Concept of Operations and Voluntary Operational Requirements for Vehicular Stability Systems (VSS) On-board Commercial Motor Vehicles

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

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Foreword

The Federal Motor Carrier Safety Administration's (FMCSA's) safety goal is to reduce the number and severity of large truck fatalities and crashes. During the last several years, FMCSA has collaborated with the trucking industry to test and evaluate several on-board safety systems for commercial motor vehicles to increase the safety and security of all roadway users. FMCSA is now promoting voluntary adoption of these systems within trucking fleets by initiating steps to work closely with the trucking industry to define vendor-independent, voluntary requirements.

The purpose of this document is to relay a better understanding of the functions of on-board safety systems for vehicle stability and to provide insight into the safety and efficiency benefits of using the systems. This document describes the concept of operations and voluntary requirements for Vehicle Stability Systems (VSS) for large trucks greater than 10,000 pounds gross vehicle weight rating (GVWR). Concepts of operations provide information about how each user interacts with these safety systems and their operational conditions. Voluntary requirements describe features and functions used to define the safety systems and their operational functionality. The information has been developed in collaboration with trucking industry stakeholders, including representatives from manufacturers, insurance companies, commercial vehicle carriers, drivers and academia.

The results from this project can be used by motor carriers as system guidelines for voluntary adoption of on-board safety systems within their trucking fleets.

This is a final report developed under FMCSA's deployment of on-board safety system program. It does not supersede an earlier report on the subject.

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16. Abstract

The Federal Motor Carrier Safety Administration's (FMCSA's) safety goal is to reduce the number and severity of large truck fatalities and crashes. During the last several years, FMCSA has collaborated with the trucking industry to test and evaluate several on-board safety systems for commercial motor vehicles to increase the safety and security of all roadway users. FMCSA is now promoting voluntary adoption of these systems within trucking fleets by initiating steps to work closely with the trucking industry to define vendor-independent, voluntary requirements.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lbs)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m2	cd/m2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lbs)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

1. INTRODUCTION

The Federal Motor Carrier Safety Administration's (FMCSA's) safety goal is to reduce the number and severity of large truck fatalities and crashes. During the last several years, FMCSA has collaborated with the trucking industry to test and evaluate several on-board safety systems for commercial motor vehicles to increase the safety and security of all roadway users. FMCSA is now promoting voluntary adoption of these systems within trucking fleets by initiating steps to work closely with the trucking industry to define vendor-independent, voluntary requirements for these systems.

The purpose of this document is to relay a better understanding of the functions of on-board safety systems and to provide insight into the safety and efficiency benefits of using the systems. The information has been developed in collaboration with expert panels consisting of trucking industry stakeholders, including representatives from manufacturers, insurance companies, commercial motor vehicle carriers, drivers, and academia.

This document describes the concept of operations and voluntary requirements for Vehicular Stability Systems (VSS) for large trucks (greater than 10,000 pounds gross vehicle weight rating). VSS include: Roll Stability Advisor (RSA), Roll Stability Control (RSC), and Electronic Stability Control (ESC) systems. Concepts of operations provide information about how each user interacts with these safety systems and their operational conditions. Voluntary requirements describe features and functions used to define the safety systems and their operational functionality.

This document discusses VSS provided by manufacturers, such as:

- Bendix Commercial Vehicle Systems
- Freightliner
- Meritor WABCO Vehicle Control Systems

Appendix A lists the commercial off-the-shelf (COTS) systems that currently exist or will be released to the market. United States Department of Transportation (USDOT) websites that contain further information on governmental research, testing and evaluation of VSS include:

www.its.dot.gov/ivi/ivi.htm
www.fmcsa.dot.gov/safetyprogs/research/researchpubs.htm

2. CONCEPT OF OPERATIONS

Roll Stability

Roll stability systems automatically apply brakes to counteract the tendency of a vehicle to tip over while cornering at high speed. The tires provide a lateral (sideways) force at the road to turn the vehicle, as shown in Figure 1, where the truck is turning to the left. The inertia of the vehicle, which tends to continue in a straight line, creates an opposing lateral force effectively acting at the vehicle's center of gravity, as indicated by F_{lat} in Figure 1. The vehicle will lean away from the curve; and, if the opposing lateral forces are great enough, the vehicle will roll over. Other factors that influence the sensitivity of a vehicle to rollover include: the vehicle's load center of gravity height, load offset, road adhesion, road cross slope, suspension stiffness, frame stiffness, and track width (distance between the tires).

Vehicle Rollover Due To Excessive Lateral Force (F_{lat})

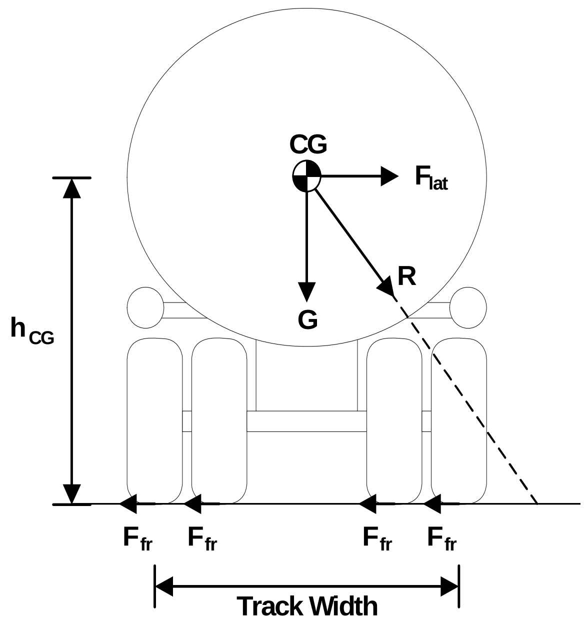

Figure 1
Key RSC System Parameters (For illustration only – not to scale.)

