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Crash Problem Definition and Safety Benefits Methodology for Stability Control for Single-Unit Medium and Heavy Trucks and Large-Platform Buses

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16. Abstract

This report presents the findings of a comprehensive engineering analysis of electronic stability control (ESC) and roll stability control (RSC) systems for single-unit medium and heavy trucks and large-platform buses. This report details the applicable crash population of these two vehicle types based on GES data and outlines a methodology to calculate safety benefits from the use of these systems.

Based on 2000-2004 GES data, an average of 147,000 single-unit medium and heavy trucks are involved in police-reported crashes per year. This study estimated that ESC and RSC systems could have helped about 1.5 percent of those vehicles that are involved in crashes, which amounts to about 2,200 single-unit medium and heavy trucks per year. Based on 1996-2007 GES data, an average of 106,000 large-platform buses are involved in police-reported crashes per year. This study estimated that ESC and RSC systems could have helped about 1 percent of those vehicles that are involved in crashes, which amounts to about 1,000 large-platform buses per year.

Although this report presents a methodology to estimate potential safety benefits from the use of ESC and RSC systems on these types of vehicles, no safety benefit estimates were calculated at this time since no ESC or RSC system effectiveness data exists for their use on single-unit trucks or buses.

17. Key Words	18. Distribution Statement
heavy trucks, single-unit, buses, electronic stability control, roll stability control, ESC, RSC, pre-crash scenarios, vehicle safety research, crash avoidance research, crash frequency	This document is available to the public on the NHTSA Web site: www.nhtsa.gov

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PREFACE

The National Highway Traffic Safety Administration in conjunction with the Research and Innovative Technology Administration's Volpe National Transportation Systems Center (Volpe Center) conduct vehicle safety research in crash avoidance and crashworthiness. In particular, extensive analyses have been performed to define the crash and injury problems, identify intervention opportunities, assess the state-of-the-art technology for crash avoidance and injury mitigation systems, and estimate potential safety benefits of promising systems. This research supports NHTSA's mission to save lives, prevent injuries, and reduce health care and other economic costs associated with motor vehicle crashes.

This report presents a summary of Volpe Center work on the topic of electronic stability control and roll stability control systems on single-unit medium and heavy trucks and large-platform buses.

Authors of this report are Marco P. daSilva, Greg Ayres, and Dr. Wassim G. Najm. The NHTSA Program Manager for this study is Alrik L. Svenson.

ACRONYMS

ABS	anti-lock braking system
CG	center of gravity
EBS	electronic braking system
ECU	electronic control unit
ESC	electronic stability control
ESP	electronic stability program
FARS	Fatality Analysis Reporting System
FMCSA	Federal Motor Carrier Safety Administration
GES	General Estimates System
NASS	National Automotive Sampling System
NCSA	National Center for Statistics and Analysis
NHTSA	National Highway Traffic Safety Administration
RSA	roll stability advisors
RSC	roll stability control
RSP	roll stability program
Volpe Center	Volpe National Transportation Systems Center
VSS	vehicle stability systems

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 yard	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
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
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	35.314	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 (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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1. INTRODUCTION

This study researched the latest in electronic stability control and roll stability control systems, queried national crash databases to determine the applicable crash population for single-unit medium and heavy vehicles (gross vehicle weight rating greater than 10,000 lbs) as well as large-platform buses (including school, intercity, and public transportation buses, and bus-platform recreational vehicles), and developed and applied a methodology to provide safety benefits estimates from the use of these systems.

Although a host of State and national vehicle crash databases exist, the National Automotive Sampling System's *General Estimates System* database was selected for this study.[1] The GES is a nationally representative sample of police-reported crashes involving all vehicle types and all severities and results in about 55,000 cases each year. For each crash it includes about 90 data elements, known as variables, collected from police reports that describe the vehicle, physical setting, and all of the people involved in the crash. The GES is limited by the content and accuracy of police reports and, since it is a national estimate of crashes, it has inherent potential sampling errors.

Another national crash database that contains data on all fatal crashes on U.S. public roads, The *Fatality Analysis Reporting System*, was also queried for initial crash estimation.[2] To be included in the FARS, a crash must involve a motor vehicle traveling on a traffic way and result in the death of a person, either a vehicle occupant or a nonmotorist, within 30 days of the crash. This database includes over 100 attributes of the crash, the vehicle(s), and the people involved. It gives an accurate national description of fatal crashes because it includes data on all fatal crashes, not just a representative sample. However, unlike the GES, it does not contain key indicators of vehicle loss of control and therefore it was not used for the detailed crash analysis presented in this report.

2. TECHNOLOGY REVIEW OF VEHICLE STABILITY CONTROL

A literature review of vehicle stability control systems was conducted to collect information on system technical capability so as to identify applicable crash scenarios. This review included recent government reports, academic research, industry bulletins, and trade group literature.

The primary function of vehicle stability control systems is to assist the driver in maintaining control of the vehicle during sudden maneuvers or a loss of traction. Stability control systems help drivers to maintain control of their vehicles in a variety of potentially dangerous situations by automatically taking corrective action, such as during sudden lane changes or while cornering at excessive speed. Stabilization of the vehicle is achieved by selective braking on each wheel while simultaneously reducing engine power. These systems may include brake demand blending, which is the ability of ESC and RSC systems to manage the braking demands of the system and the driver so that the higher braking demand takes precedence. The Federal Motor Carrier Safety Administration offers this description of RSA, RSC, and ESC systems:

> Vehicle Stability Systems (VSS) monitor lateral acceleration from on-board sensors to reduce rollovers due to excessive speed in a curve and/or prevent loss-of-control crashes due to yaw instability. Currently available VSS include Roll Stability Advisors (RSA), Roll Stability Control (RSC) systems, and Electronic Stability Control (ESC) systems, also known as Electronic Stability Programs (ESP).[3]

FMCSA names four vendors and original equipment manufacturers that either manufacture or offer RSA, RSC, and ESC systems on new vehicles: Bendix Commercial Vehicle Systems, Meritor WABCO Vehicle Control Systems, Freightliner LLC, and Volvo Trucks North America.[4]

The main difference between ESC and RSA/RSC is that ESC systems address both loss of directional control incidents (e.g., spinning out or plowing out) and rollovers, while RSA/RSC systems address only rollovers. Truck manufacturers offer RSA and RSC for some straight trucks with or without ESC included. RSA is a passive system that displays an advisory message to the driver within seconds after the event has occurred with the purpose of improving the driver's performance in similar future driving situations.[5] This type of system was not considered in this study.

This study considers the RSC and ESC types of systems. RSC systems monitor the tendency of a vehicle to tip (roll over), such as when negotiating a curve or making a turn. RSC is an "active" system that helps a driver to avoid a rollover by automatically closing the engine throttle and applying the brakes if high lateral force or the likelihood of high lateral forces is found. If the vehicle slows to a safe speed before it starts to tip over, a rollover is prevented.

ESC is a different type of active system with two functions: mitigation of yaw and roll instability and prevention of loss-of-control and rollover. The rollover function operates in the same way as RSC described above. The yaw instability function continuously monitors the vehicle's actual movements, through the yaw rate and lateral acceleration sensors, to appropriate movements given by performance models and current driver inputs (steering wheel position, throttle angle). If the vehicle shows a tendency to spin out or plow out, or if sensors read critical threshold values, the system intervenes by closing the engine throttle and/or modulating the vehicle's brakes individually to help the driver restore directional control.[6] Like RSC systems, the ESC system can reduce throttle and apply proper brake pressure to slow the vehicle and reduce rollover risk. This improves the vehicle handling and performance if there is an impending loss of control due to rotational forces. These forces may occur as a result of rapid lane change or cornering maneuvers on slippery surfaces. ESC is a safety system for commercial vehicles that allows the system to automatically intervene in situations where vehicle stability enters a critical area. ESC operates automatically and intervenes in both the drive train and the brake to support the truck or bus driver, who might not otherwise be able to safely steer or brake the vehicle.[5]

Meritor WABCO offers RSC and ESC systems. Bendix offers full-stability electronic stability program products that include the roll stability program function that mitigates rollovers through advanced sensing and automatic application of the vehicles brakes. ESC/ESP technology is capable of sensing and controlling both directional (yaw) and roll (lateral acceleration) events to maintain vehicle stability. RSC/RSP technology is also commonly referred to as "roll-only stability" system by which only potential vehicle rollover due to high lateral forces (lateral acceleration events) are sensed and controlled in order to help a driver maintain vehicle stability.

Meritor WABCO's RSC applies braking when it senses an impending rollover through sensing lateral acceleration. In RSC, an accelerometer is mounted directly to the electronic control unit (ECU) to monitor the vehicle's lateral acceleration. The system focuses on a vehicle's center of gravity, wheel speed, and the lateral acceleration threshold where rollover may occur. When critical lateral acceleration thresholds are exceeded, RSC intervenes by reducing engine torque, engaging the engine retarder and automatically applying the drive axle and trailer brakes. The deceleration resulting from the intervention reduces the vehicle speed and rollover threshold allowing improved maneuverability and stability. Meritor WABCO also offers an ESC that combines the features of the RSC system with added yaw (horizontal-plane rotation) sensing. Bendix's ESP uses a yaw sensor that enables the ESP to interact with the truck's braking system, adding additional wheel-by-wheel braking that deals very effectively with control on slippery surfaces (in a manner similar to the Meritor WABCO ESC system). The system is capable of recognizing and assisting in understeer and oversteer loss-of-control driving events, as well as in loss of traction situations due to snow, ice, rain, dust, or sand.[8]

Instability events, such as rollovers or loss-of-control situations, often begin with a steering input by the driver. Directional instability occurs when there is a loss of the vehicle's ability to follow the driver's steering, acceleration, or braking input. When a vehicle is in motion, changes in the vehicle path cause yawing or rotation (spin) around a vertical axis at the center of gravity (CG) of a heavy vehicle (tractor or bus)

RSC and ESC systems assist drivers most effectively in situations of excessive (but not reckless) speed and directional control loss on straight or curved roads, usually during abrupt (but not reckless) steering maneuvers.[7] Bendix claims its ESC and RSC systems (both equipped with steering angle sensors and vehicle models) work effectively in nearly all road conditions. Bendix also claims its systems work in the event of low tire pressure or a tire blowout.[8]

Stability systems have limits. They cannot be effective in every type of situation for which their use may be warranted. For example, excessive speed in certain maneuvers can mean that the basic physics of the situation are sufficient to overwhelm the stability system. In these scenarios, while the system may engage, it may not be able to provide enough stopping power quickly enough to prevent a rollover or loss-of-control incident from occurring. While the threshold of incident avoidance may have been surpassed, the system may still have the ability to reduce the severity of the occurrence by reducing the vehicle speed. Other variables can also impact the ability of a stability system to prevent a rollover. They cannot prevent control loss due to disabling vehicle failures (e.g., loss of a wheel) or a total loss of road friction. ESC does not work as well on cross sloped shoulders or steeply banked roads unless the lateral acceleration due to gravitational forces on the truck from the angled road surface are accounted for in the system algorithm. RSC cannot help prevent tripped rollovers caused by other vehicles, road debris, guardrails, ditches, soft soil, transitions from a low friction surface to dry pavement, and the like. Conversely, ESC can help prevent tripped rollovers by assisting the driver in avoiding these hazards. The systems, especially RSC, are compromised on trucks and buses without well functioning brakes at all four corners. Sloshing liquid or moving solid cargo loads can also compromise ESC and RSC performance. As well, neither a roll-only or full-stability system will be able to abate incidents where the driver is incapacitated. These characteristics are summarized in Table 1.

Table 1: RSC and ESC Characteristics

	Roll Stability Control	Electronic Stability Control	
Application/ Function	Rollover Function (Standalone Without ESC)	Rollover Function	Yaw Stability Function
Driver/system interface	None	None	None
Operating conditions	Moving vehicle	Moving vehicle	Moving vehicle
Operational performance	Uses lateral acceleration sensors to detect impending rollovers and closes throttle and applies brakes to assist driver to prevent crash	Uses lateral acceleration and steering angle sensors to detect impending rollovers and closes throttle and applies brakes to assist driver to prevent crash	Uses yaw rate and steering angle sensors to detect loss of directional control or yaw instability and closes throttle and/or applies brakes at appropriate wheel to reduce yaw instability and assist driver to prevent crash
System Limitations	Cannot prevent all rollovers due to disabling vehicle failures, some abrupt steering maneuvers at high speeds, tripping, road departure Less effective without all brakes functioning Less effective with sloshing liquid/moving solid loads	Cannot prevent all rollovers due to disabling vehicle failures, abrupt steering maneuvers at high speeds, tripping, road departure Less effective without all brakes functioning Less effective with sloshing liquid/moving solid loads	Cannot prevent all sliding incidents due to disabling vehicle failures, abrupt steering maneuvers at high speeds, total loss of traction Not effective without functioning brakes at all four corners Less effective on cross sloped shoulders or steeply banked roads

The conditions listed in Table 1 give rise to three crash types that are preventable with RSC and ESC systems functioning. These crash types are defined by their outcomes: rollover, other single vehicle crash, and multiple vehicle crash. These crash types are described in Table 2.

Table 2: Crash Types Preventable With RSC and ESC Systems

Crash outcome	Characteristics	Conditions	RSC/ESC role
Rollover (Untripped)	Vehicle rolls over due to steering inputs and vehicle speed only	Vehicle stays on road and does not encounter tripping mechanisms	RSC and ESC help drivers reduce vehicle speed to avoid crash
Rollover (Tripped)	Vehicle rolls over due to tripping mechanisms (on or off road) encountered as a result of a loss of directional control	Driver is alert and capable of avoiding the hazards	ESC helps driver stay on road and steer around hazards
Other Single Vehicle Crash	Vehicle collides with objects (on or off road) due to loss of directional control	Driver is alert and capable of avoiding the hazards	ESC helps driver stay on road and steer around hazards
Multiple Vehicle Crash	Vehicle collides with other vehicles (on or off road) due to loss of directional control	Driver is alert and capable of avoiding the hazards	ESC helps driver stay on road and steer around hazards

3. CRASH OVERVIEW

Two crash databases, the FARS and GES, were selected for analysis in order to estimate the target crash population and estimate potential safety benefits. As previously stated, the GES is a nationally representative sample of police reported crashes involving all vehicle types and all severities and results in about 55,000 cases each year.[1] The FARS is another national crash database that contains data on all fatal crashes on U.S. public roads.[2]

This section presents the results of an initial query using the 2004 FARS and 2004 GES databases, respectively, which contain analyses of fatal crashes and all police-reported crashes involving single-unit medium and heavy trucks and large-platform buses. A single year, 2004, was chosen for the purpose of comparing different data sources including FARS and GES as an initial first step for this study. Variables were chosen to capture the most relevant recent crash data for the vehicle and crash types considered. Each database was queried to get a count of medium and heavy truck and bus rollover crashes that ESC/RSC systems could help prevent. ESC/RSC systems are designed to help drivers avoid rollovers that occur due to excessive (but not reckless) speed and some abrupt maneuvers, not the result of a collision or roadway departure. Thus, each database was queried for rollovers that occurred as the first harmful event of a crash, before which the driver attempted corrective action but failed to prevent the rollover.

Single-unit medium and heavy trucks are defined in FARS by the codes 61-64 in the *Body Type* variable found in the *Vehicle Level* file.[2] The GES defines these vehicles in the same variable name using only code 64, found in the *Vehicle File.*[1]

Large-platform buses are defined in FARS using the *Body Type* variable with the codes 50-59.[2] These buses are defined by the codes 50, 58, and 59 in the *Body Type* variable in the GES.[1]

Appendix A contains the definitions for the GES and FARS variables and codes used in this study.

3.1. FARS Results

The 2004 FARS data were queried to determine the number of rollover fatal crashes involving single-unit medium and heavy trucks and large-platform buses.

3.1.1. Single-Unit Medium and Heavy Trucks

The 2004 FARS data revealed that a total of 1,398 fatal crashes involved single-unit medium or heavy trucks, as shown in Figure 1. The truck rolled over, as denoted by the FARS *Rollover* codes 1 or 2, in 209 of those crashes or in roughly 15 percent of all single-unit medium- and heavy-truck-involved crashes. Of those, most were tripped rollovers (93%). A steering avoidance maneuver was reported in roughly 26 percent of those rollovers. The truck rolled over in 24 percent of the 54 fatal crashes in which steering evasive maneuvers were attempted prior to the crash. Steering maneuvers were identified from the *Crash Avoidance Maneuver* variable in the FARS *Vehicle Level* file, using codes 4 and 5.

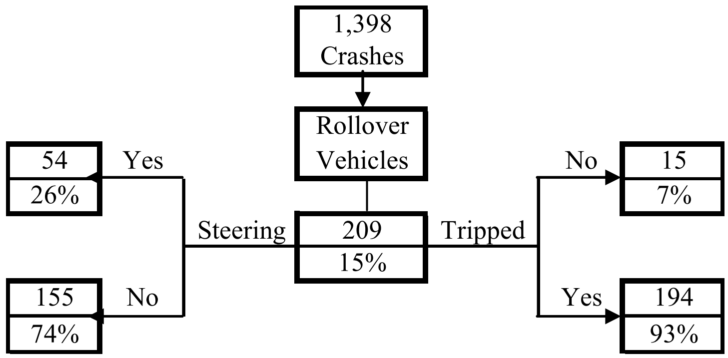

Figure 1. Fatal Crashes Involving Single-Unit Medium and Heavy Trucks (2004 FARS)

3.1.2. Large-Platform Buses
The 2004 FARS data revealed that a total of 274 fatal crashes involved large-platform buses, as shown in Figure 2. These buses rolled over in 9 of those crashes or in roughly 3 percent of all fatal crashes involving large-platform buses. Of those, all were tripped rollovers and only one contained an indication of a steering avoidance maneuver. The bus rolled over in only 5 percent of all steering evasive maneuvers that were attempted prior to all fatal crashes.

