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**National Highway
Traffic Safety Administration**

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PRELIMINARY REGULATORY IMPACT ANALYSIS

FMVSS No. 136
Electronic Stability Control Systems
On
Heavy Vehicles

Office of Regulatory Analysis and Evaluation
National Center for Statistics and Analysis
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People Saving People

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This Preliminary Regulatory Impact Analysis examines the impact of the proposal to establish Federal Motor Vehicle Safety Standard (FMVSS) No. 136, Electronic Stability Control Systems (ESC) on Heavy Vehicles. At this time, the proposal would apply to only truck tractors and buses with a GVWR greater than 11,793 kilograms (26,000 pounds). Specifically, the applicable buses (**large buses**) are those that have 16 or more designated seating positions (including the driver), and at least 2 rows of passenger seats, rearward of the driver's seating position, that are forward-facing or can convert to forward-facing without the use of tools. This proposal does not apply to school buses and urban transit buses sold for operation as a common carrier in urban transportation along a fixed route with frequent stops.

ESC is one of two types of stability control systems that have been developed for heavy vehicles. The other one is roll stability control (RSC) which is designed primarily to mitigate on-road, un-tripped rollovers. ESC, on the other hand, not only includes the RSC functions but also is designed to mitigate loss-of-control (LOC) crashes that are caused by yaw instability. The National Highway Traffic Safety Administration (NHTSA, the agency) is proposing ESC for addressing both first-event rollover and LOC crashes.

The proposal is based on a thorough examination of three Alternatives including the proposal. Based on this analysis, the proposal is highly cost-effective measured against a comprehensive baseline of $6.4 million[1] per life value (2010 economics). The proposal would also generate a positive net benefit.

Note that RSC can be implemented on truck tractors and trailers. Therefore, for clarification, hereafter, RSC and ESC are used exclusively as tractor-based or bus-based systems. Trailer-RSC as implied by the name is a trailer-based system. No tractor-trailer combination systems[2] are discussed in the analysis since the tractor-based systems are found to be the dominant systems.

Requirements

The proposal would require that truck tractors and buses with a gross vehicle weight rating (GVWR) greater than 11,793 kilograms (kg; 26,000 pounds) be equipped with an ESC system that meets the equipment, functional, and performance requirements specified in the proposed FMVSS No. 136. The proposal requires ESC to comply with two compliance tests and four performance criteria. The proposed compliance tests are 1) Slowly Increasing Steer Characterization test and 2) Sine with Dwell test. The proposed performance criteria are 1) Engine Torque Reduction, 2) Lateral Acceleration Ratio, 3) Yaw Rate Ratio, and 4) Lateral Displacement. These proposed performance requirements complemented by the equipment and functional requirements would ensure that ESC would mitigate the on-road untripped rollover and LOC crashes but not at the expense of vehicle steering responsiveness when it was activated. The truck tractors and large buses covered by the proposal are called <u>applicable</u> vehicles in this analysis. On-road untripped first event rollovers are called target rollovers.

[1] Contains both economic costs and values for intangible consequences such as lost quality of life
[2] i.e., the tractor is equipped with an ESC and the trailer is equipped with a trailer-RSC

In addition, the proposal would require manufacturers to install an ESC malfunction telltale (warning lamp) using specific symbols and/or text for the malfunction telltale. An On/Off switch to turn off ESC would not be allowed.

Technical Feasibility/Baseline

ESC is increasingly being offered as standard or optional equipment in new model year truck tractors and large buses. Based on manufacturers' product plans submitted to the agency in late 2009, the agency estimated that 14 percent of model year (MY) 2009 truck tractors and an extremely small percent of buses were equipped with ESC. By 2012, ESC installation rates are expected to increase to 26 percent for truck tractors and 80 percent for large buses. The agency believes that these ESC systems, some of which may need slight modifications, would otherwise already comply with the proposed "ESC" performance requirements.

For this analysis, the projected MY 2012 installation rates serve as the baseline compliance rates. As described earlier, with slight modifications, current ESC systems would pass the proposed compliance tests. Therefore, this analysis assumes that the 2012 model year ESC-equipped vehicles would all comply with the proposed test. Benefits and costs of the proposal thus reflect increasing ESC installation rates from 26 percent in truck tractors and 80 percent in large buses to 100 percent in both vehicle types.

Benefits[3]

ESC is estimated to reduce the target rollover and LOC crashes by 28 to 36 percent. Therefore, the proposal would eliminate 1,807 – 2,329 crashes annually including 1,332 – 1,854 rollover crashes and 475 LOC crashes once all truck tractors and large buses have ESC. As a result, annually, the proposal would save (undiscounted) 49 – 60 lives, reduce 649 – 858 MAIS 1-5 injuries[4], and eliminate 1,187 – 1,499 property damage only (PDOVs) vehicles. Of these benefits, 27 – 38 lives and 537 – 746 MAIS 1-5 injuries were from rollover crashes and 22 lives and 112 MAIS 1-5 injuries were from LOC crashes. For PDOVs, 797 – 1,109 vehicles were from target rollover crashes and 390 were from LOC crashes. Table E-1 lists these benefits.

Note that benefits for target rollover crashes are presented as a range in this analysis. This is the result of using a range of ESC effectiveness against the target rollover crashes. By contrast, at the time of publication, there is only one available effectiveness estimate for LOC. Therefore, the benefits for LOC are presented as a single point estimate. Also note that the estimated benefits were basically all from truck tractors. This is due to the small 2012-based large bus target crash population and a high ESC installation rate for large buses.

[3] Benefits of the rule are measured from a baseline of 26% ESC installation to 100% installation for truck tractors and 80% to 100% for large buses. However, the overall benefits of ESC could be measured from “no ESC” to 100% penetration rate with 0% RSC penetration rate. Overall, ESC would prevent 2,876 – 3,758 crashes, save a total of 74 – 92 lives, and eliminate 1,047 – 1,401 MAIS 1-5 injuries and 1,870 – 2,397 PDOVs annually.

[4] MAIS (Maximum Abbreviated Injury Scale) represents the maximum injury severity of an occupant at an Abbreviated Injury Scale (AIS) level. AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable).

Table E-1
Summary of Benefits
(Undiscounted)

	Low Range of Benefits			High Range of Benefits		
	Rollover Crashes	Loss-of-Control Crashes	Total	Rollover Crashes	Loss-of-Control Crashes	Total
Crashes	1,332	475	1,807	1,854	475	2,329
Fatalities	27	22	49	38	22	60
Injuries (AIS 1-5)	537	112	649	746	112	858
PDOVs	797	390	1,187	1,109	390	1,499

PDOVs: property damage only vehicles

Vehicle Technology Costs

The ESC system cost is estimated to be $1,160 (in 2010 dollars) per vehicle which includes all the components for ESC and the ESC malfunction telltale. The total incremental cost of the proposal (over the MY 2012 installation rates and assuming 150,000 unit truck tractors and 2,200 large buses sold per year) is estimated to be $113.6 million to install ESC and malfunction indicator lamps. The average incremental cost is estimated to be $746 per vehicle. Separately by vehicle type, the estimated average incremental cost is $754 per truck tractor and $232 per bus. These figures reflect the fact that 26 percent of the baseline MY 2012 truck tractors and 80 percent of MY 2012 large buses are projected to already come equipped with ESC. The costs also take into account that 16.0 percent of MY 2012 truck tractors, in addition to the 26 percent mentioned above, would already have RSC. Table E-2 summarizes the vehicle costs.

Table E-2
Summary of Vehicle Technology Costs
(2010 dollars)

	Average Vehicle Costs	Total Costs
Truck Tractors	$754	$113.1 M
Large Buses	$232	$0.5 M
Combined	$746	$113.6 M

M: million

Other Impacts

Property Damage and Travel Delay

The proposal would prevent crashes and thus would reduce property damage costs and travel delay associated with those crashes avoided. Overall, the rule would save $13.9 to $17.8 million at a 3 percent discount rate or $11.0 to $14.1 million at a 7 percent discount rate in property damage and travel delay.

Fuel Economy

The added weight from ESC, which consists primarily of just electronic sensors and wiring, is insignificant relative to the 11,793 kg (26,000 pounds) plus weight of the truck tractors and large buses. Consequently, the increase in their lifetime use of fuel is considered to be negligible.

Net Cost Per Equivalent Life Saved

As shown in Table E-3, the net cost per equivalent life saved, discounted at a 3 percent and 7 percent discount rate will range between $1.5 million and $2.6 million.

Table E-3
Cost Per Equivalent Life Saved
(2010 dollars)

	3% Discount Rate		7% Discount Rate	
	Low	High	Low	High
Net Cost per Equivalent Life Saved	$1.5 M	$2.0 M	$2.0 M	$2.6 M

M: million

Net Benefits

A net benefit analysis differs from a cost effectiveness analysis in that it requires that benefits be assigned a monetary value. This value is compared to the monetary value of costs to derive a net benefit. The proposal would accrue $155 to $310 million in net benefits as shown in Table E-4. The high net benefit of $310 million was based on a 3 percent discount rate and the low end of $155 million was based on a 7 percent discount rate. Both of these are based on a $6.4 million comprehensive value for preventing a fatality.

Table E-4
Net Benefits
With $6.4 M Cost Per Life
(2010 dollars)

	At 3% Discount		At 7% Discount	
	Low	High	Low	High
Net Benefits	$228 M	$310 M	$155 M	$222 M

M: million

Alternatives

In addition to the proposal requiring ESC, the agency also examined two less stringent alternatives that would require RSC and trailer-RSC:

- Alternative 1 would require all new applicable vehicles (i.e.., truck tractors and large buses) to be equipped with RSC,
- Alternative 2 would require trailer-RSC for all new trailers

Alternative 1 is slightly more cost-effective and lower in total costs than the proposal. However, this Alternative would save fewer lives and accrue less net benefits than the proposal. Furthermore, Alternative 1 would have significantly less impact on LOC crashes, a sizeable safety population that the agency intends to address. Therefore, Alternative 1 was not proposed.

Alternative 2 would save even fewer lives than Alternative 1. Moreover, Alternative 2 is significantly less cost-effective than both the proposal and Alternative 1 and would produce negative net benefits. Table E-5 lists the costs, equivalent lives saved, cost per equivalent life saved, and net benefits of these two Alternatives by discount rate. Therefore, Alternative 2 was not selected.

Table E-5
Cost-Benefit Measures for Alternatives 1 and 2 by Discount Rate
(2010 dollars)

Cost-Benefit Measures	**Alternative 1**		**Alternative 2**	
	At 3% Discount	At 7% Discount	At 3% Discount	At 7% Discount
Equivalent Lives Saved	31 - 43	24 – 34	5 – 7	3 – 5
Vehicle Cost*	$55.8 M	$55.8 M	$81.2 M	$81.2 M
Cost per Equivalent Life Saved	$1.0 - $1.5 M	$1.3 - $2.0 M	$11.2 - $15.9 M	$16.0 - $26.7 M
Net Benefits	$153 - $235 M	$106 - $174 M	-$35 to -$49 M**	-$50 to -$60 M**

* Not discounted since the costs occur when the vehicle is purchased
** Negative benefits indicate that costs are greater than the dollar value of benefits
M: million

Retrofitting

The analysis also examines the practicability of extending applicable vehicles to include in-service vehicles. Retrofitting ESC or RSC does not appear to be feasible because of the complexity of integration which involves the calibration of these technologies with the vehicles' engine, braking, local communication, and electronic control unit systems. Moreover, no ESC or RSC retrofitting tools are currently available. In contrast, retrofitting trailer-RSC systems are commercially available. However, retrofitting in-service trailers is extremely costly ($3.3 - $4.2 billion) and not cost effective ($0.5 - $1.7 billion per equivalent life saved). Therefore, the agency has determined that retrofitting ESC or RSC is not practical, and that retrofitting trailer-RSC is not cost beneficial.

Leadtime

The agency proposes a two-year leadtime for typical 4x2 and 6x4 truck tractors[5] and large buses. For severe service tractors, which typically have a GVWR greater than 27,000 kg (59,600 pounds), and other specialty truck tractors with three axles or more, the agency proposes a leadtime of four years.

The agency believes that the proposed leadtime would ensure that the only two current suppliers of heavy vehicle stability control systems, Bendix and Meritor WABCO, would have enough time to produce sufficient units of stability control systems to meet the demand of truck tractor

[5] The 6x4 description for a tractor represents the total number of wheel positions (six) and the total number of wheel positions that are driven (four), which means that the vehicle has three axles with two of them being drive axles. Similarly, a 4x2 tractor has four wheel positions, two of which are driven, meaning that the vehicle has two axles, one of which is a drive axle.

and bus manufacturers. It also should enable truck/bus manufacturers to make necessary design changes to their vehicles' instrumentation, brake, and electronic systems as to accommodate the new ESC systems. Consequently, this would minimize the compliance costs to manufacturers.

Summary of Annual Costs and Benefits

Table E-6 summaries the total annual costs, injury benefits, property damage and travel delay savings, cost per equivalent life saved, and net benefits of the proposal by two discount rates.

Table E-6
Estimated Annual Cost, Benefits, and Net Benefits of the Proposal
(in million of 2010 dollars**)**

	Costs	Injury Benefits	Property Damage and Travel Delay Savings	Cost Per Equivalent Live Saved	Net Benefits
At 3% Discount	$113.6	$328 – $405	$13.9 - $17.8	$1.5 - $2.0	$228 - $310
At 7% Discount	$113.6	$257 – $322	$11.0 - $14.1	$2.0 - $2.6	$155 - $222

CHAPTER I. INTRODUCTION

This Preliminary Regulatory Impact Analysis (PRIA) accompanies NHTSA's Notice for Proposed Rulemaking (NPRM) to establish Federal Motor Vehicle Safety Standard (FMVSS) No. 136, Electronic Stability Control Systems (ESC) for Heavy Vehicles. At this time, the proposal would require truck tractors and buses that have a gross vehicle weight rating (GVWR) greater than 11,793 kilograms (kg, 26,000 pounds) be equipped with ESC. This proposal would apply to these buses that have 16 or more designated seating positions (including the driver), and at least 2 rows of passenger seats, rearward of the driver's seating position, that are forward-facing or can convert to forward-facing without the use of tools. The applicable bus does not include a school bus, multifunction school activity bus, or urban transit bus sold for operation as a common carrier in urban transportation along a fixed route with frequent stops (i.e., transit bus designed for an "urban area" as defined in 49 U.S.C. Section 5301(16). These applicable buses are referred as "large buses", hereafter.

ESC and Roll Stability Control (RSC) are two types of stability control systems that have been developed for heavy vehicles. RSC is designed to mitigate on-road, un-tripped truck rollovers by automatically decelerating the vehicle by applying the foundation brakes and reducing engine torque output. ESC includes the RSC function described previously. In addition, ESC has added capability for mitigating severe oversteer or understeer conditions that can lead to vehicle loss-of-control (LOC), by automatically applying selective brakes to generate a yawing moment that helps the driver maintain directional control of the vehicle. Thus, ESC for truck tractors and large buses are designed to mitigate both untripped rollover and LOC crashes, which is different from that specified in Federal Motor Vehicle Safety Standard No. 126 (FMVSS No. 126) for light vehicles with a GVWR of 4,536 kg (10,000 pounds) or less. Note that manufacturers also developed trailer-based roll stability control technology. This technology is specified as trailer-RSC in this analysis. Therefore, ESC and RSC in this analysis represent specifically the truck tractor- or bus-based systems.

Rollover and LOC crashes comprised a significant portion of truck tractor and bus crashes. Based on 2006-2008 General Estimates System (GES) and Fatality Analysis Reporting System (FARS), annually, truck tractors and large buses were involved in 201,600 crashes (198,800 non-fatal and 2,800 fatal crashes). There crashes caused 3,721 fatalities and 60,400 non-fatal police-reported injuries. Of these truck tractor and large bus crashes, 13,200 crashes (5,700 first event rollover and 7,500 LOC crashes) would be impacted by the proposal. Consequently, the proposal would potentially further reduce the 415 fatalities and 5,400, non-fatal police-reported injuries that were associated with these rollover and LOC crashes.

Since the early 1990's, the agency has been actively addressing the heavy vehicle rollover and LOC safety problems. In 1995, the agency published a final rule mandating antilock braking systems (ABS) on truck tractors manufactured on or after March 1, 1997 and for other air-braked heavy vehicles, including single unit trucks, buses, and trailers manufactured on or after March 1, 1998. ABS, an advanced braking technology, has helped to reduce jackknife crashes and other directional loss-of-control crashes that were caused by wheel lockup during braking. However, many rollovers and LOC crashes are not caused by wheel lockup but by steering maneuvers. To specifically address these types of crashes, in the mid-1990s, the agency sponsored the development of a prototype roll stability advisor (RSA) system - a precursor of an RSC system. RSA relays stability related information such as the truck's roll stability threshold and the peak lateral acceleration achieved during cornering maneuvers to the driver.