Yaw Stability

ESC systems use automatic braking of individual wheels to prevent the vehicle's heading from changing too quickly (spinning out) or not quickly enough (plowing out). With a combination-unit truck, a jackknife crash results from an oversteer situation. The loss of traction can be caused by slippery roadway conditions or excessive speed in a curve, which can cause a loss of directional control, resulting in the tractor and trailer moving along separate paths. ESC systems cannot increase the available traction, but they maximize the possibility of keeping the vehicle under control and on the road during extreme maneuvers by monitoring the driver's natural reaction of steering in the intended direction in oversteer and understeer situations.

Figure 2 illustrates the understeer (plowing out) situation where a vehicle enters a turn, the front of the vehicle slides or plows out, and the vehicle proceeds to the edge of the curve leading to a roadway departure, if uncorrected. Figure 3 illustrates the oversteer (spinning out) situation where a tractor-trailer enters a turn, the drive axles slide or spin out, and the vehicle proceeds toward the edge of the curve. If uncorrected, this situation can lead to a roadway departure, jackknife for combination unit vehicles, or other conditions, such as tripped rollovers.

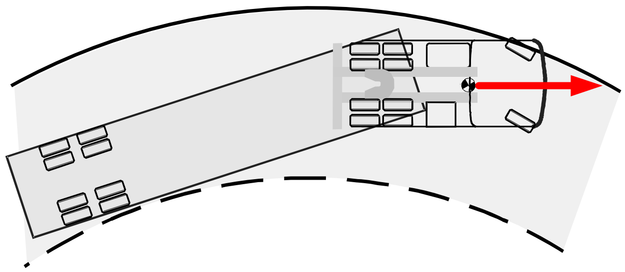

Figure 2
Illustration of Understeer Condition

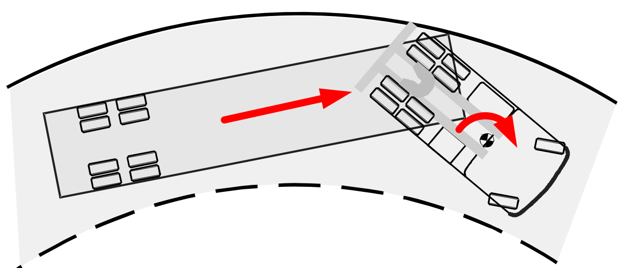

Figure 3
Illustration of Oversteer Condition

Description – Vehicular Stability Systems

Roll Stability Advisor Operation

Roll Stability Advisors (RSA) are passive systems that advise the driver about recent conditions that presented a significant risk of rollover. The RSA tested in the USDOT field operational test (FOT), did not deliver an immediate warning of an impending rollover. With the objective of modifying driver performance in similar future driving situations, RSA provided an advisory message within seconds after the event has occurred. The electronic control unit (ECU) of the RSA monitors lateral force information received from on-board sensors to determine when an advisory is warranted. The advisory is an audible alert and visual message to the driver. Increasing severity associated with the levels of rollover risk is communicated through means, such as the wording of the message, the length of display time, and the duration of an audible alert. For the system tested in the USDOT FOT, the text messages are displayed on two alternating screens: the first presents the qualitative advisory on risk, and the second presents a quantitative advisory for reduced speed. The speed reduction advisory is variable and calculated based on the observed speed and lateral acceleration during the risky event.

Roll Stability Control System Operation

The roll stability control (RSC) system automatically intervenes if a high rollover risk is detected while driving. If a rollover threat is occurring, the system intervenes and tries to minimize the rollover risk by automatically reducing the throttle and if necessary, applying the engine and foundation brakes without action by the driver. RSC systems use drive axle, trailer axle, and steer axle-braking. The RSC system is typically integrated with Antilock Braking System (ABS) controllers, but some systems are integrated with electronically controlled braking systems.

Electronic Stability Control System Operation

ESC systems, also known as Electronic Stability Programs (ESP), are active systems that automatically intervene when there is a high risk of roll over or yaw instability. In currently available systems, the ECU constantly compares the vehicle's actual movement to performance models using the wheel speed sensors, as well as lateral, yaw, and steering angle sensors. If the vehicle shows a tendency to leave an appropriate travel path, or if critical threshold values are approached, the system will intervene to assist the driver.

When a potential rollover risk is detected, the rollover function operates as previously described. The ESC system reduces the throttle and applies the proper brake pressure to slow the vehicle below the rollover risk threshold. When a vehicle slide (oversteer or understeer) is detected, the ESC system removes the throttle and then selectively applies the appropriate individual brakes to produce a counter-force to better align the vehicle with an appropriate path of travel. In an oversteer situation, the system applies the "outside" front brake; while in an understeer condition, the "inside" rear brake is applied. These systems may be integrated with electronically controlled braking systems or anti-lock braking systems.

