 - 125°C	1	1.5	1.5	$ 0.1470
Cable	UNIPOLE	T3 - 125°C	1	1.5	1.5	$ 0.1470
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.53	$ 0.0515
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.53	$ 0.0515
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.68	$ 0.0662
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.68	$ 0.0662
Cable	UNIPOLE	T3 - 125°C	1	2	0.66	$ 0.0830
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.66	$ 0.0651
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.24	$ 0.0242
Cable	UNIPOLE	T3 - 125°C	1	1.5	2.9	$ 0.2846
Cable	UNIPOLE	T3 - 125°C	1	1.5	2.9	$ 0.2846
Blocks		1-3 WAYS	3			$ 0.4640
Blocks		7-9 WAYS	1			$ 0.4230
Blocks		10-13 WAYS	1			$ 0.5640
Blocks		14-18 WAYS	1			$ 0.7050
Heat Shrink Tubes	3mm (3/1) - L=40mm	Simple+Glue	8			$ 3.1120
Heat Shrink Tubes	Other heatshrink tubes	Duraseal	1	20	0.4	$ 0.1880
Heat Shrink Tubes	Solded points protection	Simple+Glue	1	20	0.4	$ 0.6790
Tapes	PVC Tape	T3 125 °C	1			$ 0.5870

Cost and Weight Summary for Volvo VNL FCW and AEB Systems

Details of the FCW and AEB systems cost and weight analysis for the Volvo VNL are shown in the three-part table below:

Volvo VNL FCW/AEB System												
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Cycle Time [sec]	Man power	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1	**Volvo FCW system**	**$ 164.12**	**1**	**$ 164.12**			**$ 10.31**	**$ 111.89**	**$ 7.41**	**$ 5.55**	**2377.5**	**2377.5**
1.1	**Front Sensor**	**$ 31.77**	**1**	**$ 31.77**			**$ 0.62**	**$ 27.88**	**$ 1.46**	**$ 1.81**	**311.3**	**311.3**
1.1.1	Front Sensor Housing	$ 3.30	1	$ 3.30			$ 0.26	$ 1.62	$ 0.17	$ 1.25	242.8	242.8
1.1.1.1	Top Housing		1	$ 1.13	45.06	0.5	$ 0.06	$ 0.96	$ 0.03	$ 0.08	90.5	
1.1.1.2	Bottom Housing		1	$ 0.37	36.42	0.5	$ 0.06	$ 0.24	$ 0.03	$ 0.04	37.4	
1.1.1.3	Internal Housing		1	$ 1.81	19.38	1	$ 0.15	$ 0.42	$ 0.10	$ 1.14	114.9	
1.1.2	Front Sensor PCBs	$ 28.47	1	$ 28.47			$ 0.36	$ 26.26	$ 1.29	$ 0.56	68.5	68.5
1.1.2.1	Master PCB	$ 19.99	1	$ 19.99			$ 0.27	$ 18.14	$ 1.14	$ 0.44	50.7	50.7
1.1.2.1.1	PCB Components		1	$ 17.08	-	-	-	$ 17.08	-	-		
1.1.2.1.2	Circuit board		1	$ 0.82	-	-	-	$ 0.82	-	-		
1.1.2.1.3	Other materials/Scrap		1	$ 0.24	-	-	-	$ 0.24	-	-		
1.1.2.1.3.1	Soldering material		1	$ 0.04	-	-	-	$ 0.04	-	-		
1.1.2.1.4	Processing		1	$ 1.85	-	-	$ 0.27	$ -	$ 1.14	$ 0.44		
1.1.2.1.4.1	SMD component circuits		1	$ 1.11	15.54	2	$ 0.20	-	$ 0.63	$ 0.28		
1.1.2.1.4.2	Wave Soldering		1	$ 0.41	15.60	1	$ 0.06	-	$ 0.23	$ 0.12		
1.1.2.1.4.3	Circuit testing and programming		1	$ 0.29	15.54	1	$ 0.02	-	$ 0.28	-		
1.1.2.1.4.4	Setup		1	$ 0.04	-	-	-	-	-	$ 0.04		
1.1.2.2	Antenna PCB	$ 8.48	1	$ 8.48			$ 0.08	$ 8.13	$ 0.15	$ 0.12	17.8	17.8
1.1.2.2.1	PCB Components		1	$ 7.28	-	-	-	$ 7.28	-	-		
1.1.2.2.2	Circuit board		1	$ 0.75	-	-	-	$ 0.75	-	-		
1.1.2.2.3	Other materials/Scrap		1	$ 0.10	-	-	-	$ 0.10	-	-		
1.1.2.2.3.1	Label		1	$ 0.02	-	-	-	$ 0.02	-	-		
1.1.2.2.4	Processing		1	$ 0.35			$ 0.08	$ -	$ 0.15	$ 0.12		
1.1.2.2.4.1	SMD component circuits		1	$ 0.32	4.08	2	$ 0.08	-	$ 0.15	$ 0.08		
1.1.2.2.4.2	Setup		1	$ 0.03	-	-	-	-	-	$ 0.03		
1.2	**Radar Wiring Harness**	**$ 8.09**	**1**	**$ 8.09**			**$ 1.483**	**$ 6.44**	**$ 0.13**	**$ 0.04**	**255.7**	**255.7**
1.2.1	Wires		1	$ 1.32	-	-	-	$ 1.32	-	-		
1.2.2	Connectors		1	$ 1.66	-	-	-	$ 1.66	-	-		
1.2.3	Heat Shrink Tubes		1	$ 2.36	-	-	-	$ 2.36	-	-		
1.2.4	Label		1	$ 0.01	-	-	-	$ 0.01	-	-		
1.2.5	Socks		1	$ 0.86	-	-	-	$ 0.86	-	-		
1.2.6	Tapes		1	$ 0.17	-	-	-	$ 0.17	-	-		
1.2.7	Other materials/Scrap		1	$ 0.07	-	-	-	$ 0.07	-	-		
1.2.8	Processing		1	$ 1.65	278.46	1	$ 1.48	-	$ 0.13	$ 0.04		