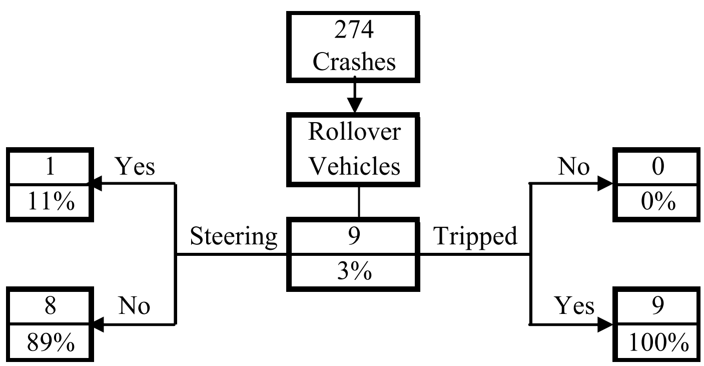

Figure 2. Fatal Crashes Involving Large-Platform Buses (2004 FARS)

3.2. GES Results

The 2004 GES data were also queried to determine the number of police-reported rollover crashes involving single-unit medium and heavy trucks and large-platform buses.

3.2.1. Single-Unit Medium and Heavy Trucks
The 2004 GES data revealed that a total of 130,000 police-reported crashes involved single-unit medium or heavy trucks, as shown in Figure 3. The truck rolled over in 6,000

of those crashes or in roughly 5 percent of all police-reported single-unit medium- and heavy-truck-involved crashes. Rollover is identified in the GES by code 1 of the *First Harmful Event* variable in the *Accident File*. Tripped rollovers were dominant at 83 percent of all rollover crashes. The *Rollover Type* variable in the GES *Vehicle File* indicates a tripped rollover by the codes 20-29. This variable indicates if a rollover, tripped or untripped, has occurred. The GES defines rollover as any vehicle rotation of 90 degrees or more about any true longitudinal or lateral axis. Rollover can occur at any time during the crash. A steering avoidance maneuver was reported in roughly one-third of those rollovers. The GES *Corrective Action Attempted* variable describes the actions taken by the driver in response to an impending danger just prior to the first harmful event. Steering maneuvers are defined in codes 6-9. The truck rolled over in 20 percent of all steering evasive maneuvers that were attempted prior to all police-reported crashes.

In comparison to the FARS data, the fatality rate for crashes involving single-unit medium and heavy trucks was about 1.1 percent (1,398/130,000). However, the fatality rate of crashes involving and resulting in single-unit medium and heavy truck rollovers was 3.5 percent (209/6,000). This indicates the significant injury risk increase associated with rollovers.

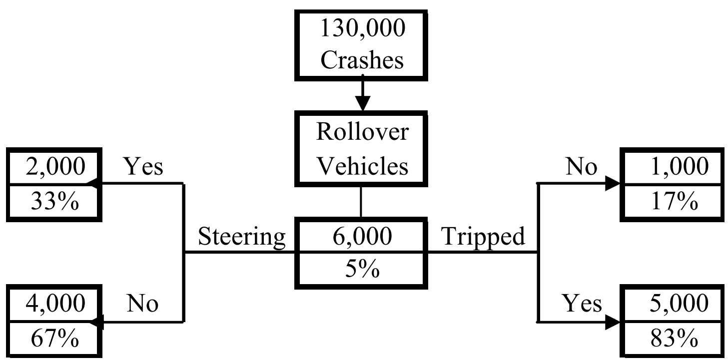

Figure 3. Police-Reported Crashes Involving Single-Unit Medium and Heavy Trucks (2004 GES)

3.2.2. Large-Platform Buses

The 2004 GES data revealed that a total of 98,000 police-reported crashes involved large-platform buses, as shown in Figure 4. These buses rolled over in 294 of those crashes or in roughly 0.3 percent of all police-reported crashes involving large-platform buses. Of those, most were tripped rollovers (96%). None of the bus rollovers involved a steering avoidance maneuver.

In comparison to the FARS data, the fatality rate for crashes involving large-platform buses was about 0.3 percent (294/98,000). However, the fatality rate of crashes involving and resulting in large-platform bus rollovers was 3.1 percent (9/294). Similar to truck results, this indicates a higher injury risk with rollovers.

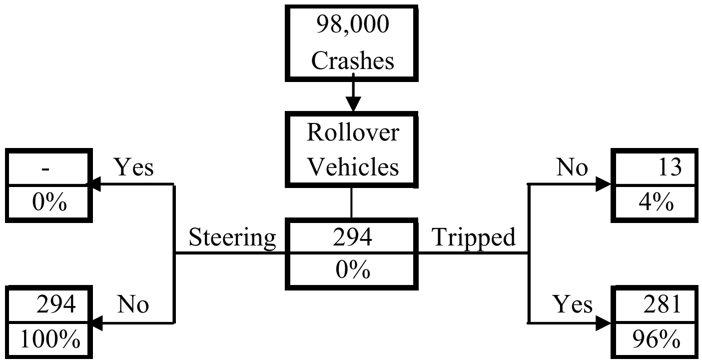

Figure 4. Police-Reported Crashes Involving Large-Platform Buses (2004 GES)

3.3. GES Results – Untripped Rollover Statistics

The 1996-2007 GES data was queried to obtain baseline statistics on the number of crashes, fatalities, and injuries for untripped rollovers and control loss crashes. The analyses were conducted on both the vehicle level and occupant level. Details of this analysis are contained in Appendix B. As shown in the tables in Appendix B, large differences in the sample sizes are apparent between years per body type. However, it should be noted that this is really due to the small sample size of these vehicle types in the GES and not a real indication of a "trend". Thus, the yearly average data from 12 years of GES data provides more accurate statistical description of the crash problem size for single-unit medium and heavy trucks and large-platform buses.

The sum of the years of life lost to fatal injuries and years of functional capacity lost to nonfatal injuries was used for the calculation of functional years lost, a measure that provides a non-monetary measure of time lost as a result of motor vehicle crashes.[9]

For the purposes of this study, untripped rollovers were defined by the following GES variables and codes: *ROLLOVER* = 10 AND *PCRASH4* = 1 AND *REL_RWY* = 1 AND *EVENT1* = 1.[1] This combination of variables and codes identify all untripped rollovers, with vehicle tracking, on roadway, and with rollover being the first harmful event.

3.3.1. Single-Unit Medium and Heavy Trucks

Based on GES statistics, there was an average of 125 single-unit medium and heavy trucks involved in untripped rollovers per year over that period. This average is about 10 percent of all vehicle types involved in untripped rollovers. The yearly distribution is shown in Figure 5 below. Only 0.11 percent of all single-unit medium and heavy trucks involved in crashes were associated with untripped rollover. This statistic is only 0.01 percent of all other vehicle types.

The analysis also indicated that four persons were killed in single-unit medium and heavy truck crashes based on a yearly average from 1996 through 2007. However, it should be noted that the GES underestimates fatalities. In terms of functional years lost, 266 functional years lost per year were estimated for single-unit medium and heavy trucks in untripped rollovers. This average accounts for 11.4 percent of all functional years lost suffered by all vehicle types in untripped rollovers. Only 1.71 percent of all functional years lost by all single-unit medium and heavy trucks involved in crashes were associated with untripped rollover. This statistic is only 0.07 percent of all functional years lost by other vehicle types. The yearly distribution is shown in below in Figure 6 and further details are contained in Appendix B.

3.3.2. Large-Platform Buses

There were no buses involved in untripped rollovers in GES data.

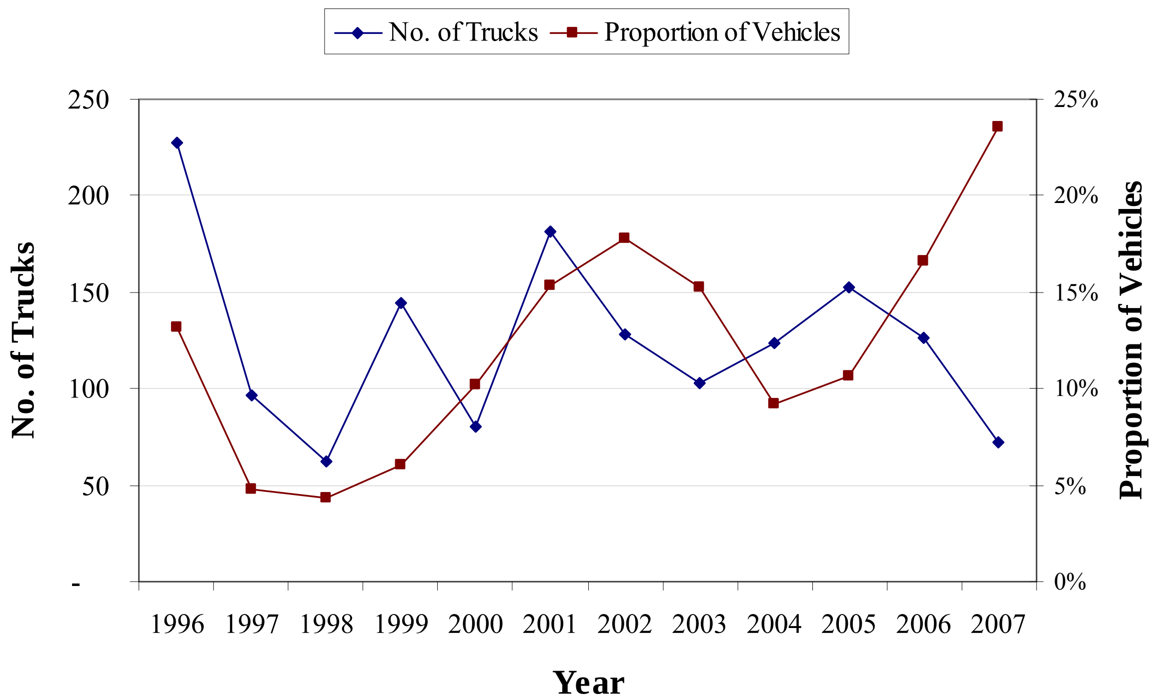

Figure 5. Number and Proportion of Single-Unit Medium and Heavy Trucks Identified as Untripped Rollovers

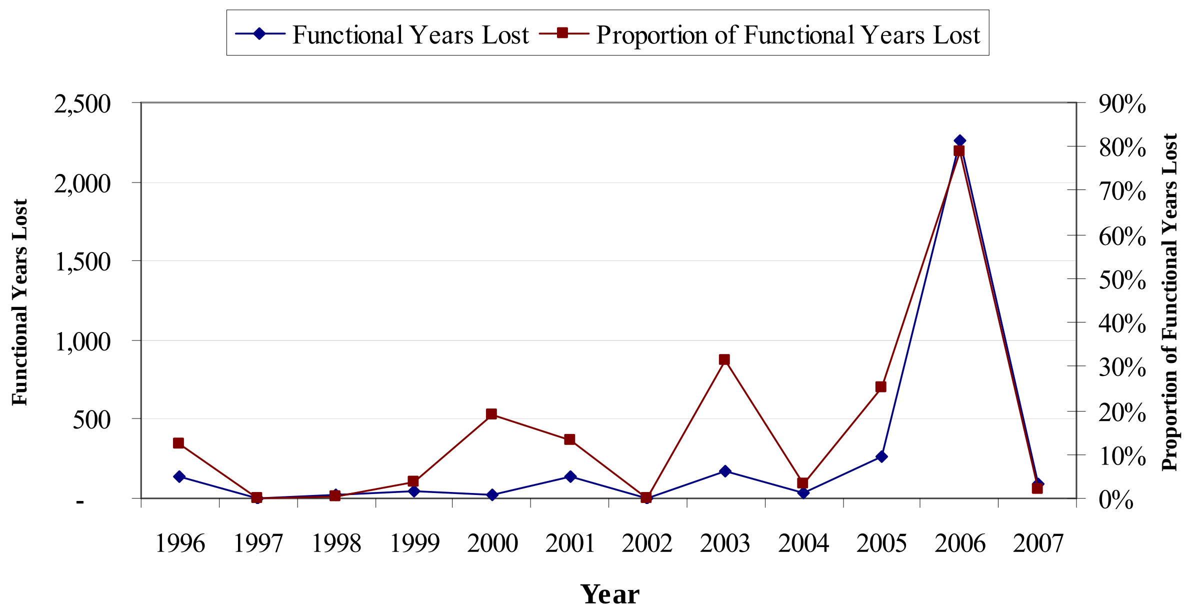

Figure 6. Number and Proportion of Functional Years Lost From Crashes Involving Single-Unit Medium and Heavy Trucks Identified as Untripped Rollovers

3.4. GES Results – Control Loss Statistics

For the purposes of this study, control loss crashes were defined by the following GES variables and codes: GES years 1996-1998: (*P_CRASH2* = 10, 20, 30, 40, 50, 60, 99 or *PCRASH4* = 2, 3, 4, 9, 98 or *ACC_TYPE* = 2, 7, 34, 36, 54, 56), GES years 1999-later: (1≤*P_CRASH2*≤9 or 2≤*PCRASH4*≤7) or *ACC_TYPE* = 2, 7, 34, 36, 54, 56. This combination of variables and codes identify all crashes that contain a clear indication of vehicle control loss.

3.4.1. Single-Unit Medium and Heavy Trucks

Based on GES statistics from 1996 through 2007, there was an average of 9,000 single-unit medium and heavy trucks involved in control loss crashes per year. This average is about 0.8 percent of all vehicle types involved in control loss crashes. The yearly distribution is shown in Figure 7 below. About 8.1 percent of all single-unit medium and heavy trucks involved in crashes were associated with control loss. This statistic is only 10.0 percent of all other vehicle types (excluding large-platform buses).

The GES indicates that 45 people were killed in this vehicle type based on a yearly average from 1996 through 2007. Again, it should be noted that the GES underestimates fatalities. In terms of functional years lost, 4,282 functional years lost per year were estimated for single-unit medium and heavy trucks in control loss crashes. This average accounts for 0.5 percent of all functional years lost suffered by all vehicle types in control loss crashes. About 27.5 percent of all functional years lost by all single-unit medium and heavy trucks involved in crashes were associated with control loss crashes. This statistic is 28.3 percent of all functional years lost by other vehicle types (excluding large-platform buses). The yearly distribution is shown in below in Figure 8 and further details are contained in Appendix B.

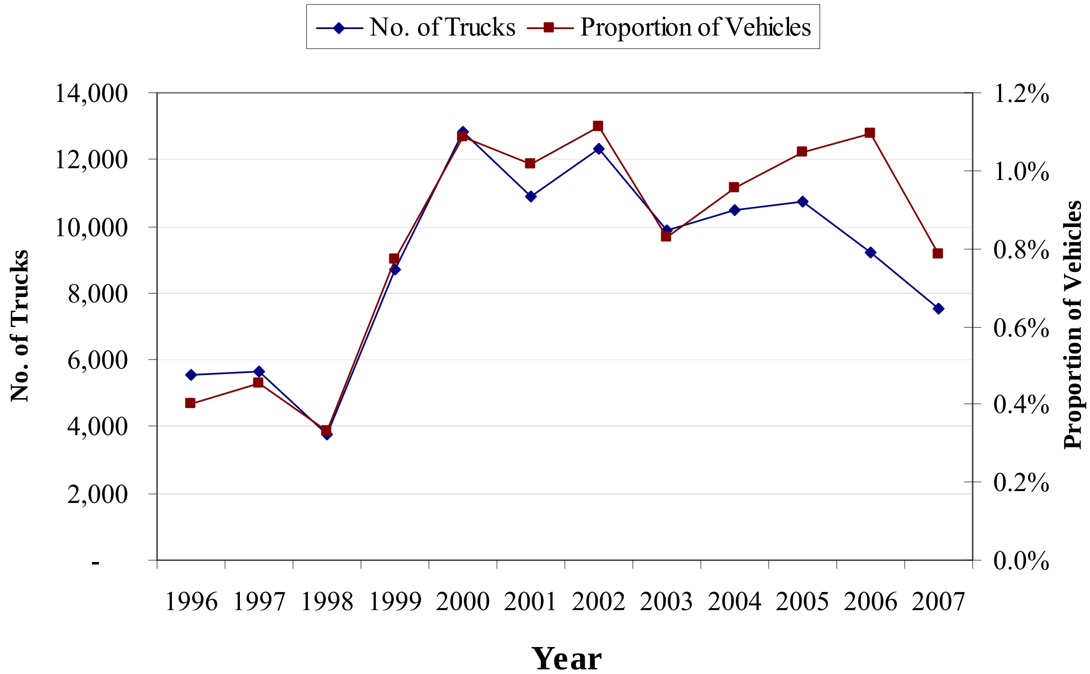

Figure 7. Number and Proportion of Single-Unit Medium and Heavy Trucks Identified as Control Loss

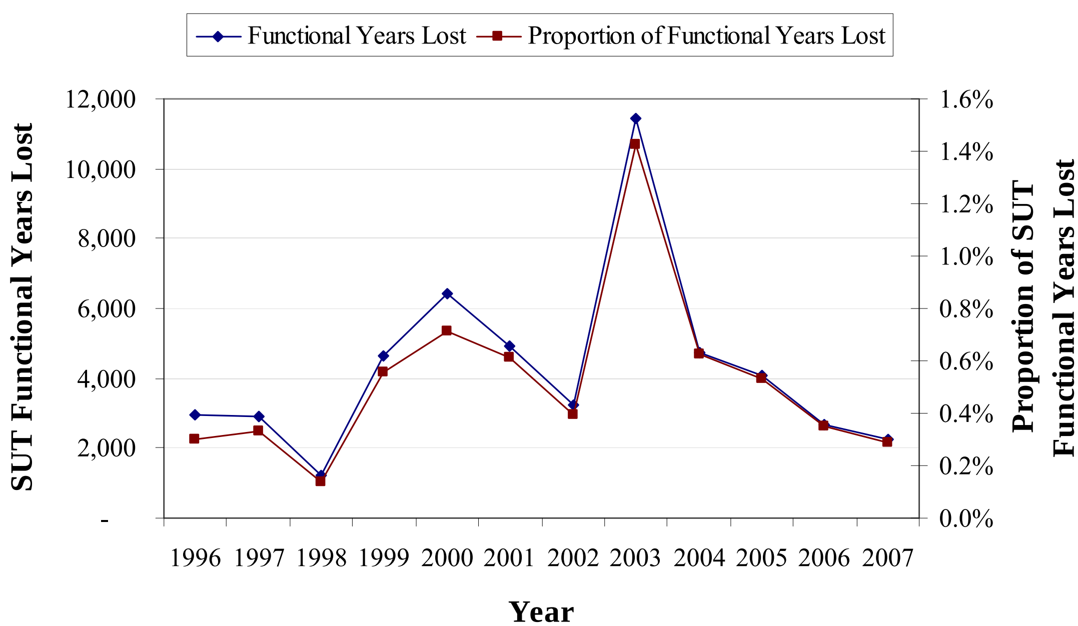

Figure 8. Number and Proportion of Functional Years Lost From Crashes Involving Single-Unit Medium and Heavy Trucks Identified as Control Loss

3.4.2. Large-Platform Buses
Based on GES statistics from 1996 through 2007, there was an average of 1,500 large-platform buses involved in control loss crashes per year. This average is about 0.13 percent of all vehicle types involved in control loss crashes. The yearly distribution is shown in Figure 9 below. About 2.7 percent of all large-platform buses involved in crashes were associated with control loss. This statistic is only 10.0 percent of all other vehicle types (excluding single-unit medium and heavy trucks).