Crash Prevention

Vehicle Stability Systems can help prevent the following types of crashes. This data is derived from the 2002 and 2003 General Estimates System (GES) Accident database:[1]

- **Rollover** – Large trucks were involved in 10,200 rollover crashes in 2002 according to the FMCSA publication "Large Truck Crash Facts 2002". These crashes resulted in 190 fatalities. Rollovers can occur at speeds below 30 miles per hour, which can be too fast on an exit ramp. With regard to excessive speed, drivers may be under the speed limit, but operating too fast for conditions. Although drivers may think that they know how fast the truck is traveling by the way it feels, their estimates of speed can be off by 10 to 20 miles per hour. As a result, RSC and ESC systems can reduce the speed of the vehicle to prevent many rollover incidents.
- **Loss of Control Crashes** – Many loss of control crashes occur as the result of an aggressive control action by the driver. Steering to avoid another vehicle and over-correction from a lane departure are typical loss of control actions. In 2003, large trucks accounted for approximately 9,600 loss of control crashes resulting in 230 fatalities. ESC systems use automatic braking of individual wheels to prevent the vehicle's heading from changing too quickly (spinning out) or not quickly enough (plowing out).

ESC and RSC systems will not prevent all crashes, such as tripped rollovers and those caused by sudden turns at high speed or travel on cross-sloped shoulders.

[1] The General Estimates System is directed by the National Center for Statistics and Analysis, which is a component of The Office of Research and Development in NHTSA. Data for GES come from a nationally representative sample of police reported motor vehicle crashes of all types, from minor to fatal. The system began operation in 1988, and was created to identify traffic safety problem areas, provide a basis for regulatory and consumer initiatives, and form the basis for cost and benefit analyses of traffic safety initiatives. The information is used to estimate how many motor vehicle crashes of different kinds take place, and what happens when they occur.

Operations and Users

This section describes how drivers, fleet managers, and fleet maintenance personnel interact with VSS and potential benefits that each stakeholder may realize with these systems.

The commercial vehicle population is comprised of a wide variety of vehicle types and uses. At a high level, two types of vehicles are predominant, combination vehicles (tractors-trailers) and straight trucks. These two types of vehicles have very different operating characteristics. In general, straight trucks tend to be used in a more local setting and used to provide deliveries of goods and services to customers generally within a 50 to 100 mile radius of their base of operations. Combination vehicles are more often utilized in regional and long distance applications and account for about 30% of total commercial vehicles, but 65% of the commercial vehicle miles traveled.

The trucking industry is actually a broad collection of many industries, each with operating characteristics as diverse as the industries they service. Segmentation of the trucking industry is often based on the size of fleets, the geographic range of its operations, and the commodities hauled. Usually one characteristic is not adequate to describe a particular segment, but rather combinations of characteristics are required to best describe operations. For example, there may be a trucking firm with a large fleet providing package delivery type service to a relatively small geographic area, while there may be a single truck company that provides general freight services to all states in the continental United States.

The movement of goods by truck is conducted on all types of roads, at all hours of the day, and in all types of driving conditions. Since loss of vehicle stability can occur along any route, many fleet types may benefit from using VSS, yet they may be most promising for tractor-trailer combinations, trucks with high mileage accumulated over their operational life, or trucks that operate under conditions that may present driving challenges, such as roadways of geometry or configuration that can be difficult to negotiate.

The value of the system to a fleet or an owner-operator depends on the risk of these crashes in the particular business and the cost of the crashes. During the USDOT FOT, the RSA and RSC systems were found to be particularly beneficial for fleets with tractors pulling tank trailers. Additional secondary benefits may be derived from the prevention of the previously mentioned severe crashes involving cargo loss by lowering costs of clean up and reducing traffic congestion.

Drivers

Drivers are the primary VSS users. They interact with the system in a number of basic driving and operating situations:

> **Normal system startup operation** – When the driver starts the vehicle, the VSS performs a power-up self-test, and the driver scans the warning indicator to determine any system malfunctions. If necessary, the driver may alert fleet maintenance for corrective action.
>
> **Vehicle stability events** – When a driver transverses a curve at an excessive speed in a rollover risk situation, RSC and ESC systems automatically initiate braking to slow the vehicle without driver intervention. During a loss of control situation due to sliding, the ESC system initiates braking. The RSA issues an advisory message to the driver following the detection of a rollover risk. The RSC and ESC systems may provide audible and/or visual warnings to the driver about the rollover risk and activation of automatic braking.
>
> **System fault conditions** – If a VSS system fault occurs, a system status indicator will alert the driver; however, the vehicle will operate normally. The driver may be notified of a VSS system fault via an audible alert or visual message.

Various road types and conditions – A driver may encounter several types of roads and conditions. Normally, VSS will be in a monitoring mode during driving situations. Most untripped rollovers caused by lateral acceleration occur on curved roads and exit ramps. On flat roadways, rollovers occur on dry pavement when the roadway friction prevents the vehicle from sliding sideways. Jackknifing, plowing out, and spinning out tend to occur on roadways with reduced traction. The driver should be aware that in limited-traction conditions, RSC systems will not prevent limited-traction, sliding incidents while ESC systems address both sliding and rollover situations.

Fleet Management

Fleet managers are responsible for all administrative, financial, and operational aspects of the fleet. Safety officers focus on the fleet's operational safety issues and examine the operational safety aspects of the fleet's vehicles in accordance with USDOT safety regulations. They also work with drivers to provide safety and operational training, verify that drivers are completing their hours-of-service requirements, and examine how well drivers operate their vehicles (e.g., logging accidents and traffic infractions).