In 2006, with the further advancement of avoidance technologies and the agency's experience with ESC on light vehicles[6], the agency initiated a test program at the Vehicle Research and Test Center (VRTC) to evaluate the performance of heavy vehicle stability control systems and to develop objective test procedures and performance measures. Researchers tested three tractors, each equipped with either RSC or ESC systems, one semi-trailer equipped with a trailer-based RSC system, and three buses equipped with an ESC system. Additionally, the agency tested five baseline semi-trailers not equipped with a stability control system, including an unbraked control trailer that is used to conduct tractor braking tests as prescribed by FMVSS No. 121, *Air brake systems*. These research efforts form the basis of this proposal. Research results are summarized in one paper and two technical reports:

a. NHTSA's Class 8 Truck-Tractor Stability Control Test Track Effectiveness, 2009 ESV paper, No. 09-0552[7],
b. Tractor-Semitrailer Stability Objective Performance Test Research – Roll Stability, May 2011, DOT HS 811 467, and
c. Tractor-Semitrailer Stability Objective Performance Test Research – Yaw Stability (to be published)

[6] On April 6, 2007, the agency issued a final rule (72 FR 17236) that established Federal Motor Vehicle Standard (FMVSS) No. 126, Electronic Stability Control Systems, which requires passenger cars, multipurpose passenger vehicles, trucks and buses with a gross vehicle weight rating of 4,536 kg (10,000 lb) or less to be equipped with an electronic stability control system beginning model year 2012.

[7] Available from www.regulations.gov; see Docket No. NHTSA-2010-0034-0008

Furthermore, NHTSA has sponsored several research programs with stability control system developers and manufactures and universities to study the effectiveness of the RSC and ESC on truck tractors against untripped first-event rollovers (i.e., target rollovers) and LOC crashes. These studies include:

- A study with Meritor WABCO and the University of Michigan Transportation Research Institute (UMTRI) to examine the potential safety effectiveness of RSC and ESC systems for five-axle tractor-trailer combination vehicles (UMTRI study)[8],
- A study with the University of Iowa using the National Advanced Driving Simulator (NADS)[9] to determine the effectiveness of RSC and ESC for scenarios that were most likely to induce rollover and jackknife crashes, and
- An ongoing project started in February 2009 with Virginia Tech Transportation Institute (VTTI) to assess the real-world safety benefits of the Bendix stability system. The project is focused on RSC and the project report is still underway at the publication of the analysis.

After the completion of the UMTRI's study, the agency published a Research Note[10] which describes the process of deriving the effectiveness rates of ESC and RSC in truck tractors. The Research Note was built upon the UMTRI study and revised the effectiveness of RSC and ESC. The Research Note concluded that ESC would prevent 28 to 36 percent of target rollovers and LOC crashes. RSC would prevent 21 to 30 percent of these crashes.

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[8] Safety Benefits of Stability Control Systems for Tractor-Semitrailers, DOT HS 811 205, October 2009, available from www.regulations.gov; see Docket No. NHTSA-2010-0034-0006

[9] Heavy Truck ESC Effectiveness Study Using NADS, DOT HS 811 233, November 2009, The final report is available from www.regulations.gov, Docket No. NHTSA-2010-0034-0007

[10] Wang, Jing-Shiarn, Research Note "Effectiveness of Stability Systems for Truck Tractors" , DOT HS 811 437, January 2011

As for large buses, in October 2009, NHTSA issued a Vehicle Safety Priority Plan, which describes the agency plans for rulemaking and research for calendar years 2009 to 2011. The Priority Plan includes stability control on Heavy Vehicles, and states that the agency plans to develop test procedures for a Federal motor vehicle safety standard on stability control for truck tractors, with the countermeasures of roll stability control and electronic stability control, which are aimed at addressing rollover and loss-of-control crashes. In addition, the Department of Transportation Motorcoach Safety Action Plan[11], issued in November 2009, includes an action item for NHTSA to assess the safety benefits for stability control on motorcoaches and develop objective performance standards for these systems.

Following the Motorcoach Safety Priority Plan, NHTSA's VRTC has evaluated the performance of ESC on three motorcoaches using the test maneuvers and performance criteria developed for truck tractors. The three motorcoaches were two 2007 MCI D4500 with the Meritor WABCO ESC system and a 2009 Prevost H3 with the Bendix ESC system. Overall this research concluded that an identical set of test maneuvers and similar performance criteria can be applied to both motorcoaches and truck tractors to discern ESC performance in preventing target rollovers and LOC crashes.

The National Transportation Safety Board (NTSB) has issued several safety recommendations relevant to ESC systems on heavy and other vehicles. Recommendation H-08-15 addresses ESC systems on commercial vehicles. Recommendations H-10-05 and H-10-06 address stability control systems on buses with a GVWR above 10,000 pounds. Two other safety recommendations, H-01-06 and H-01-07, on adaptive cruise control and collision warning

[11] Motorcoach definition used in the action plan is equivalent to the bus terminology used in this proposal.

systems on commercial vehicles are indirectly related to ESC on heavy vehicles because the addressed technologies and ESC all require active braking without driver input[12].

The trucking industry has implemented the stability control technologies to mitigate rollover and LOC crashes. The industry first introduced RSC in the U.S. for truck tractors in 2002 and later ESC in 2005. Based on the trucking industry's input and product plans submitted to the agency, the agency estimates that about 7.4 percent of truck tractors sold in 2007 were already equipped with ESC and additional 10.5 percent were equipped with RSC only systems. The ESC installation rate is expected to increase to 26.2 percent and RSC to 16.0 percent for model year (MY) 2012 truck tractors. The stability control systems were introduced for large buses much later. The agency estimates that the ESC and RSC installations were extremely low for those sold in 2007. However, ESC installation is expected to rapidly rise to 80.0 percent for MY 2012 large buses.

Given that the agency's research has developed feasible and repeatable test maneuvers and viable performance criteria, that ESC is found to be effective in reducing rollover and LOC crashes, and that the ESC technologies are mature, the agency has decided to propose requiring ESC on truck tractors and buses with a GVWR greater than 11,793 kg (26,000 pounds) to reduce the occurrence of rollovers and LOC crashes in these new heavy vehicles.

[12] Active braking involves using the vehicle's brakes to maintain a certain, preset distance between vehicles.

Organization of the Remaining Analysis

This PRIA estimates the benefits, cost, cost-effectiveness, and net benefits of the rule. The following discussion outlines the remaining structure of this document. Chapter II describes the requirements of the proposed Standard No. 136. Chapter III discusses current ESC systems and their functional capabilities. This Chapter also summarizes the test results performed by the agency. Chapter IV estimates the benefits. Chapter V discusses the costs and leadtime. Chapter VI provides cost-effectiveness and net benefits analysis. Chapter VII discusses alternatives. Finally, Chapter VIII examines the impacts of the proposal on small business entities. In addition, Appendix A examines the practicability of retrofitting. Appendix B revises comprehensive costs to reflect the value of a statistical life (VSL) of $6.0 million that was specified in a 2009 DOT guideline on value of life.

CHAPTER II. PROPOSED REQUIREMENTS

The proposal would establish Federal Motor Vehicle Safety Standard (FMVSS) No. 136, Electronic Stability Control Systems (ESC) for Heavy Vehicles, which requires truck tractors and buses having a gross vehicle weight rating (GVWR) greater than 11,793 kilograms (26,000 pounds) to be equipped with an ESC system that meets the requirements of the standard. This proposal would apply to these buses with 16 or more designated seating positions (including the driver), and at least 2 rows of passenger seats, rearward of the driver's seating position, that are forward-facing or can convert to forward-facing without the use of tools. [13] Applicable buses include those that were sold for intercity, tour, and commuter bus service, but do not include school buses, or urban transit buses sold for operation in urban transportation along a fixed route with frequent stops..

Note that the agency is not proposing to include single unit trucks with a GVWR greater than 4,536 kg (10,000 pounds) and buses with a GVWR 11,793 kg (26,000 pounds) or less at this time, primarily because stability control systems are not yet available for a broad segment of these vehicles. Substantial variations in brake type, vehicle weight, wheelbase, number of axles, center of gravity height, and cargo type, exist among single unit trucks. Furthermore, the development of stability control system for heavy vehicles has been focused on air-braked vehicles which include truck tractors and large buses that were covered by the proposed rule. These factors have made it challenging for the agency to devise test procedures and conduct vehicle testing to evaluate stability control system performance on single unit trucks.

[13] Definition was proposed in an NPRM for motorcoach seat belt, 75 FR 50,958 (Aug. 18, 2010).

The agency also is not proposing to apply this standard to in-service vehicles due to the lack of feasibility of retrofitting ESC. The integration of the systems into in-service vehicles involves the vehicle's chassis, engine, braking, and other stability related systems (e.g., traction control), vehicle local network communication systems, and electronic control units, which would place a tremendous financial burden especially on bus operators, of which 80 percent operate with a bus fleet size of less than 10 vehicles[14]. Moreover, the agency is not aware of any available ESC retrofitting service, most likely due to integration complexity. See Appendix A for a more detailed analysis of retrofitting issues.

In addition to retrofitting ESC, the agency also studied the impacts of retrofitting trailer-RSC since this retrofitting tool is commercially available. Based on the available cost information and the agency's test data on trailer-RSC, the agency determined that retrofitting trailer-RSC is not cost-effective. Thus, it is also not practical to require retrofitting trailer-RSC. Appendix A provides the agency's analysis on retrofitting issues.

The proposal specifies (a) the Definition of ESC, (b) the Equipment and Functional Requirements of ESC, (c) the Performance Requirements of ESC, and (d) ESC Activation, Malfunction, Telltale, and Symbol Requirements. The following sections summarize these requirements. Interested parties should consult the preamble of the NPRM for the details. In addition, comprehensive technical background information for deriving the requirements can be found in the agency research reports listed in Chapter I.

[14] Motorcoach Facts, 2009, American Bus Association, www.buses.org

A. DEFINITION OF ESC

The definition of ESC compliments the performance-based criteria to ensure the ESC is operational at a full range of rollover and vehicle stability conditions without the burden of requiring a battery of tests to cover a wide array of possible loading configurations and operating ranges for heavy vehicles. ESC is defined as a system that has all of the following attributes:

1) Augments vehicle directional stability by applying and adjusting vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the vehicle to induce correcting yaw moment to limit vehicle oversteer and to limit vehicle understeer.
2) Enhances rollover stability by applying and adjusting the vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the vehicle to reduce lateral acceleration of a vehicle.
3) Computer-controlled with the computer using a closed-loop algorithm to induce correcting yaw moment and enhance rollover stability.
4) Has a means to determine the vehicle's lateral acceleration.
5) Has a means to determine the vehicle's yaw rate and to estimate its side slip or side slip derivative with respect to time.
6) Has a means to estimate vehicle mass or, if applicable, combination vehicle mass.
7) Has a means to monitor driver steering input.
8) Has a means to modify engine torque, as necessary, to assist the driver in maintaining control of the vehicle.
9) When installed on a truck tractor, has the means to provide brake pressure to automatically apply and modulate the brake torques of a towed semi-trailer.

To ensure that a vehicle is equipped with an ESC system that meets the proposed definition and to allow the agency to verify that the ESC system meets operational requirements that may not necessarily be validated under the proposed performance tests, the agency is proposing that vehicle manufacturers make the following information available to the agency:

(1) A system diagram that identifies all ESC system hardware,

(2) A written explanation describing the ESC system's basic operational characteristics,

(3) A discussion of the pertinent inputs to the computer and how its algorithm uses that information to mitigate rollover and limit oversteer and understeer, and

(4) For truck tractors, information that shows how the tractor provides brake pressure to a towed trailer.

The requested information would enable the agency to ascertain that an ESC system includes the proposed components and attributes. This information also would aid the test engineers with execution and completion of the proposed compliance tests.

B. PERFORMANCE REQUIREMENTS

An ESC-equipped vehicle must satisfy performance test criteria to ensure sufficient rollover stability and oversteer or understeer intervention (i.e., mitigating the tendency for the vehicle to spinout or plow out in a curve). The agency is proposing the two compliance tests and four performance criteria:

(1) Slowly Increasing Steer Maneuver (SIS)

- Engine Torque Output Criterion

(2) Sine with Dwell Maneuver (SWD)

- Lateral Acceleration Ratio (LAR)

- Yaw Rate Ratio (YRR)
- Lateral Displacement (LD)

Slowly Increasing Steer Maneuver (SIS)

The SIS maneuver is used to determine a steering wheel angle which then is used to normalize the severity of the subsequent SWD maneuver. SIS is also used to evaluate the engine torque reducing capability of ESC to demonstrate that it mitigates both rollover and understeer.

Test Maneuver

The SIS maneuver is conducted at a constant speed of 48.3 kilometer per hour (km/h) with 1.6 km/h acceptable speed variation (i.e., 30 mph ± 1mph). A steering controller gradually increases the steering wheel angle from 0 to 270 degrees at continuous rate of 13.5 degrees per second. The 270 degrees is held constant for one second and the maneuver concludes. Each vehicle is subjected to two series of runs, with three tests performed for each series (i.e., a total of 6 runs). One series uses counterclockwise steering and the other uses clockwise steering. During each test run, ESC system activation must be confirmed. If ESC system activation does not occur during the maneuver, then the steering wheel angle is increased in 270-degree increments until the vehicle's maximum allowable steering wheel angle is reached or until ESC activation is confirmed.

The steering wheel angle determined by SIS would be used to program the automated steering machine for subsequent SWD test. The steering wheel angle is that which would produce 0.5 g of lateral acceleration in the test vehicle at a constant speed of 30 mph. This angle is determined by extrapolating the linear regression results of the steering wheel angle and lateral acceleration from the SIS test data. The 0.5 g lateral acceleration at 30mph is a level at which a loaded heavy vehicle is highly likely to experience roll instability.   As we understand, the relationship between the steering wheel angle and lateral acceleration varies with vehicles due to differences in steering gear ratios, suspension systems, wheelbase, and other vehicle characteristics. Using the established steering wheel angle in the subsequent SWD tests is to ensure that each vehicle is subjected to the same test severity and is likely to experience the same instability condition.

Engine Torque Reduction Criterion

ESC would be required to reduce the engine torque output by a minimum of 10 percent from the torque output requested by the driver at 1.5 seconds after it is activated. For the confirmation of ESC activation and evaluating the engine torque reduction capability by ESC, engine torque output and driver requested torque are collected from the vehicle's J1939 communication data link and compared. During the initial stages of an SIS test, the rate of change over a period of time for engine torque output and driver requested torque will be consistent. If ESC is activated, engine torque will be reduced and the rate of change for engine torque output and driver requested torque will diverge over time. The agency believes that 1.5 seconds after the ESC is activated, appreciable engine torque reduction can be measured.

Sine With Dwell Maneuver (SWD)

The proposed SWD maneuver subjects a vehicle to both roll and yaw instabilities and thus allows the agency to verify the performance of ESC in mitigating those instabilities. ESC would be required to comply with the proposed lateral stability, yaw stability, and responsiveness criteria.

Test Maneuver

SWD is a maneuver based on a 0.5 Hz (half cycle per second) sinusoidal steering input with a pause (i.e., dwell) of 1.0 second after completion of the third quarter-cycle of the sinusoid. Hence, the total time for the steering maneuver is three seconds. Figure II-1 depicts the SWD maneuver. To ensure accurate, repeatable, and reproducible results, the performance test uses a steering machine to deliver the maneuver to the steering wheel. Steering is initiated at 72 km/h (45 mph) with an allowable variation in initial speed of 1.6 km/h (i.e., 45 mph ± 1.0 mph). One series uses counterclockwise steering for the first half cycle. The other series uses clockwise steering for the first half cycle. The steering amplitude for the initial run of each series is 0.3A, where A is the steering wheel angle determined from the SIS maneuvers. In each of the successive test runs, the steering amplitude would be increased by increments of 0.1A until a steering amplitude of 1.3A, or 400 degrees maximum is achieved.