The GES indicates that only one person was killed in this vehicle type based on a yearly average from 1996 through 2007. In terms of functional years lost, 720 functional years lost per year were estimated for large-platform buses involved in control loss crashes. This average accounts for 0.09 percent of all functional years lost suffered by all vehicle types in control loss crashes. Only 7.3 percent of all functional years lost by all large-platform buses involved in crashes were associated with control loss crashes. This statistic is 28.3 percent of all functional years lost by other vehicle types (excluding single-unit medium and heavy trucks). The yearly distribution is shown in below in Figure 10 and further details are contained in Appendix B.

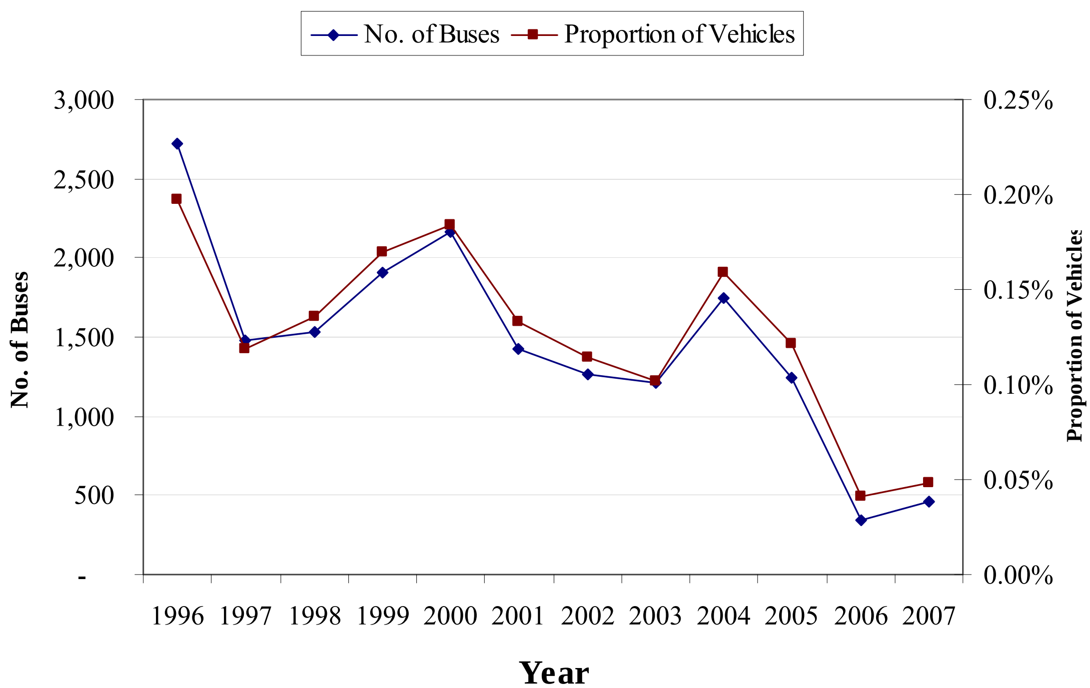

Figure 9. Number and Proportion of Large-Platform Buses Identified as Control Loss

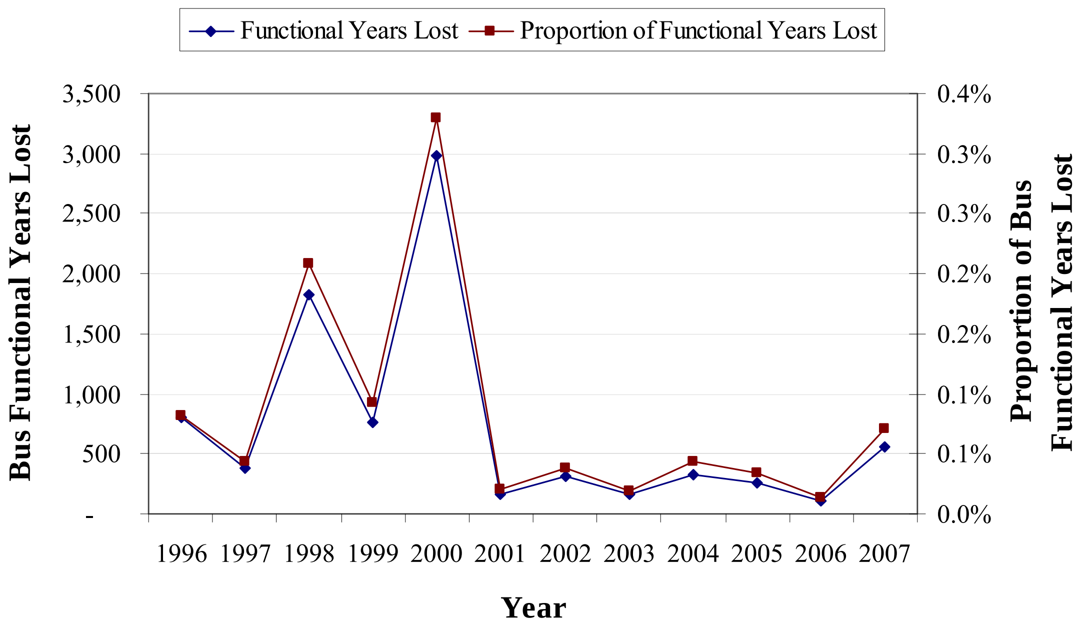

Figure 10. Number and Proportion of Functional Years Lost From Crashes Involving Large-Platform Buses Identified as Control Loss

4. DETAILED ANALYSIS OF APPLICABLE SINGLE-UNIT MEDIUM AND HEAVY TRUCK CRASHES

Although relevant crashes can be found in both GES and FARS, the former was chosen for a more detailed analysis because only the GES provides nationwide representative crash population estimates. FARS covers only fatal crashes. Furthermore, the FARS data sets do not contain the *Accident Type* and *Critical Event* variables used in this study to assess the vehicle stability. Therefore, only GES data are used in this detailed analysis presented in this and subsequent sections. It should be noted, however, that the FARS results presented in Section 3 correlate well with the NHTSA's *National Center for Statistics and Analysis Traffic Safety Facts* data reports.[10]

A total of 5 years of GES data, using the 2000-2004 data sets, were used for the analysis of single-unit medium and heavy truck crashes. A total of 735,000 of these types of trucks were involved in police-reported crashes over this 5-year period, averaging about 147,000 per year. The applicable crash population was determined by the querying the data based on four different filters as described below. The logic and variables used within each of these four filters are shown in flowcharts in this Section.

4.1. Filter Definitions

For each filter, GES variables were carefully selected to represent as faithfully as possible all the crash types preventable with ESC and RSC (listed in Table 2). In addition, GES variables were carefully chosen to represent as closely as possible the conditions in Table 1 under which ESC and RSC perform the best.

Four queries were constructed using four different filters. Within each filter, one data set captured all the crashes that the yaw instability function of ESC could address (filters labeled 1a, 2a, 3a, and 4a), while a second data set captured all the crashes that RSC alone or the rollover function of ESC could address (filters labeled 1b, 2b, 3b, and 4b). The total number of crashes addressed by ESC (roll and yaw instability combined) is the sum of the two data sets within each filter.

The four filters varied in the number of restrictions used to qualify crashes for the crash population. A tradeoff in precision is implied when a filter with many restrictions is chosen over a more general one. Filters 3 or 4 included only crashes that were very likely to be prevented by use of ESC and RSC systems. However, these filters required data that were precisely and correctly coded to avoid losing relevant crashes that were not well coded. Filters 1 and 2 contained fewer restrictions and therefore included more of these crashes, but were also more likely to include crashes that were not truly relevant to ESC and RSC systems. An example is the case of the GES variable *Precrash Vehicle Control* in the *Vehicle File*. This variable assesses the stability of the vehicle during the period immediately prior to the vehicle's initial involvement in the crash sequence. Code 2 of this variable indicates longitudinal skidding, with rotation less than 30 degrees. This might be the case when a driver swerves to avoid a hazard or roadway departure but the vehicle under steers (plows out). In this case, ESC would engage to help the driver steer through the turn. However, panic braking could also cause the longitudinal skidding, which reduces or eliminates steering control. In most of these cases, ABS would help the driver maintain steering control, and ESC would not engage (today's ESC systems are coupled with ABS). The GES data do not indicate whether or not a given vehicle was equipped with ABS or whether longitudinal skidding was due to panic braking. Queries 1, 2, and 3 include all crashes with longitudinal skidding, whereas Query 4 does not.

4.2. First Filter

The first filter, as defined in the flowchart contained in Figure 11, was the least restrictive of all four filters. This filter was applied to the 5-year total single-unit medium and heavy truck crash population and identified an ESC and/or RSC applicable crash size averaging about 12,000 single-unit medium and heavy trucks per year, or about 8.1 percent of all single-unit medium and heavy trucks involved in all types of crashes over the 5-year period. These estimates were based on a total of 1,893 single-unit medium and heavy truck vehicle files in the 2000-2004 GES.

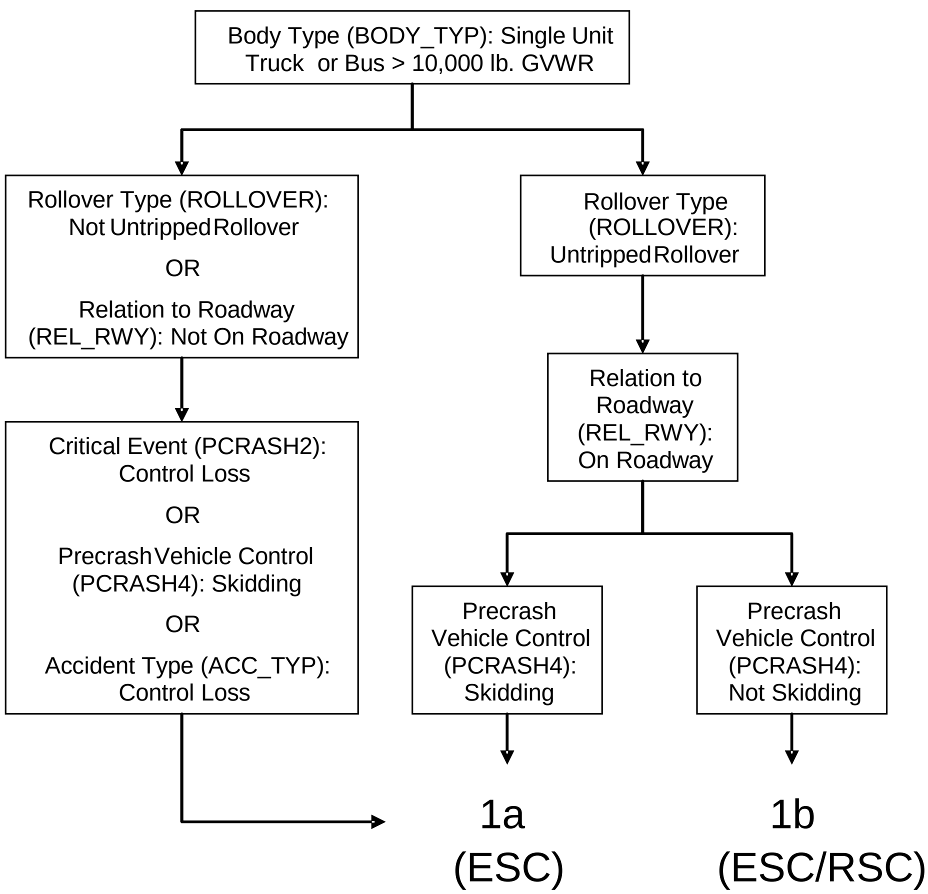

Figure 11. Filter 1 Flowchart

4.2.1. ESC

Filter labeled 1a, which was the first filter for ESC-applicable crashes, targeted those in which the vehicle data for the single-unit medium and heavy truck indicated any of the following:

- Vehicle loss of control in untripped rollover on the roadway (GES variables: *Critical Event = 1-9*, *Rollover Type = 10*, *Relation to Roadway = 1*)
- Tripped rollover (GES variable: *Rollover Type = 20-29*)
- Crashes off the roadway (GES variable: *Relation to Roadway = 2-10*)

The *Critical Event* variable in the GES *Vehicle File* identifies the event that made the crash imminent. The *Relation to Roadway* variable in the GES *Accident File* indicates the location of the first harmful event. A yearly average of 11,600 single-unit medium and heavy trucks satisfied these filter conditions. These corresponded to about 7.9 percent of the overall single-unit medium and heavy truck crash population. The types of control loss associated with these trucks were also analyzed. The applicable population was broken down by three GES variables by a process of elimination through the following order: *Critical Event*, *Precrash Vehicle Control*, and *Accident Type*. The GES *Vehicle File* contains the *Accident Type* variable that categorizes the precrash situation.

Over 5,000, or 45 percent, of the applicable truck population per year identified by filter 1a were identified by the *Critical Event* variable. The values valid for this identifier of control loss and their relative frequency are shown in Figure 12. Almost one half of all applicable trucks identified through this variable contained the value of *Excessive Speed*.

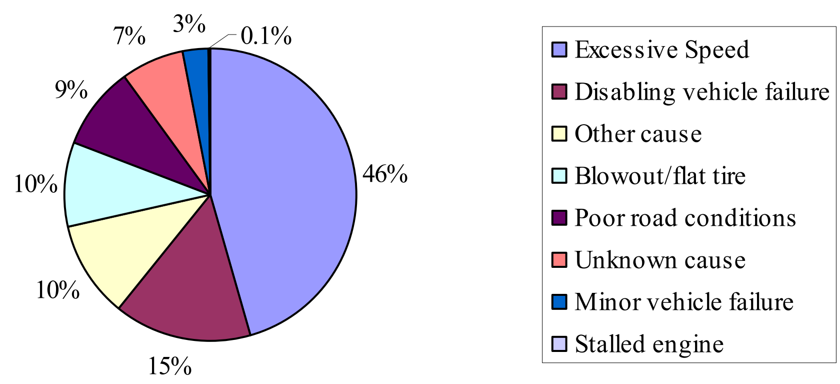

Figure 12. Filter 1a – *Critical Event* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

Another 6,000 per year, or 53 percent, of the applicable truck population contained a control loss identifier within the *Precrash Vehicle Control* variable. Figure 13 shows the values valid for this filter and their relative frequency. About 81 percent of the trucks identified through this variable indicated a longitudinal skidding condition just prior to crash.

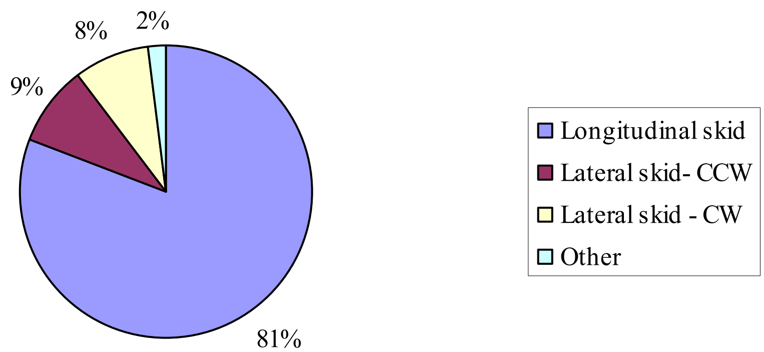

Figure 13. Filter 1a – *Precrash Vehicle Control* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

A further 200 single-unit medium and heavy trucks per year, or 2 percent, of the applicable truck population was identified by the *Accident Type* variable. The values valid for this filter and their relative frequency are shown in Figure 14.