These personnel examine various types of available safety equipment, justify the purchase of all equipment, determine the effectiveness of this equipment, and calculate the return on investment (ROI) for their fleet. They work with the maintenance department and drivers to explain VSS benefits. Using operational data from VSS via the in-vehicle network, fleet managers may analyze the data to review systemic problems with their fleet operations (e.g., disproportionate number of rollover warnings with certain drivers) and to train drivers. Safety managers have a number of theories about the primary causes of tanker rollovers. They point to four basic factors: excessive speed, driver inattention, driver fatigue, and inadequate training and experience.[2] Research has indicated that the monitoring of driver behavior can have a positive effect on driver and fleet safety.[3, 4]

Maintenance Management and Installation

Maintenance managers and service technicians are responsible for the proper functioning of all equipment installed on the fleet's vehicles and for installing and maintaining VSS on the fleet. They support fleet management by collecting operational data on the reliability of VSS and how well VSS suppliers work with the fleet to resolve any problems.

Since VSS are typically an extension of ABS, the maintenance requirements for a vehicle equipped with VSS should not be more complicated than requirements for standard ABS.

3. VOLUNTARY REQUIREMENTS

The voluntary requirements included in the following sections define fundamental VSS features and the ability of the VSS to withstand the electrical and environmental extremes commonly found on commercial vehicles.

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[2]Wilson, Charles E. Cargo Tank Rollovers Need Industry Focus. Bulk Transporter. October 1, 2002.

[3] Knipling, R.R. and Olsgard, P.J. Prospectus: The Behavioral Power of On-Board Safety Monitoring Feedback. Proceedings of the 10th Annual Meeting of the Intelligent Transportation Society of America (ITS America), Boston, M.A., May 1-4, 2000.

[4] Roetting, M.; Huang, Y.-H.; McDevitt, J.R.; and Melton, D. When Technology Tells You How To Drive – Truck Driver's Attitudes Toward Feedback By Technology. Transportation Research Part F, Elsevier Publishing, pp 275-287, 2003.

The types of voluntary requirements for VSS include:

1. Functional Requirements
2. Data Requirements
3. Hardware and Software Requirements
4. Driver Vehicle Interface (DVI) Requirements
5. Maintenance and Support Requirements

VSS manufacturers may include additional functions and features that may be useful beyond minimum VSS functionality; the operational features that fall into this category are labeled with the term "OPTIONAL". However, in all cases VSS must comply with all existing FMCSA Safety Regulations. The requirement numbering system designates optional features with a "T" and system defining requirements with an "R".

3.1 Functional Requirements

Functional requirements described here refer to basic system functionality and operation of all types of VSS.

R1-1 VSS should perform a self-test to test all major system components and be fully operational within 30 seconds of starting the vehicle, and relay the results of the self-test to the driver.

R1-2 VSS should be able to provide vehicle dynamics monitoring, control actions, and/or warnings in all lighting conditions (e.g., bright sunlight, moonless night, dusk/dawn, etc.).

R1-3 VSS should be able to provide vehicle dynamics monitoring, control actions, and/or warnings in all weather conditions (e.g., dry, rain, snow, ice, fog, etc.).

R1-4 RSC and ESC systems should be capable of control actions when the vehicle is moving at least 16 kph (10 mph). Vehicle instability can occur at low speeds on certain graded roadways (e.g., down-grade tight-turn driveways).

R1-5 VSS should dynamically calculate rollover thresholds based on changing vehicle parameters. For example, currently available VSS estimate the vehicle's center-of-gravity (CG) height based on the vehicle's mass, including its cargo.

R1-6 RSC and ESC systems should use foundation brakes to reduce the speed of the vehicle to minimize the risk of rollover. ESC systems should use foundation brakes to reduce the speed of the vehicle to minimize the risk of oversteer or understeer situations. RSC and ESC systems may also use other control actions, such as engine dethrottling, retarder activation, and transmission downshifting, as appropriate.

R1-7 RSC and ESC systems should blend the braking demands of the system and the driver so that the higher braking demand takes precedence. By directly measuring driver brake demand, RSC and ESC systems should accurately transition between driver-intended and system-intended braking pressure.

R1-8 If integrated with RSC and ESC systems, ABS functionality should be maintained to manage wheel slip and wheel lock conditions.

T1-1 **OPTIONAL** – ESC, RSC, and RSA systems may be integrated into one system, and they may be integrated into ABS and traction-control systems.

T1-2 **OPTIONAL** – RSC and ESC systems may produce a net vehicle speed that is lower than the posted speed limit for a particular set of operating conditions when an impending rollover is detected and control actions are taken.

3.2 Data Requirements

Data requirements define the format of data generated by or can be obtained directly in real-time from VSS systems. Two Society of Automotive Engineers (SAE) standards specify in-vehicle data communication in heavy trucks:

- SAE J1587, "Electronic Data Interchange between Microcomputer Systems in Heavy-Duty Vehicle Applications" (message definition for the J1708 data bus), or
- SAE J1939-71, "Recommended Practice for Control and Communications Network for On-Highway Equipment – Vehicle Application Layer"

Although neither of these standards defines VSS messages, it would be beneficial for system users if VSS suppliers adopt a common set of standard VSS messages for users to obtain diagnostic data via the in-vehicle data network.

T2-1 **OPTIONAL** – VSS may provide operational data to the SAE J-1708 or J-1939 data network in a format compatible to the SAE standard.

T2-2 **OPTIONAL** – RSC and ESC systems may record data on-board, which can be used for other purposes, such as evaluation of driver performance and warning system performance.