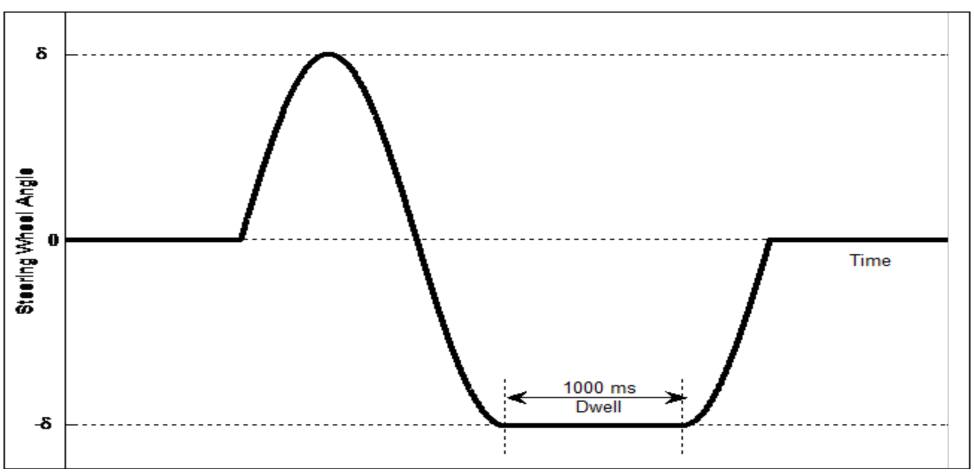


Figure II-1
Sine with Dwell by Steering Wheel Angle Inputs

For a truck tractor, the SWD test would be conducted with the tractor coupled to a test trailer and loaded to 80 percent of the tractor's GVWR. The trailer is equipped with outriggers in case the

ESC system does not function properly to prevent the tractor-trailer combination from rolling over. The trailer loaded with ballast that has a low center-of-gravity (CG) height which minimizes the likelihood of trailer rollover. This load and test configuration enables the tractor's ESC mass estimation program to sense that the tractor is heavily loaded and thus provide full tractor braking intervention during the SWD maneuver.

For a bus, the vehicle is loaded with a 68 kg (150 pounds) water dummy in each of the vehicle's designated seating positions, which would bring the bus' weight to less than its GVWR. No additional ballast is required to maintain the desired CG height of the test load.

Initially, the agency examined six maneuvers for roll stability and six maneuvers for yaw stability performance. Maneuvers for roll stability included: SIS, SWD, Constant Radius Increasing Velocity, 150-foot Radius J-turns, Double-Lane-Change, and Ramp Steer Maneuver (RSM). Maneuvers for testing roll stability performance included SIS, SWD, Half Sine with Dwell, RSM, Ramp with Dwell, and 150-foot Radius Braking-in-a-Curve. In addition, the agency also reviewed test maneuvers suggested by the industry and suppliers of stability control systems. These maneuvers include: a 500-foot Wet Jennite Curve Drive-Through from the Truck & Engine Manufacturers Association (EMA)[15] for yaw stability, a sinusoidal steering maneuver and a ramp with dwell maneuver from Bendix, and a lane change maneuver (on a large diameter circle) from Volvo.

After completing this research, SIS and SWD maneuvers were selected. Specifically, SWD was selected over other maneuvers due to its objectivity, practicability, repeatability, and

[15] Previously, Truck Manufacturers Association (TMA)

representativeness. SWD is highly objective because it will initiate roll, oversteer, and understeer intervention for every tested ESC system and because it will discriminate strongly between many vehicles with and without ESC (or with ESC disabled). The maneuver is practicable because it can easily be programmed into the steering machine and because it simplifies the test instrumentation due to its lack of closed-loop feedback control (e.g., yaw acceleration). It is repeatable due to the use of a steering machine thereby minimizing driver effects. In addition, the maneuver, similar to the test maneuver specified in the FMVSS No. 126, is representative of steering inputs produced by human drivers in an emergency obstacle avoidance situation such as performing severe lane change maneuver. Furthermore, SWD is able to address rollover, lateral stability, and responsiveness while other maneuvers are required to be paired in order to achieve the similar test condition. Finally, the SWD maneuver can be applied to both truck tractors and large buses for evaluating ESC performance while other tests may not be able to. Thus, proposing SWD reduces the number of required performance tests for ESC. Readers interested in the detailed test maneuvers and test results can consult the NHTSA research reports that were listed in Chapter I.

<u>Performance Criteria</u>

Lateral Acceleration Ratio (LAR)

LAR is developed to evaluate the ability of ESC in mitigating rollovers, i.e., to evaluate the RSC function of the ESC system. LAR is the ratio of lateral acceleration corrected for the vehicle's roll angle at a specific time to the maximum lateral acceleration measured between 4.5 seconds after the beginning of steering and the time when steering is completed. The beginning of steering is the point at which the maneuver begins and the steering wheel angle begins to change from 0 degree. The completion of steering is the point at which the maneuver ends and the steering wheel angle returns to 0 degree. ESC would be required to meet two LAR performance limits (i.e., the maximum allowable value of the ratio):

(1) 0.75 second after completion of the steering input for the 0.5 Hz, 72 km/h Sine with Dwell maneuver, LAR has to be less than or equal to 30 percent.

(2) 1.50 second after completion of the steering input for the 0.5 Hz, 72 km/h Sine with Dwell maneuver, LAR has to be less than or equal to 10 percent.

LAR can be represented in mathematical notations as follows:

$$\frac{A_{(t_0+0.75)}}{A_{\max imum}} \times 100 <= 30\% \text{ and}$$

$$\frac{A_{(t_0+1.75)}}{A_{\max imum}} \times 100 <= 10\%$$

Where,

$$\begin{aligned} \mathrm{A_t} &= \text{Lateral acceleration at time t (in seconds)} \\ \mathrm{A_{maximum}} &= \text{Maximum lateral acceleration between 1.0 of sterring input and } \mathrm{t_0} \\ \mathrm{t_0} &= \text{Time to completion of steering input} \end{aligned}$$

LAR is considered as the normalized lateral acceleration measure which is found to be a more robust measurement than simply the lateral acceleration for assessing roll stability performance. Based on the agency’s test experience, LAR adequately differentiated vehicles equipped with RSC (i.e., the RSC function of the ESC) and without RSC under the roll stability test conditions.

Other than LAR and lateral acceleration, the agency also examined a wheel lift measurement for roll stability performance. Although wheel lift is the most straightforward measure among all the measurements that were evaluated by the agency, its indication of an imminent rollover is less certain than LAR and the lateral acceleration. Certain vehicle suspensions are designed to permit wheel lift during severe cornering maneuvers. Non-uniform road surfaces also can cause brief wheel lift events. These wheel lifted conditions do not necessarily imply that rollover is imminent. Thus, wheel lift is not considered as a performance measure in the agency's proposal.

Yaw Rate Ratio (YRR)

YRR is developed to evaluate the ability of ESC in mitigating LOC crashes. YRR is the ratio of vehicle yaw rate at a specified time to the first local peak yaw rate generated by the 0.5 Hz Sine with Dwell steering reversal. The performance limits (i.e., the two maximum allowable values of the ratio) establish a five percent spinout threshold when ESC intervenes. In other words, an ESC-equipped vehicle has a less than five percent probability of not satisfying NHTSA's spinout definition if the vehicle meets the required lateral criteria. More specifically, YRR measures how quickly the vehicle stops turning or rotating about its vertical axis, after the steering wheel is returned to the straight-ahead position. A vehicle that continues to turn or rotate about its vertical axis for an extended period after the steering wheel has been returned to a straight-ahead position is most likely experiencing loss of control. ESC is required to meet the following two YRR performance limits:

(1) 0.75 seconds after completion of the steering input for the 0.5 Hz Sine with Dwell maneuver, the yaw rate of the vehicle has to be less than or equal to 40 percent of the first local peak yaw rate produced by the steering reversal.

(2) 1.50 seconds after completion of the steering input, the yaw rate of the vehicle has to be less than or equal to 15 percent of the first local peak yaw rate produced by the steering reversal.

The YRR criteria can be noted as:

$$\frac{\dot{\psi}_{(t_0+0.75)}}{\dot{\psi}_{Peak}} \times 100 <= 40\%\text{, and}$$

$$\frac{\dot{\psi}_{(t_0+1.50)}}{\dot{\psi}_{Peak}} \times 100 <= 15\%$$

Where,

$$\dot{\psi}_{t} = \text{Yaw rate at time t (in seconds)}$$
$$\dot{\psi}_{Peak} = \text{First local peak yaw rate generated by the 0.5 Hz Sine with Dwell sterring input}$$
$$t_0 = \text{Time to completion of steering input}$$

Based on the agency's analysis, we anticipate that an ESC system meeting these lateral stability criteria would significantly prevent the probability of a spinout during the conduct of the SWD maneuvers.

Lateral Displacement (LD)

LD will be used to measure the ability of a vehicle to respond to the driver's inputs during an ESC intervention. The criterion is defined as the lateral displacement of the vehicle's center of gravity with respect to its initial straight path during the initial stage of the sine with dwell maneuver. The criterion performance limit establishes the displacement threshold to ensure that the ESC intervention used to achieve acceptable lateral stability does not compromise the ability of the vehicle to respond to the driver's input. The proposal requires that an ESC-equipped vehicle would have a lateral displacement of at least 2.13 meters (7 feet) at 1.50 seconds after the initiation of steering for truck tractors, and 1.52 meters (5 feet) for large buses. The lateral displacement at 1.50 seconds after initiation of the steering input (the 1.50-seconds-lateral-displacement) can be calculated using the following double integration formula:

$$\text{Lateral Displacement} = \int_{t_0}^{t_0+1.50}\int_{t_0}^{t_0+1.50} Ay_{C.G.}(t)dt$$

$$\begin{cases} \geq 2.13 \text{ meters, for truck tractors} \\ \geq 1.52 \text{ meters, for motorcoaches} \end{cases}$$

Where,

t_0 = Steering wheel input starting time

$A_{C.G}$ = Lateral acceleration, corrected for the effects of roll angle and sensor offset from the vehicle C.G. position.

The double integration technique for calculating the lateral displacement was presented by the Alliance on September 7, 2005.[16] The technique was adapted by the agency and is incorporated in FMVSS No. 126.

C. ESC Malfunction Telltale and Symbol

The proposal would require a yellow ESC malfunction telltale identified by either the acronym "ESC" or the following symbol:

[16] Docket Number NHTSA-2005-19951

This symbol and the alternative text are included in Table 1 of FMVSS No. 101, Controls and Displays. The malfunction telltale is required to be mounted inside the occupant compartment in front of and in clear view of the driver. The malfunction telltale is required to illuminate after the occurrence of one or more ESC malfunctions that affect the generation or transmission of control or response signals in the vehicle's ESC system. Such telltale is required to remain continuously illuminated for as long as the malfunction exists, whenever the ignition locking system is in the "On" ("Run") position. The ESC malfunction telltale must extinguish at the initiation of the next ignition cycle after any malfunctions have been corrected.

D. ESC Off Switch, Telltale and Symbol

The proposal would not allow an ESC on/off switch in truck tractors or large buses. Based on our observation on light vehicle ESC systems, although ESC on/off switches are permitted in FMVSS No. 126, disabling the ESC system reduces the potential safety benefits of the system. The agency believes that heavy vehicles handling and control characteristics differ substantially compared to light vehicles and as a result the agency does not believe there is a needs for allowing an ESC on/off switch in heavy vehicles. The agency believes that all truck tractors currently sold with ESC systems are also equipped with traction control systems. Therefore, there would be no need to turn off the ESC when starting to move the vehicle on a slippery or loosely-packed road surface.

CHAPTER III. HOW ESC WORKS

A. ESC SYSTEMS

Meritor WABCO pioneered the ESC system for commercial vehicles in 2001 when the company offered the system as an option on the company's electronic braking system (EBS). The company is one of the leading providers of electronic braking, stability, suspension and transmission control systems for the commercial vehicle industry. Currently, ESC for heavy trucks and large buses primarily are produced by two companies[17]: Meritor WABCO and Bendix.

An ESC system utilizes computers to control individual wheel brake torque and assists the driver in maintaining control of the vehicle by keeping the vehicle headed in the direction the driver is steering even when the vehicle nears or reaches the limits of road traction. For example, during sudden lane changes or while cornering at excessive speed, ESC can help prevent truck-trailer combinations from rolling-over, skidding, or jack-knifing. Stabilization of the vehicle is achieved by selective braking on each wheel, or simultaneous application the brakes on several wheels, concurrent with automatic reductions in engine power.

A. How ESC Prevents Rollovers

Lateral acceleration is the primary cause of rollovers. Figure III-1 depicts a simplified rollover condition. As shown, when the lateral force (i.e., lateral acceleration) is sufficient large and

[17] Haldex also produce stability control systems but for trailers only

exceeds the roll stability threshold of the tractor-trailer combination vehicle, the vehicle will roll over. Many factors related to the drivers' maneuvers, heavy vehicle loading conditions, vehicle handling characteristics, roadway design, and road surface properties would result in various lateral accelerations and influences on the rollover propensity of a vehicle. For example, given other factors are equal, a vehicle entering a curve at a higher speed is more likely to roll than a vehicle entering the curve at a lower speed. Transporting a high center of gravity (CG) load would increase the rollover probability more than transporting a relatively lower CG load. Contributing factors in truck rollover crashes include: the driver making an abrupt steering input during a lane-change maneuver, or attempting to recover from a run-off-road event; driving with improperly secured cargo that can shift in transit; other shifting or sloshing loads ((such as transporting cattle or partial loads of liquids in tanker trailers),); vehicle in-service defects such as worn or broken suspension components or underinflated or worn (low tread depth) tires; improper superelevation design or construction of curved roadways; driving on roadway shoulders that may have the wrong superelevation direction for a given curve; and improper or missing curve speed warning signs. These operational issues can all lead to an increased likelihood of a truck rollover.

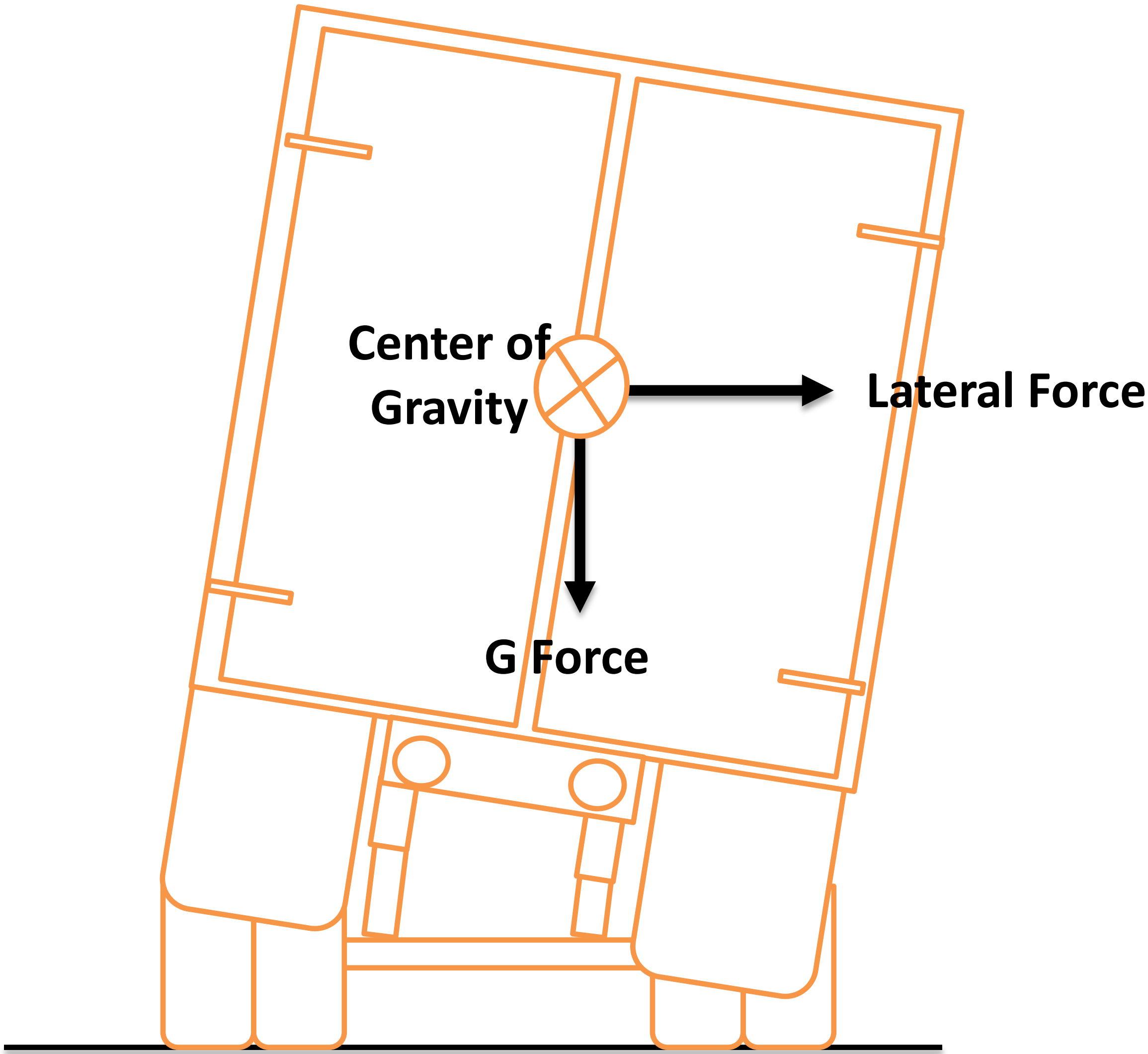


Figure III-1 Rollover Condition

The RSC function within an ESC system uses a lateral accelerometer to measure lateral acceleration. When RSC detects the acceleration reaching the estimated roll stability threshold of the truck, it intervenes and decelerates the vehicle by reducing engine throttle and engaging the tractor drive axle and trailer brakes to reduce the lateral acceleration of the vehicle and prevent a rollover from occurring.