Volvo VNL FCW/AEB System												
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Cycle Time [sec]	Man power	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1.3	**Camera**	**$ 43.04**	**1**	**$ 43.04**			**$ 0.56**	**$ 36.95**	**$ 3.14**	**$ 2.38**	**128**	**128**
1.3.1	Camera Housing	$ 1.83	1	$ 1.83			$ 0.15	$ 0.34	$ 0.10	$ 1.24	88.6	88.6
1.3.1.1	Top Housing		1	$ 0.98	7.80	1	$ 0.08	$ 0.23	$ 0.05	$ 0.62	49.6	
1.3.1.2	Bottom Housing		1	$ 0.86	7.80	1	$ 0.08	$ 0.11	$ 0.05	$ 0.62	39	
1.3.2	Camera PCBs	$ 41.20	1	$ 41.20			$ 0.41	$ 36.62	$ 3.04	$ 1.14	39.4	39.4
1.3.2.1	Master PCB	$ 37.75	1	$ 37.75			$ 0.36	$ 33.73	$ 2.60	$ 1.06	37.6	37.6
1.3.2.1.1	PCB Components		1	$ 32.76	-	-	-	$ 32.76	-	-		
1.3.2.1.2	Circuit board		1	$ 0.51	-	-	-	$ 0.51	-	-		
1.3.2.1.3	Other materials/Scrap		1	$ 0.45	-	-	-	$ 0.45	-	-		
1.3.2.1.3.1	Screws		4	$ 0.02	-	-	-	$ 0.02	-	-		
1.3.2.1.3.2	Protection rubber		1	$ 0.01	-	-	-	$ 0.01	-	-		
1.3.2.1.4	Processing		1	$ 4.03	-	-	$ 0.36	$ 0.01	$ 2.60	$ 1.06		
1.3.2.1.4.1	SMD component circuits		1	$ 1.77	16.20	2	$ 0.16	-	$ 1.18	$ 0.43		
1.3.2.1.4.2	Wave Soldering		1	$ 0.28	15.60	1	$ 0.04	-	$ 0.16	$ 0.08		
1.3.2.1.4.3	Axial and Radial Soldering		1	$ 0.09	16.20	1	$ 0.09	$ 0.01	-	-		
1.3.2.1.4.4	Circuit testing and programming		1	$ 1.33	16.20	1	$ 0.07	-	$ 1.26	-		
1.3.2.1.4.5	Setup		1	$ 0.56	-	-	-	-	-	$ 0.56		
1.3.2.2	Slave PCB	$ 3.46	1	$ 3.46			$ 0.05	$ 2.89	$ 0.44	$ 0.08	1.8	1.8
1.3.2.2.1	PCB Components		1	$ 0.56	-	-	-	$ 0.56	-	-		
1.3.2.2.2	Circuit board		1	$ 0.19	-	-	-	$ 0.19	-	-		
1.3.2.2.3	Other materials/Scrap		1	$ 2.15	-	-	-	$ 2.15	-	-		
1.3.2.2.3.1	Screws		4	$ 0.02	-	-	-	$ 0.02	-	-		
1.3.2.2.3.2	Flex PCB		1	$ 0.18	-	-	-	$ 0.18	-	-		
1.3.2.2.3.3	Mini Camera		1	$ 1.80	-	-	-	$ 1.80	-	-		
1.3.2.2.3.4	Al Bracket		1	$ 0.06	-	-	-	$ 0.06	-	-		
1.3.2.2.4	Processing		1	$ 0.57			$ 0.05	$ -	$ 0.44	$ 0.08		
1.3.2.2.4.1	SMD component circuits		1	$ 0.11	1.62	2	$ 0.03	-	$ 0.05	$ 0.03		
1.3.2.2.4.2	Circuit testing and programming		1	$ 0.41	1.62	1	$ 0.02	-	$ 0.39	-		
1.3.2.2.4.3	Setup		1	$ 0.05	-	-	-	-	-	$ 0.05		
1.4	**Side Sensor**	**$ 57.93**	**2**	**$ 28.97**			**$ 1.71**	**$ 26.06**	**$ 0.58**	**$ 0.62**	**662.7**	**1325.4**
1.4.1	Side Sensor Housing	$ 1.79	1	$ 1.79			$ 0.37	$ 0.72	$ 0.24	$ 0.47	284.4	284.4
1.4.1.1	Top Plastic Cover		1	$ 0.91	85.80	0.5	$ 0.13	$ 0.53	$ 0.09	$ 0.15	151.7	
1.4.1.2	Aluminium Cover		1	$ 0.10	120.00	0.5	$ 0.01	$ 0.04	$ 0.02	$ 0.03	22.4	
1.4.1.3	Antenna Housing		1	$ 0.79	300.00	4.0	$ 0.23	$ 0.15	$ 0.13	$ 0.28	110.3	
1.4.2	Front Sensor PCBs	$ 42.81	1	$ 42.81			$ 0.09	$ 22.54	$ 0.24	$ 0.11	353.1	353.1
1.4.2.1	Side Sensor Master PCB	$ 19.84	1	$ 19.84				$19.84			316	316
1.4.2.2	Side SensorAntenna PCB	$ 3.13	1	$ 3.13			$ 0.09	$ 2.70	$ 0.24	$ 0.11	37.1	37.1
1.4.2.2.1	PCB Components		1	$ 1.37	-	-	-	$ 1.37	-	-		
1.4.2.2.2	Circuit board		1	$ 1.10	-	-	-	$ 1.10	-	-		
1.4.2.2.3	Other materials/Scrap		1	$ 0.22	-	-	-	$ 0.22	-	-		
1.4.2.2.3.1	Screws		7	$ 0.02	-	-	-	$ 0.02	-	-		
1.4.2.2.3.2	Washer		7	$ 0.01				$ 0.01				
1.4.2.2.3.3	Sponge		2	$ 0.02				$ 0.02				
1.4.2.2.4	Processing		1	$ 0.44			$ 0.09	$ -	$ 0.24	$ 0.11		
1.4.2.2.4.1	SMD component circuits		1	$ 0.30	4.44	2	$ 0.08	-	$ 0.14	$ 0.08		
1.4.2.2.4.2	Circuit testing and programming		1	$ 0.10	4.44	1	$ 0.01	-	$ 0.09	-		
1.4.2.2.4.3	Setup		1	$ 0.04	-	-	-	-	-	$ 0.04		
1.4.3	Side Sensor Cable	**$ 4.20**	**1**	**$ 4.20**			**$ 1.25**	**$ 2.81**	**$ 0.11**	**$ 0.03**	**25.2**	**25.2**
1.4.3.1	Wires		1	$ 0.09	-	-	-	$ 0.09	-	-		
1.4.3.2	Connectors		1	$ 0.58	-	-	-	$ 0.58	-	-		
1.4.3.3	Co-molded Terminal		1	$ 1.23	-	-	-	$ 1.23	-	-		
1.4.3.4	Clip/Strip		1	$ 0.01	-	-	-	$ 0.01	-	-		
1.4.3.5	Socks		1	$ 0.86	-	-	-	$ 0.86	-	-		
1.4.3.6	Other materials/Scrap		1	$ 0.04	-	-	-	$ 0.04	-	-		
1.4.3.7	Process		1	$ 1.39	235.38	1	$ 1.25	-	$ 0.11	$ 0.03		

Volvo VNL FCW/AEB System												
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Cycle Time [sec]	Man power	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1.5	**Head Up Display**	**$ 4.65**	**1**	**$ 4.65**			**$ 0.81**	**$ 2.98**	**$ 0.42**	**$ 0.44**	**118.2**	**118.2**
1.5.1	Front Sensor Housing	$ 1.06	1	$ 1.06			$ 0.26	$ 0.32	$ 0.16	$ 0.32	105.9	105.9
1.5.1.1	Top Housing		1	$ 0.43	38.88	0.5	$ 0.08	$ 0.21	$ 0.05	$ 0.09	71.5	
1.5.1.2	Bottom Housing		1	$ 0.30	28.98	0.5	$ 0.07	$ 0.09	$ 0.04	$ 0.10	28.7	
1.5.1.3	Bezel		1	$ 0.33	300.00	4	$ 0.11	$ 0.02	$ 0.06	$ 0.14	5.7	
1.5.2	Head Up PCB	$ 3.59	1	$ 3.59			$ 0.55	$ 2.66	$ 0.26	$ 0.12	12.3	12.3
1.5.2.1	PCB		1	$ 2.70			$ 0.06	$ 2.32	$ 0.21	$ 0.11		
1.5.2.1.1	PCB Components		1	$ 1.64	-	-	-	$ 1.64	-	-		
1.5.2.1.2	Circuit board		1	$ 0.17	-	-	-	$ 0.17	-	-		
1.5.2.1.3	Other materials/Scrap		1	$ 0.51	-	-	-	$ 0.51	-	-		
1.5.2.1.3.1	Label		1	$ 0.02	-	-	-	$ 0.02	-	-		
1.5.2.1.3.2	Screws		3	$ 0.03				$ 0.03				
1.5.2.1.3.3	Surface treatment		1	$ 0.35				$ 0.35				
1.5.2.1.5	Processing		1	$ 0.38	-	-	$ 0.06	$ -	$ 0.21	$ 0.11		
1.5.2.1.4.1	SMD component circuits		1	$ 0.21	2.64	2	$ 0.05	-	$ 0.10	$ 0.05		
1.5.2.1.4.3	Circuit testing and programming		1	$ 0.12	2.64	1	$ 0.01	-	$ 0.12	-		
1.5.2.1.4.4	Setup		1	$ 0.05	-	-	-	-	-	$ 0.05		
1.5.2.2	Harness		1	$ 0.89	92.28	1.0	$ 0.49	$ 0.35	$ 0.04	$ 0.01		
1.6	**Carmera Wire Harness**	**$ 18.64**	**1**	**$ 18.64**			**$ 5.12**	**$ 11.57**	**$ 1.69**	**$ 0.26**	**238.9**	**238.9**
1.4.3.1	Wires		1	$ 4.66	-	-	-	$ 4.66	-	-		
1.4.3.2	Connectors		1	$ 2.16	-	-	-	$ 2.16	-	-		
1.4.3.3	Heat Shrink Tubes		1	$ 3.98	-	-	-	$ 3.98	-	-		
1.4.3.4	Tape		1	$ 0.59	-	-	-	$ 0.59	-	-		
1.4.3.6	Other Materials/Scrap		1	$ 0.18	-	-	-	$ 0.18	-	-		
1.4.3.7	Process		1	$ 7.07	1193.88	1	$ 5.12	-	$ 1.69	$ 0.26		

Ricardo contacted Bendix Commercial Vehicle Systems to verify lengths and weights of the camera wire harness[66]. Comparisons of measured lengths and weights to those specified by Bendix are shown in the following table:

Dimension	Bendix Nominal Specification	Measured
Length (mm)	300	285
Diameter (mm)	30	20
Weight (grams)	250	239

International LT™ Class 8 Truck

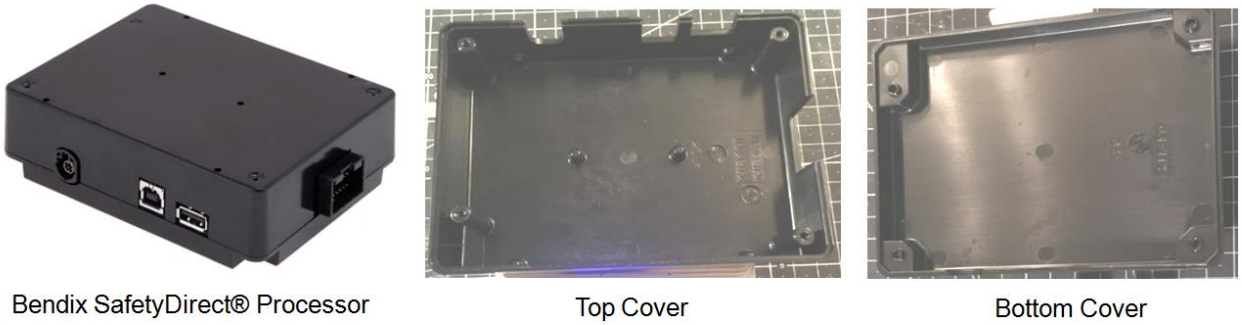
The International Class 8 truck includes 10 primary components for the Bendix® Wingman® Fusion™ AEB/FCW System. The parts subjected to the tear-down and weight analyses are shown in the following table and photos:

[66] Teleconference with Bendix Commercial Vehicles Systems, 10 July 2018, Dimensions and Functionality of Bendix® Wingman® Fusion™ Camera Wire Harness, connections, connectors, wire lengths, weights.