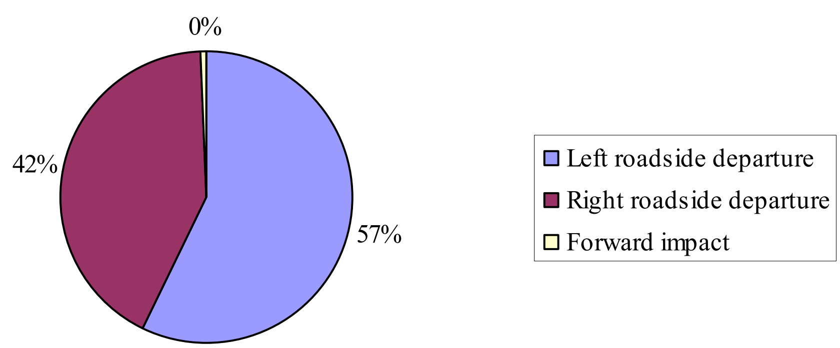

Figure 14. Filter 1a – *Accident Type* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

4.2.2. RSC

Filter labeled 1b, which was the first filter for RSC-applicable crashes, targeted those in which the vehicle data for the single-unit medium and heavy trucks indicated no vehicle loss of control in untripped rollover on the roadway (GES variables: *Critical Event = 10-98*, *Rollover Type = 10*, *Relation to Roadway = 1*).

A total of 2,000 single-unit medium and heavy trucks over the 5-year period, or about 400 per year, satisfied this filter condition, which corresponded to about 0.2 percent of the overall single-unit medium and heavy truck crash population. The causes of these untripped rollovers associated with these trucks were also analyzed. The applicable population was broken down by two GES variables by a process of elimination through the following order: *Critical Event*, and *Accident Type*. About 72 percent of the applicable truck population identified by filter 1b was identified by the *Critical Event* variable, and the contributing factors to these rollover crashes based on *Critical Event* are shown in Figure 15. The remaining 28 percent of the applicable single-unit medium and heavy truck population was identified by the *Accident Type* variable.

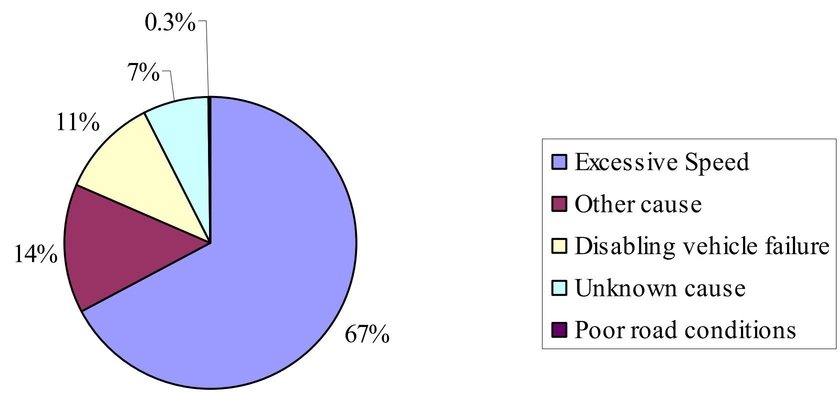

Figure 15. Filter 1b – *Critical Event* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

4.3. Second Filter

The second filter, as defined in the flowchart contained in Figure 16 (red font denotes changes from preceding filter), was the second-least restrictive. Similarly to filter 1, it was applied to the 5-year total single-unit medium and heavy truck crash population. Overall, the second filter identified an ESC and/or RSC applicable crash size averaging about 11,000 single-unit medium and heavy trucks per year, or about 7.4 percent of all single-unit medium and heavy trucks involved in all types of crashes over the 5-year period.

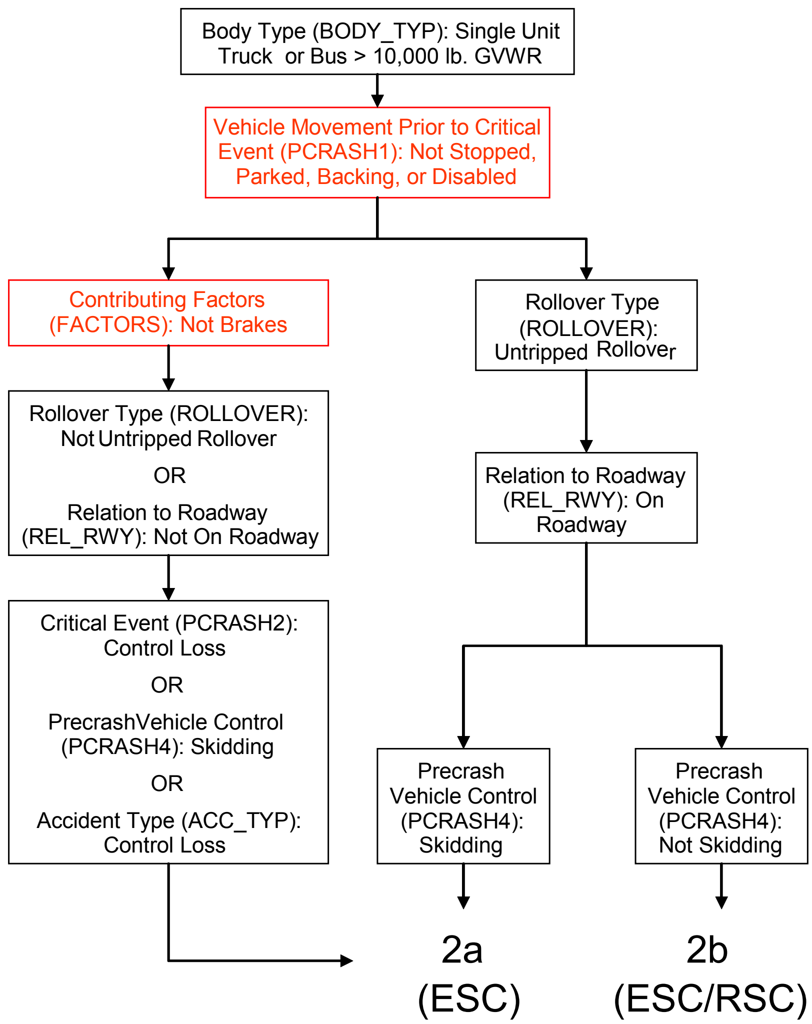

Figure 16. Filter 2 Flowchart

4.3.1. ESC

Filter labeled 2a, which was the second filter for ESC-applicable crashes, targeted the same truck population as defined in filter 1a but with the added restrictions as follows:

- Not performing a backing maneuver (GES variables: *Movement Prior to Critical Event* $\neq 13$)
- Brakes failure (GES variable: *Vehicle Contributing Factors* = *2*)

The *Movement Prior to Critical Event* variable in the GES *Vehicle File* records the attribute that best describes the vehicle's activity prior to the driver's realization of an impending critical event or just prior to impact if the driver took no action or had no time to attempt any evasive maneuver. The *Vehicle Contributing Factors* variable in the GES *Vehicle File* indicates vehicle factors that may have contributed to the cause of the crash. A yearly average of 10,600 single-unit medium and heavy trucks satisfied these filter conditions. These corresponded to about 7.2 percent of the overall single-unit medium and heavy truck crash population. The types of control loss associated with these trucks were also analyzed. The applicable population was broken down by three GES variables by a process of elimination through the following order: *Critical Event*, *Precrash Vehicle Control*, and *Accident Type*.

About 42 percent of the applicable truck population, amounting to 4,400 per year, identified by filter 2a were identified by the *Critical Event* variable. The values valid for this identifier of control loss and their relative frequency are shown in Figure 17. Just over half of all applicable trucks identified through this variable contained the value of *Excessive Speed*.

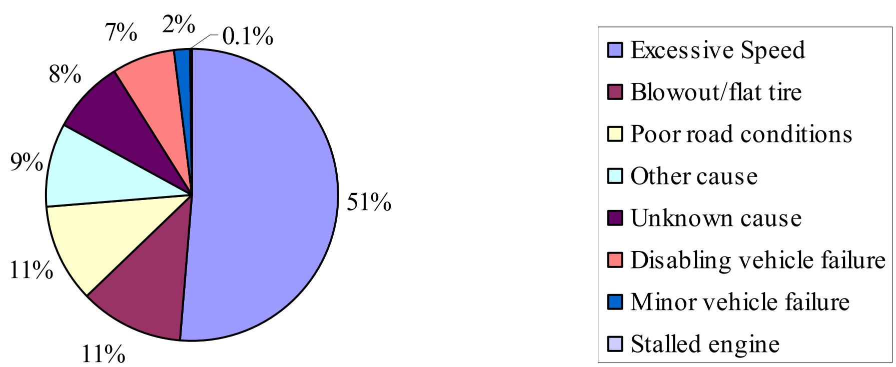

Figure 17. Filter 2a – *Critical Event* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

Another 56 percent of the applicable truck population, amounting to 6,000 per year, contained a control loss identifier within the *Precrash Vehicle Control* variable. The values valid for this filter and their relative frequency are shown in Figure 18. About 82 percent of the truck vehicle files identified through this variable indicated a longitudinal skidding condition just prior to crash.

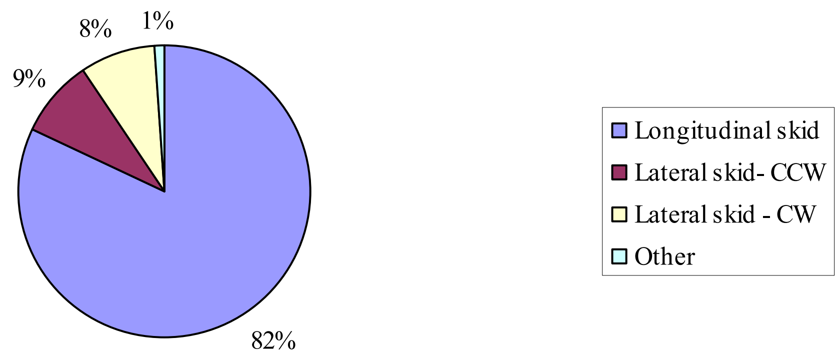

Figure 18. Filter 2a – *Precrash Vehicle Control* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

A further 2 percent of the applicable single-unit medium and heavy truck population was identified by the *Accident Type* variable. The values valid for this filter and their relative frequency are shown in Figure 19.

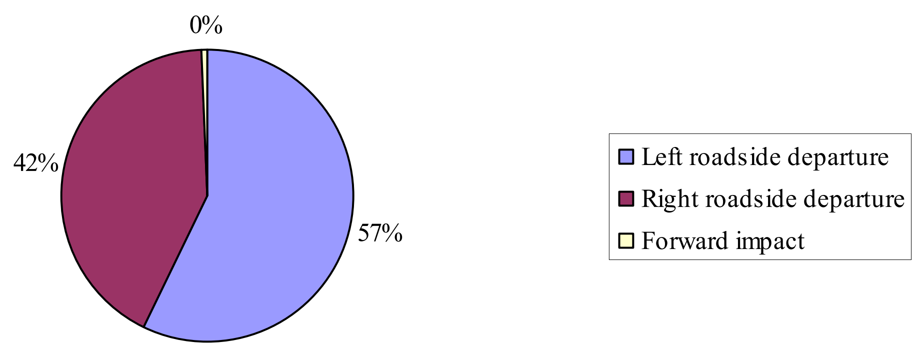

Figure 19. Filter 2a – *Accident Type* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

4.3.2. RSC

Filter labeled 2b, which was the second-least restrictive filter for RSC-applicable crashes, targeted the same truck population as defined in filter 1b but with the added restriction as follows:

- Not performing a backing maneuver (GES variables: *Movement Prior to Critical Event* $\neq$ *13*)

Even though this filter incorporated an added restriction, the target single-unit medium and heavy truck population remained the same and therefore the results for filter 2b mirror the results presented above for filter 1b.

4.4. Third Filter

The third filter, as defined in the flowchart contained in Figure 20 (red font denotes changes from preceding filter), was more restrictive than the previous two. Overall, the third filter identified an ESC and/or RSC applicable crash size averaging about 7,600 single-unit medium and heavy trucks per year, or about 5.2 percent of all single-unit medium and heavy trucks involved in all types of crashes over the 5-year period.

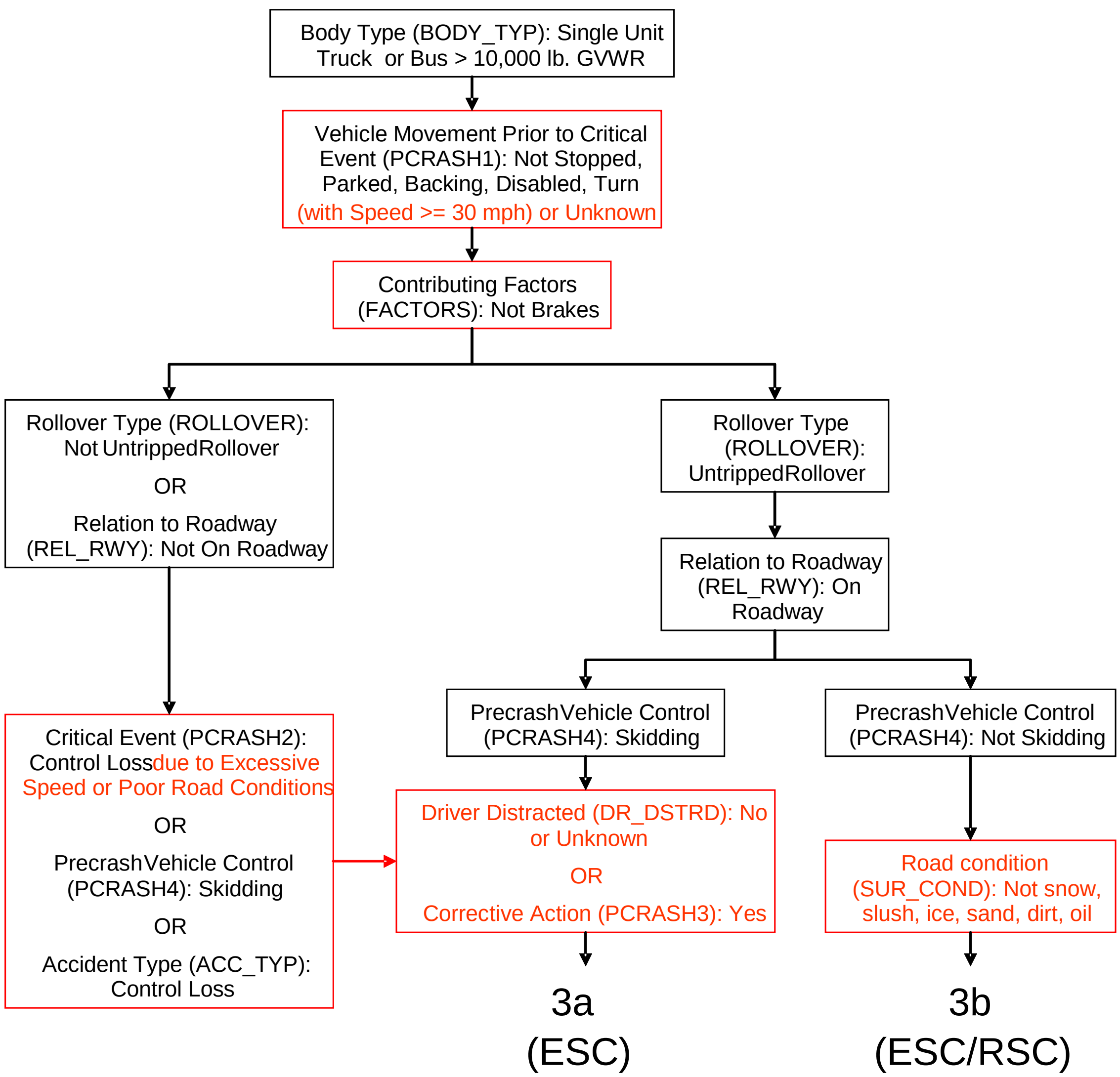

Figure 20. Filter 3 Flowchart

4.4.1. ESC

Filter labeled 3a, which was the third filter for ESC-applicable crashes, targeted the same truck population as defined in filter 2a but with the added restrictions as follow:

- Not performing a turning maneuver (GES variables: *Movement Prior to Critical Event* $\neq$ *10-12*)
- Not traveling at low travel speed (GES variable: *Travel Speed* $\geq$ *30 mph*)
- Control loss type was limited to poor road conditions or excessive speed (GES variable: *Critical Event* = 5 or 6)
- Corrective action was attempted (GES variable: *Corrective Action Attempted= 2-98*)

A yearly average of 7,400 single-unit medium and heavy trucks satisfied these filter conditions. These corresponded to about 5.0 percent of the overall single-unit medium and heavy truck crash population. The types of control loss associated with these trucks were also analyzed. The applicable population was broken down by three GES variables by a process of elimination through the following order: *Critical Event*, *Precrash Vehicle Control*, and *Accident Type*.

About 22 percent of the applicable truck population identified by filter 3a, amounting to 4,400 per year, were identified by the *Critical Event* variable. The two values valid in this filter for this identifier of control loss, along with their relative frequency, are shown in Figure 21. About 80 percent of all vehicle files of the applicable trucks identified through this variable contained the value of *Excessive Speed*.