B. How ESC Prevents Loss of Control

In addition to a lateral acceleration sensor, ESC uses two additional sensors to monitor the vehicle for yaw instability (oversteer) or for loss of directional control (understeer). One is a steering wheel angle sensor which senses the intended direction of a vehicle. The other one is a yaw rate sensor which measures the actual turning movement of the vehicle. When imbalance between these two measures occurs, the vehicle is either in an understeering (plowing out) or oversteering (spinning out) condition. When ESC detects an imbalance, it automatically intervenes by using selective braking of individual wheels on the tractor. ESC is further differentiated from RSC in that it has the ability to selectively apply the front steer axle brakes whereas the RSC system does not incorporate this feature.

Figure III-2 illustrates the oversteering and understeering conditions[18]. While Figure III-1 may suggest that a particular vehicle lose control due to either oversteer or understeer, it is quite possible that a vehicle could require both understeering and oversteering interventions during progressive phases of a complex crash avoidance maneuver such as a double lane change.

Oversteering. Figure III-2, the right side shows that the truck tractor entered a right curve that is too sharp for the speed that the tractor is traveling. The rear of the vehicle begins to slide which would lead to a non-ESC vehicle spinning out. If the tractor is towing a trailer, this is also called a jackknife crash; the tractor spins around and may make physical contact with the side of the trailer. An oversteering vehicle is considered to be yaw-unstable because the tractor rotation

[18] Adopted from the report "Concept of Operation and Voluntary Operational Requirements for Vehicle Stability Systems (VSS) On-Board Commercial Motor Vehicles", Federal Motor Carrier Safety Administration, July 2005, FMCSA-MCRR-05-006

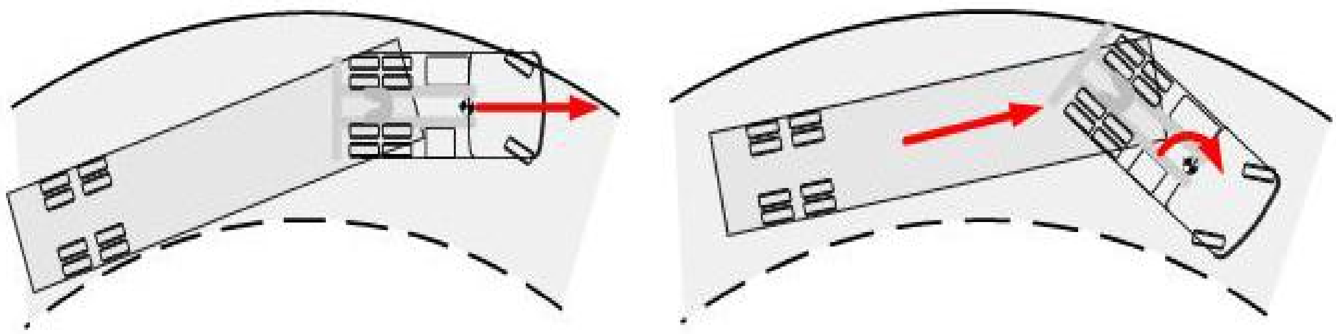
occurs without a corresponding increase in steering wheel angle by the driver, and the driver has also lost directional control of the vehicle (i.e., loss-of-control or LOC).

Understeering. Figure III-2, the left side shows a similar situation faced by a truck tractor whose response as it exceeds the limits of road traction is first sliding at the front (“plowing out”). Such a vehicle is considered to be yaw-stable because no increase in tractor rotation occurs when the driver increases the steering wheel angle. However, the driver has lost directional control of the tractor.

An ESC system maintains what is known as “yaw” (or heading) control by determining the driver’s intended heading via steering wheel angle sensors, measuring the vehicle’s actual response, and automatically adjusting the turning behavior of the vehicle if its response does not match the driver’s intention. However, with ESC, turning is accomplished by unbalanced forces at the tire-road interface from the brake torque being applied at a particular corner of the vehicle, from the brake torque rather than from steering input. Speed and steering angle measurements are used to determine the driver’s intended heading. The vehicle response is measured in terms of lateral acceleration and yaw rate by onboard sensors. If the vehicle is responding properly to the driver, the vehicle is considered to be yaw-stable and the driver has full directional control of the vehicle.

The concept of “yaw rate” can be illustrated by imagining the view from above of a truck following a large circle painted on a parking lot. One is looking at the top of the roof of the vehicle and seeing the circle. If the truck starts in a heading pointed north and drives half way around circle, its new heading is south. Its yaw angle has changed 180 degrees. If it takes 10 seconds to go half way around the circle, the “yaw rate” is 180 degrees per 10 seconds (deg/sec) or 18 deg/sec. If the speed stays the same, the truck is constantly rotating at a rate of 18 deg/sec around a vertical axis that passes through the vehicle’s center of gravity. If the speed is doubled, the yaw rate increases to 36 deg/sec.

As depicted in Figure III-2, for example, while driving in a circle, the driver notices that he must hold the steering wheel tightly to avoid sliding toward the passenger seat. The bracing force is necessary to overcome the lateral acceleration that is caused by the truck tractor following the curve. When the speed is doubled, the lateral acceleration increases by a factor of four if the truck follows the same circle. There is a fixed physical relationship between the truck’s speed, the radius of its circular path, and its lateral acceleration. Since the ESC system measures the truck’s speed and its lateral acceleration, it can compute the radius of the circle and subsequently the correct yaw rate for a vehicle following the path. The ESC system then compares the actual measured yaw rate acquired from the onboard yaw rate sensor to that computed for the path the truck is following. When the computed and measured yaw rates begin to diverge as the vehicle’s speed is increased to the point where the driver is beginning to lose control, A vehicle unassisted by ESC soon would have a heading significantly different from the desired path and would be out-of-control either by spinning out or plowing out. An ESC system has the ability to detect the imbalance and attempts to correct it by automatically applying brake torque (typically at one corner of the vehicle, but sometimes at more than one corner of the vehicle) - rather than by redirecting the vehicle's steer tires. The intervention of ESC will cause the vehicle's heading to change thus allow the driver to regain control of the vehicle.



Understeering ("Plowing

Oversteering ("Spinning

Figure III-2 Loss-of-Control Conditions

CHAPTER IV. BENEFITS

ESC is a crash avoidance countermeasure that would prevent crashes from occurring. Preventing crashes not only saves lives and reduces injuries. ESC also alleviates crash-related travel delays and property damage. Therefore, the estimated benefits include both injury and non-injury components. The “injury benefits” discussed in this chapter are the estimated fatalities and injuries that would be prevented by the proposal. The non-injury benefits include the travel delay and property damage savings from crashes that would be avoided by ESC.

Basically, the size of the benefits depends on two elements: (1) the target crash population (P) and (2) the ESC effectiveness (e) against that population. The overall injury reduction benefit of the proposal is equal to the product of these two elements and can be expressed mathematically by the following generic formula:

$$B = P * e$$

Where, B = Benefit of the rule,

P = Target crash population, and

e = Effectiveness of ESC.

The target population includes fatalities, non-fatal injuries measured by the maximum abbreviated injury scale (MAIS), and property damage only vehicles (PDOVs). Fatalities and MAIS injuries are used for estimating injury reduction benefits. They also combined with

PDOVs for for calculating non-injury benefits, i.e., property damage and travel delay savings. The estimated injury benefits are then translated into fatal equivalents to derive cost-effectiveness and net benefit estimates of the proposal. The estimated property damage and travel delay savings are included in the cost to derive the “net cost” of the proposal.

Annual benefits and costs are expressed for a future time when all new vehicles must comply with the standard and the full on-road vehicle fleet has been converted to comply with the standard. Under these circumstances, assuming a constant rate of sales over time, the lifetime impacts on a single model year’s fleet will equal the full on-road fleet impacts in any given calendar year. The target population was initially derived from the most current available real-world crash data. The initial target population was then projected to the 2012 level through a series of adjustments in order to correspond to the cost estimates for ESC which are based on the 2012 model year applicable vehicles. The projection takes into account the impacts of ESC and RSC that are estimated to be increasingly voluntarily implemented in the future fleet (i.e., 2012 model year vehicles). The impact of stability control system technology not only depends upon its installation rate on vehicles but also on its effectiveness in preventing crashes. Therefore, the technology effectiveness is discussed first. Initial target crashes, projected target crashes, and benefits are discussed in the subsequent sections.

A. Effectiveness of ESC and RSC

As stated previously, the agency's 2011 Research Note on the effectiveness of stability control systems for truck tractors found overall that ESC is 28 – 36 percent effective in reducing untripped rollover (i.e., target rollovers) and LOC crashes[19]. When segregated by crash type, ESC would reduce 40 – 56 percent of target rollover crashes and 14 percent of LOC crashes. By comparison, RSC is 21 – 30 percent effective against the same target rollover and LOC crashes. Separately, RSC is 37 – 53 effective against target rollovers and 3 percent effective against LOC crashes[20]. Table IV-1 lists these effectiveness rates which are used in the PRIA for the benefit analysis.

Table IV-1
Effectiveness Rates for ESC and RSC by Target Crashes
(Current NHTSA Estimates)*

Technology	Overall	Rollover	LOC
ESC	28 – 36	40 - 56	14
RSC	21 – 30	37 - 53	3

*Adopted from the 2011 NHTSA Research Note "Effectiveness of Stability Control Systems for Truck Tractors"

These effectiveness rates were built upon two earlier studies: (1) a 2008 study on RSC that was conducted by American Transportation Research Institute and sponsored by the Federal Motor Carrier Safety Administration (FMCSA)[21] and (2) a 2009 study that was conducted by the University of Michigan Transportation Research Institute (UMTRI) and Meritor WABCO and

[19] Effectiveness of Stability Control for Truck Tractor, Research Note, DOT HS 811 437, January 2011
[20] these LOC were followed by rollovers

[21] Murray, D., Shackelford S., House, A., Analysis of Benefits and Costs of Roll Stability Control Systems, FMCSA-PRT-08-007 October 2008

sponsored by NHTSA[22]. The effectiveness rates from both studies were based on computer simulation results, expert panel assessments of available crash data, input from trucking fleets that had adopted the technology, and research experiments. A statistical analysis of vehicles with and without the technology using real-world crash data was not feasible (even now) since ESC and RSC penetration in the national in truck tractors is still small since these are relatively new technologies that have only been installed on a small percentage of new tractors over the past few years.

The 2008 FMCSA study examined only the effectiveness of RSC and was limited to rollover crashes. The study estimated that RSC is 37 - 53 percent effective against rollover crashes. The high end of the effectiveness was based on simulation results for rollovers on curved roadways due to excessive speed (i.e., untripped rollovers). The low end of the effectiveness was based on motor carriers' feedback on 106 rollover cases, of which 39 were considered to have been preventable by RSC.

The 2009 NHTSA study examined both the effectiveness of RSC and ESC. The study found that ESC would reduce rollovers by 0 to 75 percent and LOC crashes by18 to 40 percent. The magnitude of the effect varies depending on roadway alignment (straight, curved) and roadway surface conditions (dry, wet). These effectiveness estimates were aggregated from the initial effectiveness rates of these technologies for 159 cases that were identified from FMCSA's large truck crash causation study (LTCCS) as candidate target crashes. Eventually, the effectiveness rates of ESC and RSC against untripped rollover and LOC crashes were aggregated by roadway

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[22] Woodroffe, J., Blower, D., and Green, P., Safety Benefits of Stability Control Systems for Tractor-Semitrailers, DOT HS 811 205, October 2009

alignment (straight versus curved) and roadway condition (dry versus wet). Four sets of aggregated effectiveness estimates were established for ESC and for RSC. However, these aggregated effectiveness rates did not take into account the probability of occurrence for individual cases. Furthermore, in 2010 NHTSA revised the effectiveness of ESC and RSC downwards for six LTCCS cases and re-categorized the crash type for another two other cases. After these case revisions, the range of estimated ESC effectiveness against rollovers is 0 percent on straight, not dry roadways to 75 percent on curved, dry roadways. The ESC effectiveness against LOC crashes ranged from 7 percent on straight, dry roadways to 19 percent on curved, dry roadways. For RSC, the corresponding range was 0 to 72 percent against rollovers and 0 to 7 percent against LOC crashes. The effectiveness rates estimated in the 2011 Research Note were modified by considering the probability of occurrence of each of the 159 LTCCS cases and by incorporating the mentioned changes for 8 cases. The revised estimated effectiveness for ESC is a 47 percent reduction of first-event rollovers and a 14 percent reduction of LOC crashes. The corresponding revised effectiveness for RSC is 44 and 3 percent for rollover and LOC crashes, respectively.

The revised RSC effectiveness of 44 percent is close to the mid-point between the 37 and 53 percent that were estimated by the 2008 FMCSA study. For the consideration of uncertainty inherent in the study methodologies, the 2011 Research Note adopted the range of 37 to 53 percent as the effectiveness of RSC for rollover crashes. The effectiveness of ESC against rollover crashes ranged from 40 to 56 percent, 3 percent higher than those of RSC. The 3 percent is the difference between the RSC and ESC effects that were derived from the 2009 NHTSA study. Due to only one available study that examined the LOC crashes, a point effectiveness estimate is used for LOC crashes. ESC and RSC would reduce LOC crashes by 14 and 3 percent, respectively.

As described previously, only ESC has the ability to apply individual brakes at the corners of a vehicle to generate re-stabilizing yaw moments about the vehicle's center of gravity, to prevent a vehicle from going into a severe understeer or oversteer event. RSC on the other hand typically applies all of the tractor drive axle brakes using a uniform braking air pressure at all of the drive axle brakes. As the lateral acceleration of a vehicle increases during a hard cornering event, the RSC is able to detect this condition and apply the brakes to slow the vehicle down, thus preventing the vehicle from exceeding the limits of lateral tire traction. This is how RSC is able to mitigate loss of control. However, when the vehicle is on a slippery road surface and begins to lose control[23], only an ESC system can intervene to maintain vehicle control, since the lateral acceleration at the limit of lateral tire traction may be low enough not to activate an RSC system (provided that the vehicle is, for example, in a lightly-loaded condition such that RSC would allow up to 0.6 g of lateral acceleration before activating). This is why the effectiveness rate for preventing LOC crashes is higher for ESC than for RSC.

Note that due to limited large bus crash data, it is not feasible to conduct a statistical analysis of RSC/ESC performance for large buses. Therefore, the RSC/ESC effectiveness developed for truck tractors is also applied to large buses.

[23] For example, LTCCS cases 821005770 and 808006121 are examples of LOC on a slippery road surface. However, these cases were not included in the agency's effectiveness estimates, since one involved a bobtail tractor and the other involved double trailers. The agency's effectiveness estimates only included tractor-semitrailer crash-involved vehicles.