Parts for FCW/AEB Components of Bendix® Wingman® Fusion™ System for International LT Class 8 Truck			
ID	**Part Number**	**Description**	**Quantity on Vehicle**
1	2516066C2	Camera	1
2	2516071C3	Processor (Safety Direct)	1
3	2516065C2	Radar	1
4	BXK120829N002	Display	1
5	BXK073215	Radar bracket and Standoffs	1
6	2515172C91	Camera Bracket	1
7	6127277C91	Cable (connects camera and SafetyDirect® processor)	1
8	6128868F94	4-Wire Harness (from radar sensor)	1
9	6128955F94	2-Wire Harness (connects radar sensor and main harness)	1
10	6127439C93	Camera and SafetyDirect® Processor Harness (connects camera, processor and roof harness)	1

Parts List for FCW/AEB System for the International LT™ Class 8 Truck

Since the camera and radar are identical for the Volvo VNL and International LT™ versions of the Bendix® Wingman® Fusion™ AEB/FCW System, photos of these two components are not repeated in this section of the Appendix.



Bendix SafetyDirect® Processor | Top Cover | Bottom Cover

Bendix® Wingman® Fusion™ SafetyDirect® Processor Housing (photo credits: Bendix and MeC S.r.l.)

Bendix® Wingman® Fusion™ SafetyDirect® Processor PCB Top (right) and Bottom (left) (photo credit: MeC S.r.l.)

Bendix Driver Interface Unit (Display)

Top Cover Outside

Top Cover Inside

Bendix® Wingman® Fusion™ Driver Interface Unit (Display) Top Cover Outside (left) and Inside (right) (photo credits: Ricardo and MeC S.r.l.)

Bendix® Wingman® Fusion™ Driver Interface Unit (Display) Bottom Cover Inside (left) and Outside (right) (photo credit: MeC S.r.l.)

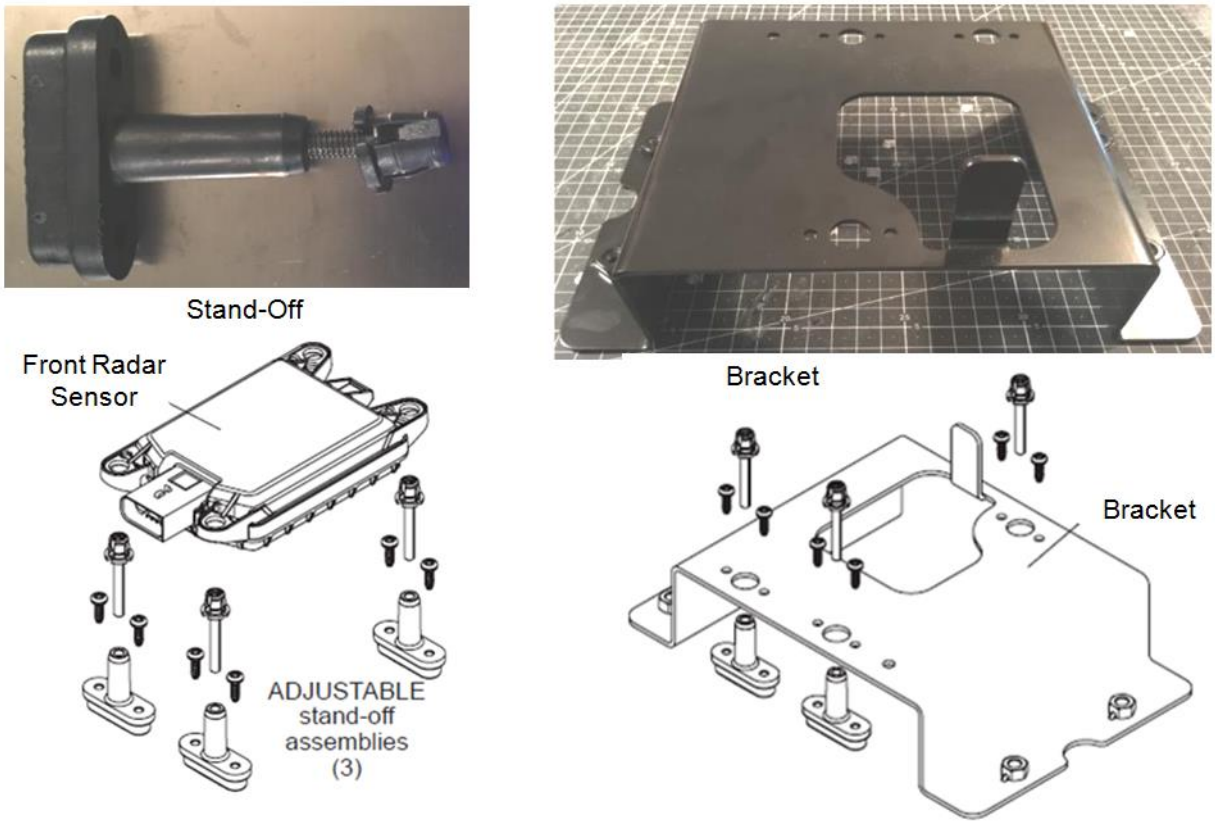
Bendix® Wingman® Fusion™ Driver Interface Unit (Display), LCD and Button Support Outside (left) and Inside (right) (photo credit: MeC S.r.l.)

Bendix® Wingman® Fusion™ Driver Interface Unit (Display), Selection Buttons (photo credit: MeC S.r.l.)

Bendix® Wingman® Fusion™ Driver Interface Unit (Display), LCD Display Assembly (photo credit: MeC S.r.l.)

Bendix® Wingman® Fusion™ Driver Interface Unit (Display), PCB 1 Top (left) and Bottom (right) (photo credit: MeC S.r.l.)

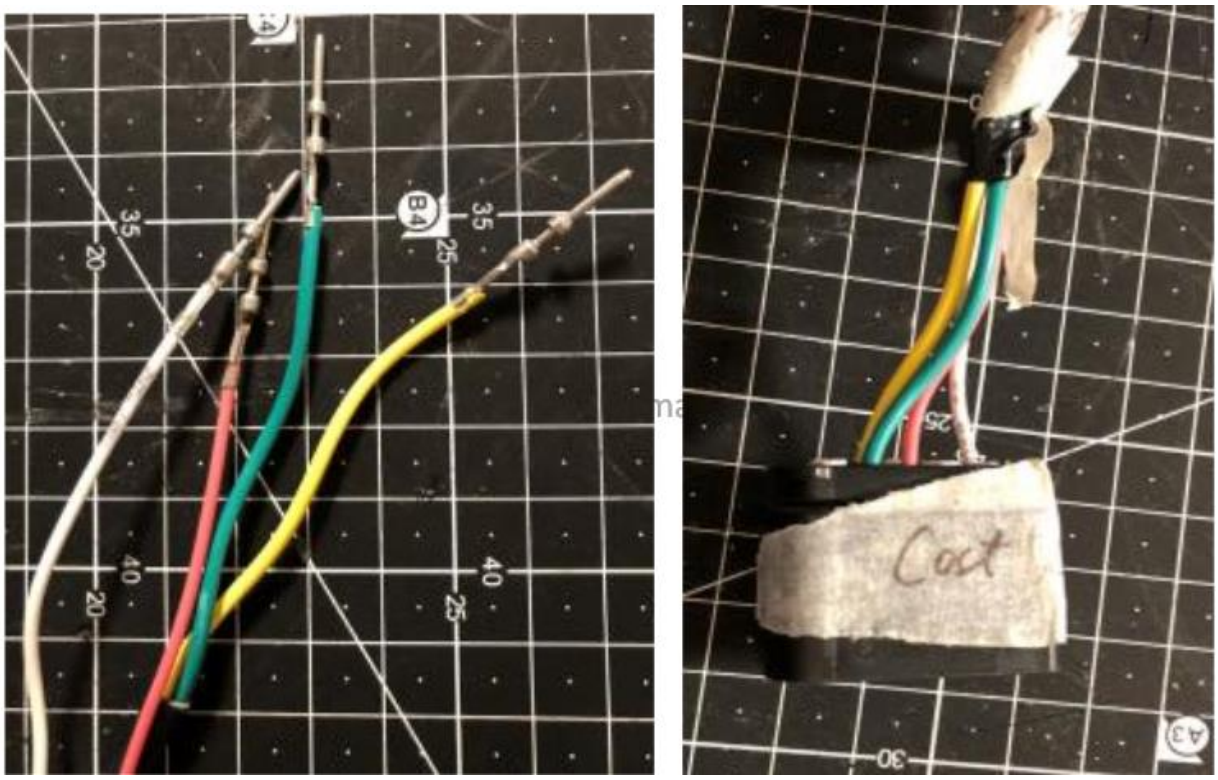
Bendix® Wingman® Fusion™ Driver Interface Unit (Display), PCB 2 Top (left) and Bottom (right) (photo credit: MeC S.r.l.)