3.3 Hardware and Software Requirements

Hardware and software requirements deal directly with the detailed functionality of the hardware, environmental and electrical concerns, mounting/installation issues, and software design. Figures 4 through 6 illustrate the major functional components and interfaces of RSA, RSC, and ESC systems as described in the following sections, respectively. Figure 4 shows the inter-relationship of the RSA system components. The ECU obtains the lateral force or acceleration data. Through the vehicle network (J1708 or J1939), the ECU transmits messages to the vehicle message center, where they can be seen by the driver. Messages might be status indicators or alerts. Figure 5 shows the inter-relationship of the RSC system components. The RSC has all the same components of the RSA system. In addition, the ECU can send a signal to ABS control, commanding it to apply vehicle foundation brakes. Figure 6 shows the inter-relationship of the ESC system components. The ESC has all the same components of the RSC system. The ESC requires two additional inputs—the vehicle's yaw rate and the steering wheel angle.

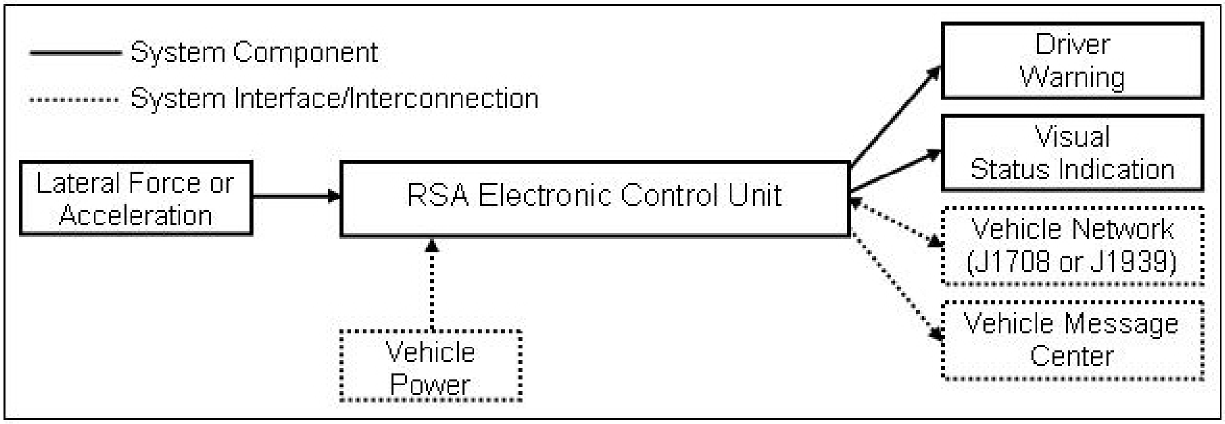

Figure 4
RSA Major Functional Components

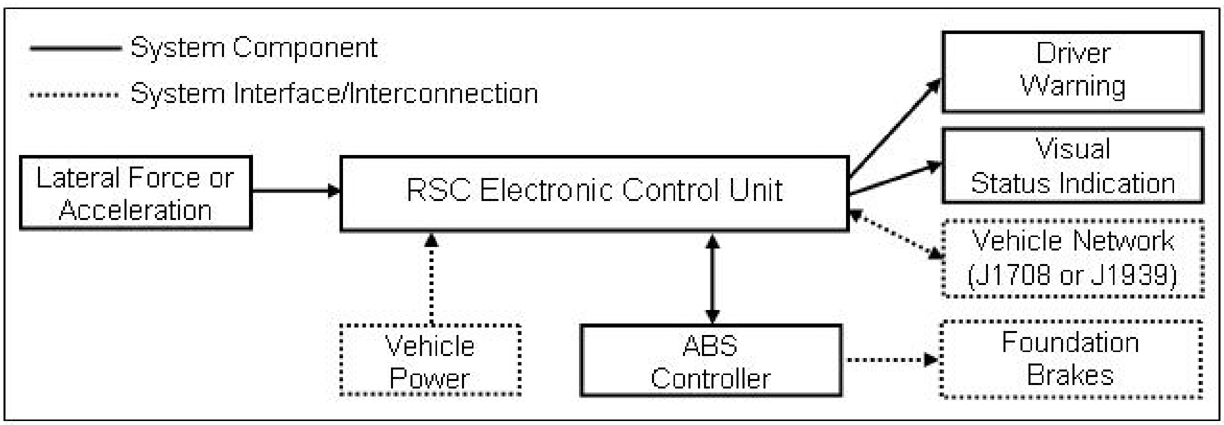

Figure 5
RSC System Major Functional Components

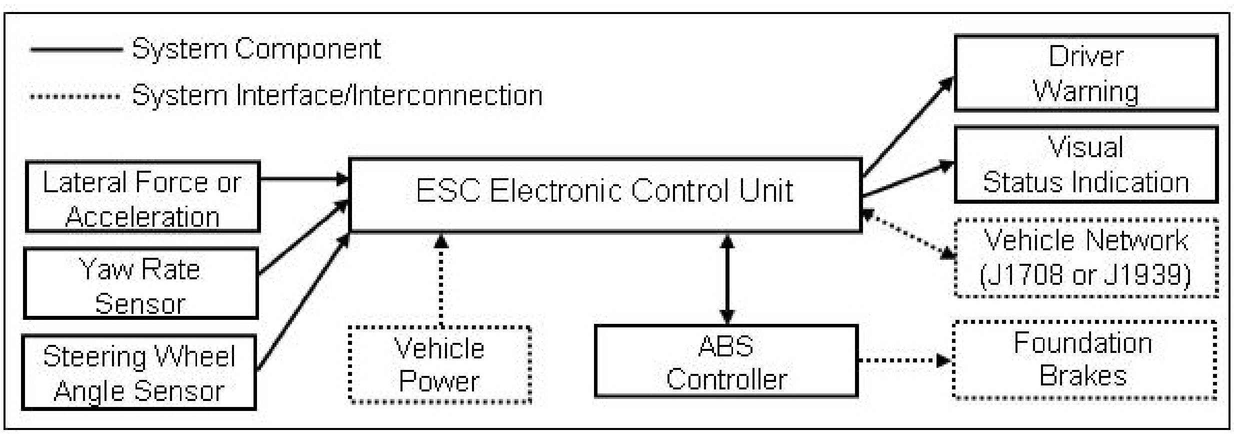

Figure 6
ESC System Major Functional Components

Typical System Hardware

This section describes the functionality of the primary physical components of the VSS. They refer to the functional blocks as shown in Figure 4 through 6.

<u>R3-1</u> **Lateral Force or Acceleration** – VSS should provide a sensor to measure the vehicle's lateral acceleration. The sensor may reside within a VSS or be a discrete sensor.

<u>R3-2</u> **Yaw rate sensor** – ESC systems should provide a sensor to measure the vehicle's yaw rate. This sensor may reside within an ESC system or be a discrete sensor.

<u>R3-3</u> **Steering angle sensor** – ESC systems should provide a sensor to measure the vehicle's steering angle. This sensor typically resides within the steering column and is used by an ESC system.

<u>R3-4</u> **Electronic Control Unit** (ECU) – The VSS's ECU should be used to gather sensor data and calculating key parameters used to determine the vehicle's likelihood of rollover. The ECS's ECU should also be used to gather sensor data and calculating key parameters used to determine the vehicle's likelihood of an oversteer or understeer situation.

<u>R3-5</u> **Vehicle power** – VSS should rely on vehicle power for operation.

<u>R3-6</u> **Visual status indication** – VSS should provide a visual indication of the status of the system. System status includes operational/non-operational and system fault conditions similar to the manner in which ABS indicators are currently used. See Section 3.4 for additional user interface requirements.

<u>R3-7</u> **Engine throttle control** – RSC systems should dethrottle the engine if a rollover is detected. ESC systems should also dethrottle the engine if an oversteer or understeer risk is detected.

<u>R3-8</u> **Engine brake** – RSC and ESC systems should activate the engine brake (if vehicle is so equipped) if a rollover is detected. ESC systems should also activate the engine brake (if vehicle is so equipped) if an oversteer or understeer risk is detected.