B. Initial Target Population

The initial target population for benefit estimates includes all occupant fatalities, MAIS 1+ non-fatal injuries, and PDOVs in: (a) first-event untripped rollover crashes (i.e., target rollovers) and (b) LOC crashes (e.g., jackknife, cargo shift, avoiding, swerving) that involved the applicable vehicles and might be prevented if the subject vehicle were equipped with an ESC. For this analysis, the subject vehicle, specifically in multi-vehicle crashes, is defined as at-fault or the striking applicable vehicles (i.e., truck tractor/large buses). The target crashes are the two crash types described above. The criteria used to define target rollovers and LOC crashes are consistent with or comparable to that used in the 2009 NHTSA report for truck tractors[24] and that used by VOLPE in defining safety problems[25]. Furthermore, crashes in which vehicle mechanical problems with tires, braking systems, or transmission were cited as contributing factors, or in which the driver was drowsy or blacked-out or incapacitated were also excluded from the target crashes. Generally, the target fatalities and non-fatal injuries should be limited to target crashes where ESC and RSC were not already standard safety devices in any of the involved subject vehicles. However, due to insufficient information, the agency was unable to identify ESC- or RSC-equipped truck-tractors or large buses in the current FARS and GES crash

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[24] John Woodrooffe, Daniel Blower, Timothy Gordon, Paul E. Green, Brad Liu, Peter Sweatman, Safety Benefits of Stability Control Systems for Tractor-Semitrailers, Final Report, The University of Michigan Transportation Research Institute, October 2009, DOT HS 811 205 http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2009/811205.pdf

[25] Marco P. daSilva, Greg Ayres, and Wassim G. Najm, Crash Problem Definition and Safety Benefits methodology for Stability Control for Single-Unit Medium and Heavy Trucks and Large Platform Buses, Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center, October 2009, DOT HS 811 099 http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2009/811099.pdf

data systems[26]. Thus, the fatalities and injuries in these vehicles were not excluded from the initial target population. These populations, however, will be excluded from the projected target population in the next section by using adjustment factors.

Target crashes involving LOC with tractor jackknife included crashes caused by braking-related lockup of the tractor drive axle wheels for which the countermeasure is the installation of an antilock brake system (ABS). Since the agency required ABS to be installed on heavy vehicles starting in 1997, braking-related jackknife crashes have been reduced, but have not been eliminated due to older tractors remaining in service and due to some ABS-equipped tractors not having the ABS maintained in proper working condition. Braking-related jackknife crashes have been accounted for in the effective estimates of RSC and ESC, so that they are not double-counted as being preventable by both ABS and RSC/ESC[27]

The initial target populations were retrieved from the 2006-2008 FARS and GES. FARS is a census of fatalities that occurred in fatal crashes on public roadways. FARS was used to derive the incidence of fatal target crashes and associated fatalities and non-fatal injuries. GES is a sampling system of all police-reported crashes. GES was used to derive the MAIS 1+ injuries in non-fatal target crashes and PDOVs. The purpose of using multiple years of crash data primarily was to limit variations of large bus crashes and reduce the effects of the recent recession on crashes involving heavy trucks. Tractor tractors were identified by the vehicle body type

[26] The agency notes, however, that the tractor model years from the LTCCS study typically pre-dated the availability of RSC and ESC technologies. Thus the derived effectiveness rates assumes that none of the crash-involved tractors in that study were equipped with RSC or ESC.

[27] For example, in the NHTSA 2011 Research Note, LTCSS Case 333006958 was removed from the RSC/ESC applicable categories since tractor and trailer ABS were considered by the agency to be the correct countermeasures to the crash.

variable (body type = 66) in both GES and FARS. Large buses were identified as "Intercity/cross country" bus type or unknown bus types but with a GVWR greater than 26,000 lbs.

As described previously, the 2009 NHTSA study estimated the effectiveness of ESC based on computer simulations and engineering judgment on 159 LTCCS cases. Then, the study established comparable target crash definitions in GES that were represented by those 159 cases. The PRIA adopted these GES definitions for identifying non-fatal target crashes.

FARS was used for establishing fatal target crashes. Variables, data attributes, and data structure are different between FARS and GES. Fatal target crashes thus cannot be defined as precisely as those in the GES. Alternatively, a comparable definition was developed by mapping the GES-variables closely to those in the FARS. FARS variables that were used to define the target crashes included vehicle forms submitted, vehicle body type, trailing unit, striking/struck status, the first harmful event, relation to roadway, roadway alignment, roadway condition, rollover type, jackknife status, driver contributing factor, and vehicle contributing factor. Of these variables, driver contributing factor, vehicle contributing factors, and vehicle striking/stuck status were used to refine the target population to exclude crashes in which incapacitated or drowsy drivers, or vehicle mechanical failures such as brake systems, tires, steering, and transmissions were cited as contributing factors.

Based on 2006-2008 GES and FARS, annually, there were 10,313 policed-reported target crashes (5,510 first event rollover crashes; 4,803 LOC crashes) [28] that involved truck tractors. A total of 327 fatalities (K-Injuries), 1,042 incapacitating injuries (A-Injuries), 1,635 non-capacitating injuries (B-Injuries) and 1,075 possible injuries (C-Injuries) were associated with these target crashes[29]. In addition to these injuries, there were 7,332 vehicles subjected to property-damage only impacts (PDOVs). Table IV-2 shows these initial target crashes, injuries, PDOVs by crash type (target rollover, LOC crashes), and crash severity (fatal, nonfatal).

From the same crash data sources, the agency estimates that, annually, an average of one target rollover and one LOC crash involving large buses would be impacted by the proposal. The small initial population for large buses combined with a high projected voluntary ESC installation in MY 2012 large buses results in negligible benefits. Therefore, hereafter, target population and subsequent benefit estimates for large buses are not presented in the analysis. The target population for truck tractors thus represents the target population of the proposal.

Table IV-2
Initial **Target Crashes, KABCO injuries, and PDOVs**
by Crash Type, Crash Severity, and Injury Severity

Crash Type	Crashes	Police-Reported KABCO Injuries					
		K	A	B	C	O	PDOVs
Rollover	5,510	111	630	1,107	754	275	3,297
LOC	4,803	216	412	528	321	243	3,935
Total	10,313	327	1,042	1,635	1,075	518	7,332

Source: 2006 - 2008 FARS, 2006 - 2008 GES
Rollover: first event rollover crashes; LOC: loss-of-control crashes; PDOVs: property damage only vehicles

[28] This estimate excludes first event rollover and LOC crashes where (1) the subject vehicles were the struck vehicles, (2) drivers of the subject vehicles were drowsy and used alcohol, (3) and tire, brake, transmission, steering column is cited as contributing factor.

[29] Police-reported injury severity (KABCO), K: fatality, A: incapacitated injury, B: non-incapacitated injury, C: possible injury, and O: no injury.

The next step is to translate the initial target population from police-reported KABCO injuries to AIS 1-5 injuries through a KABCO-AIS conversion table. The conversion allows the use of the crash unit costs which were developed by the agency and were based on the Abbreviated Injury Scale (AIS) system[30]. A conversion table was established using two data systems: 2000 – 2008 Crashworthiness Data Systems (CDS) and 1982 – 1986 National Accident Sampling System (Old NASS). CDS is a sample system of passenger vehicle crashes in which at least one passenger vehicle was towed away from the crash site. CDS collects injury information only for passenger vehicle occupants in a more severe crash environment (i.e., at least one passenger vehicle was towed). Therefore, a KABCO-to-AIS translation table derived solely from CDS might not be representative of the overall injury outcomes especially for those involving heavy vehicles. The Old NASS data, on the other hand, were a nationally representative sample of all crashes of all vehicle types on public roadways. However, as the name indicated, the Old NASS system is a relatively ancient crash database. The crash environment and vehicle technologies have changed since 1986, the last year of the Old NASS system. Further, the AIS system was revised several times (1995, 1998, and 2005)[31] to take into account the improvement of emergency response and advancement of medical technologies. A conversion table derived solely from the Old NASS thus might not appropriately reflect the current injury outcomes. In order to balance the representation of crash sample, sample size, and the reflection of AIS coding updates, non-CDS types of crashes from Old NASS were combined with CDS incidents to generate the conversion table. The translated AIS injuries are assumed to be the maximum severity injuries (i.e., MAIS) for associated occupants. Table IV-3 shows the KABCO-to-MAIS

[30] See Footnote 3.

[31] The 1995 version is implemented in the current CDS up to 2009.

conversion table. Note that the police-reported fatal injuries (K) were all attributed to fatalities in MAIS system.

Table IV-3
KABCO-to-MAIS Conversion Table

	Police-Reported Injury Severity System						
MAIS	O	C	B	A	K	U	
	No Injury	Possible Injury	Non Incapacitating	Incapacitating	Fatality	Injured, Severity Unknown	Unknown
0	0.92535	0.23431	0.08336	0.03421	0.00000	0.21528	0.42930
1	0.07257	0.68929	0.76745	0.55195	0.00000	0.62699	0.41027
2	0.00198	0.06389	0.10884	0.20812	0.00000	0.10395	0.08721
3	0.00008	0.01071	0.03187	0.14371	0.00000	0.03856	0.04735
4	0.00000	0.00142	0.00619	0.03968	0.00000	0.00442	0.00606
5	0.00003	0.00013	0.00101	0.01775	0.00000	0.01034	0.00274
Killed	0.00000	0.00025	0.00128	0.00458	1.00000	0.00046	0.01707
Total	1.00001	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

Source: 1982-1986 Old NASS; 2000-2008 CDS

Applying the KABCO-to-MAIS conversion factors to corresponding initial KABCO non-fatal injuries reported in Table IV-2 derives the initial non-fatal MAIS injuries. For example, of the A injuries, 3.34 percent would be MAIS 0 injuries, 55.20 percent would be MAIS 1 injuries, 20.81 percent would be MAIS 2 injuries, 14.37 percent would be MAIS 3 injuries, 3.97 percent would be MAIS 4 injuries, 1.78 percent would be MAIS 5 injuries, and 0.46 percent would be fatalities. Thus, the 1,042 A injuries reported in Table IV-25 were translated into MAIS injuries according to these percentages and became: 575 MAIS 1 injuries, 217 MAIS 2 injuries, 150 MAIS 3 injuries, 41 MAIS 4 injuries, 18 MAIS 5 injuries. Table IV-4 reported these translated initial MAIS 1-5 injuries. As shown in Tables IV-4, there were a total of 3,358 target MAIS non-fatal injuries. Of these, 2,217 were associated with the target rollover crashes and 1,141 were associated with LOC crashes.

Table IV-4
Initial **Target Crashes, MAIS injuries, and PDOVs**
by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

Crash Type	Crashes	Fatalities	MAIS Non-Fatal Injuries						PDOVs
			1	2	3	4	5	1-5	
Rollover	5,510	111	1,738	300	134	33	12	2,217	3,297
LOC	4,803	216	871	164	79	19	8	1,141	3,935
Total	10,313	327	2,609	464	213	52	20	3,358	7,332

Source: 2006 - 2008 FARS, 2006 - 2008 GES
Rollover: first event rollover crashes; LOC: loss-of-control crashes; PODVs: property damage only vehicles

C. Projected Target Population

As described earlier, the projected target population is the target crashes at the 2012 level. The 2012 level was chosen to correspond to the cost estimate (Chapter V) that was based on the 2012 model applicable vehicles. Basically, the projection takes into account the impact of higher ESC/RSC installation rates in the 2012 model applicable vehicles. ESC and RSC both are found to reduce rollover and LOC crashes. Therefore, their effects are required to be considered simultaneously when projecting the target population.

Generally, the "potential" target crashes, i.e., initial target crashes combined with those that will have been prevented by the ESC and RSC technologies is the base for projecting the future level of target crashes. Those crashes that will be prevented by ESC and RSC can be estimated if their installation rates in the initial target crashes can be established. Due to a lack of detailed truck information in GES and FARS, which were used to establish the initial target population, the ESC/RSC installation rates for truck tractors cannot be obtained. Alternatively, the analysis used the initial target crashes as the base for projection and used adjustment factors to address this issue.

Two crash-based adjustment factors are developed to account for both the impacts of the increased RSC/ESC installation rates and the impacts of using the initial target crashes as the base. These adjustment factorswere established by using the ESC and RSC installation rates among the operational fleet of truck tractors in calendar year 2006 to 2008 to correspond the years of crash data that were used to derive the initial target population and the estimated installation rates in MY 2012 truck tractors. Therefore, the process eliminates the need for acquiring the installation rates in the real-world crash database. The estimated/projected ESC and RSC installation rates for MY 2005 to 2012 truck tractors are presented in Chapter V, Cost and Leadtime. Of these, installation rates for MY 2005 to 2008 and were used for deriving the overall ESC and RSC installation rates in the operational fleet of truck tractors. Installation rates for MY 2004 and older truck tractors are assumed to be zero percent.

These two factors are: (1) the ratio of projected rollover and LOC crashes in 2012 that would not involve ESC- and RSC-equipped applicable vehicles to those at the baseline level (f_1) and (2) the relative portion of projected target crashes that already had RSC and can be further impacted by ESC (f_2) to those projected crashes without either ESC and RSC. Applying the first factor, f_1, to the initial target crashes derives the projected target crashes in which the involved applicable vehicles would have neither ESC nor RSC (Base 1). Applying the second factor, f_2, to Base 1 derives additional crashes in which the involved applicable vehicles would already have RSC but can be further benefited by ESC (Base 2). Base 1 and Base 2 combined is the total target population for calculating the benefits of ESCs. However, Base 1 would benefit from the overall effectiveness of ESC. Base 2 would benefit from ESC incrementally over RSC.

The base target population of the proposal thus can be represented as:

PP = (Base 1) + (Base 2)

= IP * f_1 + IP * f_1* f_2

Where, PP = target crashes (rollovers or LOC crashes)

IP = initial target crashes

f_1 = ratio of 2012 target crashes with no RSC or ESC to the initial target crashes

f_2 = ratio of 2012 target crashes with RSC to Base 1.

These crash-based adjustment factors are also applied to the initial target fatalities, injuries, and PDOVs to derive the base injury population and PDOVs.

The First Adjustment Factor f_1

For each target crash type (i.e., rollovers or LOC), the adjustment factor, f_1, is the ratio of that crash type without ESC or RSC at the 2012 level to the initial target crashes of that type. The ratio can be derived from ESC/RSC effectiveness and ESC/RSC installation rates in the 2012 model fleet and those in the on-road fleet of truck tractors from the base years 2006 to 2008. For each target crash type, f_1 can be mathematically expressed as follows:

$$f_1 = \frac{(1 - I^F_{Combined})}{(1 - I^I_{Combined}) + I^I_{ESC}(1 - e_{ESC}) + I^I_{RSC}(1 - e_{RSC})}$$

Where, $I^F_{Combined}$ = Future combined ESC and RSC installation rate (i.e., 2012)

I_i^I = Initial installation rate for technology i (i=ESC, RSC, or ESC and RSC combined)

e_i = Effectiveness of technology i (i = ESC or RSC) against a specific target crash type.

Of the parameters in f_1, the installation rates (e_i) were based on the industry's response to the agency's request for historic and projected ESC and RSC installation information. From their submissions[32], the agency estimates that about 1.9 percent of the on-road fleet of truck tractors (up to 2008 models) were equipped with ESC and 3.3 percent were equipped with RSC. In 2012, about 26.2 percent of truck tractors manufactured that year would be equipped with ESC and an additional 16.0 percent would be equipped with RSC.

The effectiveness rates of ESC and RSC against rollovers each is represented by a range. Therefore, the values of f_1 (f_2 also, see the following section) for rollovers should also be a range. However, the range is narrow enough that it would not significantly affect the projected target population and subsequent benefit analysis. Therefore, to simplify the projection process, the average between the lower and higher effectiveness of ESC (RSC also) against rollovers were used to derive the mean f_1 (also f_2).

Therefore, for truck tractors, the following numbers were used to drive the f_1 factor for rollover crashes: I_{ESC}^I= 1.9 percent, I_{RSC}^I= 3.3 percent, $I_{Combined}^I$= 5.2 percent (= 1.9 + 3.3), $I_{Combined}^F$= 42.2 percent (= 26.2 + 16.0), e_{ESC}= 48 percent, and e_{RSC}= 45 percent. Thus, f_1 = 59.2 percent. Of these, the 48 percent effectiveness for ESC and 45 percent effectiveness for RSC, as described, are the average of the lower and upper bounds of the rollover effectiveness. For LOC

[32] There are only 7 heavy truck manufacturers. Since the number of submissions is small, their data are not published here to ensure confidentiality and preserve each company's competitiveness.

crashes, f_1 = 58.0 percent. In this case, values for various installation rates are the same as shown above. The only changes are the effectiveness rates: e_{ESC}= 14 percent and e_{RSC}= 3 percent.

For large buses, no on-road vehicles in the fleet for the base years were equipped with ESC or RSC (i.e., $I^{I}_{Combined} = I^{I}_{ESC} = I^{I}_{RSC}$ = 0.0 percent). About 80.0 percent of MY 2012 large buses would be equipped with ESC and 0 percent would with RSC. Therefore, $I^{F}_{Combined}$= 80.0 percent. Using the same effectiveness that was found for truck tractors, f_1 = 20.0 percent for both rollovers and LOC crashes.