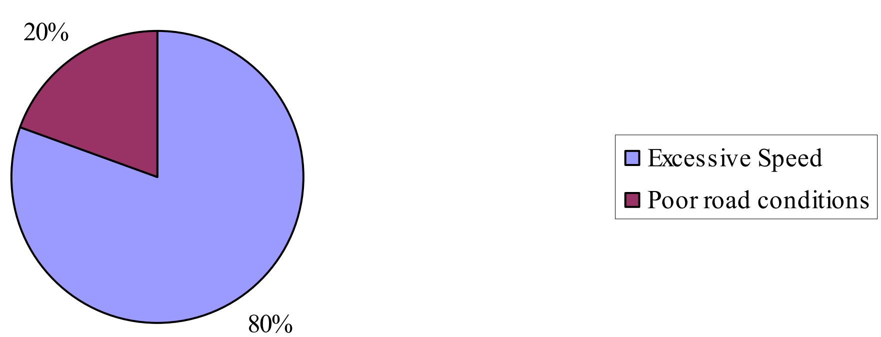

Figure 21. Filter 3a – *Critical Event* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

Another 76 percent of the applicable truck population, amounting to over 5,600 per year, contained a control loss identifier within the *Precrash Vehicle Control* variable. The values valid for this filter and their relative frequency are shown in Figure 22. About 84 percent of the truck vehicle files identified through this variable indicated a longitudinal skidding condition just prior to crash.

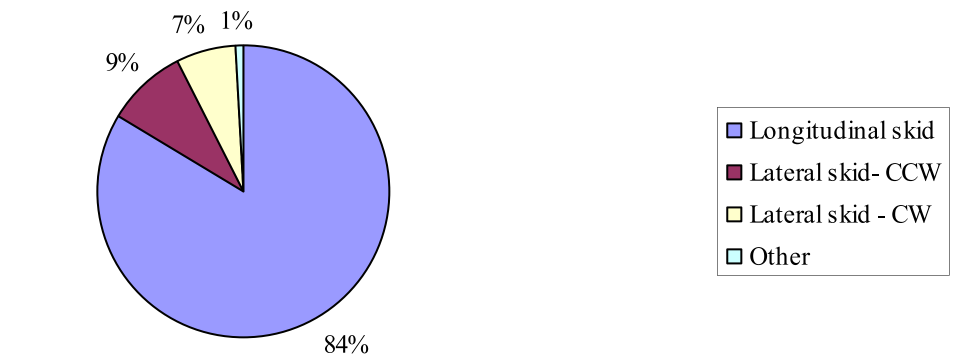

Figure 22. Filter 3a – *Precrash Vehicle Control* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

A further 2 percent of the applicable truck population was identified by the *Accident Type* variable. The values valid for this filter and their relative frequency are shown in Figure 23.

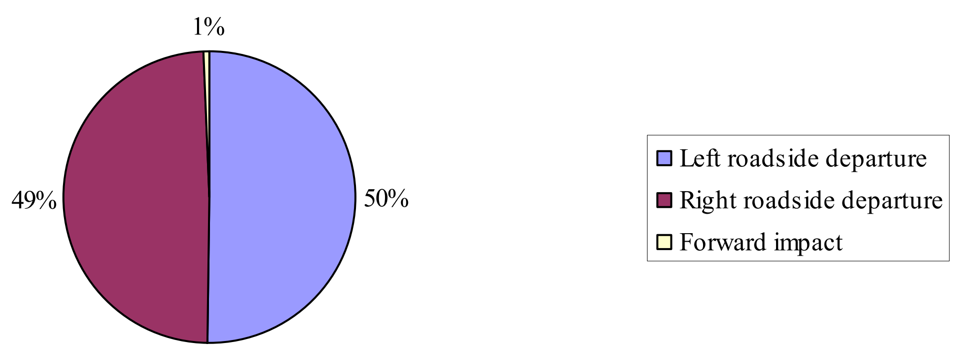

Figure 23. Filter 3a – *Accident Type* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

4.4.2. RSC

Filter labeled 3b, which was the third filter for RSC-applicable crashes, targeted the same truck population as defined in filter 2b but with the added restrictions as follow:

- Not performing a turning maneuver (GES variables: *Movement Prior to Critical Event* $\neq$ *10-12*)
- Not traveling at low travel speed (GES variable: *Travel Speed* $\geq$ *30 mph*)
- Not on slippery road surface conditions (GES variable: *Roadway Surface Condition* $\neq$ *3-5*)

A yearly average of 200 single-unit medium and heavy trucks over the 5-year period satisfied this filter condition, which corresponded to about 0.1 percent of the overall single-unit medium and heavy truck crash population. The factors of rollovers associated with these trucks were also analyzed. The applicable population was broken down by two GES variables by a process of elimination through the following order: *Critical Event*, and *Accident Type*. About 82 percent of the applicable truck population identified by filter 3b was identified by the *Critical Event* variable and all of those were coded as *excessive speed*. The remaining 18 percent of the applicable single-unit medium and heavy truck population was identified by the *Accident Type* variable. GES variable: *Roadway Surface Condition* ≠ *3-5* was added to exclude crash events that occurred on low coefficient of friction surfaces.

4.5. Fourth Filter

The fourth and last filter, which is defined in the flowchart contained in (red font denotes changes from preceding filter) and was the most restrictive of all, was similarly applied to the 5-year total single-unit medium and heavy truck crash population. Overall, the fourth filter identified an ESC and/or RSC applicable crash size averaging about 2,200 single-unit medium and heavy trucks per year, or about 1.5 percent of all single-unit medium and heavy trucks involved in all types of crashes over the 5-year period.

4.5.1. ESC

The filter labeled 4a, which was the fourth filter for ESC-applicable crashes, targeted the same truck population as defined in filter 3a but with one added restriction as follows:

- Experiencing lateral skidding only or other (GES variables: *Precrash Vehicle Control = 3, 4, or 7*)

A yearly average of 2,000 single-unit medium and heavy trucks satisfied this added filter condition. These corresponded to about 1.4 percent of the overall single-unit medium and heavy truck crash population. The types of control loss associated with these trucks were also analyzed. The applicable population was broken down by three GES variables by a process of elimination through the following order: *Critical Event*, *Precrash Vehicle Control*, and *Accident Type*.

About 46 percent of the applicable truck population identified by filter 4a, amounting to about 1,000 per year, were identified by the *Critical Event* variable. The two values valid in this filter for this identifier of control loss, along with their relative frequency, are shown in Figure 25. The vast majority of all vehicle files of the applicable trucks identified through this variable contained the value of *Excessive Speed*.

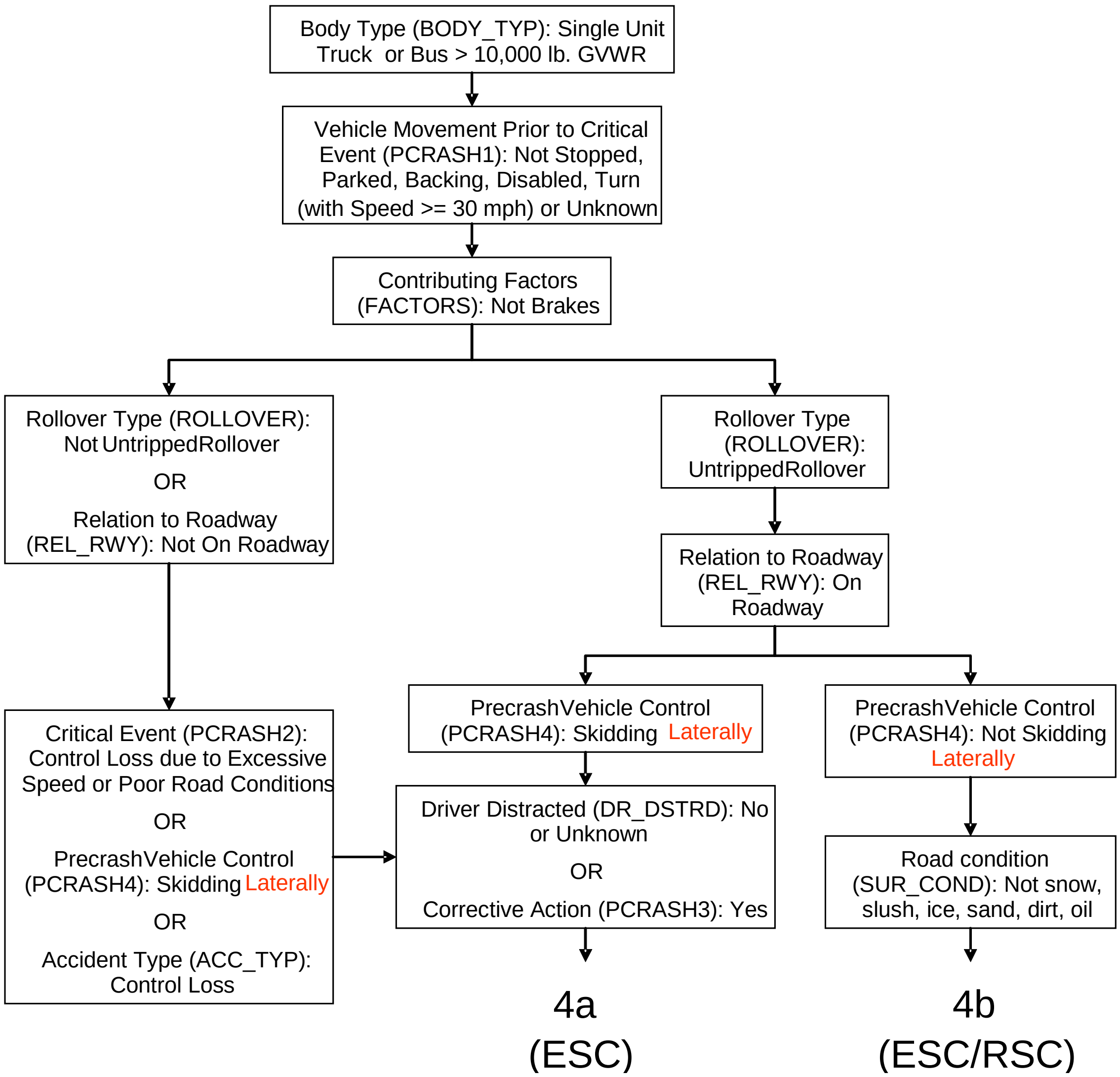

Figure 24. Filter 4 Flowchart

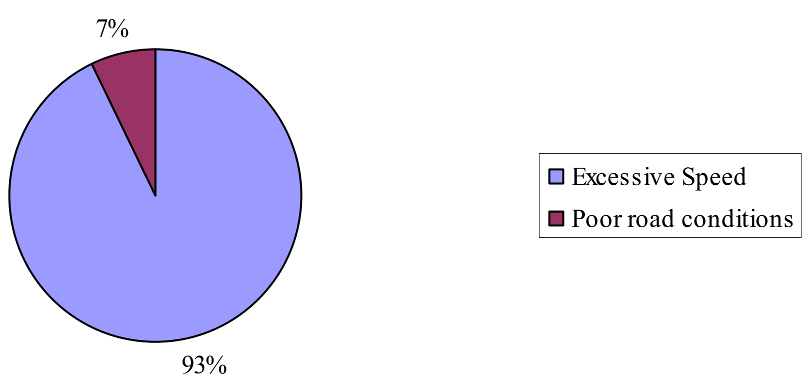

Figure 25. Filter 4a – *Critical Event* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

Another 46 percent of the applicable truck population, amounting to one,000 per year, contained a control loss identifier within the *Precrash Vehicle Control* variable. The values valid for this filter and their relative frequency are shown in Figure 26.

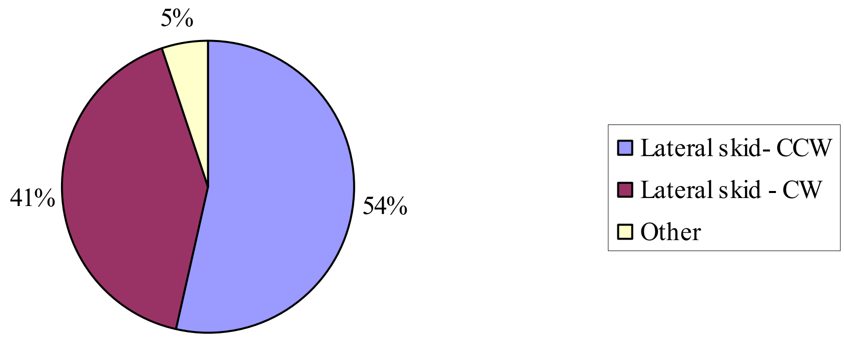

Figure 26. Filter 4a – *Precrash Vehicle Control* Codes and Frequencies for Single-Unit Medium and Heavy Truck Crash Population

A further 8 percent of the applicable single-unit medium and heavy truck population, or about 200 per year, was identified by the *Accident Type* variable. Even though this filter incorporated an added restriction, the target single-unit medium and heavy truck population identified by the *Accident Type* variable remained the same and therefore the results for filter 4a mirror the results presented above for filter 3a.

4.5.2. RSC

Filter labeled 4b, which was the fourth and last filter for roll-applicable crashes, targeted the same truck population as defined in filter 3b but with the added restriction as follows:

- Experiencing lateral skidding only or other (GES variables: *Precrash Vehicle Control = 3, 4, or 7*)

A yearly average of 200 single-unit medium and heavy trucks over the 5-year period satisfied this filter condition, which corresponded to about 0.1 percent of the overall single-unit medium and heavy truck crash population. The types of control loss associated with these trucks were also analyzed. The applicable population was broken down by two GES variables by a process of elimination through the following order: *Critical Event*, and *Accident Type*. About 74 percent of the applicable truck population identified by filter 4b was identified by the *Critical Event* variable and all of those were coded as *excessive speed*. The remaining 26 percent of the applicable single-unit medium and heavy truck population was identified by the *Accident Type* variable.

4.6. Summary

The overall relative frequency of applicable single-unit medium and heavy truck population for each filter is summarized in Figure 27. Overall, the first filter identified the largest ESC and/or RSC applicable crash size of about 8.1 percent of the 147,000 estimated single-unit medium and heavy trucks involved in crashes per year, as estimated by the analysis of the 2000-2004 GES data. However, filters 1 and 2 contained the fewest restrictions and therefore most likely included many crashes that were not truly relevant to ESC and RSC systems. Filters 3 and 4 included only crashes that were likely or very likely to be prevented by use of ESC and RSC systems. The most restrictive fourth filter identified an applicable crash size of about 1.5 percent (about 2,200) of the 147,000 estimated single-unit medium and heavy trucks involved in crashes per year.

RSC helps prevent or reduce the severity of crashes that are classified as untripped rollovers, while ESC helps prevent or reduce the severity of these crashes plus those that result from yaw instability. Within each filter, the ESC functionality addressed most of the applicable crash population while the RSC function added little more (0.2% at the most, as shown within filter 1).

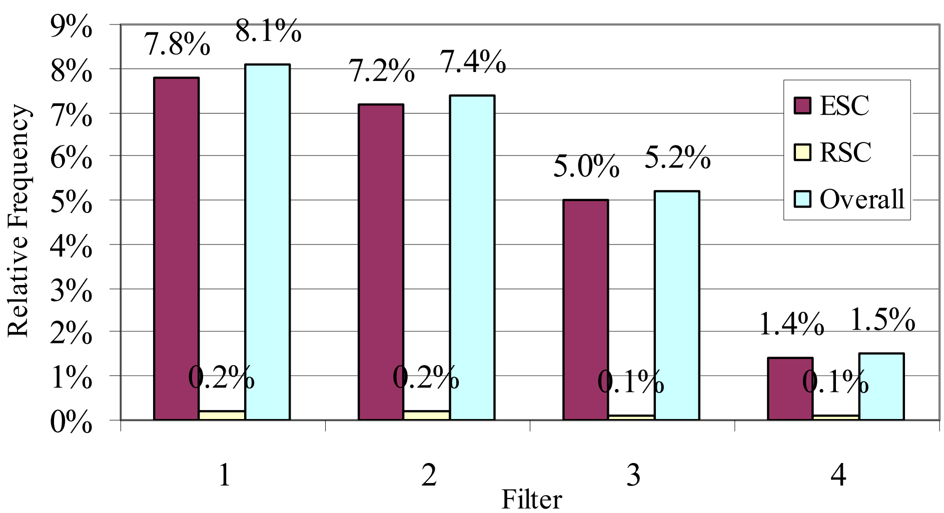

Figure 27. Relative Frequency of Applicable Single-Unit Medium and Heavy Truck Crash Population

The numerical results obtained from the application of the four filters to applicable single-unit medium and heavy truck crashes are contained in Appendix C.

5. DETAILED ANALYSIS OF APPLICABLE LARGE-PLATFORM BUS CRASHES

The methodology used to provide applicable crash estimates for single-unit medium and heavy trucks in the previous section was also followed for estimating the applicable crash problem for large-platform buses. However, due to the less frequent nature of bus crashes, a total of 10 years of GES data, using the 1996-2005 data sets, was used for this analysis. According to GES data, a total of 1.06 million of these types of buses were involved in crashes over the 10-year period from 1996-2005, which averages to about 106,000 per year. The applicable crash population was determined by the querying the data based on four different filters as described below.

5.1. Filter Definitions

Four queries were constructed using the same four different filter definitions used for the single-unit medium and heavy truck analysis (see Section 4). Within each filter, one data set captured all the large-platform bus crashes that the yaw instability function of ESC could address (filters labeled 1a, 2a, 3a, and 4a), while a second data set captured all the crashes that RSC alone or the rollover function of ESC could address (filters labeled 1b, 2b, 3b, and 4b). The total number of crashes addressed by the combination of ESC and RSC is the sum of the two data sets within each filter. However, it should be noted that the large-platform bus data did not contain any crashes that identified with any of the rollover-target filters (filters labeled 1b, 2b, 3b, and 4b) and therefore this section does not present results for those filters. The results presented in this Section are for ESC applicable crashes only.