<u>R3-9</u> **Foundation brakes** – RSC and ESC systems should activate the foundation brakes if a rollover is detected. ESC systems should also activate the foundation brakes if an oversteer or understeer risk is detected.

<u>R3-10</u> **Visual display** – RSA systems should use a visual display that presents operational messages to the driver to indicate the risk of rollover.

<u>T3-1</u> **<u>OPTIONAL</u>** – **Driver warning** – RSC and ESC systems may provide a warning to the driver when the systems are actively controlling the vehicle. The warning can be audible, visual, or tactile.

<u>T3-2</u> **<u>OPTIONAL</u>** – **Vehicle network** – VSS may use the in-vehicle data network (SAE J1708, or J1939) for data communication to data recording or diagnostic devices.

<u>T3-3</u> **<u>OPTIONAL</u>** – **Transmission Retardation** – RSC and ESC systems may use the vehicle transmission to apply vehicle control actions.

Environmental Requirements

The environmental conditions that exist in large trucks are severe. The SAE has developed a comprehensive standard that describes various aspects of the heavy truck environment in its J1455 standard. The standard also includes procedures that are used to verify system compliance.

R3-11 VSS should meet the environmental requirements as stated in the most recent version of the following SAE standard:

SAE Standard J1455, "Joint SAE/Technology Maintenance Council (TMC) Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks)".

The following environmental aspects are covered by the standard:

- Altitude
- Fungus
- Mechanical Shock
- Mechanical Vibration
- Relative Humidity
- Temperature
- Salt Spray Atmosphere
- Immersion and Splash
- Steam Cleaning and Pressure Washing
- Dust, Sand, and Gravel Bombardment

Electrical Requirements

In a truck's electrical power distribution system, the system voltage may vary, the alternator may generate electrical noise, and various types of transients may momentarily place over 100 volts direct current (VDC) on the electrical distribution system's wiring. In addition, there may be electrostatic discharge into the system from a buildup of static electricity. Because VSS connect to the truck's electrical power distribution system, they should function normally throughout all of these perturbations without damage.

R3-12 VSS should meet the electrical requirements as stated in the most recent version of the following SAE standards:

SAE Standard J1455, "Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks)".

SAE Standard J1113, "Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft) (60 Hz to 18 GHz)".

The following environmental aspects are covered by the standards:

- Steady State Electrical Characteristics
- Transient Electrical Characteristics
- Electromagnetic Susceptibility
- Electromagnetic Emission

R3-13 VSS data should not be destroyed nor corrupted during a power surge.

Mounting and Installation Requirements

Mounting and installation requirements include all aspects related to the installation of the VSS hardware onto the truck, including the mounting of the individual system components. There are no specific requirements pertaining to system size or weight.