The Second Adjustment Factor f_2

The factor determines the size of Base 2 relative to Base 1. It can be mathematically represented as:

$$f_2 = \frac{I^{F}_{RSC}}{(1 - I^{F}_{Combined})}$$

Where, I^{F}_{RSC} = Future RSC installation rate (i.e., 2012)

$I^{F}_{Combined}$ = Future combined ESC and RSC installation rate (i.e., 2012)

Substituting the above parameters with appropriate values derives 27.7 percent for f_2, i.e., f_2 = 27.7 percent. This percentage indicates that the size of the additional rollovers and LOC crashes (i.e., crashes among tractors equipped with RSC) that can be incrementally benefited by ESC is about 27.7 percent of the Base 1. Table IV-5 summarizes the values of f_1 and f_2 factors. Table IV-6 lists all the values that are used to calculate f_1 and f_2.

Table IV-5
Adjustment Factors for Establishing Projected Baseline Population

Crash Type	f_1	f_2
Rollover	59.2%	27.7%
LOC	58.0%	27.7%

Table IV-6
Values for Deriving f_1 and f_2 Adjustment Factors

	Initial			Future (2012)		
	ESC	RSC	Combined	ESC	RSC	Combined
Installation Rate (I_i^j)	1.9%	3.3%	5.2%	26.0%	16.0%	42.2%
Effectiveness Against Rollover (e_i)*	48%	45%	NA	48%	45%	NA
Effectiveness Against LOC (e_i)	14%	3%	NA	14%	3%	NA

* Average of low and high effectiveness rates

Projected Population

Applying the adjustment factors shown in Table IV-5 to the corresponding initial target crash population (Table IV-4) derives the projected 2012 baseline population. Table IV-7 lists the projected baseline population. The first potion of the table presents the Base 1 population. The second potion is the Base 2 population and the third potion is the total projected population (i.e., Base 1 + Base 2).

As shown in Table VI-7, the proposal would eliminate a portion of 7,723 crashes. Thus it would further reduce the 244 fatalities, 2,522 MAIS 1-5 injuries, and 5,407 PDOVs that were associated with these crashes (i.e., Base 1 + Base 2). When separating by target crash type, for rollover crashes, the proposal would impact 4,166 target rollovers, 84 fatalities, 1,677 MAIS 1-5 injuries, and 2,492 PDOVs. For LOC crashes, the proposal would impact 3,557 LOC crashes, 160 fatalities, 845 MAIS 1-5 injuries, and 2,915 PDOVs. When separating the projected safety population by the degree to which it would be impacted by the proposed ESC technology, 6,049 crashes, 191 fatalities, 1,975 MAIS 1-5 injuries, and 4,235 PDOVs would be benefited by the full effectiveness of ESC (i.e., Base 1 population). The remaining 1,674 crashes, 53 fatalities, 547 MAIS 1-5 injuries, and 1,172 PDOVs would be impacted by ESC incrementally over RSC (i.e., Base 2 population).

Table IV-7
Projected **Baseline Crashes, MAIS injuries, and PDOVs** for 2012 Level

Base 1

Crash Type	Crashes	Fatalities	MAIS Non-Fatal Injuries						PDOVs
			1	2	3	4	5	1-5	
Rollover	3,263	66	1,029	178	79	20	7	1,313	1,952
LOC	2,786	125	505	95	46	11	5	662	2,283
Total	6,049	191	1,534	273	125	31	12	1,975	4,235

Base 2

Crash Type	Crashes	Fatalities	MAIS Non-Fatal Injuries						PDOVs
			1	2	3	4	5	1-5	
Rollover	903	18	285	49	22	6	2	364	540
LOC	771	35	140	26	13	3	1	183	632
Total	1,674	53	425	75	35	9	3	547	1,172

Base 1 + Base 2 (Projected Target Population)

Crash Type	Crashes	Fatalities	MAIS Non-Fatal Injuries						PDOVs
			1	2	3	4	5	1-5	
Rollover	4,166	84	1,314	227	101	26	9	1,677	2,492
LOC	3,557	160	645	121	59	14	6	845	2,915
Total	7,723	244	1,959	348	160	40	15	2,522	5,407

Source: 2006 - 2008 FARS, 2006 - 2008 GES
Rollover: first event rollover crashes; LOC: loss-of-control crashes; PODVs: property damage only vehicles

Note that the analysis does not adjust the projected baseline population to address the effects of current finalized safety regulations and regulations that have not yet been fully phased in. Current finalized safety regulations on truck tractors and buses that the Agency anticipates will have an influence on fatalities and injuries include reduced stopping distance requirements for truck tractors under FMVSS No. 121, *Air brake systems*. The agency believes that the new FMVSS No. 121, stopping distance requirements would not impact this rule significantly since rollover and LOC crashes generally are vehicle stability issues involving the modulation and balance of brake as opposed to the braking force problems addressed by the FMVSS No. 121 final rule. Similarly, the analysis does not adjust the baseline to account for possible increases in vehicle miles traveled (VMT), a historical trend. Without adjusting for VMT, the benefits estimated in this analysis would be relatively conservative comparing to those with the VMT adjustment.

D. Benefits

The benefits of the proposal were derived by multiplying the projected target population (i.e., crashes, fatalities, MAIS 1-5 injuries, and PDOVs) by the corresponding effectiveness rates. Table IV-8-A shows the estimated benefits in which MAIS 1-5 injury benefits are aggregated. The subsequent Table IV-8-B presents only the MAIS injury benefits but by individual MAIS level. Both tables summarize the benefits in an identical three-part format. The first part of the table lists the benefits from the Base 1 population, the second part presents the benefits from Base 2 population, and the third part is the estimated overall benefits of the proposal (i.e., Base 1 and Base 1 combined).

As shown in Tables IV-8-A, the proposal would prevent 1,807 – 2,329 target crashes, save 49 – 60 fatalities, and reduce 649 – 858 MAIS 1-5 injuries that were associated with these avoided crashes. Furthermore, the proposal would eliminate 1,187 – 1,499 PDOVs. When disaggregated by target crash type, the proposal would eliminate 1,332 - 1,854 target rollover crashes and 475 LOC crashes. It is estimated that 27 – 38 fatalities, 537 – 746 MAIS injuries, and 797 – 1,109 PDOVs associated with the prevented target rollovers would be reduced by the proposal. By preventing 475 LOC crashes, the proposal would also save 22 lives, reduce 112 MAIS 1-5 injuries, and prevent 390 PDOVs.

Table IV-8-A
Estimated Benefits of the Proposal

Base 1 Benefits

Crash Type	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs
Rollover	1,305 – 1,827	26 – 37	526 - 735	781 – 1,093
LOC	390	18	93	320
Total	1,695 – 2,217	44 – 55	619 – 828	1,101 – 1,413

Base 2 Benefits

Crash Type	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs
Rollover	27	1	11	16
LOC	85	4	19	70
Total	112	5	30	86

Benefits of the Proposal (Base 1 + Base 2)

Crash Type	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs
Rollover	1,332 – 1,854	27 – 38	537 - 746	797 – 1,109
LOC	475	22	112	390
Total	1,807 – 2,329	49 – 60	649 – 858	1,187 – 1,499

Source: 2006 - 2008 FARS, 2006 - 2008 GES
Rollover: first event rollover crashes; LOC: loss-of-control crashes; PDOVs: property damage only vehicles

Table IV-8-B
Estimated Expanded MAIS 1-5 Injury Benefits of the Proposal

Base 1 Benefits

Crash Type	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
Rollover	412 - 576	71 - 100	32 – 44	8 - 11	3 – 4
LOC	71	13	6	2	1
Total	483 - 647	84 – 113	38 – 50	10 - 13	4 - 5

Base 2 Benefits

Crash Type	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
Rollover	9	1	1	0	0
LOC	15	3	1	0	0
Total	24	4	2	0	0

MAIS 1-5 Injury Benefits of the Proposal (Base 1 + Base 2)

Crash Type	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
Rollover	421 - 585	72 - 101	33 – 45	8 - 11	3 – 4
LOC	86	16	7	2	1
Total	507 - 671	88 – 117	40 – 52	10 - 13	4 - 5

Source: 2006 - 2008 FARS, 2006 - 2008 GES
Rollover: first event rollover crashes; LOC: loss-of-control crashes; PODVs: property damage only vehicles

Note that these benefits were derived by applying the full effectiveness of ESC to the Base 1 target population and an incremental effectiveness of ESC over RSC to the Base 2 population. The range of benefits is a reflection of the effectiveness range that is used against rollover crashes. Although the effectiveness rates are crash-based (i.e., against crashes), these rates are applied directly to fatalities, injuries, and PDOVs to derive benefits. This approach is considered to be appropriate since preventing a crash would prevent all injuries that would have resulted from that crash. In addition, the effectiveness rates were derived for all crash severity levels and thus were uniformly applied to crashes regardless of crash severity (e.g., fatal, nonfatal, or PDO). Further note that, as described earlier, these estimated benefits were exclusively from truck tractors. With an extremely small number of target crashes and a projected high ESC installation rate for MY 2012 large buses, the impact of the proposal on large bus target crashes is negligible.

E. Travel Delay and Property Damage Savings

The non-injury component of the benefits includes savings from the elimination of crash-related travel delay and vehicle property damage. These unit costs are expressed on a per person basis for all MAIS injury levels and on a per vehicle basis for PDOVs. In 2002, NHTSA estimated these unit costs based on the value of statistical life (VSL) of $3.0 million and in 2000 economics[33]. Recently, the DOT issued two new guidelines on VSL. One was in 2008 that revised the value of VSL from $3.0 million to $5.8 million (2007 economics). Then in 2009, the value of VSL was revised again to $6.0 million (2008 economics). In response, NHTSA revised the unit costs by MAIS injury level and fatality accordingly. Appendix B describes the process of revising the unit costs based on a VSL of $6.0 million (2008 economics). These unit costs presented in Appendix B were then further adjusted to a 2010 value using a factor of 1.01884 (= 110.668/108.598). This factor was derived using the implicit price deflator for the gross domestic product (GDP)[34].

However, the unit costs estimated by NHTSA are the average costs of all the vehicle crashes and thus were dominated by the costs of light vehicle crashes. Given the greater mass of the heavy trucks, the varied cargoes and sometimes hazardous materials that they carry, and the types of roadways they travel, heavy truck crashes are expected to cause greater property damage and

[33] Table 2, Blincoe, L., *et al.*, The Economic Impact of Motor Vehicle Crashes 2000, Washington, DC, DOT HS 809 446, May 2002

(in 2000 $)	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	PDO
Travel Delay	$777	$846	$940	$999	$9,148	$9,148	$803
Property Damage	$3,844	$3,954	$6,799	$9,833	$9,446	$10,273	$1,484

[34] Published by Bureau of Economic Analysis, U.S. Department of Commerce, as of May 26, 2011

travel delay than do light vehicles. Therefore, NHTSA's unit travel delay and property damage costs which were based on all vehicle types might underestimate the costs for heavy truck and large bus crashes. Due to this concern, in 2009 when the agency issued a final rule for FMVSS No. 121 Air Brake Systems, amending the stopping distance requirements for truck tractors, revised property damage costs (including travel delay) based on a 1991 assessment by the Federal Highway Administration (FHWA)[35] were used in the Final Regulatory Impact Analysis (FRIA) for that rule. The revised unit property damage costs in that 2009 FRIA were in 2007 economics.

However, the 1991 unit cost estimates that the 2009 FRIA was based on are now 20 years old. Since then, vehicle safety technologies, roadway design, traffic congestion, and emergency medical response systems have evolved. Therefore, the 1991 cost estimates might not be representative for the current heavy vehicle crash patterns and injury profile. Furthermore, the 1991 cost estimates did not separate PDO and travel delay and was not specifically for truck tractors. Therefore, the analysis used the unit costs that were developed specifically for truck tractor crashes by the Pacific Institute in December 2006[36]. The Pacific Institute produced two sets of KABCO-based unit costs. One set of costs is per-person based costs and the other set is per-crash based costs. Property damage and travel delay unit costs that were used in this analysis are a weighted average of those for truck-tractors with one trailer and those for truck-tractors with two or three trailers. The KABCO-based weighted unit costs were then translated into MAIS-based costs through a MAIS-KABCO translator.

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[35] Final Regulatory Impact Analysis, FMVSS No. 121, Air Brake Systems, Amending Stopping Distance, July 27, 2009, Docket No. 2009-0083-0002.1 (74 FR 37122)

[36] Zaloshnja, E. and Miller, T., Unit Costs of Medium and Heavy Truck Crashes, Pacific Institute, December 2006

The Pacific Institute did not provide unit costs per PDOV in their 2006 estimates. Therefore, the unit costs for PDOV were produced from the unit cost per PDO crash (PDOC) by dividing the weighted average unit costs per PDOC from the two truck tractor categories by a factor of 1.82, the average number of vehicles per truck tractor PDOC. This factor was derived from the 2006-2008 GES truck tractor PDOCs. Afterwards, all these unit costs were revised to 2010 economics by multiplying by a GDP deflator of 1.1067 (= 110.668/100).

Table IV-9 presents the weighted average KABCO-based unit costs and the initial unit costs and corresponding incidents that were used to derive the weighted costs (2005 economics). Table IV-10 presents the MAIS-KABCO translator that was used to translate the KABCO-based unit costs to the MAIS-based costs. The translator was derived using the same process and data sources as was used for KABCO-MAIS translator which was presented in the target population section. Table IV-11 presents the translated MAIS-based injury unit costs in 2005 economics. Table IV-12 shows these unit costs in 2010 economics. For comparison, Table IV-12 also provides the unit costs that were developed by NHTSA for all vehicles and those published in the 2009 FRIA for truck tractor stopping distance requirements.

As shown in Table IV-12, the revised property damage unit costs grow progressively higher with the severity level. The property damage unit costs ranged from $4,110 to $28,906 with the lower value for PDOVs and the higher value for fatalities. The travel delay unit costs ranged from $3,048 to $6,798.

The following shows the calculation of property damage unit costs for MAIS 1. This is used as an example to demonstrate the process for developing the unit costs that were shown in Table IV-12.

Example: the development of revised property damage cost for MAIS 1

Step 1: deriving the weighted KABCO-based unit costs as shown in Table IV-9

$$\text{The weighted cost for O} = \$2{,}423 = \frac{\$2{,}313*215{,}614+\$1{,}794*5{,}593}{221{,}207}$$

Where, \$2,313 in the numerator is the property damage unit cost per O injury and 215,614 is the total number of O injuries in crashes involving truck tractors with one trailer. The numbers \$1,794 and 5,593 in the second term of the numerator represent the corresponding unit cost and incidents for O injuries for truck tractors with two or three trailers, respectively. The weighted property unit costs for other policed-reported injury severities and PDOCs can be derived using the same process.

Step 2: translating KABCO-based unit costs to MAIS-based unit costs (Table IV-11)

The property damage unit cost for MAIS 1

= \$5,651

=\$2,423*0.34403 + \$6,681*0.29350+ \$8,175*0.19569 +

\$2,423*0.34403 + \$6,681*0.29350+ \$8,175*0.19569 +

\$3,488*0.06507

Where, the dollar numbers represent the weighed property damage costs for O, C, B, A K, U (injured, unknown severity), and unknown if injured (from Table IV-9). The fractions (from Table IV-10) represent the proportion of each KABCO-based weighted unit cost that is contributed to the unit cost for MAIS 1. Unit costs for the remaining MAIS injury levels and fatalities can be derived using the same format.

Step 3, revising the costs to 2010 economics (Table IV-12)

Property damage unit cost for MAIS 1 in 2010 economics = $6,254

= $5,651 * 1.1067.