5.2. First Filter

The first filter, which was the least restrictive, was applied to the 10-year total large-platform bus crash population. Overall, the first filter identified an ESC applicable crash size averaging about 5,100 large-platform buses per year, or about 4.8 percent of all large-platform buses involved in all types of crashes over the 10-year period. These estimates were based on a total of 469 large-platform bus vehicle files in the 1996-2005 GES.

The types of control loss associated with these buses were also analyzed. The applicable population was broken down by three GES variables by a process of elimination through the following order: *Critical Event*, *Precrash Vehicle Control*.

About 43 percent of the applicable bus population identified by filter 1a, amounting to almost 2,200 per year, were identified by the *Critical Event* variable. The values valid for this identifier of control loss and their relative frequency are shown in Figure 28. As shown, about 45 percent indicated *poor road conditions* and another 37 percent indicated *excessive speed*.

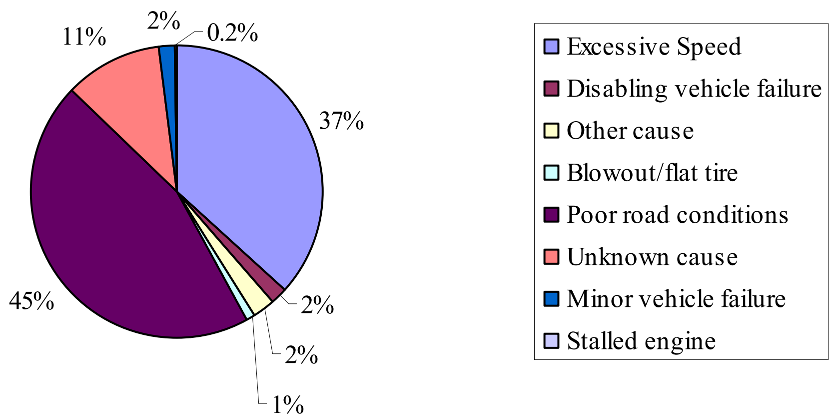

Figure 28. Filter 1a – *Critical Event* Codes and Frequencies for Large-Platform Bus Crash Population

Another 57 percent of the applicable truck population, amount to almost 2,900 per year, contained a control loss identifier within the *Precrash Vehicle Control* variable. The values valid for this filter and their relative frequency are shown in Figure 29. About two-thirds of the bus vehicle files identified through this variable indicated a longitudinal skidding condition just prior to crash.

No large-platform buses of the applicable population were identified by the *Accident Type* variable with filter 1a.

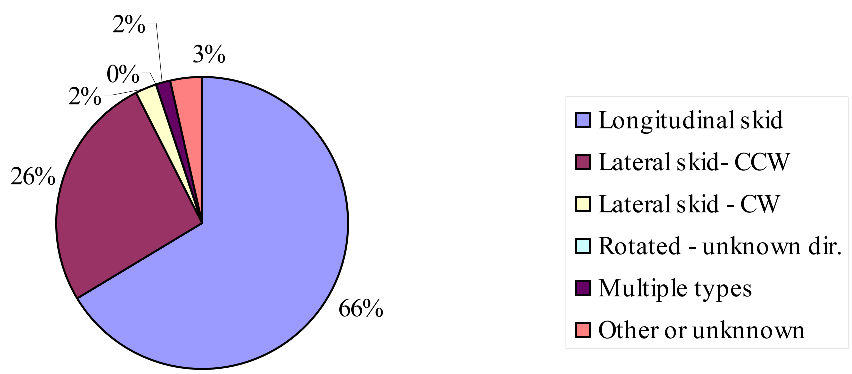

Figure 29. Filter 1a – *Precrash Vehicle Control* Codes and Frequencies for Large-Platform Bus Crash Population

5.3. Second Filter

The second filter, which was the second-least restrictive, was similarly applied to the 10-year total large-platform bus crash population. Overall, the second filter identified an ESC applicable crash size averaging about 4,400 large-platform buses per year, or about 4.1 percent of all large-platform buses involved in all types of crashes over the 10-year period.

The types of control loss associated with these buses were also analyzed. The applicable population was broken down by three GES variables by a process of elimination through the following order: *Critical Event*, *Precrash Vehicle Control*, and *Accident Type*.

About 46 percent of the applicable bus population identified by filter 2a, amounting to about 2,000 per year, were identified by the *Critical Event* variable. The values valid for this identifier of control loss and their relative frequency are shown in Figure 30. Just about half of all vehicle files of the applicable buses identified through this variable contained the value of *Excessive Speed* while a further 42 percent contained the value of *poor road conditions*.

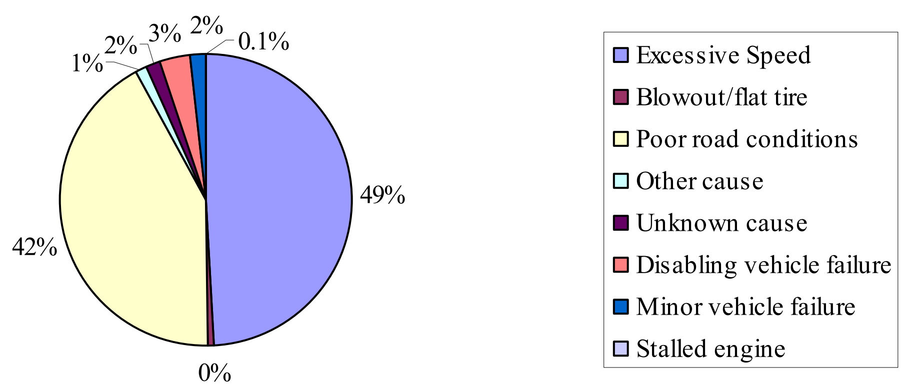

Figure 30. Filter 2a – *Critical Event* Codes and Frequencies for Large-Platform Bus Crash Population

Another 54 percent of the applicable bus population, amounting to almost 2,400 per year, contained a control loss identifier within the *Precrash Vehicle Control* variable. The values valid for this filter and their relative frequency are shown in Figure 31. Over 90 percent of the bus vehicle files identified through this variable indicated a longitudinal skidding condition just prior to crash.

No large-platform buses of the applicable population were identified by the *Accident Type* variable with filter 2a.

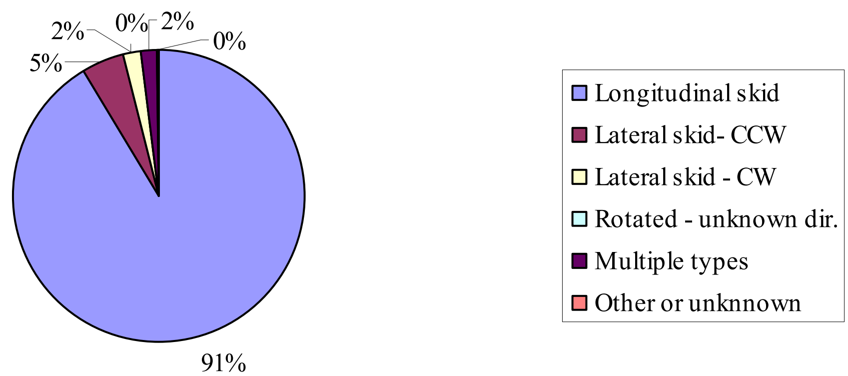

Figure 31. Filter 2a – *Precrash Vehicle Control* Codes and Frequencies for Large-Platform Bus Crash Population

5.4. Third Filter

The third filter, which was more restrictive than the previous two, was similarly applied to the 10-year total large-platform bus crash population. Overall, the third filter identified an ESC and or RSC applicable crash size averaging about 3,600 large-platform buses per year, or about 3.4 percent of all large-platform buses involved in all types of crashes over the 10-year period.

The types of control loss associated with these buses were also analyzed. The applicable population was broken down by three GES variables by a process of elimination through the following order: *Critical Event*, *Precrash Vehicle Control*, and *Accident Type*.

About 38 percent of the applicable bus population identified by filter 3a, amounting to almost 1,400, were identified by the *Critical Event* variable. The two values valid in this filter for this identifier of control loss, along with their relative frequency, are shown in Figure 32.

Another 62 percent of the applicable bus population, amounting to over 2,200 per year, contained a control loss identifier within the *Precrash Vehicle Control* variable. The values valid for this filter and their relative frequency are shown in Figure 33. About 94 percent of the bus vehicle files identified through this variable indicated a longitudinal skidding condition just prior to crash.

No large-platform buses of the applicable population were identified by the *Accident Type* variable with filter 3a.

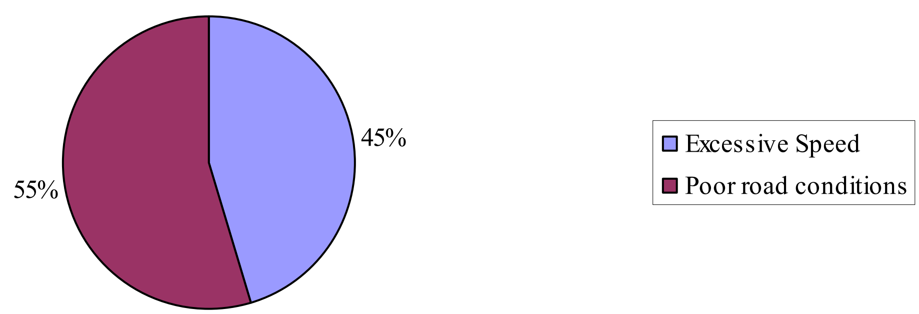

Figure 32. Filter 3a – *Critical Event* Codes and Frequencies for Large-Platform Bus Crash Population

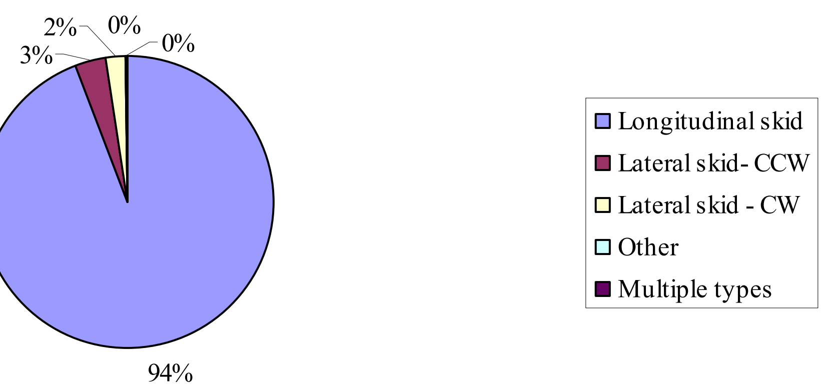

Figure 33. Filter 3a – *Precrash Vehicle Control* Codes and Frequencies for Large-Platform Bus Crash Population

5.5. Fourth Filter

The fourth and last filter, which was the most restrictive of all, was similarly applied to the 10-year total large-platform bus crash population. Overall, the fourth filter identified an ESC and or RSC applicable crash size averaging about 1,000 large-platform buses per year, or about 1.0 percent of all single-unit medium and heavy trucks involved in all types of crashes over the 10-year period.

The types of control loss associated with these buses were also analyzed. The applicable population was broken down by three GES variables by a process of elimination through the following order: *Critical Event*, *Precrash Vehicle Control*, and *Accident Type*.

About 88 percent of the applicable bus population identified by filter 4a, amounting to about 900 per year, were identified by the *Critical Event* variable. The two values valid in this filter for this identifier of control loss, along with their relative frequency, are shown in Figure 34.

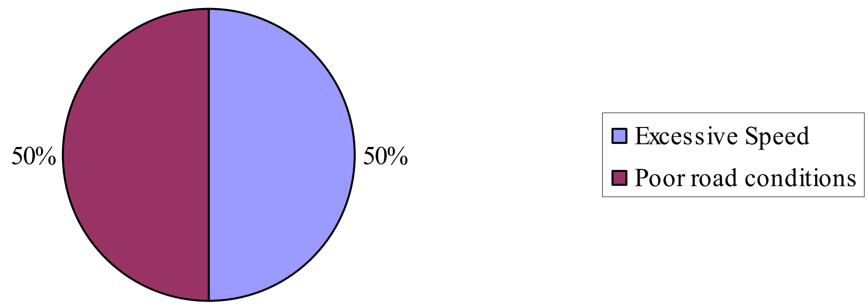

Figure 34. Filter 4a – *Critical Event* Codes and Frequencies for Large-Platform Bus Crash Population

Another 12 percent of the applicable bus population, amounting to about 100 per year, contained a control loss identifier within the *Precrash Vehicle Control* variable. The values valid for this filter and their relative frequency are shown in Figure 35.

No large-platform buses of the applicable population were identified by the *Accident Type* variable with filter 4a.

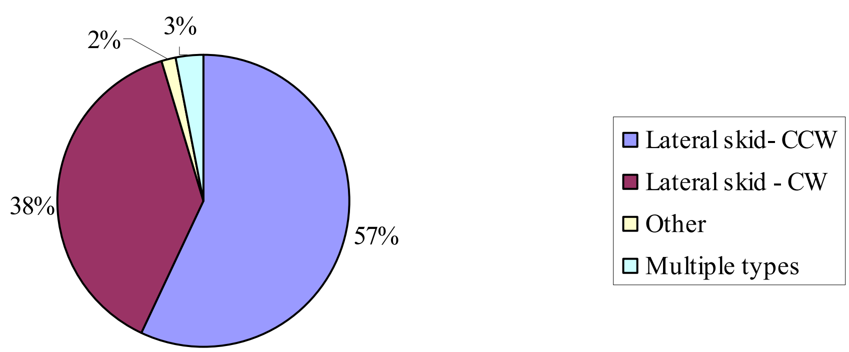

Figure 35. Filter 4a – *Precrash Vehicle Control* Codes and Frequencies for Large-Platform Bus Crash Population

5.6. Summary

The overall relative frequency of applicable large-platform bus population for each filter is summarized in Figure 36. Overall, the first filter identified the largest ESC applicable crash size of about 4.8 percent of the 106,000 estimated large-platform buses involved in crashes per year, as estimated by the analysis of the 1996-2005 GES data. However, filters 1 and 2 contained the fewest restrictions and therefore most likely included many crashes that were not truly relevant to ESC and RSC systems. Filters 3 and 4 included only crashes that were likely or very likely to be prevented by use of ESC and RSC systems. The most restrictive fourth filter identified an applicable crash size of about 1 percent (about 1,000) of the 106,000 estimated large-platform buses involved in crashes per year.

Within each filter, the ESC functionality addressed all of the applicable crash population. The analysis revealed no platform bus crashes identified by any of the four rollover-target filters for RSC applicability.

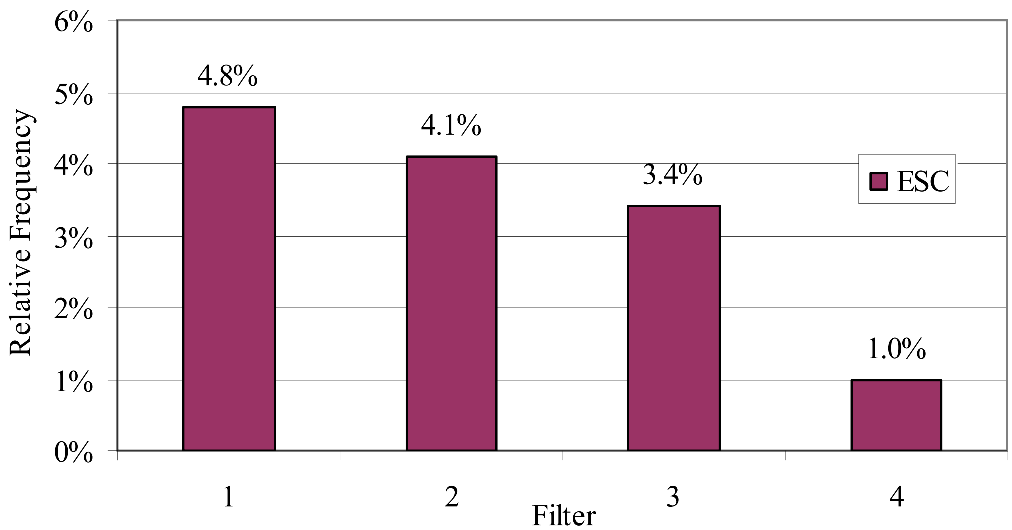

Figure 36. Relative Frequency of Applicable Large-Platform Bus Crash Population

The numerical results obtained from the application of the four filters to applicable large-platform bus crashes are contained in Appendix D.

6. SAFETY BENEFITS

A simple methodology has previously been developed by the Volpe Center for estimating the safety benefits of safety systems both in terms of reduction in number of crashes and the number and severity of crash-related injuries.[11] The methodology has been well documented and used extensively in the evaluation of intelligent vehicle safety systems, such as rear-end, lane change, and road departure collision warning systems in field tests.

The first measure of safety benefits, the crash reduction, can be determined by[12]

$$C_A = C_{wo} \cdot D_{ESC/RSC} \cdot SE \qquad (1)$$

Where,
C_A = Annual number of target crashes avoided *with* ESC/RSC deployment
C_{wo} = Annual number of target crashes prior to ESC/RSC deployment
$D_{ESC/RSC}$ = Potential ESC/RSC deployment rate in the vehicle fleet
SE = Total ESC/RSC effectiveness in mitigating crashes

The second safety benefits component, the reduction in number and severity of crash-related injuries, can be determined by[11]

$$H_R = H_{wo} \cdot D_{ESC/RSC} \cdot SR \quad \text{,and} \qquad (2)$$

$$SR = 1 - [P_w(C) \times H^{avg}_w] / [P_{WO}(C) \times H^{avg}_{WO}]$$

Where,
H_R = Annual reduction in total harm *with* ESC/RSC deployment
H_{wo} = Annual total harm caused by target crash injuries prior to ESC/RSC deployment
SR = Total ESC/RSC effectiveness in reducing harm caused by crash injuries
H^{avg}_w = Average harm per crash *with* ESC/RSC assistance
H^{avg}_{WO} = Average harm per crash *without* ESC/RSC assistance
$P_w(C)$ = Probability of a target crash per Vehicle Distance (miles) Traveled (VDT) *with* ESC/RSC assistance
$P_{wo}(C)$ = Probability of a target crash per VDT *without* ESC/RSC assistance

The two equations above, labeled (1) and (2), can be easily used to calculate the safety benefits of these two stability safety systems once the necessary data are known. It should be noted that although safety benefits in terms of injury reduction can be calculated, this study calculated only crash reduction estimates for single-unit medium and heavy trucks and large-platform buses.