Bendix® Wingman® Fusion™ Front Radar Sensor Bracket and Stand-Off Assemblies (photo and graphics credits: MeC S.r.l. and International Parts)

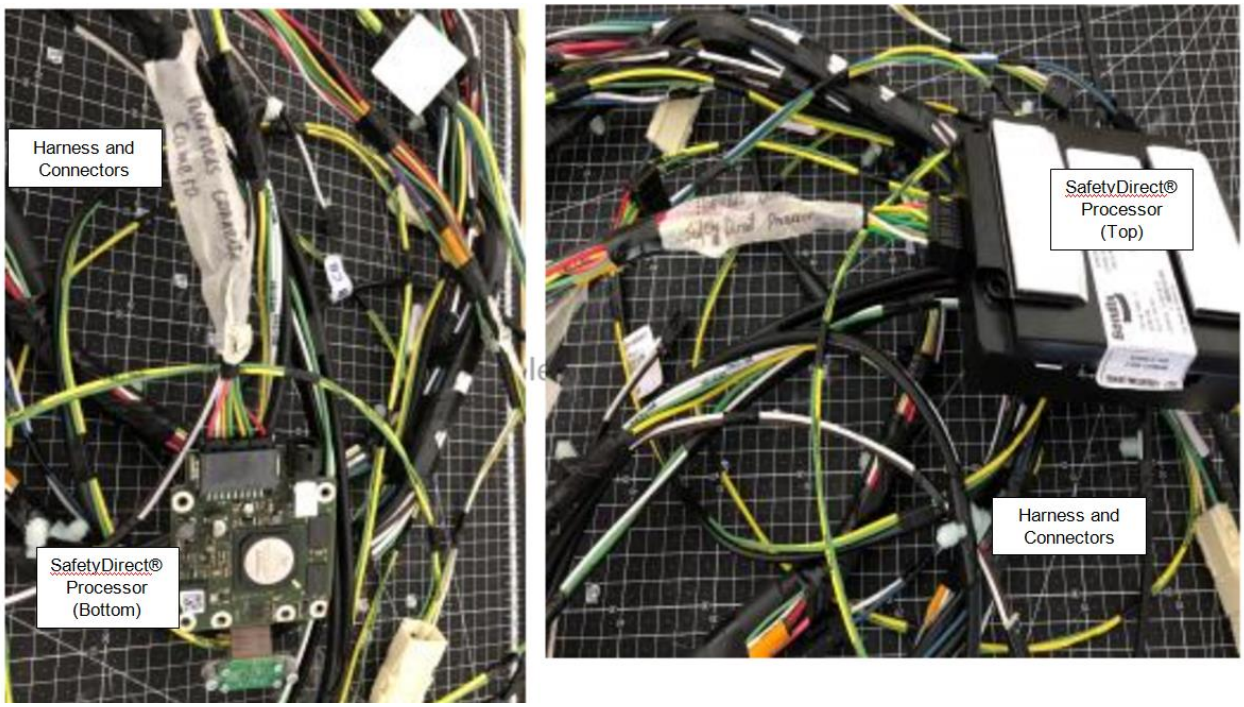
Bendix® Wingman® Fusion™ Camera Bracket (photo credit: MeC S.r.l.)

Bendix® Wingman® Fusion™ Cable and Connectors (connects to camera, SafetyDirect® Processor, and roof harness) (photo credit: MeC S.r.l.)



Bendix® Wingman® Fusion™ Wire Harness and Connectors (connects to front radar sensor) (photo credit: MeC S.r.l.)

Bendix® Wingman® Fusion™ Wire Harness and Connectors (connects radar sensor to main harness) (photo credit: MeC S.r.l.)



Bendix® Wingman® Fusion™ Wire Harness and Connectors (connects to camera and SafetyDirect® Processor) (photo credit: MeC S.r.l.)

Bills of Materials (BOMs) for International LT™ FCW and AEB Systems

The following tables include the bills of materials for the 10 subsystem components of the International LT™ FCW and AEB system.

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of**	**Cost Each**	**Cost Total**
Radar Sensor, Master PCB Components						
Passive components	Fixed Inductors	SMD 47uH 0.59amps	1		$ 0.298	$ 0.298
Passive components	Fixed Inductors	PCC 47uH	2		$ 0.493	$ 0.986
Passive components	Aluminium Electrolytic Capacitors	Low Impedance Electrolytic	1		$ 0.119	$ 0.119
Passive components	Aluminium Electrolytic Capacitors	General Purpose Electrolytic	1		$ 0.079	$ 0.079
Passive components	Tantalum Capacitors	A107C - 503P4	2		$ 0.143	$ 0.286
Passive components	Tantalum Capacitors	22B - 7BB - Z48	1		$ 0.088	$ 0.088
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	19		$ 0.006	$ 0.117
Passive components	Ceramic Capacitor SMD	Evarage Value	69		$ 0.004	$ 0.254
Passive components	Ceramic Capacitor SMD	High Q Multilayer Ceramic Capacitors for General Purpose	29		$ 0.004	$ 0.107
Active components	Diode SMD SOD123	Various Values 1,5x2,8x1,2	66		$ 0.009	$ 0.567
Active components	Diode	T1	1		$ 0.052	$ 0.052
Active components	Diode	ESD Suppressors - RJ49	3		$ 0.136	$ 0.408
Active components	Diode	ESD Suppressors - J35 GFM	4		$ 0.165	$ 0.660
Active components	Transistor/Diode SOT23	General Purpose	4		$ 0.071	$ 0.284
Active components	Transistor	TGHQ	1		$ 0.092	$ 0.092
Passive components	Resistor SMD 1/2 W	Various Values	5		$ 0.006	$ 0.031
Passive components	Resistor SMD	Various Values	1		$ 0.001	$ 0.001
Passive components	Resistor SMD	Various Values	2		$ 0.002	$ 0.004
Various integrated	Integrated Circuit	General Purpouse	1		$ 0.123	$ 0.123
Various integrated	Integrated Circuit	TI7A 0VKQ	1		$ 0.177	$ 0.177
Various integrated	Switching Voltage Regulators	8366EV-27u-61749	1		$ 0.198	$ 0.198
Various integrated	Transistor LDO Voltage Regulators	SG 1801 - 4266 G	2		$ 0.371	$ 0.742
Various integrated circuits	Supervisory Circuits Low Voltage Detector	1H49A8	1		$ 0.189	$ 0.189
Various integrated circuits	Matsushita Sensor	S54GW-792413 EEEstimated Valueted Valueted Value	1		$ 3.356	$ 3.356
Various integrated	CAN Interface	A51051/3	2		$ 0.336	$ 0.672
Micro-controllers	MCU	SPC5604PVLL6	1		$ 6.756	$ 6.756
Connectors	18 pin SMD		1		$ 0.209	$ 0.209
Active components	FotoDiode SO6	Opto Semiconductor	1		$ 0.221	$ 0.221

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Radar Antenna PCB Components						
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	6		$ 0.006	$ 0.037
Passive components	Ceramic Capacitor SMD	Evarage Value	30		$ 0.004	$ 0.110
Passive components	Ceramic Capacitor SMD	High Q Multilayer Ceramic Capacitors for General Purpose	51		$ 0.004	$ 0.188
Active components	Diode SMD SOD123	Various Values 1,5x2,8x1,2	30		$ 0.009	$ 0.258
Active components	Transistor/Mos Fet SOT223	General Purpose	2		$ 0.061	$ 0.123
Passive components	Resistor SMD	Various Values	1		$ 0.002	$ 0.002
Various integrated circuits	Integrated Operational Amplifiers	V74-A408-730	1		$ 1.875	$ 1.875
Various integrated circuits	Integrated Circuit	General Purpose	1		$ 0.113	$ 0.113
Active components	Transistor	SOT-37	4		$ 0.213	$ 0.852
Various integrated circuits	LDO Voltage Regulators	V8535-180-RHJ	1		$ 0.443	$ 0.443
Various integrated circuits	Operational Amplifiers	33075Y-GZRH737	1		$ 0.251	$ 0.251
Various integrated circuits	Precision Amplifiers	AD-6846-a#746	2		$ 0.710	$ 1.421
Various integrated circuits	Drivers/Receivers	ADW-24003	1		$ 0.786	$ 0.786
Connectors	18 pin SMD		1		$ 0.209	$ 0.209
Various integrated circuits	Real Clock RTC	160077	1		$ 0.613	$ 0.613