Table IV-9
Process of Deriving Weighted KABCO-Based Unit Costs for Truck Tractors
(2005 $)

Injury Severity	Number of Incidents			Cost Per Incident					
				1 Trailer (d)		2+ Trailers (f)		Weighted Unit Cost (g)	
	1 Trailer (a)	2+ Trailers (b)	Total (c)	PD	TD	PD	TD	PD	TD
O	215,614	5,593	221,207	$2,313	$1,794	$6,673	$1,844	$2,423	$1,795
C	29,283	1,064	30,347	$6,274	$4,109	$17,877	$4,138	$6,681	$4,110
B	27,240	939	28,179	$7,708	$4,477	$21,713	$4,451	$8,175	$4,476
A	15,429	1,603	17,032	$9,314	$4,740	$26,294	$4,751	$10,912	$4,741
K	3,296	214	3,510	$23,509	$6,143	$66,336	$6,143	$26,120	$6,143
U	1,172	28	1,200	$4,601	$3,036	$10,102	$1,880	$4,729	$3,009
Unknown	13,843	456	14,299	$3,381	$1,891	$6,744	$2,051	$3,488	$1,896
PDOC	179,181	4,976	184,157	$6,493	$5,024	$16,350	$4,568	$6,759	$5,012

U: injured, severity unknown; PD: property damage; TD: travel delay; PDOC: property damage only crashes

Note: unit costs for PDOC is per crash, the remaining is cost per injured person

$g = \frac{a*d+b*f}{c}$

Table IV-10
MAIS to KABCO Translator

MAIS	O	C	B	A	K	Injured	Unknown
	No Injury	Poss Inj	Non Incap	Incapaci	Killed	Severity U	
0	0.94853	0.02735	0.00526	0.00126	0.00002	0.00119	0.01638
1	0.34403	0.29350	0.19569	0.08836	0.00011	0.01324	0.06507
2	0.08242	0.23931	0.24411	0.29306	0.00014	0.01930	0.12166
3	0.00887	0.10263	0.18282	0.51754	0.00087	0.01831	0.16898
4	0.00185	0.06244	0.16386	0.65931	0.00292	0.00970	0.09992
5	0.03346	0.01478	0.06555	0.71902	0.00116	0.05510	0.11094
Killed	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000

Source: 1982-1986 Old NASS; 2000-2008 CDS

Table IV-11
Property Damage and Travel Delay Unit Costs by MAIS
(2005 $)

MAIS	Property Damage	Travel Delay
0	$2,601	$1,879
1	$5,651	$3,283
2	$7,511	$3,903
3	$8,548	$4,091
4	$9,426	$4,356
5	$9,239	$4,206
Killed	$26,120	$6,143
PDOC	$3,714	$2,754

PDOC: property damage only crashes

Table IV-12
Property Damage and Travel Delay Unit Costs
(2010 $)

Injury Severity	Unit Costs Used in This PRIA*			2009 FRIA for FMVSS No. 121**	NHTSA Estimates for All Vehicles***		
	PD	TD	PD+TD	PD + TD	PD	TD	PD + TD
MAIS 1	$6,254	$3,633	$9,887	$10,268	$4,898	$1,037	$5,935
MAIS 2	$8,312	$4,319	$12,631	$10,644	$5,038	$1,129	$6,167
MAIS 3	$9,460	$4,527	$13,987	$10,490	$8,663	$1,254	$9,917
MAIS 4	$10,432	$4,821	$15,253	$10,712	$12,528	$1,333	$13,861
MAIS 5	$10,225	$4,655	$14,880	$10,699	$12,035	$12,210	$24,245
Fatality	$28,906	$6,798	$35,704	$27,824	$13,089	$12,210	$25,299
PDO Vehicle	$4,110	$3,048	$7,158	$10,002	$1,890	$1,072	$2,962

* Based on the unit costs derived by the Pacific Institute
** Revised from the 1991 FHWA estimates
*** Based on value of statistical life of $6.0 million for all vehicles, not just truck tractors

The total travel delay and property damage costs for each MAIS level and PDOVs are simply the product of the individual unit cost (Table IV-12) and the corresponding incidences that would be prevented by the proposal (Table IV-8). Table IV-13 presents the travel delay and property damage unit costs, MAIS incidences, PDOVs, and the total travel delay and property damage savings. Table IV-14 shows these savings separately by target crash type. As shown in Table IV-13, the proposal would save (undiscounted) $17.1 to $22.0 million from travel delay and property damage associated with the crashes that would be prevented by the proposal. Of these savings, $15.2 to $21.2 million are from target rollover crashes and $4.8 million is from LOC crashes. All of these costs are in 2010 dollars.

Table IV-13
Total Travel Delay and Property Damage Savings
(Undiscounted 2010 $)

Lower Bound

	Unit Cost*			Total Costs		
MAIS	Property Damage	Travel Delay	Incidents Prevented**	Property Damage	Travel Delay	Property Damage + Travel Delay
1	$6,254	$3,633	507	$3,170,778	$1,841,931	$5,012,709
2	$8,312	$4,319	88	$731,456	$380,072	$1,111,528
3	$9,460	$4,527	40	$378,400	$181,080	$559,480
4	$10,432	$4,821	10	$104,320	$48,210	$152,530
5	$10,225	$4,655	4	$40,900	$18,620	$59,520
Fatal	$28,906	$6,798	49	$1,416,394	$333,102	$1,749,496
PDOV	$4,110	$3,048	1,187	$4,878,570	$3,617,976	$8,496,546
Total				$10,720,818	$6,420,991	$17,141,809

Higher Bound

	Unit Cost*			Total Costs		
MAIS	Property Damage	Travel Delay	Incidents Prevented**	Property Damage	Travel Delay	Property Damage + Travel Delay
1	$6,254	$3,633	671	$4,196,434	$2,437,743	$6,634,177
2	$8,312	$4,319	117	$972,504	$505,323	$1,477,827
3	$9,460	$4,527	52	$491,920	$235,404	$727,324
4	$10,432	$4,821	13	$135,616	$62,673	$198,289
5	$10,225	$4,655	5	$51,125	$23,275	$74,400
Fatal	$28,906	$6,798	60	$1,734,360	$407,880	$2,142,240
PDOV	$4,110	$3,048	1,499	$6,160,890	$4,568,952	$10,729,842
Total				$13,742,849	$8,241,250	$21,984,099

* from Tables IV-12
** from IV-8-A and IV-8-B
PDOV: property damage only vehicle

Table IV-14
Total Travel Delay and Property Damage Savings by **Crash Type**
(Undiscounted 2010 $)

Rollover(1) – Low Benefit

	Unit Cost**			Total Costs		Total
MAIS	Property Damage	Travel Delay	Incidents Prevented***	Property Damage	Travel Delay	Property Damage + Travel Delay
1	$6,254	$3,633	421	$2,632,934	$1,529,493	$4,162,427
2	$8,312	$4,319	72	$598,464	$310,968	$909,432
3	$9,460	$4,527	33	$312,180	$149,391	$461,571
4	$10,432	$4,821	8	$83,456	$38,568	$122,024
5	$10,225	$4,655	3	$30,675	$13,965	$44,640
Fatal	$28,906	$6,798	27	$780,462	$183,546	$964,008
PDOV	$4,110	$3,048	797	$3,275,670	$2,429,256	$5,704,926
Total				$7,713,841	$4,655,187	$12,369,028

Rollover(1) – High Benefit

	Unit Cost**			Total Costs		Total
MAIS	Property Damage	Travel Delay	Incidents Prevented***	Property Damage	Travel Delay	Property Damage + Travel Delay
1	$6,254	$3,633	585	$3,658,590	$2,125,305	$5,783,895
2	$8,312	$4,319	101	$839,512	$436,219	$1,275,731
3	$9,460	$4,527	45	$425,700	$203,715	$629,415
4	$10,432	$4,821	11	$114,752	$53,031	$167,783
5	$10,225	$4,655	4	$40,900	$18,620	$59,520
Fatal	$28,906	$6,798	38	$1,098,428	$258,324	$1,356,752
PDOV	$4,110	$3,048	1,109	$4,557,990	$3,380,232	$7,938,222
Total				$10,735,872	$6,475,446	$17,211,318

LOC(2)

	Unit Cost**			Total Costs		Total
MAIS	Property Damage	Travel Delay	Incidents Prevented***	Property Damage	Travel Delay	Property Damage + Travel Delay
1	$6,254	$3,633	86	$537,844	$312,438	$850,282
2	$8,312	$4,319	16	$132,992	$69,104	$202,096
3	$9,460	$4,527	7	$66,220	$31,689	$97,909
4	$10,432	$4,821	2	$20,864	$9,642	$30,506
5	$10,225	$4,655	1	$10,225	$4,655	$14,880
Fatal	$28,906	$6,798	22	$635,932	$149,556	$785,488
PDOV	$4,110	$3,048	390	$1,602,900	$1,188,720	$2,791,620
Total				$3,006,977	$1,765,804	$4,772,781

(1) first event rollovers
(2) point estimate only, i.e., low benefit = high benefit
* from Tables IV-12
** from IV-8-A and IV-8-B
PDOV: property damage only vehicle
LOC: loss-of-control crashes

F. Summary

The following summarizes the estimated benefits of the proposal. The estimated injury benefits, PDOV reductions, and property damage and travel delay savings of the proposal are measured from a baseline of a 26.2 percent ESC installation rate in truck tractors and an 80 percent installation rate in large buses, to a 100 percent installation rate among both vehicle types. Furthermore, the benefits also reflect the impact from the 16.0 percent of truck tractors that would have RSC only systems. Note that due to rounding, the sum of benefits from individual crash types might not equal the total.

Overall Benefits of the Proposal

- Prevent 1,807 – 2,329 crashes
    - 1,332 – 1,854 rollover crashes
    - 475 LOC crashes
- Save 49 – 60 lives
    - 27 - 38 from rollover crashes
    - 22 from LOC crashes
- Eliminate 649 – 858 MAIS 1-5 injuries
    - 537 – 746 from rollover crashes
    - 112 from LOC crashes
- Eliminate 1,187 – 1,409 PDOVs
    - 797 – 1,109 from rollover crashes
    - 390 from loss-of-control crashes
- Save $17.1 – $22.0 million (undiscounted) from travel delay and property damage

  - $12.4 – $17.2 million from rollover crashes
  - $4.8 million from loss-of-control crashes.

The benefits of the ESC system itself (including both voluntary installations and regulated installations), which are measured from a baseline of no ESC installation to 100 percent installations and 0 percent RSC-only installations, are summarized below. Due to rounding, the sum of subgroups might not equal the total.

<u>ESC Benefits (0% to 100% ESC Installation)</u>

- Prevent 2,876 – 3,758 crashes
  - 2,204 – 3,086 rollover crashes
  - 672 loss-of-control crashes
- Save 74 – 92 lives
  - 44 - 62 from rollover crashes
  - 30 from loss-of-control crashes
- Eliminate 1,047 – 1,401 MAIS 1-5 injuries
  - 887 – 1,241 from rollover crashes
  - 160 from loss-of-control crashes
- Eliminate 1,870 – 2,397 PDOVs
  - 1,319 – 1,846 from rollover crashes
  - 551 from loss-of-control crashes

- Save \$27.2 - \$35.3 million (undiscounted) from travel delay and property damage
  - \$20.4 - \$28.6 million from rollover crashes
  - \$6.7 million from loss-of-control crashes.

CHAPTER V. COSTS AND LEADTIME

The cost of the proposal comprises only the technology costs. Generally, fuel economy impacts of any regulations are included in the cost assessment. For this proposal, however, the required ESC (and also RSC) technology is built upon the ABS platform. Thus, the added weight for the installation of ESC (and RSC) primarily is from additional sensors and air brake system valves. The total additional weight is estimated to be less than 5 pounds and is considered negligible compared to the 15,000 pound or greater curb weight of truck tractors and large buses. Therefore, the proposal is not expected to impact fuel economy.

A. Technology Costs

As stated, the cost of the proposal comprises only the technology cost which includes the costs for all the components and the telltale malfunction indicator lamp. Basically, the technology cost is the product of two values: (a) average unit cost and (b) the number of applicable vehicles that would be impacted by the proposal (impacted vehicles). The impacted vehicles are either those vehicles that would need the full installation of ESC, or those that would need an upgrade from RSC to ESC. The numbers of impacted vehicles can be derived from the total new vehicle sales and technology installation rates. The average unit cost varies with the type of installation (i.e., full ESC or an RSC upgrade) needed. Therefore, technology cost can be expressed as the following mathematical formula:

$$
\begin{aligned}
\mathrm{TC} &= \mathrm{U_{ESC}} * \mathrm{V_{ESC}} + (\mathrm{U_{ESC}} - \mathrm{U_{RSC}}) * \mathrm{V_{RSC}} \\
&= \mathrm{U_{ESC}} * (1 - \mathrm{I^F_{ESC}} - \mathrm{I^F_{RSC}}) * \mathrm{V} + (\mathrm{U_{ESC}} - \mathrm{U_{RSC}}) * \mathrm{I^F_{RSC}} * \mathrm{V}
\end{aligned}
$$

Where:

TC = Total technology cost

U_{ESC} = Average unit cost of a full ESC

U_{RSC} = Average unit cost of RSC

V_{ESC} = Total units needing a full ESC

V_{RSC+} = Total units needing an upgrade from RSC to ESC

V = Total annual production of applicable vehicles

I_{ESC}^{F} = Projected future (i.e., 2012) ESC installation rate

I_{RSC}^{F} = Projected future RSC installation rate.

In the formula, $1 - I_{ESC}^{F} - I_{RSC}^{F}$ represents the portion of applicable vehicles that do not have ESC or RSC. The RSC installation rate, I_{RSC}^{F}, represents the portion that already had RSC and would need an upgrade.

To establish unit costs (i.e., U_{ESC} and U_{RSC}) and projected baseline ESC and RSC installation rates (i.e., I_{ESC}^{F} and I_{RSC}^{F}), in 2009 the agency requested cost and product plan information from the seven truck tractor manufacturers. The seven manufacturers are: Daimler Trucks North America, Ford Motor Company, Isuzu Manufacturing Services of America, Mack Trucks, Navistar, PACCAR, and Volvo Group of North America. Five of these manufacturers provided the requested information. MY 2012 was chosen as the baseline because it was the last year for which available/projected data were submitted to the agency. Therefore, MY 2012 serves as the baseline against which both costs and benefits are measured. ESC and RSC installation rates for new truck tractors beyond MY 2012 are assumed to be at the MY 2012 levels. Thus, the cost of the proposal is the incremental cost of going from the MY 2012 planned installations to the 100 percent installation of ESC.

Note that the agency also requested RSC and ESC installation plans from bus manufacturers. The agency did not receive any cost information specific to large buses. Given that Bendix and Meritor WABCO are the only two system suppliers that produce ESC and RSC and that the components used for these technologies are not substantially different between truck tractors and large buses, unit costs estimated for truck tractors are also used for large buses.

Technology Unit Costs

Unit costs of ESC (U_{ESC}) and RSC (U_{RSC}) for both truck tractors and large buses, as described, are based on truck tractor manufacturers' submissions. The unit cost of ESC per vehicle submitted by five responding manufacturers ranged from $470 to $2,080. The unit cost of RSC per vehicle ranged from $300 to $1,500. For the remaining two vehicle manufacturers, one stated that it did not produce truck tractors and one did not respond. The one manufacturer that did not respond has a significant market share of truck tractor sales. In order to account for it, the analysis used the minimal installation rates reported from the responding manufacturers for this particular manufacturer. The rationale is that we believe for competitiveness reasons, this manufacturer will follow the industry trend and will gradually offer ESC or RSC. The average unit costs reported by those responders were also used for this manufacturer. After factoring in their respectively average Class 8 truck tractor sales volumes between 2005 and 2009[37], the analysis estimated that the average unit cost for RSC is $640 and for ESC is $1,160. Thus, the incremental cost of upgrading from RSC to full ESC is estimated to be $520 per vehicle.

[37] 2006 to 2010 Ward's Automotive Yearbook

The calculation of average unit cost of ESC and RSC is based on the weighted average of all unit costs that were submitted by the truck tractor manufacturers. Market shares are used as the weights. The weighted average unit cost formula can be noted as:

$$U=\frac{\sum_{1}^{n} m_i * u_i}{\sum_{1}^{n} m_i}$$

Where, U = the weighted average unit cost

m_i = market share for manufacturer i

u_i = unit cost for manufacturer i

n = number of manufacturers.

To ensure confidentiality and prevent the possibility that cost information for individual manufacturers can be identified through the few submissions within a small group of manufacturers, the agency will not publish the detailed company responses on cost data and production information.

The agency is planning to perform an ESC/RSC cost tear-down study to assess the required components and their unit costs but that has not been accomplished in time for this NPRM. Therefore, the primary components for ESC and RSC that are summarized below are based on information the agency has acquired and on the manufacturers' and suppliers' publications. Additionally, primary components for trailer-RSC, which is one of the alternatives the agency has examined (see the Alternatives Chapter), are also presented here. Note that the agency expects to revise the cost estimates in the final rule based on the ESC/RSC tear-down study.

RSC components include: two electro-pneumatic brake application valves (one for the tractor drive axles, and one for the trailer brake control line); one lateral accelerometer; an ECU including software; associated wiring and air brake hoses and fittings; brackets; and the instrument panel warning lamp.