6.1. System Effectiveness

Currently, the major impediment to accurate estimations of safety benefits of ESC and RSC on single-unit medium and heavy trucks and large-platform buses is the lack of driver/vehicle performance data and associated research into the system effectiveness of these technologies. No available reports of studies assessing the effectiveness of countermeasures to prevent single-unit truck or large-platform bus stability/rollover crashes were found at the time of this study.

Although recent studies have analyzed the effectiveness of similar stability control systems on passenger cars and SUVs, the findings from those analyses were deemed not applicable to the truck and bus types analyzed in this report. Furthermore, even though all published studies show some benefit from the use of stability control technologies on passenger cars and SUVs, the estimates vary widely. Single-unit medium and heavy trucks and large-platform buses have very different vehicle characteristics and dynamic responses than those of light vehicles. Variations in the physical characteristics of single-unit trucks include GVWR, wheelbase, number of axles, center of mass height and cargo type. In addition to the vehicle attributes, there are distinct functional or vehicle task variations including urban, rural, high density variable loads such as dump trucks, low density variable loads like package delivery vehicle, and fixed loads such utility vehicles. There are similar variations in buses including vehicle mass, vehicle shape and vehicle functions such as transit, hotel shuttle buses and highway coaches. All of these factors complicate the determination of RSC and ESC effectiveness for these types of vehicles.

Since no effectiveness of stability control technologies were obtained for single-unit medium and heavy trucks or large-platform buses, preliminary safety benefits were not calculated as part of this study. It should be noted that this analysis could be easily updated with calculations of safety benefits based on the methodology above once ESC and RSC system effectiveness data for single-unit medium and heavy trucks and large-platform buses becomes available.

7. CONCLUSIONS

The study summarized in this report analyzed the potential safety impact of ESC and RSC on single-unit medium and heavy trucks and large-platform buses. The applicable crash population was determined from analysis of multi-year GES data and a methodology was used to estimate safety benefits estimates from the use of these automotive safety technologies.

Based on 2000-2004 GES data, an average of 147,000 single-unit medium and heavy trucks are involved in police-reported crashes per year. Those crashes that were most likely to be prevented by the use of ESC or RSC systems were identified using the fourth and most restrictive filter in this study. The analysis showed that ESC and RSC systems could have helped about 2,200 single-unit medium and heavy trucks per year avoid a crash. This amounted to about 1.5 percent of all single-unit medium and heavy trucks involved in all types of crashes over the 5-year period. The analysis showed that ESC would have been applicable in about 91 percent of these crashes, while RSC would have been applicable in only the other 9 percent.

Based on 1996-2007 GES data, an average of 106,000 large-platform buses are involved in police-reported crashes per year. Those crashes that were most likely to be prevented by the use of ESC or RSC systems were identified using the fourth and most restrictive filter in this study. Overall, the fourth filter identified an ESC and/or RSC applicable crash size averaging about 1,000 large-platform buses per year, or about 1.0 percent of all single-unit medium and heavy trucks involved in all types of crashes over the 10-year period. The analysis showed that ESC would have been applicable in all of these crashes, while no crashes identified through the application of the fourth filter were deemed to be RSC-applicable.

These statistics do not incorporate data from non-police-reported crashes as those are not included in the GES. Also, since no ESC or RSC system effectiveness data exists for their use on single-unit trucks or buses, no safety benefits estimates were calculated at this time. However, the analysis should be updated using the safety benefits methodology detailed in Section 6 once relevant data and research becomes available. Furthermore, potential benefits resulting from the reduction in number and severity of crash-related injuries should also be estimated by conducting further research into the injury risk associated with these types of crashes.

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APPENDIX A

Definitions of NASS-CDS[1] and FARS[2] Variables and Codes

The GES variables selected, definitions, and possible values for the years queried (1996-2005) are listed below:[1]

Body Type (BODY_TYP):

64 = Single-unit straight truck
50 = School bus type (designed to carry students, not cross country or transit, not van-based)
58 = Other bus (e.g., transit, intercity, bus-based motor home, not van based)
59 = Unknown bus type (not van-based)

First Harmful Event (EVENT1): Indicates the first property damaging or injury producing event in the crash

1=Rollover/Overturn

Rollover Type (ROLLOVER): Indicates if a rollover occurred (tripped or untripped). Rollover is defined as any vehicle rotation of 90 degrees or more about any true longitudinal or lateral axis. Rollover can occur at any time during the crash.

0 = No rollover
10 = Untripped rollover
10-29 = Tripped rollover
99 = Rollover, unknown whether untripped or tripped

Relation to Roadway (REL_RWY): Indicates the location of the first harmful event

1 = On Roadway
1-10 Off Roadway
99= Unknown

Critical Event (PCRASH2): Identifies the critical event that made the crash imminent (i.e., something occurred that made the collision possible). A critical event is coded for each vehicle and identifies the circumstances leading to the vehicle's first impact in the crash.

(1994-1998)
This Vehicle Loss of Control Due to:
10=Blow out or flat tire
20=Stalled engine
30=Disabling vehicle failure (e.g., wheel fell off)
40=Minor vehicle failure
50=Poor road conditions (puddle, pothole, ice, etc.)
60=Excessive speed
99=Other or unknown reason
(1999-Later)

This Vehicle Loss of Control Due to:
1=Blow out or flat tire
2=Stalled engine
3=Disabling vehicle failure (e.g., wheel fell off)
4=Minor vehicle failure
5=Poor road conditions (puddle, pothole, ice, etc.)
6=Excessive speed
8=Other cause of control loss
9=Unknown cause of control loss

Vehicle Control After Corrective Action (PCRASH4): Assesses the stability of the vehicle during the period immediately after the attempted corrective action up to the initial impact in the crash sequence. The stability of the vehicle prior to a corrective action is not considered.

(1995-1998)
1=Tracking
2=Vehicle rotated (yawed) clockwise
3=Vehicle rotated (yawed) counter-clockwise
4=Vehicle slid/skid longitudinally-no rotation
9=Vehicle rotated (yawed) unknown direction
98=Other or unknown type of vehicle control was lost
(1999-Later)
1= Tracking
2=Skidding longitudinally-rotation less than 30 degrees
3=Skidding laterally-clockwise rotation
4=Skidding laterally-counterclockwise rotation
7=Other vehicle loss of control (specify)
9=Precrash Stability Unknown

Accident Type (ACC_TYP): Categorizes the precrash situation

Single Driver, Right Roadside Departure
2=Control/Traction Loss
Single Driver, Left Roadside Departure
7=Control/Traction Loss
Configuration E: Forward Impact, Same Trafficway, Same Direction
34=This Vehicle's Frontal Area Impacts Another Vehicle
36=This Vehicle's Frontal Area Impacts Another Vehicle
Configuration H: Forward Impact, Same Trafficway, Opposite Direction
54=This Vehicle's Frontal Area Impacts Another Vehicle.
56=This Vehicle's Frontal Area Impacts Another Vehicle.

Movement Prior to Critical Event (PCRASH1): Records the attribute that best describes this vehicle's activity prior to the driver's realization of an impending critical event or just prior to impact if the driver took no action or had no time to attempt to any evasive maneuvers.

1= Going Straight
2= Decelerating in Traffic Lane
3= Accelerating in traffic lane
4= Starting in Traffic Lane
5= Stopped in Traffic Lane
6= Passing or Overtaking Another Vehicle
7= Disabled or Parked in Travel Lane
8=Leaving a Parked Position
9= Entering a Parked Position
10= Turning Right
11= Turning Left
12= Making U-turn
13= Backing Up (other than for parking purposes)
14= Negotiating a Curve
15= Changing Lanes
16= Merging
17= Successful Corrective Action to a Previous Critical Event
97= Other
99= Unknown

Vehicle Contributing Factors (FACTORS): Indicates vehicle factors that may have contributed to the cause of the crash.

0 = None
2 = Brake System

Travel Speed (SPEED): Travel speed in miles per hour

Driver Distracted By (DR_DSTRD): Identifies a distraction that may have influenced driver performance and contributed to the cause of the crash. The distraction can be either inside the vehicle (internal) or outside the vehicle (external). If a driver had more than one distraction, the lowest of the attribute codes is chosen.

0= Not Distracted
1-98= Distracted
99= Unknown if Distracted

Corrective Action Attempted (PCRASH3): Describes the actions taken by the driver of the vehicle in response to the impending danger. Because this variable focuses upon the driver's action just prior to the first harmful event it is coded independently of any maneuvers associated with this vehicle's Accident Type.

0= No driver present
1= No avoidance maneuver

2-98= Avoidance maneuver
99 = Unknown if driver attempted any corrective action

Roadway Surface Condition (SUR_COND): Condition of road surface at the time of the crash

1 = Dry
2 = Wet
3 = Snow or Slush
4 = Ice
5 = Sand, Dirt, Oil
8 = Other
9 = Unknown

The FARS variables selected, definitions, and possible values for the years queried (2004) are listed below:[2]

BODY TYPE (V9):

61 = Single-unit straight truck (10,000 lbs. < GVWR < or= 19,500 lbs.)
62 = Single-unit straight truck (19,500 lbs. < GVWR < or= 26,000 lbs.)
63 = Single-unit straight truck (GVWR > 26,000 lbs.)
64 = Single-unit straight truck (GVWR unknown)
50 = School Bus
51 = Cross Country/Intercity Bus (i.e., Greyhound)
52 = Transit Bus (City Bus)
58 = Other Bus Type
59 = Unknown Bus Type

FIRST HARMFUL EVENT (A17): Indicates the first property damaging or injury producing event in the crash

01 = Overturn/Rollover

ROLLOVER (V18): Rollover is defined as any vehicle rotation of 90 degrees or more, about any true longitudinal or lateral axis. Rollover can occur at any time during the unstabilized situation. Subsequent Event refers to a rollover that occurs after the first harmful event.

1 = First Event
2 = Subsequent Event

CRASH AVOIDANCE MANEUVER (V17): This element is collected to indicate if an avoidance maneuver was taken by the driver to avoid the crash.

4 = Steering (evidence or stated)
5 = Steering and Braking (evidence or stated)

APPENDIX B

The 1996-2007 GES data was queried to obtain baseline statistics on the number of crashes, fatalities, and injuries for untripped rollovers and control loss crashes. Details of this analysis are contained herein.

For the purposes of this study, untripped rollovers were defined by the following GES variables and codes: *ROLLOVER* = 10 AND *PCRASH4* = 1 AND *REL_RWY* = 1 AND *EVENT1* = 1.[1] Control loss crashes were defined by the following GES variables and codes: GES years 1996-1998: (*P_CRASH2* = 10, 20, 30, 40, 50, 60, 99 or *PCRASH4* = 2, 3, 4, 9, 98 or *ACC_TYPE* = 2, 7, 34, 36, 54, 56), GES years 1999-later: (1≤*P_CRASH2*≤9 or 2≤*PCRASH4*≤7) or *ACC_TYPE* = 2, 7, 34, 36, 54, 56. This combination of variables and codes identify all crashes that contain a clear indication of vehicle control loss.

Note: SUT = Single-Unit Truck = Single-Unit Medium or Heavy Truck, Bus = Large-Platform Bus

Year	SUT	Bus	Other Vehicles	% SUT
1996	227	-	1,500	13%
1997	96	-	1,934	5%
1998	62	-	1,377	4%
1999	144	-	2,243	6%
2000	81	-	714	10%
2001	181	-	998	15%
2002	128	-	590	18%
2003	103	-	572	15%
2004	124	-	1,218	9%
2005	152	-	1,271	11%
2006	126	-	632	17%
2007	72	-	235	24%
Avg.	125	-	1,107	10%

Table B1. Yearly Number of Untripped Rollover Vehicles

Year	SUT	Bus	Other Vehicles	% SUT	% Bus
1996	5,548	2,723	1,373,767	0.4%	0.2%
1997	5,639	1,478	1,240,261	0.5%	0.1%
1998	3,758	1,533	1,125,687	0.3%	0.1%
1999	8,696	1,906	1,112,300	0.8%	0.2%
2000	12,806	2,166	1,164,945	1.1%	0.2%
2001	10,895	1,426	1,060,932	1.0%	0.1%
2002	12,320	1,268	1,095,491	1.1%	0.1%
2003	9,885	1,212	1,184,194	0.8%	0.1%
2004	10,512	1,745	1,088,592	1.0%	0.2%
2005	10,767	1,246	1,017,968	1.0%	0.1%
2006	9,213	346	831,375	1.1%	0.04%
2007	7,516	458	947,665	0.8%	0.05%
Avg.	8,963	1,459	1,103,598	0.8%	0.13%

Table B2. Yearly Number of Loss of Control Vehicles

Single Unit Trucks					
Year	**Rollover**	**Control Loss**	**Other Crash Types**	**% Rollover**	**% Control Loss**
1996	227	5,548	46,831	0.43%	10.5%
1997	96	5,639	49,259	0.18%	10.3%
1998	62	3,758	37,831	0.15%	9.0%
1999	144	8,696	96,696	0.14%	8.2%
2000	81	12,806	125,724	0.06%	9.2%
2001	181	10,895	127,979	0.13%	7.8%
2002	128	12,320	122,833	0.09%	9.1%
2003	103	9,885	124,857	0.08%	7.3%
2004	124	10,512	109,420	0.10%	8.8%
2005	152	10,767	124,981	0.11%	7.9%
2006	126	9,213	126,360	0.09%	6.8%
2007	72	7,516	125,394	0.05%	5.7%
Avg.	125	8,963	101,514	0.11%	8.1%

Table B3. Yearly Number of Single-Unit Medium and Heavy Trucks Identified as Untripped Rollovers or Control Loss

Buses				
Year	**Rollover**	**Control Loss**	**Other Crash Types**	**% Control Loss**
1996	-	2,723	54,273	4.8%
1997	-	1,478	51,926	2.8%
1998	-	1,533	51,771	2.9%
1999	-	1,906	59,177	3.1%
2000	-	2,166	53,639	3.9%
2001	-	1,426	52,272	2.7%
2002	-	1,268	55,948	2.2%
2003	-	1,212	55,838	2.1%
2004	-	1,745	49,901	3.4%
2005	-	1,246	49,339	2.5%
2006	-	346	50,476	0.7%
2007	-	458	55,883	0.8%
Avg.	-	1,459	53,370	2.7%

Table B4. Yearly Number of Large-Platform Buses Identified as Untripped Rollovers or Control Loss

Other Vehicle Types					
Year	Rollover	Control Loss	Other Crash Types	% Rollover	% Control Loss
1996	1,500	1,373,767	10,561,695	0.01%	11.5%
1997	1,934	1,240,261	10,451,841	0.02%	10.6%
1998	1,377	1,125,687	10,134,477	0.01%	10.0%
1999	2,243	1,112,300	9,904,139	0.02%	10.1%
2000	714	1,164,945	9,959,055	0.01%	10.5%
2001	998	1,060,932	9,907,695	0.01%	9.7%
2002	590	1,095,491	9,844,171	0.01%	10.0%
2003	572	1,184,194	9,768,832	0.01%	10.8%
2004	1,218	1,088,592	9,658,587	0.01%	10.1%
2005	1,271	1,017,968	9,610,632	0.01%	9.6%
2006	632	831,375	9,530,462	0.01%	8.0%
2007	235	947,665	9,377,178	0.00%	9.2%
Avg.	1,107	1,103,598	9,892,397	0.01%	10.0%

Table B5. Yearly Number of Other Vehicle Types Identified as Untripped Rollovers or Control Loss

Year	SUT	Bus	Other Vehicles	% SUT
1996	136	-	951	12.5%
1997	1	-	884	0.1%
1998	23	-	6,232	0.4%
1999	45	-	1,150	3.7%
2000	24	-	99	19.2%
2001	142	-	921	13.4%
2002	1	-	7,186	0.02%
2003	172	-	375	31.4%
2004	35	-	1,003	3.4%
2005	268	-	804	25.0%
2006	2,257	-	601	79.0%
2007	91	-	4,555	2.0%
Avg.	266	-	2,063	11.4%

Table B6. Functional Years Lost Per Year From Crashes Involving Untripped Rollover Vehicles (occupant statistics)

Year	SUT	Bus	Other Vehicles	% SUT	% Bus
1996	2,938	801	982,719	0.3%	0.1%
1997	2,904	381	870,994	0.3%	0.0%
1998	1,202	1,828	876,883	0.1%	0.2%
1999	4,624	762	822,802	0.6%	0.1%
2000	6,442	2,980	896,237	0.7%	0.3%
2001	4,920	160	799,629	0.6%	0.0%
2002	3,215	316	816,264	0.4%	0.0%
2003	11,417	158	788,449	1.4%	0.0%
2004	4,736	328	750,814	0.6%	0.0%
2005	4,082	265	761,038	0.5%	0.0%
2006	2,660	108	758,336	0.3%	0.01%
2007	2,245	552	780,904	0.3%	0.07%
Avg.	4,282	720	825,422	0.5%	0.09%