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Radar Sensor, 4-Wire Harness Components						
Cable	UNIPOLE	T3 - 125°C	2	1.5	$ 0.840	$ 0.082
Cable	UNIPOLE	T3 - 125°C	2	2	$ 0.840	$ 0.105
Terminals	standard	Simply crimped	4			$ 0.064
Blocks		10-13 WAYS complex	1			$ 0.564
Heat Shrink Tubes	Solded points protection	Simple+Glue	1	20	$ 0.400	$ 0.078
Tapes	PVC Tape	T3 125 °C	1			$ 0.044

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Radar Sensor, 2-Wire Harness Components (Connects Radar Sensor to Main Harness)						
Cable	UNIPOLE	T3 - 125°C	2	2	$ 0.040	$ 0.011
Cable	UNIPOLE	T3 - 125°C	2	2	$ 0.090	$ 0.021
Cable	UNIPOLE	T3 - 125°C	2	2	$ 0.370	$ 0.092
Terminals	standard	Simply crimped	2			$ 0.032
Heat Shrink Tubes		Simple+Glue	1	3	$ 0.400	$ 0.073
Heat Shrink Tubes		Simple+Glue	1	10	$ 0.400	$ 0.028
Heat Shrink Tubes	Other heatshrink tubes	Simple+Glue	1	20	$ 0.400	$ 0.047
Heat Shrink Tubes	Solded points protection	Simple+Glue	1	20	$ 0.400	$ 0.093

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Camera Master PCB Components						
Various integrated circuits	Memory CI SDRAM (FBGA)	MT41K64M16TW-107 (7VBI7)	2		$ 2.320	$ 4.640
Passive components	Electrolytic Capacitors SMD 10x10x10,5	470uF 25V 10x10x10,5	1		$ 0.101	$ 0.101
Passive components	Inductor SMD on ferrite 11x11x8,4	220 1191 Vishay - EEstimated Valueted Value	1		$ 0.613	$ 0.613
Passive components	Inductor SMD on ferrite 10x10x5	100 8494 Vishay - EEstimated Valueted Value	1		$ 0.491	$ 0.491
Passive components	Inductor SMD 5x5,4x5	225K 9022 Vishay	1		$ 0.245	$ 0.245
Passive components	Quartz SMD 5kHz	5.00C69 11,4 x 4,83 x 4,3	1	2	$ 0.147	$ 0.442
Passive components	Resistor SMD mini-melf	Various Values	8	6	$ 0.004	$ 0.052
Passive components	Ceramic Capacitor SMD	Evarage Value	45	180	$ 0.004	$ 0.828
Passive components	Ceramic Capacitor SMD array x 4	C Array x 4	7		$ 0.015	$ 0.103
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	11	12	$ 0.006	$ 0.141
Passive components	Resistor SMD	Various Values 0402-0603-0805-1206	30		$ 0.001	$ 0.037
Active components	Diode SGS (SMC)	Various Values 6x7x2,4	2	8	$ 0.184	$ 1.840
Active components	Transistor/Mos Fet D-PAK	BSP 452 Driver HS	1	1	$ 0.331	$ 0.662
Connectors	RCA Jack mono 4 vie		1		$ 0.250	$ 0.250
Connectors	MQS 9 vie	EEstimated Valueted Value	1		$ 0.200	$ 0.200
Various integrated circuits	Double . Op. Ampl.	LM2904 Operational Amplifier x 2 SO8	5		$ 0.130	$ 0.650
Various integrated circuits	CI	EEstimated Valueted Value	1	4	$ 0.110	$ 0.550
Various integrated circuits	Driver	VN5016A (M157 x n° 2) PSSO12 HSD 16 mOhm 40A	1		$ 0.491	$ 0.491
Active components	Transistor/Mos Fet SOT223		1		$ 0.061	$ 0.061
Various integrated circuits	Analog Mux/Demux	74HCT4051D 8 Ch Analog Mux/Demux	1		$ 0.081	$ 0.081
Micro-controllers	STMicroelectronics AA721052TWN	EEstimated Valueted Value	1		$ 8.200	$ 8.200
External memory IC	M29W256GL BGA	Flash memory 256 Mbit	1		$ 4.300	$ 4.300
Active components	FotoDiode SO6	SFH 3201-03	1	1	$ 0.221	$ 0.442
Active components	Diode SGS (SMA)	Various Values 2,6x4,2x2,2		4	$ 0.025	$ 0.098
Active components	Diode SGS (SMC)	Various Values 6x7x2,4		1	$ 0.184	$ 0.184
Connectors	Zif per flat Display 40 vie SMD	-		1	$ 0.491	$ 0.491
Micro-controllers	Microcontroller a 32 bit - MCU	SPC5604PVLL6		1	$ 3.230	$ 3.230
CAN/LIN transceivers	C-CAN Transcevier	TLE6250		2	$ 0.331	$ 0.662
Various integrated circuits	Supervisor Circuit Quad	16001A TE747 BJDO		1	$ 1.520	$ 1.520
Passive components	Double Inductor SMD EPCOS	BB2793		2	$ 0.331	$ 0.662
Active components	Transistor BJT	EEstimated Valueted Value		4	$ 0.123	$ 0.492

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Camera Slave PCB Components						
Passive components	Ceramic Capacitor SMD	Evarage Value	13		$ 0.004	$ 0.048
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	1		$ 0.006	$ 0.006
Passive components	Resistor SMD	Various Values 0402-0603-0805-1206	8		$ 0.001	$ 0.010
Connectors	Zif per flat Display 40 vie SMD	-	1		$ 0.491	$ 0.491

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
SafetyDirect® Processor PCB Components						
Micro-controllers	Altera	Cyclone II EP2C5F256IBNK CBD9Y1743U	1	0	$ 11.800	$ 11.800
Micro-controllers	Texas Instrument	Davinci TMS320DM6437ZWTQ5	1	0	$ 15.523	$ 15.523
External memory IC	Windbond Flash Memory IC	W29N01GVSIAA	1	0	$ 0.870	$ 0.870
External memory IC	Windbond DRAM	W9751G6KB DDR2 512 Mb (32 M x 16)	1	0	$ 1.070	$ 1.070
Micro-controllers	Cypress Semiconductor	OTG Interface HPI, HSS, I²C, SPI, UART 48-FBGA (7x7)	1	0	$ 7.858	$ 7.858
Voltage regulators	Voltage regulator	Switching Voltage regulators (StepDown Conv)	1	0	$ 0.352	$ 0.352
Active components	Comparators	Analog Comparators Quad Low-Voltage	1	0	$ 0.217	$ 0.217
Active components	Transistor/Mos Fet	MOSFT PCh -100V -0.4A 60mOhm 120nC	1	0	$ 0.541	$ 0.541
Active components	Transistor/Mos Fet	MOSFET 20V -100V P-CH FET 480mOhms 18nC	1	0	$ 0.124	$ 0.124
Passive components	Resistor SMD Array x 4	R Array x 4	8	6	$ 0.005	$ 0.069
Passive components	Resistor SMD	Various Values 0402-0603-0805-1206	123	119	$ 0.001	$ 0.297
Passive components	Resistor SMD Low Tolerance	0.5% tolerance	17	5	$ 0.006	$ 0.132
Passive components	Resistor SMD Low Tolerance	0.25%	8	0	$ 0.012	$ 0.096
Passive components	Resistor SMD Low Tolerance	1%	3	0	$ 0.014	$ 0.042
Passive components	Resistor SMD	1R0	1	0	$ 0.036	$ 0.036
Passive components	Ceramic Capacitor SMD	Evarage value	91	181	$ 0.004	$ 1.001
Passive components	Tantalum Capacitor SMD Case A	Case A 3.2x1.6x1.6	3	3	$ 0.049	$ 0.294
Passive components	Inductor SMD chip		5	3	$ 0.025	$ 0.196
Passive components	Inductor SMD onferrite 7x7x2,5	3R3	0	3	$ 0.368	$ 1.104
Passive components	Inductor SMD onferrite 11x11x8,4	220 1191 Vishay - Estimated Value	0	1	$ 0.613	$ 0.613
Passive components	Aluminium Electrolytic Capacitors SMD 6,2x6,2x6,2	100uF 16V 6,2x6,2x6,2	3	0	$ 0.056	$ 0.169
Active components	Transistor/Diode SOT23	BJT	23	8	$ 0.018	$ 0.570
Active components	Transistor/Mos Fet SOT223	BCP 56	4	0	$ 0.061	$ 0.245
Active components	Diode SGS (SMA)		7	5	$ 0.025	$ 0.294
Active components	Diode SGS (SMC)		2	4	$ 0.184	$ 1.104
Passive components	Quarzo SMD 4kHz		2	1	$ 0.147	$ 0.442
Passive components	Fuse		3	9	$ 0.143	$ 1.716
Various integrated circuits	Battery	BATTERY ALKA 1.5V BUTTON 11.6MM	0	1	$ 0.265	$ 0.265
Passive components	SMT Chokes	COMMON MODE CHOKE 14A 2LN SMD	0	1	$ 1.690	$ 1.690
Various integrated circuits	Digital/Analog Converter	1 DAC bit 12 TSOT-23-8	1	0	$ 1.257	$ 1.257
CAN/LIN transceivers	C-CAN Transcevier	NXP A1051/3 84 04 nDS01	2	0	$ 0.331	$ 0.662
Various integrated circuits	Buffers & Line Drivers	2-3.6V Quad Bus 3-State	0	1	$ 0.170	$ 0.170
CAN/LIN transceivers	C-CAN Transcevier	CAN CONTROLLER W/SPI 18SOIC	0	1	$ 0.331	$ 0.331
Connectors	Clamp	Clamp	0	2	$ 0.470	$ 0.940
Connectors	RCA Jack	Mono	0	1	$ 0.250	$ 0.250