R3-13 VSS should use one or more fuses or other protective devices to protect the vehicle's power supply and power distribution wiring.

R3-14 All settings for the specific make and model of the vehicle should be supplied to the installers, or VSS should come pre-configured for use with the vehicle.

R3-15 All VSS cables, connectors, and components should be rated for automotive duty as defined by the SAE and be appropriate for their operational environment (e.g., VSS components mounted on the exterior of the vehicle should be rated for exterior duty).

R3-16 Major VSS components, other than cabling or small mounting components, should be marked with the manufacturer's identification.

R3-17 VSS in-cab components should remain securely mounted in the event of a crash.

Software Requirements

Software requirements refer to the embedded software that runs in VSS and controls all system functionality. The VSS's microcontroller or microprocessor continuously runs the system software when the system is active.

T3-4 **OPTIONAL** – The embedded software in VSS may be field upgradeable via the in-vehicle network connection (i.e., J1587 or J1939) or other common data interface (e.g., RS-232 or Universal Serial Bus (USB)).

T3-5 **OPTIONAL** – VSS may include software for downloading ASCII data files that can be easily read into a statistical, database, or spreadsheet software package.

3.4 Driver Vehicle Interface Requirements

These requirements define specific ways in which VSS interact/interface with the driver, and include indicators, displays, and warning methods. As it applies to VSS driver interface issues, the National Highway Traffic Safety Administration (NHTSA) Federal Motor Vehicle Safety Standard 101 (FMVSS 101) should be used as a guide for VSS indicators.

R4-1 VSS should indicate to the driver that they are fully operational. This indication may be performed by momentarily lighting a VSS status indicator lamp during power on system check, similar to the ABS lamp currently used on large trucks.

R4-2 VSS should indicate a system failure by continuously lighting a VSS indicator lamp, similar to the ABS system lamp currently used on large trucks.

R4-3 Warnings generated by VSS should be clearly distinguishable from indicators generated by other vehicle systems.

R4-4 VSS should not have an on/off switch or a disable button.

R4-5 An indication or label should be supplied with the vehicle notifying the driver that the vehicle has been equipped with a VSS.

R4-6 VSS warnings, alerts, and messages should be readily understood by the driver and not interfere with the driver's primary duty of operating the vehicle.[5]

[5] FHWA, In-Vehicle Display Icons and Other Information Elements: Volume II: Final Report, Report No. FHWA-HRT-03-063, September 2004.

R4-7 VSS indicators should be clearly discernable in direct sunlight and should not distract the driver in darkness.

T4-1 **OPTIONAL** – VSS may provide a visual, audible, or tactile warning to indicate a vehicle rollover is imminent or control actions are taking place.

T4-2 **OPTIONAL** – VSS may audibly indicate a system failure or component malfunction.

T4-3 **OPTIONAL** – VSS may allow the audible warning volume to be adjusted, but not turned down completely.

T4-4 **OPTIONAL** – VSS may provide diagnostic messages such as “Sensor Failure” on an alphanumeric display to alert the driver of specific problems or concerns.

3.5 Maintenance and Support Requirements

Maintenance and support requirements include functionality/features that should be provided to ensure VSS systems will be operated correctly and properly maintained.

R5-1 VSS should require no more maintenance than that currently required by available ABS systems.

R5-2 VSS should automatically maintain calibration.

R5-3 A procedure to verify VSS functionality and calibration should be provided via an installation/maintenance manual or other document.

R5-4 Users should be provided with a manual and training for VSS.

R5-5 The user’s manual should describe the minimum vehicle speed at which the VSS operates. It should also describe how the VSS functions and list the various rollover, oversteer, and understeer risk situations that the VSS can and cannot help mitigate.

R5-6 Manufacturers should provide product support for users and fleets to ask questions regarding capabilities and resolve problems with systems.

T5-1 **OPTIONAL** – The VSS may provide blink codes, observed at the system status indicator, that indicate various VSS faults.

T5-2 **OPTIONAL** – Video, audio, or computer-based training material may be provided for fleet management and/or drivers.

4. ACRONYMS

Acronym	Definition
ABS	Antilock Braking System
ASCII	American Standard Code for Information Exchange
CG	Center-of-Gravity
COTS	Commercial Off-The-Shelf
ECU	Electronic Control Unit
ESC	Electronic Stability Control
ESP	Electronic Stability Program
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
FOT	Field Operational Test
GES	General Estimates System
GVWR	Gross Vehicle Weight Rating
kph	Kilometers per Hour
mph	Miles per Hour
NHTSA	National Highway Traffic Safety Administration
ROI	Return on Investment
RSA	Roll Stability Advisor(s)
RSC	Roll Stability Controller(s)
RSP	Roll Stability Program(s)
SAE	Society of Automotive Engineers
TMC	Technology and Maintenance Council
USB	Universal Serial Bus
USDOT	United Stated Department of Transportation
VDC	Volts Direct Current
VSS	Vehicular Stability System(s)

5. REFERENCES

FHWA, In-Vehicle Display Icons and Other Information Elements: Volume II: Final Report, Report No. FHWA-HRT-03-063, September 2004.

SAE Standard J1113, “Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft) (60 Hz to 18 GHz)”, July 1995.

SAE Standard J1455, “Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks)”, August 1994.

SAE Standard J1587, “Electronic Data Interchange between Microcomputer Systems in Heavy-Duty Vehicle Applications”, February 2002.