Table B7. Functional Years Lost Per Year From Crashes Involving Control Loss Vehicles (occupant statistics)

Single Unit Trucks					
Year	**Rollover**	**Control Loss**	**Other Crash Types**	**% Rollover**	**% Control Loss**
1996	136	2,938	1,930	2.72%	58.7%
1997	1	2,904	6,834	0.01%	29.8%
1998	23	1,202	1,685	0.78%	41.3%
1999	45	4,624	4,829	0.47%	48.7%
2000	24	6,442	12,776	0.12%	33.5%
2001	142	4,920	12,265	0.82%	28.4%
2002	1	3,215	19,279	0.01%	14.3%
2003	172	11,417	16,206	0.62%	41.1%
2004	35	4,736	13,589	0.19%	25.8%
2005	268	4,082	13,126	1.53%	23.4%
2006	2,257	2,660	16,184	10.70%	12.6%
2007	91	2,245	13,882	0.56%	13.8%
Avg.	266	4,282	11,049	1.71%	27.5%

Table B8. Functional Years Lost Per Year From Crashes Involving Single-Unit Medium and Heavy Trucks Identified as Untripped Rollovers or Control Loss (occupant statistics)

Buses				
Year	**Rollover**	**Control Loss**	**Other Crash Types**	**% Control Loss**
1996	-	801	8,432	8.7%
1997	-	381	7,516	4.8%
1998	-	1,828	5,244	25.8%
1999	-	762	10,552	6.7%
2000	-	2,980	14,743	16.8%
2001	-	160	13,177	1.2%
2002	-	316	10,680	2.9%
2003	-	158	9,483	1.6%
2004	-	328	8,662	3.6%
2005	-	265	7,817	3.3%
2006	-	108	6,516	1.6%
2007	-	552	6,320	8.0%
Avg.	-	720	9,095	7.3%

Table B9. Functional Years Lost Per Year From Crashes Involving Large-Platform Buses Identified as Untripped Rollovers or Control Loss (occupant statistics)

Other Vehicle Types					
Year	**Rollover**	**Control Loss**	**Other Crash Types**	**% Rollover**	**% Control Loss**
1996	951	982,719	2,331,766	0.03%	29.6%
1997	884	870,994	2,125,303	0.03%	29.1%
1998	6,232	876,883	2,196,787	0.20%	28.5%
1999	1,150	822,802	2,262,350	0.04%	26.7%
2000	99	896,237	2,410,787	0.00%	27.1%
2001	921	799,629	2,125,008	0.03%	27.3%
2002	7,186	816,264	2,024,142	0.25%	28.7%
2003	375	788,449	1,959,932	0.01%	28.7%
2004	1,003	750,814	1,929,273	0.04%	28.0%
2005	804	761,038	1,890,233	0.03%	28.7%
2006	601	758,336	1,941,434	0.02%	28.1%
2007	4,555	780,904	1,821,446	0.17%	30.0%
Avg.	2,063	825,422	2,084,872	0.07%	28.3%

Table B10. Functional Years Lost Per Year From Crashes Involving Other Vehicle Types Identified as Untripped Rollovers or Control Loss (occupant statistics)

APPENDIX C

The following Tables present the numerical results obtained from the application of the filters defined in Section 4 to applicable single-unit medium and heavy truck crashes. The results reflect yearly averages of the total number of crash cases, weighted counts, and weighted frequencies based on 2000-2004 GES data. The data presented in Section 4 is derived from these tables.

2000-2004 GES - Single-Unit Medium/Heavy Trucks (Yearly Averages) - # Cases, Weighted Count, and Frequency (weighted)

Filter 1a (ESC-applicable crashes): Vehicle loss of control in untripped rollover on the roadway, tripped rollover, or off the roadway crashes.

cases	362	
weighted	11,600	*
freq. (weighted)	**7.8%**	

Critical Event			
Excessive Speed	78	2,389	46%
Disabling vehicle failure	26	801	15%
Other cause	17	550	10%
Blowout/flat tire	21	500	10%
Poor road conditions	12	479	9%
Unknown cause	10	359	7%
Minor vehicle failure	4	154	3%
Stalled engine	1	7	0%
Total	169	5,239	100%
		5,000 *	

Precrash Vehicle Control			
Longitudinal skid	142	4,913	81%
Lateral skid- CCW	23	545	9%
Lateral skid - CW	16	502	8%
Other	5	126	2%
Total	185	6,085	100%
		6,000 *	

Accident Type			
Left roadside departure	4	112	57%
Right roadside departure	4	83	42%
Forward impact	0	1	0%
Total	8	196	100%
		200 **	

Critical Event	45%
Precrash Vehicle Control	53%
Accident Type	2%

Filter 1b (RSC-applicable crashes): No vehicle loss of control in untripped rollover on the roadway.

cases	16	
weighted	400	**
freq. (weighted)	**0.2%**	

Critical Event			
Excessive Speed	7	154	13%
Other cause	2	32	3%
Disabling vehicle failure	1	25	2%
Unknown cause	1	17	1%
Poor road conditions	0	1	0.1%
Total	11	229	20%
		- *	

Accident Type			
Other	5	88	100%
Total	5	88	100%
		100 **	

Critical Event	72%
Accident Type	28%

*rounded to nearest thousand **rounded to nearest hundred

Figure C1. Filter 1 Results for Single-Unit Medium and Heavy Truck Crashes (Yearly Averages)

2000-2004 GES - Single-Unit Medium/Heavy Trucks (Yearly Averages) - # Cases, Weighted Count, and Frequency (weighted)	
Filter 2a (ESC-applicable crashes): Same as filter 1,a excluding parking or backing maneuvers or brakes failure.	
cases	334
weighted	10,600 *
freq. (weighted)	**7.2%**

Critical Event			
Excessive Speed	76	2,265	51%
Blowout/flat tire	18	500	11%
Poor road conditions	11	476	11%
Other cause	15	413	9%
Unknown cause	9	356	8%
Disabling vehicle failure	13	307	7%
Minor vehicle failure	1	83	2%
Stalled engine	1	6	0%
Total	144	4,405	100%
		4,000 *	

Precrash Vehicle Control			
Longitudinal skid	139	4,882	82%
Lateral skid- CCW	22.8	524	9%
Lateral skid - CW	15.4	501	8%
Other	4	60	1%
Total	181	5,966	100%
		6,000 *	

Accident Type			
Left roadside departure	4	112	57%
Right roadside departure	4	83	42%
Forward impact	0	1	0%
Total	8	196	100%
		200 **	

Critical Event	42%
Precrash Vehicle Control	56%
Accident Type	2%

Filter 2b (RSC-applicable crashes): Same as filter 1,b excluding parking or backing maneuvers.	
cases	16
weighted	400 **
freq. (weighted)	**0.2%**

Critical Event			
Excessive Speed	7	154	67%
Other cause	2	32	14%
Disabling vehicle failure	1	25	11%
Unknown cause	1	17	7%
Total	11	228	100%
		200 **	

Accident Type			
Other	5	88	100%
Total	5	88	100%
		100 **	

Critical Event	72%
Accident Type	28%

*rounded to nearest thousand **rounded to nearest hundred

Figure C2. Filter 2 Results for Single-Unit Medium and Heavy Truck Crashes (Yearly Averages)

2000-2004 GES - Single-Unit Medium/Heavy Trucks (Yearly Averages) - # Cases, Weighted Count, and Frequency (weighted)	
Filter 3a (ESC-applicable crashes): Same as filter 2a, excluding turning maneuvers or low travel speed (< 30 mph).	
cases	222
weighted	7,400 *
freq. (weighted)	**5.0%**

Control loss is limited to excessive speed or poor road conditions.
Exclude cases in which driver did not attempt any corrective action.

Critical Event			
Excessive Speed	39	1,298	80%
Poor road conditions	5	315	20%
Total	44	1,613	100%
		2,000 *	

Precrash Vehicle Control			
Longitudinal skid	134	4,729	84%
Lateral skid- CCW	20	494	9%
Lateral skid - CW	14	379	7%
Other	3	47	1%
Total	171	5,649	100%
		6,000 *	

Accident Type			
Left roadside departure	3	80	50%
Right roadside departure	3	79	49%
Forward impact	0	1	1%
Total	6	160	100%
		200 **	

Critical Event	22%
Precrash Vehicle Control	76%
Accident Type	2%

Filter 3b (RSC-applicable crashes): Same as filter 2b, excluding turning maneuvers or low travel Also exclude slippery road surface conditions.	
cases	7.4
weighted	200 **
freq. (weighted)	**0.1%**

Critical Event			
Excessive Speed	4	133	100%
Total	4	133	20%
		100 **	

Accident Type			
Other	3	28	100%
Total	3	28	100%
		- **	

Critical Event	82%
Accident Type	18%

*rounded to nearest thousand **rounded to nearest hundred

Figure C3. Filter 3 Results for Single-Unit Medium and Heavy Truck Crashes (Yearly Averages)

2000-2004 GES - Single-Unit Medium/Heavy Trucks (Yearly Averages) - # Cases, Weighted Count, and Frequency (weighted)

Filter 4a (ESC-applicable crashes): Same as filter 3a, including only lateral skidding.

cases	71	
weighted	2,000	*
freq. (weighted)	**1.4%**	

Critical Event			
Excessive Speed	25	846	93%
Poor road conditions	2	66	7%
Total	27	911	100%
		1,000 *	

Precrash Vehicle Control			
Lateral skid- CCW	20	494	54%
Lateral skid - CW	14	379	41%
Other	3	47	5%
Total	37	920	100%
		1,000 *	

Accident Type			
Left roadside departure	3	80	50%
Right roadside departure	3	79	49%
Forward impact	0	1	1%
Total	6	160	100%
		200 **	

Critical Event	46%
Precrash Vehicle Control	46%
Accident Type	8%

Filter 4b (RSC-applicable crashes): ESC or RSC fourth filter: Same as filter 3b, including only lateral skidding.

cases	9	
weighted	200	**
freq. (weighted)	**0.1%**	

Critical Event			
Excessive Speed	5	146	100%
Total	5	146	20%
		100 **	

Accident Type			
Other	3	50	100%
Total	3	50	100%
		100 **	

Critical Event	74%
Accident Type	26%

*rounded to nearest thousand **rounded to nearest hundred

Figure C4. Filter 4 Results for Single-Unit Medium and Heavy Truck Crashes (Yearly Averages)

APPENDIX D

The following Tables present the numerical results obtained from the application of the filters defined in Section 4 to applicable large-platform bus crashes. The results reflect yearly averages of the total number of crash cases, weighted counts, and weighted frequencies based on 1996-2005 GES data. The data presented in Section 5 is derived from these tables.

1996-2005 GES - Large Platform Buses (Yearly Averages) - # Cases, Weighted Count, and Frequency (weighted)

Filter 1a (ESC-applicable crashes): Vehicle loss of control in untripped rollover on the roadway, tripped rollover, or off the roadway crashes.

cases	47	
weighted	5,100	**
freq. (weighted)	**4.8%**	

Critical Event			
Excessive Speed	7	804	37%
Disabling vehicle failure	1	47	2%
Other cause	1	53	2%
Blowout/flat tire	0	16	1%
Poor road conditions	6	997	45%
Unknown cause	2	235	11%
Minor vehicle failure	0	41	2%
Stalled engine	0	4	0%
Total	17	2,197	100%
		2,000 *	

Precrash Vehicle Control			
Longitudinal skid	21	1,898	66%
Lateral skid- CCW	8	752	26%
Lateral skid - CW	1	66	2%
Rotated - unknown	-	-	0%
Multiple types	0	45	2%
Other or unknnown	1	100	3%
Total	30	2,862	100%
		3,000 *	

Accident Type			
Left roadside departure	0	-	n.a.
Right roadside departure	0	-	n.a.
Forward impact	0	-	n.a.
Total	0	-	n.a.
		-	

Critical Event	43%
Precrash Vehicle Control	57%
Accident Type	0%

Filter 1b (RSC-applicable crashes): No vehicle loss of control in untripped rollover on the roadway.

cases	-
weighted	-
freq. (weighted)	**0.0%**

Critical Event			
Excessive Speed	0	-	n.a.
Other cause	0	-	n.a.
Disabling vehicle failure	0	-	n.a.
Unknown cause	0	-	n.a.
Poor road conditions	0	-	n.a.
Total	0	-	n.a.
		-	

Accident Type			
Other	0	-	n.a.
Total	0	-	n.a.
		-	

Critical Event	n.a.
Accident Type	n.a.

*rounded to nearest thousand **rounded to nearest hundred

Figure D1. Filter 1 Results for Large-Platform Bus Crashes (Yearly Averages)

1996-2005 GES - Large Platform Buses (Yearly Averages) - # Cases, Weighted Count, and Frequency (weighted)	
Filter 2a (ESC-applicable crashes): Same as filter 1,a excluding parking or backing maneuvers or brakes failure.	
cases	43
weighted	4,400 **
freq. (weighted)	**4.1%**

Critical Event			
Excessive Speed	8	978	49%
Blowout/flat tire	0	9	0%
Poor road conditions	5	840	42%
Other cause	1	29	1%
Unknown cause	1	35	2%
Disabling vehicle failure	1	65	3%
Minor vehicle failure	0	31	2%
Stalled engine	0	2	0%
Total	16	1,988	100%
		2,000 *	

Precrash Vehicle Control			
Longitudinal skid	25	2,167	91%
Lateral skid- CCW	1	108	5%
Lateral skid - CW	1	49	2%
Rotated - unknown	-	-	0%
Multiple types	0	40	2%
Other or unknnown	0	4	0%
Total	27	2,369	100%
		2,000 *	

Accident Type			
Left roadside departure	0	-	n.a.
Right roadside departure	0	-	n.a.
Forward impact	0	-	n.a.
Total	0	-	n.a.
		-	

Critical Event	46%
Precrash Vehicle Control	54%
Accident Type	0%

Filter 2b (RSC-applicable crashes): Same as filter 1,b excluding parking or backing maneuvers.	
cases	-
weighted	-
freq. (weighted)	**0.0%**

Critical Event			
Excessive Speed	0	-	n.a.
Other cause	0	-	n.a.
Disabling vehicle failure	0	-	n.a.
Unknown cause	0	-	n.a.
Poor road conditions	0	-	n.a.
Total	0	-	n.a.
		-	

Accident Type			
Other	0	-	n.a.
Total	0	-	n.a.
		-	

Critical Event	n.a.
Accident Type	n.a.

*rounded to nearest thousand **rounded to nearest hundred

Figure D2. Filter 2 Results for Large-Platform Bus Crashes (Yearly Averages)

1996-2005 GES - Large Platform Buses (Yearly Averages) - # Cases, Weighted Count, and Frequency (weighted)	
Filter 3a (ESC-applicable crashes): Same as filter 2a, excluding turning maneuvers or low travel speed (< 30 mph).	
cases	34
weighted	3,600 **
freq. (weighted)	**3.4%**

Critical Event			
Excessive Speed	4	622	45%
Poor road conditions	4	751	55%
Total	8	1,373	100%
		1,000 *	

Precrash Vehicle Control			
Longitudinal skid	23	2,094	94%
Lateral skid- CCW	1	74	3%
Lateral skid - CW	1	49	2%
Other	0	2	0%
Multiple types	0	4	0%
Total	25	2,223	100%
		2,000 *	

Accident Type			
Left roadside departure	0	-	n.a.
Right roadside departure	0	-	n.a.
Forward impact	0	-	n.a.
Total	0	-	n.a.
		-	

Critical Event	38%
Precrash Vehicle Control	62%
Accident Type	0%

Filter 3b (RSC-applicable crashes): Same as filter 2b, excluding turning maneuvers or low speed (< 30 mph).	
cases	-
weighted	-
freq. (weighted)	**0.0%**

Critical Event			
Excessive Speed	0	-	n.a.
Total	0	-	n.a.
		-	

Accident Type			
Other	0	-	n.a.
Total	0	-	n.a.
		-	

Critical Event	n.a.
Accident Type	n.a.

*rounded to nearest thousand **rounded to nearest hundred

Figure D3. Filter 3 Results for Large-Platform Bus Crashes (Yearly Averages)

1996-2005 GES - Large Platform Buses (Yearly Averages) - # Cases, Weighted Count, and Frequency (weighted)											
Filter 4a (ESC-applicable crashes): Same as filter 3a, including only lateral skidding.											
cases	8										
weighted	1,000 *										
freq. (weighted)	**1.0%**										
Critical Event				**Precrash Vehicle Control**				**Accident Type**			
Excessive Speed	3	459	50%	Lateral skid- CCW	1	74	57%	Left roadside departure	0	-	n.a.
Poor road conditions	3	461	50%	Lateral skid - CW	1	49	38%	Right roadside departure	0	-	n.a.
Total	6	919	100%	Other	0	2	2%	Forward impact	0	-	n.a.
		1,000	*	Multiple types	0	4	3%	Total	0	-	n.a.
				Total	2	130	100%			-	
						100	**				
								Critical Event		88%	
								Precrash Vehicle Control		12%	
								Accident Type		0%	
Filter 4b (RSC-applicable crashes): ESC or RSC fourth filter: Same as filter 3b, including only lateral skidding.											
cases	-										
weighted	-										
freq. (weighted)	**0.0%**										
Critical Event								**Accident Type**			
Excessive Speed	0	-	n.a.					Other	0	-	n.a.
Total	0	-	n.a.					Total	0	-	n.a.
		-								-	
								Critical Event		n.a.	
								Accident Type		n.a.	

*rounded to nearest thousand **rounded to nearest hundred

Figure D4. Filter 4 Results for Large-Platform Bus Crashes (Yearly Averages)

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