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Driver Interface Unit LCD Display PCB Components						
Passive components	Ceramic Capacitor SMD	Evarage Value	21		$ 0.004	$ 0.077
Passive components	Ceramic Capacitor SMD 2,5x3	Various Values	4		$ 0.006	$ 0.025
Passive components	Resistor SMD 1/2 W	Various Values 1810 2,5 x 5 mm	4		$ 0.006	$ 0.025
Active components	Diode SMD SOD123	Various Values 1,5x2,8x1,2	3		$ 0.009	$ 0.026
Active components	Diode SGS (SMA)	Various Values 2,6x4,2x2,2	1		$ 0.025	$ 0.025
Active components	Transistor/Mos Fet D-PAK	BSP 452 Driver HS	2		$ 0.331	$ 0.662
Passive components	Resistor with a dense film	R40F - 1W	1		$ 0.280	$ 0.280
SMD LEDs	Orange 605 nm	LOT676 - TLOE1100		8	$ 0.031	$ 0.245
-	Fuse resettable SMD	F100/33X-2	1		$ 0.140	$ 0.140
Various integrated circuits	Quad . Op. Ampl.	LM2902 Operational Amplifier x 4 SO14	1		$ 0.130	$ 0.130

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Driver Interface Unit Display Wire Harness						
Cable	UNIPOLE	T3 - 125°C	6	2	0.45	$ 0.113
Blocks		1-3 WAYS complex	1			$ 0.155
Heat Shrink Tubes		Simple+Glue	1			$ 0.078

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Quantity**	**Section (mm)**	**Length (m)**	**Cost Total**
Wire Harness: Connects Camera and SafetyDirect® Processor						
Cable	UNIPOLE	T3 - 125°C	1	4	0.9	$ 0.218
Blocks		4-6 WAYS	2			$ 0.559
Heat Shrink Tubes	Other heatshrink tubes	Simple+Glue	1	20	0.4	$ 0.047
Heat Shrink Tubes	Solded points protection	Simple+Glue	1	20	0.4	$ 0.031

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Driver Interface Unit Display Master PCB Components						
Passive components	Ceramic Capacitor SMD	Evarage value	9	13	$ 0.004	$ 0.081
Passive components	Aluminium Electrolytic Capacitors SMD 6,2x6,2x6,2	100uF 16V 6,2x6,2x6,2	9	0	$ 0.056	$ 0.508
Passive components	Tantalum Capacitor SMD Case A	Case A 3.2x1.6x1.6	1	0	$ 0.049	$ 0.049
Passive components	Resistor SMD Low Tolerance	0.50%	16	15	$ 0.006	$ 0.186
Passive components	Inductor SMD onferrite 7x7x2,5	3R3	1	0	$ 0.368	$ 0.368
Passive components	Shielded Inductor	154 Coilcraft F	1	0	$ 0.486	$ 0.486
Active components	Transistor/Mos Fet D-PAK	BSP 452 Driver HS	2	0	$ 0.331	$ 0.662
Active components	Transistor/Mos Fet SOT223	BCP 56	1	2	$ 0.061	$ 0.184
Active components	Transistor/Diode SOT23	BJT	8	2	$ 0.018	$ 0.184
Active components	Diode SGS (SMA)	Various Values 2,6x4,2x2,2	1	0	$ 0.025	$ 0.025
Passive components	Resistor SMD	R02F	1	0	$ 0.110	$ 0.110
Various integrated circuits	Solid State Relays		0	1	$ 2.184	$ 2.184

International LT FCW/AEB System BOMs						
TYPE	**COMPONENT**	**DESCRIPTION**	**Number of Components: Top of PCB**	**Number of Components: Bottom of PCB**	**Cost Each**	**Cost Total**
Driver Interface Unit Display Slave PCB Components						
Passive components	Ceramic Capacitor SMD	Evarage value	21	6	0.004	0.099
Passive components	Resistor SMD Array x 4	R Array x 4	10	2	0.005	0.059
Passive components	Resistor SMD low tolerance	0.50%	31	6	0.006	0.222
Active components	Transistor/Diode SOT23	Various Values	2	0	0.018	0.037
Various integrated circui	Real Clock RTC	PCA8565TS Estimated Value in atte	1	0	0.613	0.613
Passive components	Tantalum Capacitor SMD Case B	Case B 3.5x2.8x1.9	2	0	0.059	0.118
Active components	Transistor/Mos Fet SOT223	BCP 56	5	0	0.061	0.307
Active components	Transistor/Diode SOT23	BJT	3	1	0.018	0.074
Various integrated circui	Voltage Regulator - Linear	TLE42712GATMA1	1	0	0.63	0.63
Connectors	Zif per flat Display 22 vie SMD	-	1	0	0.209	0.209
Micro-controllers	NXP MC9S12XDT512CAL	IC MCU 16BIT 512KB FLASH 112LQFF	1	0	7.24	7.24
Various integrated circui	Voltage Regulator - Linear	317LB Linear Output 1.2 V ~ 37 V 10	1	0	0.082	0.082
SMD LEDs	White	LWT6SG	0	25	0.123	3.067
Passive components	Resistor SMD	Various Values 0402-0603-0805-120	0	4	0.001	0.005
Various integrated circui	Led Driver	MAX6971 LED DRIVER LIN 55MA 24	0	1	1.21	1.21
Various integrated circui	Configurable Oscillator	LVPECL VCXO Pin Configurable Osc	0	1	3.28	3.28
Switches SMD	Switches SMD	Button	0	3	0.098	0.294

International LT FCW/AEB System BOMs						
TYPE	COMPONENT	DESCRIPTION	Quantity	Section (mm)	Length (m)	Cost Total
Driver Interface Unit Display Wire Harness						
Cable	UNIPOLE	T3 - 125°C	1	2	2.45	$ 0.3077
Cable	UNIPOLE	T3 - 125°C	1	2	2.85	$ 0.3581
Cable	UNIPOLE	T3 - 125°C	1	2	2.75	$ 0.3455
Cable	UNIPOLE	T3 - 125°C	1	1.5	3.15	$ 0.3087
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.4	$ 0.0389
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.13	$ 0.0126
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.72	$ 0.0704
Cable	UNIPOLE	T3 - 125°C	1	1.5	2.23	$ 0.2184
Cable	UNIPOLE	T3 - 125°C	1	1.5	2.8	$ 0.2741
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.76	$ 0.0746
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.76	$ 0.0746
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.62	$ 0.0609
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.62	$ 0.0609
Cable	UNIPOLE	T3 - 125°C	1	2	1.6	$ 0.2006
Cable	UNIPOLE	T3 - 125°C	1	2	1.6	$ 0.2006
Cable	UNIPOLE	T3 - 125°C	1	2	1.11	$ 0.1397
Cable	UNIPOLE	T3 - 125°C	1	2	1.11	$ 0.1397
Cable	UNIPOLE	T3 - 125°C	1	1.5	1.11	$ 0.1092
Cable	UNIPOLE	T3 - 125°C	1	1.5	1.11	$ 0.1092
Cable	UNIPOLE	T3 - 125°C	1	2	0.21	$ 0.0263
Cable	UNIPOLE	T3 - 125°C	1	2	0.21	$ 0.0263
Cable	UNIPOLE	T3 - 125°C	1	2	0.92	$ 0.1155
Cable	UNIPOLE	T3 - 125°C	1	2	0.92	$ 0.1155
Cable	UNIPOLE	T3 - 125°C	1	1.5	1.5	$ 0.1470
Cable	UNIPOLE	T3 - 125°C	1	1.5	1.5	$ 0.1470
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.53	$ 0.0515
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.53	$ 0.0515
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.68	$ 0.0662
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.68	$ 0.0662
Cable	UNIPOLE	T3 - 125°C	1	2	0.66	$ 0.0830
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.66	$ 0.0651
Cable	UNIPOLE	T3 - 125°C	1	1.5	0.24	$ 0.0242
Cable	UNIPOLE	T3 - 125°C	1	1.5	2.9	$ 0.2846
Cable	UNIPOLE	T3 - 125°C	1	1.5	2.9	$ 0.2846
Blocks		1-3 WAYS	3			$ 0.4640
Blocks		7-9 WAYS	1			$ 0.4230
Blocks		10-13 WAYS	1			$ 0.5640
Blocks		14-18 WAYS	1			$ 0.7050
Heat Shrink Tubes	3mm (3/1) - L=40mm	Simple+Glue	8			$ 3.1120
Heat Shrink Tubes	Other heatshrink tubes	Duraseal	1	20	0.4	$ 0.1880
Heat Shrink Tubes	Solded points protection	Simple+Glue	1	20	0.4	$ 0.6790
Tapes	PVC Tape	T3 125 °C	1			$ 0.5870