SAE Standard J1708, “Serial Data Communications between Microcomputer Systems”, October 1993.

SAE Standard J1939-71, “Recommended Practice for Control and Communications Network for On-Highway Equipment – Vehicle Application Layer”, September 2002.

Wang, J.S.; Knipling, R.R.; and Blincoe, L.J. The Dimensions Of Motor Vehicle Crash Risk. Journal of Transportation and Statistics. Volume 2, No. 1, pp. 19-43, ISSN 1094-8848, May 1999.

Knipling, R.R. and Olsgard, P.J. Prospectus: The Behavioral Power of On-Board Safety Monitoring Feedback. Proceedings of the 10th Annual Meeting of the Intelligent Transportation Society of America (ITS America), Boston, M.A., May 1-4, 2000.

Roetting, M.; Huang, Y.-H.; McDevitt, J.R.; and Melton, D. When Technology Tells You How To Drive – Truck Driver’s Attitudes Toward Feedback by Technology. Transportation Research Part F, Elsevier Publishing, pp. 275-287, 2003

Wierwille, W.W.; Lewin, M.G.; and Fairbanks, R.J. III. Final Report: Research on Vehicle-Based Driver Status/Performance Monitoring; Part I. Vehicle Analysis and Simulation Laboratory, Virginia Polytechnic Institute and State University, Publication No. DOT HS 808 638, September 1996.

Wierwille, W.W.; Lewin, M.G.; and Fairbanks, R.J. III. Final Report: Research on Vehicle-Based Driver Status/Performance Monitoring; Part II. Vehicle Analysis and Simulation Laboratory, Virginia Polytechnic Institute and State University, Publication No. DOT HS 808 638, September 1996.

Wierwille, W.W.; Lewin, M.G.; and Fairbanks, R.J. III. Final Report: Research on Vehicle-Based Driver Status/Performance Monitoring; Part III. Vehicle Analysis and Simulation Laboratory, Virginia Polytechnic Institute and State University, Publication No. DOT HS 808 638, September 1996.

Wilson, Charles E. Cargo Tank Rollovers Need Industry Focus. Bulk Transporter. October 1, 2002.

A. APPENDIX A – COMMERCIAL-OFF-THE-SHELF (COTS) VSS

The following Commercial Off-the-Shelf (COTS) VSS are currently available:

Bendix Commercial Vehicle Systems (BCVS) (www.bendix.com) – Bendix offers two systems:

1. The "ABS-6 Advanced with RSP (Roll Stability Program)" includes roll stability control for high-CG straight trucks.
2. The "ABS-6 Advanced with ESP (Electronic Stability Program)" includes roll and yaw stability control for tractors pulling tankers/trailers.

Both of these systems are supplemental functions of the ABS controller. Additional sensors and brake system valves/piping are added to the standard ABS to allow this functionality. The system's driver interface includes a dashboard warning indicator, similar to an ABS indicator.

Meritor WABCO Vehicle Control Systems (www.meritorwabco.com) – Meritor WABCO offers four systems:

1. The "Roll Stability Control for Trucks/Tractors" is a supplemental function of the ABS controller. Additional sensors and brake system valves/piping added to the standard ABS allows this functionality. It is a roll-only control system. The system's driver interface includes a dashboard warning indicator, similar to an ABS indicator.
2. The "Roll Stability Support for Trailer Applications" system performs roll stability control as a supplemental function of the trailer ABS controller. It is an independent roll-only stability control system. Additional sensors and brake system valves/piping are added to the standard trailer ABS to allow this functionality.
3. The "Tractor Electronic Stability Control" system is a combination roll and yaw control system which is a supplemental function of the tractor ABS. It is an enhanced version of the RSC system and offers improved total stability control.

Freightliner (www.freightliner.com) – Freightliner is the supplier of the RSA system tested in the USDOT FOT. Their RSA systems are typically combined with RSC systems. Freightliner only offers RSA on their Century and Argosy vehicles. These vehicles have an integrated in-dash "message center" (alphanumeric display) on which the RSA messages appear.

Summary of COTS System Features

Table A-1 provides comparative information relative to the features of each of the COTS systems described in this appendix. Each manufacturer provided this information.

Table A-1
Summary of COTS VSS Features

Feature	Bendix CVS	Meritor WABCO	Freightliner
VSS Type	**RSC/ESC**	**RSC/ESC**	**RSA**
Currently Installed by OEMs	**Yes**	**Yes**	**Yes**
Wheel Speed Sensing	**Yes**	**Yes**	**Yes**
Lateral Acceleration Sensing	**Yes**	**Yes**	**Yes**
Steer Angle Sensing	**Yes**	**Yes**	**No**
Yaw Rate Sensing	**Yes**	**Yes**	**No**
Engine Throttle Control	**Yes**	**Yes**	**No**
Engine Retarder Control	**Yes**	**Yes**	**No**
Drive Axle Braking Control	**Yes**	**Yes**	**No**
Trailer Axle Braking Control	**Yes**	**Yes**	**No**
Steer Axle Braking Control	**Yes**	**Yes**	**No**
Brake Demand Blending	**Yes**	**Yes**	**No**
Specific Tuning for Each Vehicle Model	**Yes**	**Yes**	**No**
Rollover Advisory Message	**No**	**No**	**Yes**
Data Link Protocol	**J-1587/ J-1939**	**J-1587/ J-1939**	**J-1587/ J-1939**

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