Cost and Weight Summary for International LT™ FCW and AEB Systems

Details of the FCW and AEB systems cost and weight analysis for the Volvo VNL are shown in the three-pat table below:

International LT FCW/AEB System												
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Cycle Time [sec]	Man power	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1	**International FCW system**	**$ 197.51**	**1**	**$ 197.51**			**$ 10.14**	**$166.59**	**$ 13.20**	**$ 7.58**	**3101.4**	**3101.4**
1.1	**Radar**	**$ 31.77**	**1**	**$ 31.77**			**$ 0.62**	**$ 27.88**	**$ 1.46**	**$ 1.81**	**311.3**	**311.3**
1.1.1	Radar Housing	$ 3.30	1	$ 3.30			$ 0.26	$ 1.62	$ 0.17	$ 1.25	242.8	242.8
1.1.1.1	Top Housing		1	$ 1.13	45.06	0.5	$ 0.06	$ 0.96	$ 0.03	$ 0.08	90.5	
1.1.1.2	Bottom Housing		1	$ 0.37	36.42	0.5	$ 0.06	$ 0.24	$ 0.03	$ 0.04	37.4	
1.1.1.3	Internal Housing		1	$ 1.81	19.38	1	$ 0.15	$ 0.42	$ 0.10	$ 1.14	114.9	
1.1.2	Radar PCBs	$ 28.47	1	$ 28.47			$ 0.36	$ 26.26	$ 1.29	$ 0.56	68.5	68.5
1.1.2.1	Master PCB	$ 19.99	1	$ 19.99			$ 0.27	$ 18.14	$ 1.14	$ 0.44	50.7	50.7
1.1.2.1.1	PCB Components		1	$ 17.08	-	-	-	$ 17.08	-	-		
1.1.2.1.2	Circuit board		1	$ 0.82	-	-	-	$ 0.82	-	-		
1.1.2.1.3	Other materials/Scrap		1	$ 0.24	-	-	-	$ 0.24	-	-		
1.1.2.1.3.1	Soldering material		1	$ 0.04	-	-	-	$ 0.04	-	-		
1.1.2.1.4	Processing		1	$ 1.85	-	-	$ 0.27	$ -	$ 1.14	$ 0.44		
1.1.2.1.4.1	SMD component circuits		1	$ 1.11	15.54	2	$ 0.20	-	$ 0.63	$ 0.28		
1.1.2.1.4.2	Wave Soldering		1	$ 0.41	15.60	1	$ 0.06	-	$ 0.23	$ 0.12		
1.1.2.1.4.3	Circuit testing and programming		1	$ 0.29	15.54	1	$ 0.02	-	$ 0.28	-		
1.1.2.1.4.4	Setup		1	$ 0.04	-	-	-	-	-	$ 0.04		
1.1.2.2	Antenna PCB	$ 8.48	1	$ 8.48			$ 0.08	$ 8.13	$ 0.15	$ 0.12	17.8	17.8
1.1.2.2.1	PCB Components		1	$ 7.28	-	-	-	$ 7.28	-	-		
1.1.2.2.2	Circuit board		1	$ 0.75	-	-	-	$ 0.75	-	-		
1.1.2.2.3	Other materials/Scrap		1	$ 0.10	-	-	-	$ 0.10	-	-		
1.1.2.2.3.1	Label		1	$ 0.02	-	-	-	$ 0.02	-	-		
1.1.2.2.4	Processing		1	$ 0.35			$ 0.08	$ -	$ 0.15	$ 0.12		
1.1.2.2.4.1	SMD component circuits		1	$ 0.32	4.08	2	$ 0.08	-	$ 0.15	$ 0.08		
1.1.2.2.4.2	Setup		1	$ 0.03	-	-	-	-	-	$ 0.03		
1.2	**Radar Bracket and Standoff**	**$ 2.42**	**1**	**$ 2.42**			**$ 0.22**	**$ 1.66**	**$ 0.12**	**$ 0.42**	**1201.4**	**1201.4**
1.2.1	Standoff		3	$ 0.09	13.08	0.5	$ 0.01	$ 0.08	$ 0.00	$ 0.01	25.4	
1.2.2	Bracket		1	$ 2.14	45.66	1	$ 0.20	$ 1.43	$ 0.11	$ 0.40	1125.2	
1.3	**4 - Wire Harness (from Radar Sensor)**	**$ 1.76**	**1**	**$ 1.76**			**$ 0.726**	**$ 0.96**	**$ 0.06**	**$ 0.02**	**238.9**	**238.9**
1.3.1	Wires		1	$ 0.19	-	-	-	$ 0.19	-	-		
1.3.2	Terminals		1	$ 0.06				$ 0.06				
1.3.3	Connectors		1	$ 0.56	-	-	-	$ 0.56	-	-		
1.3.4	Heat Shrink Tubes		1	$ 0.08	-	-	-	$ 0.08	-	-		
1.3.5	Tapes		1	$ 0.04	-	-	-	$ 0.04	-	-		
1.3.6	Other materials/Scrap		1	$ 0.02	-	-	-	$ 0.02	-	-		
1.3.7	Processing		1	$ 0.81	136.08	1	$ 0.73	-	$ 0.06	$ 0.02		
1.4	**2 - Wire Harness (connects radar sensor and main harness)**	**$ 1.92**	**1**	**$ 1.92**			**$ 0.846**	**$ 0.42**	**$ 0.62**	**$ 0.04**	**213**	**213**
1.4.1	Wires		1	$ 0.12	-	-	-	$ 0.12	-	-		
1.4.2	Terminals		1	$ 0.03				$ 0.03				
1.4.3	Heat Shrink Tubes		1	$ 0.24	-	-	-	$ 0.24	-	-		
1.4.4	Other materials/Scrap		1	$ 0.02	-	-	-	$ 0.02	-	-		
1.4.5	Processing		1	$ 1.51	254.58	1	$ 0.85	-	$ 0.62	$ 0.04		

International LT FCW/AEB System												
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Cycle Time [sec]	Man power	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1.5	**Camera**	**$ 43.04**	**1**	**$ 43.04**			**$ 0.56**	**$ 36.95**	**$ 3.14**	**$ 2.38**	**128**	**128**
1.5.1	Camera Housing	$ 1.83	1	$ 1.83			$ 0.15	$ 0.34	$ 0.10	$ 1.24	88.6	88.6
1.5.1.1	Top Housing		1	$ 0.98	7.80	1	$ 0.08	$ 0.23	$ 0.05	$ 0.62	49.6	
1.5.1.2	Bottom Housing		1	$ 0.86	7.80	1	$ 0.08	$ 0.11	$ 0.05	$ 0.62	39	
1.5.2	Camera PCBs	$ 41.20	1	$ 41.20			$ 0.41	$ 36.62	$ 3.04	$ 1.14	39.4	39.4
1.5.2.1	Master PCB	$ 37.75	1	$ 37.75			$ 0.36	$ 33.73	$ 2.60	$ 1.06	37.6	37.6
1.5.2.1.1	PCB Components		1	$ 32.76	-	-	-	$ 32.76	-	-		
1.5.2.1.2	Circuit board		1	$ 0.51	-	-	-	$ 0.51	-	-		
1.5.2.1.3	Other materials/Scrap		1	$ 0.45	-	-	-	$ 0.45	-	-		
1.5.2.1.3.1	Screws		4	$ 0.02	-	-	-	$ 0.02	-	-		
1.5.2.1.3.2	Protection rubber		1	$ 0.01	-	-	-	$ 0.01	-	-		
1.5.2.1.4	Processing		1	$ 4.03	-	-	$ 0.36	$ 0.01	$ 2.60	$ 1.06		
1.5.2.1.4.1	SMD component circuits		1	$ 1.77	16.20	2	$ 0.16	-	$ 1.18	$ 0.43		
1.5.2.1.4.2	Wave Soldering		1	$ 0.28	15.60	1	$ 0.04	-	$ 0.16	$ 0.08		
1.5.2.1.4.3	Axial and Radial Soldering		1	$ 0.09	16.20	1	$ 0.09	$ 0.01	-	-		
1.5.2.1.4.4	Circuit testing and programming		1	$ 1.33	16.20	1	$ 0.07	-	$ 1.26	-		
1.5.2.1.4.5	Setup		1	$ 0.56	-	-	-	-	-	$ 0.56		
1.5.2.2	Slave PCB	$ 3.46	1	$ 3.46			$ 0.05	$ 2.89	$ 0.44	$ 0.08	1.8	1.8
1.5.2.2.1	PCB Components		1	$ 0.56	-	-	-	$ 0.56	-	-		
1.5.2.2.2	Circuit board		1	$ 0.19	-	-	-	$ 0.19	-	-		
1.5.2.2.3	Other materials/Scrap		1	$ 2.15	-	-	-	$ 2.15	-	-		
1.5.2.2.3.1	Screws		4	$ 0.02	-	-	-	$ 0.02	-	-		
1.5.2.2.3.2	Flex PCB		1	$ 0.18	-	-	-	$ 0.18	-	-		
1.5.2.2.3.3	Mini Camera		1	$ 1.80	-	-	-	$ 1.80	-	-		
1.5.2.2.3.4	Al Bracket		1	$ 0.06	-	-	-	$ 0.06	-	-		
1.5.2.2.4	Processing		1	$ 0.57			$ 0.05	$ -	$ 0.44	$ 0.08		
1.5.2.2.4.1	SMD component circuits		1	$ 0.11	1.62	2	$ 0.03	-	$ 0.05	$ 0.03		
1.5.2.2.4.2	Circuit testing and programming		1	$ 0.41	1.62	1	$ 0.02	-	$ 0.39	-		
1.5.2.2.4.3	Setup		1	$ 0.05	-	-	-	-	-	$ 0.05		
1.6	**Camera Bracket**	**$ 1.08**	**1**	**$ 1.08**	**10.68**	**0.5**	**$ 0.02**	**$ 1.03**	**$ 0.01**	**$ 0.02**	**47.6**	**47.6**
1.7	**Processor**	**$ 60.01**	**1**	**$ 60.01**			**$ 0.59**	**$ 54.71**	**$ 3.53**	**$ 1.18**	**248.2**	**248.2**
1.7.1	Processor Housing	$ 0.76	1	$ 0.76			$ 0.06	$ 0.59	$ 0.04	$ 0.07	154	154
1.7.1.1	Housing 1		1	$ 0.51	24.96	1	$ 0.03	$ 0.42	$ 0.02	$ 0.03	62.1	
1.7.1.2	Housing 2		1	$ 0.26	24.54	1	$ 0.03	$ 0.17	$ 0.02	$ 0.03	91.9	
1.7.2	Processor PCB	$ 59.25	1	$ 59.25			$ 0.53	$ 54.12	$ 3.49	$ 1.11	94.2	94.2
1.7.2.1	PCB Components		1	$ 52.34	-	-	-	$ 52.34	-	-		
1.7.2.2	Circuit board		1	$ 1.19	-	-	-	$ 1.19	-	-		
1.7.2.3	Other materials/Scrap		1	$ 0.59	-	-	-	$ 0.59	-	-		
1.7.2.4	Processing		1	$ 5.13	-	-	$ 0.53	$ -	$ 3.49	$ 1.11		
1.7.2.4.1	SMD component circuits		1	$ 2.96	24.66	2	$ 0.28	-	$ 1.95	$ 0.73		
1.7.2.4.2	Wave Soldering		1	$ 1.05	24.60	1	$ 0.17	-	$ 0.57	$ 0.31		
1.7.2.4.3	Circuit testing and programming		1	$ 1.04	24.66	1	$ 0.08	-	$ 0.96	-		
1.7.2.4.4	Setup		1	$ 0.08	-	-	-	-	-	$ 0.08		
1.8	**Cable (connects camera and safety direct processor)**	**$ 1.28**	**1**	**$ 1.28**			**$ 0.361**	**$ 0.87**	**$ 0.04**	**$ 0.01**	**238.9**	**238.9**
1.8.1	Wires		1	$ 0.22	-	-	-	$ 0.22	-	-		
1.8.2	Connectors		1	$ 0.56	-	-	-	$ 0.56	-	-		
1.8.3	Heat Shrink Tubes		1	$ 0.08	-	-	-	$ 0.08	-	-		
1.8.4	Other materials/Scrap		1	$ 0.01	-	-	-	$ 0.01	-	-		
1.8.5	Processing		1	$ 0.41	136.08	1	$ 0.36	-	$ 0.04	$ 0.01		

International LT FCW/AEB System												
Item	Description	Total Manufact-uring Cost	Quantity per Vehicle	Cost to Manu-facture per Unit	Cycle Time [sec]	Man power	Labor	Material	Variable	Fixed	Unit Weight [g]	Total Weight per Vehicle [g]
1.9	**Display**	**$ 35.61**	**1**	**$ 35.61**			**$ 1.08**	**$ 30.54**	**$ 2.53**	**$ 1.45**	**235.2**	**235.2**
1.9.1	Display Housing	$ 3.29	1	$ 3.29			$ 0.56	$ 2.05	$ 0.30	$ 0.39	149.1	149.1
1.9.1.1	Housing 1		1	$ 0.47	60.66	0.5	$ 0.07	$ 0.23	$ 0.07	$ 0.10	64.9	
1.9.1.2	Housing 2		1	$ 1.96	60.18	0.5	$ 0.17	$ 1.59	$ 0.09	$ 0.11	49.7	
1.9.1.3	Display Cover		1	$ 0.45	58.98	0.5	$ 0.19	$ 0.10	$ 0.08	$ 0.09	15.7	
1.9.1.4	Display Buttons		1	$ 0.12	120.00	0.5	$ 0.05	$ 0.01	$ 0.03	$ 0.04	3.6	
1.9.1.5	Display Case		1	$ 0.29	42.54	0.5	$ 0.09	$ 0.12	$ 0.03	$ 0.04	15.2	
1.9.2	Display PCBs	$ 32.32	1	$ 32.32			$ 0.52	$ 28.50	$ 2.23	$ 1.07	86.1	86.1
1.9.2.1	Master PCB	$ 7.19	1	$ 7.19			$ 0.27	$ 5.76	$ 0.72	$ 0.43	52.2	52.2
1.9.2.1.1	PCB Components		1	$ 5.03	-	-	-	$ 5.03	-	-		
1.9.2.1.2	Circuit board		1	$ 0.67	-	-	-	$ 0.67	-	-		
1.9.2.1.3	Other materials/Scrap		1	$ 0.07	-	-	-	$ 0.07	-	-		
1.9.2.1.4	Processing		1	$ 1.42	-	-	$ 0.27	$ -	$ 0.72	$ 0.43		
1.9.2.1.4.1	SMD component circuits		1	$ 0.69	4.80	2	$ 0.18	-	$ 0.33	$ 0.18		
1.9.2.1.4.2	Wave Soldering		1	$ 0.48	34.80	1	$ 0.07	-	$ 0.27	$ 0.13		
1.9.2.1.4.3	Circuit testing and programming		1	$ 0.14	4.80	1	$ 0.02	-	$ 0.12	-		
1.9.2.1.4.4	Setup		1	$ 0.12	-	-	-	-	-	$ 0.12		
1.9.2.2	Slave PCB	$ 25.13	1	$ 25.13			$ 0.25	$ 22.74	$ 1.51	$ 0.63	33.9	33.9
1.9.2.2.1	PCB Components		1	$ 17.55	-	-	-	$ 17.55	-	-		
1.9.2.2.2	Circuit board		1	$ 0.41	-	-	-	$ 0.41	-	-		
1.9.2.2.3	Other materials/Scrap		1	$ 4.78	-	-	-	$ 4.78	-	-		
1.9.2.2.3.1	Flex PCB		1	$ 0.91	-	-	-	$ 0.91	-	-		
1.9.2.2.3.2	LCD Display 2.7"		1	$ 3.62	-	-	-	$ 3.62	-	-	10.4	
1.9.2.2.4	Processing		1	$ 2.40			$ 0.25	$ -	$ 1.51	$ 0.63		
1.9.2.2.4.1	SMD component circuits		1	$ 1.46	10.80	2	$ 0.14	-	$ 0.96	$ 0.35		
1.9.2.2.4.2	Wave Soldering		1	$ 0.64	37.20	1	$ 0.10	-	$ 0.35	$ 0.18		
1.9.2.2.4.3	Circuit testing and programming		1	$ 0.20	10.80	1	$ 0.01	-	$ 0.19	-		
1.9.2.2.4.4	Setup		1	$ 0.10	-	-	-	-	-	$ 0.10		
1.10	**Camera and Safety Direct Processor Harness (connects camera, processor and roof harness)**	**$ 18.63**	**1**	**$ 18.63**			**$ 5.116**	**$ 11.56**	**$ 1.69**	**$ 0.26**	**238.9**	**238.9**
1.10.1	Wires		1	$ 4.66	-	-	-	$ 4.66	-	-		
1.10.2	Connectors		1	$ 2.16	-	-	-	$ 2.16	-	-		
1.10.3	Heat Shrink Tubes		1	$ 3.98	-	-	-	$ 3.98	-	-		
1.10.4	Tapes		1	$ 0.59	-	-	-	$ 0.59	-	-		
1.10.5	Other materials/Scrap		1	$ 0.18	-	-	-	$ 0.18	-	-		
1.10.6	Processing		1	$ 7.07	1193.88	1	$ 5.12	-	$ 1.69	$ 0.26		