ESC components include all of the above RSC components as well as the following: an ESC ECU in lieu of the RSC ECU; one additional air application valve to control the tractor steer axle brakes; one steering angle sensor; one yaw rate sensor; and a service brake application pressure sensor. Moreover, the ESC ECU is relatively more complex than the RSC ECU since ESC has both yaw and roll sensing capabilities and thus it requires more signal processing capability and it also provides additional vehicle control outputs. The steering angle sensor also needs to be carefully calibrated using diagnostic tools to initialize the ESC system when the vehicle is new or when this sensor requires servicing

Trailer-RSC components include: one electro-pneumatic brake application valve; one lateral accelerometer; and an ECU. No additional wiring, air brake hose/fittings, or brackets are believed to be required for the installation of trailer-RSC compared to a baseline trailer equipped with an ABS system.

To further illustrate the difference among these three systems in terms of data that are collected by the sensors, processed by the ECUs, and transmitted through the vehicle communication networks, Table V-1 lists the sensor inputs and outputs that are marked by "X"[38] for each

[38] Adopted from Table 2.1, Tractor Semitrailer Stability Objective Performance Test Research – Roll Stability, May 2011, DOT 811 467

system.   As shown in Table V-1, ESC is the most complex technology among these stability control systems. ESC acquires relatively more sensor inputs and has a greater array of braking strategies than the tractor RSC or trailer-RSC systems.

Table V-1
Sensor Inputs and Outputs for the Three Stability Technologies

	Inputs				Outputs				
	Wheel Speed	Lateral Accelera -tion	Steer Angle	Yaw Rate	Engine Torque	Engine Retarder	Drive Axle Brakes	Steer Axle Brakes	Trailer Brakes
ESC	X	X	X	X	X	X	X	X	X
RSC	X	X			X	X	X		X
Trailer-RSC	X	X							X

Source: Tractor-Semitrailer Stability Objective Performance Test Research – Roll Stability, May 2011, DOT HS 811 467

<u>Cost Increase Impacts on Sales</u>

The agency assumes that costs will be fully passed on to consumers, which are trucking companies and bus transit companies. All of the consumers are businesses, and the trucks or buses are vital to their operations. Sales are much more affected by demand for freight movement or passengers (and even the price of diesel) than they are by increased new vehicle prices. The additional cost per vehicle of $1,160 for ESC is a business expense that will have very little bearing on the demand for new trucks or large buses. If the demand for their services is there, they will provide trucks or large buses and raise the price for their services. Of course, price can affect demand.

We have looked into truck freight demand elasticity and it ranges between -1.0 and -1.5 (and averages around -1.174 over the variety of goods delivered) [39]. The average cost of a truck tractor is estimated to be $110,000 which is based on the average of one quoted price and three prices[40] paid by the agency for vehicles used in field testing. The price of a heavy truck would go up by 1.05% ($1,160/$110,000). However, the price charged by companies that provide freight service includes the amortized cost of the truck, the cost of fuel, the drivers wages and benefits, rent on company buildings, energy costs, salaries for non-driver personal, other overhead, and profit. Data indicate that payments for the purchase or lease of trucks and trailers account for roughly 21% of truck operating costs[41], which are a subset of the total costs incurred by trucking companies. Based on an average elasticity of (-1.174), a 1.05% increase in truck prices could reduce demand for truck shipping services by 0.259% (.0105x.21x-1.174). If you assumed a direct relationship between freight demand and truck purchases, with sales of 150,000 heavy trucks per year, the impact on truck sales would be only 388 units. Given that costs other than direct operating costs as well as profits influence freight rates, and since these costs would not be affected by the cost of ESC, the actual impact on sales would be less than 388 units.

Most large bus operators have determined that ESC makes good business sense for them, as sales of ESC are expected to hit 80% by 2012. For large buses, ESC is even a smaller percent (.29% = $1,160/$400,000) of the new vehicle price. We don’t have a specific elasticity for large buses. Assuming it were the same as trucks and 2,200 large bus sales a year, the impact would

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[39] Clark, C., Naughton, HT., Proulx, B., and Thoma, P., A Survey of the Freight Transportation Demand Literature and a Comparison of Elasticity Estimates, January 2005

[40] The quoted price is $93,945 and the purchasing price for the three truck tractors are $100,000, 115,000, and 125,000, respectively. The average cost of these vehicles is rounded to $110,000.

[41] American Transportation Research Institute, An Analysis of the Operational Costs of Trucking, December 2008

be an impact on sales of a loss of 2 large buses per year (2,200*.0.21*0.0029*-1.174 = 2 large buses).

ESC/RSC Installation Rates

The ESC installation rate in truck tractors has gradually increased since the introduction of the technologies in 2002. Based on manufacturer's product plans, the ESC installation rate was about 0.2 percent in MY 2005 truck tractors and it is expected to reach 26.2 percent in 2010. As for RSC, the installation rate is estimated to peak at 17.0 percent in 2009 and remain around15-16 percents thereafter. After 2012, its installation rate is expected to steadily decrease due to industry's moving towards equipping their trucks with ESC. The RSC system installation rate is projected to be 16.0 percent in 2012. Table V-2 lists the estimated installation rates for truck tractors from 2005 to 2012. Note that not all manufacturer's product plans are uniformly provided up to 2012. Installation rates for those model years that were not provided by individual tractor manufacturers were assumed to be the same rates for the last model year that was reported.

Table V-2
Estimated RSC and ESC Installations for Truck Tractors by Model Year
(% of the fleet)

	Model Year							
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
RSC	5.4	6.4	10.5	12.0	17.0	12.3	14.8	16.0
ESC	0.2	3.2	7.4	12.1	13.8	21.8	23.3	26.2
None	94.4	90.4	82.1	75.9	69.2	65.9	61.9	57.8

For large buses, manufacturers have indicated that most likely they will equip their large buses with ESC and bypass RSC to fully realize the full safety benefits of the ESC technology. Based on their input, the analysis estimates that 80 percent of MY 2012 large buses (primarily Class 8 buses) would be equipped with ESC. The remaining 20 percent will not be equipped with any of the technologies. Data provided by the bus manufacturers were not sufficient to establish the installation trends as was done for truck tractors. Note that for confidentiality purposes, this analysis does not publish the detailed installation rates provided by the manufacturers.

Based on the assumptions stated above and the data provided in Table V-2, the percent of the MY 2012 fleet that needs ESC and that needs an incremental system upgrade over RSC, in order to reach 100 percent of the fleet with ESC are shown in the Table V-3.

Table V-3
Percent of Fleet Needing Technology to Achieve 100% ESC

	ESC	Incremental ESC	None
Truck Tractors	57.8	16.5	26.2
Large Buses	20.0	0.0	80.0

NHTSA estimated a future annual production volume of 150,000 truck tractors and 2,200 large buses. The truck tractor production was derived from the Class 7 and 8 truck sales data from 2000 to 2009 published in Ward's Automotive Yearbooks[42]. Tenyears of historic truck output data were used rather than more recent years in order to address the impact of the recent recession on truck production[43]. During those 10 years, an average of 76,352 Class 7 trucks and

[42] Yearbook from 2000 to 2010

[43] Based on Ward's Automotive Yearbook 2008, in 2007, the sales for Class 8 heavy-duty trucks fell about 47% while Class 6 and 7 heavy trucks fell 22 percent from the 2006 level. Furthermore, the Yearbook 2009 indicated that Class 8 order in February 2009 fell 60% versus February 2008. Ward's indicated that the freight market possibly would contract a further 10 percent in 2009.

175,840 Class 8 trucks were produced annually. Truck tractors were not separately reported in the Ward's Yearbook but the agency estimates that about 10 percent of Class 7 and 80 percent of Class 8 trucks are truck tractors and the remainders are single-unit trucks. Therefore, it is estimated that an average of 148,307 new truck tractors were produced annually. Furthermore, based on 2000-2009 R. L. Polk registration data, the average number of age one and two (years old) tractors (a proxy for new truck tractors) is close to 134,000 and 149,000, respectively[44]. Therefore, the analysis uses the round number of 150,000 tractors produced annually.

For large buses, the agency used sales data published from several sources[45,46,47]. Based on these sources, from 1993 to 2007 the average annual sales were about 2,260 units. Since the recession, sales have dropped significantly. In 2007, the industry purchased 2,173 new large buses, down 8.7 percent from 2006. Sales between years 2008 and 2010 dropped further below 2,000 units. As the economy stabilizes, the annual sales are expected to be more in line with the historical trend. Therefore, the analysis used the rounded number of 2,200 units for the average annual new large bus output.

Combining stability control system unit costs shown in the previous section with the technology needs in Table V-3, and using the assumed production volumes, yields the costs in Table V-4 for

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[44] Ages 1 and 2 truck tractors both were used as proxy for new truck tractors because the number of age 2 truck tractors is higher than that of age 1. This might due to the coding of vehicle model year.

[45] National Bus Trader / January, 2011, http://www.busmag.com/PDF/MCIPOC.pdf

[46] ABA Motorcoach Census (http://www.buses.org/ABA-Foundation/Research)

[47] Damuth, R., "The Economic Impacts and Social Benefits of the U.S. Motorcoach" by Nathan Associates, December 2008. Statistics cited in this report was based on the data published in Bus&MotorcoachesNEWs, Feb. 15, 2008.

the proposal. As shown, 57.8 percent of truck tractors would be required to be equipped with the full ESC system at a cost of about $100.6 million. In addition, the cost for upgrading from RSC to ESC for an additional 16.0 percent of the truck tractors would cost $12.5 million. For large buses, the estimated cost for the 20 percent of large buses that would need to be equipped with the full ESC system is $0.5 million. The remaining 80 percent of large buses are expected to already be equipped with ESC. Thus, no other additional costs would be needed for those large buses.

Table V-4
Total Costs for the Proposal
(2010 $)

	Technology Upgrade Needed		
Truck Tractors	None	Incremental ESC	ESC
% Needing Improvements	26.2%	16.0%	57.8%
150,000 Sales Estimated	39,300	24,000	86,700
Costs per Affected Vehicle	0	$520	$1,160
Total Costs	0	$12.5 M	$100.6 M
Large Buses			
% Needing Improvements	80%	0%	20%
2,200 Sales Estimated	1,760	0	440
Costs per Affected Vehicle	0	$520	$1,160
Total Costs	0	$0 M	$0.5 M

M: million

Overall, as summarized in Table V-5, the incremental vehicle costs of providing ESC compared to manufacturer's planned production for the MY 2012 fleet will add $113.6 million to new truck tractors and large buses at a cost averaging $746.1 per vehicle. The total cost for truck tractors is estimated to be $113.1 million with an average cost of $753.7 per truck tractor. The total cost for large buses is estimated to be 0.5 million with an average cost of $232.0 per motocoach.

Table V-5
Summary of Vehicle Costs
(2010 $)

	Average Vehicle Costs	Total Costs
Truck Tractors	$ 753.7	$ 113.1 M
Large Buses	$ 232.0	$ 0.5 M
Total	$ 746.1	$ 113.6 M

Compliance Cost

The agency estimates that the compliance cost for executing both of the proposed SIS and SWD maneuvers per tractor would be $15,000 assuming that the manufacturers already have access to test facilities, tracks, and vehicles. The estimated costs include:

(1) $10,000 for preparing for and executing the proposed maneuvers,

(2) $2,000 for executing FMVSS No. 121 brake burnish test, and

(3) $3,000 for other miscellaneous preparations and required equipment such as

- Brake conditioning between maneuvers,
- Jackknife cable maintenance,
- ballast loading, and
- Post data processing, i.e., LAR and Torque reduction process.

Due to the lack of information on the number of tests that manufacturers might choose to run to certify a specific make model and whether a certification test for a specific make model would also be applicable to other similar models, the agency does not provide the total compliance cost estimate for manufacturers. Compliance costs in the analysis are considered as Research and Development or overhead costs to the manufacturers. Compliance costs are already implicitly included in the estimated consumer cost, since consumer cost (or the retail price equivalent) is determined by taking variable costs and multiplying by a 1.5 markup to account for fixed and overhead costs. In other words, compliance costs are already included in the estimated vehicle technology costs in this analysis.

Note that the 1.5 markup factor is based on an examination of historical financial data contained in 10-K reports filed by light vehicle manufacturers with the Securities and Exchange Commission (SEC). It represents the ratio between the retail price of motor vehicles and the direct costs of all of the activities that manufacturers engage in, including the design, development, manufacturing, assembly, and sales of new vehicles, refreshed vehicle designs, and modifications to meet safety or fuel economy standards. These data indicate that over the last 30 years, the retail price of motor vehicles has, on average, been roughly 50 percent above the direct cost expenditures of manufacturers. This ratio has been remarkably consistent, averaging roughly 1.5.

C. Leadtime

For truck tractors, the agency is proposing a leadtime of two years for typical 4x2 and 6x4 truck tractors, and a leadtime of four years for severe service tractors that typically have a GVWR greater than 27,000 kg (59,600 pounds), and other specialty truck tractors with four or more axles.

For large buses, the agency is proposing a leadtime of two years after the final rule is published. Although, the agency estimated that in 2012, almost all Class 8 buses will be equipped with ESC as standard equipment, ESC is not expected to be available for Class 7 buses. Therefore, to accommodate manufacturers of Class 7 buses, the agency believes two year leadtime is adequate for these manufacturers to develop, test, and install ESC on Class 7 buses.

CHAPTER VI. COST-EFFECTIVENESS AND BENEFIT-COST

This chapter provides cost-effectiveness and benefit-cost analysis for the proposed ESC rule. The Office of Management and Budget (OMB) requires all agencies to perform both analyses in support of rules, effective January 1, 2004.[48]

Cost-effectiveness measures the net cost per equivalent life saved (i.e., per equivalent fatality), while benefit-cost measures the net benefit which is the difference between the monetized value of the benefits and the net costs. The net cost in this analysis is equal to the technology cost minus the savings from the prevention of crash-related travel delays and property damage. Thus, injury reduction benefits, travel delay and property damage savings, and vehicle technology costs are the primary components for deriving these two measures. In cost-effectiveness, injury benefits are expressed as fatal equivalents which are further translated into a monetary value in the benefit-cost analysis. Injury benefits (i.e., fatal equivalents) and travel delays and property damage savings represent savings throughout the vehicle's life, and are discounted to reflect their present values (2009 $ value). The discounting procedure for future benefits and costs in regulatory impact analyses is based on the guidelines published in Appendix V of the "Regulatory Program of the United States Government", April 1, 1990 - March 31, 1991.

There is general agreement within the economic community that the appropriate basis for determining discount rates is the marginal opportunity costs of lost or displaced funds. When these funds involve capital investment, the marginal, real rate of return on capital must be considered. However, when these funds represent lost consumption, the appropriate measure is

[48] See OMB Circular A-4.

the rate at which society is willing to trade-off future for current consumption. This is referred to as the "social rate of time preference," and it is generally assumed that the consumption rate of interest, i.e., the real, after-tax rate of return on widely available savings instruments or investment opportunities, is the appropriate measure of its value.

Estimates of the social rate of time preference have been made by a number of authors. Robert Lind[49] estimated that the social rate of time preference is between zero and six percent, reflecting the rates of return on Treasury bills and stock market portfolios. Kolb and Sheraga[50] put the rate at between one and five percent, based on returns of stocks and three-month Treasury bills. Moore and Viscusi[51] calculated a two percent real time rate of time preference for health, which they characterize as being consistent with financial market rates for the period covered by their study. Moore and Viscusi's estimate was derived by estimating the implicit discount rate for deferred health benefits exhibited by workers in their choice of job risk. OMB Circular A-4 recommends the use of a 3 percent discount rate as the social rate of time preference.

OMB Circular A-4 states that a real discount rate of 7 percent should be used as a base-case for regulatory analysis. The 7 percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy. It is a broad measure that reflects the return of real estate

[49] Lind, R.C., "A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options," in Discounting for Time and Risks in Energy Policy, 1982, (Washington, D.C., Resources for the Future, Inc.).

[50] J. Kolb and J.D. Sheraga, "A Suggested Approach for Discounting the Benefits and Costs of Environmental Regulations,: unpublished working papers.

[51] Moore, M.J. and Viscusi, W.K., "Discounting Environmental Health Risks: New Evidence and Policy Implications," Journal of Environmental Economics and Management, V. 18, No. 2, March 1990, part 2 of 2.

and small business capital as well as corporate capital. It approximates the opportunity cost of capital, and it is the appropriate rate whenever the main effect of a regulation is to displace or alter the use of capital in private sector. OMB recommends that agencies use both 3 percent and 7 percent discount rates for their regulatory analyses.

A. Discounting Factors

Safety benefits can occur at any point in time during the vehicle's lifetime and are discounted at both 3 and 7 percent to reflect their values in 2010 dollars. For this analysis, the agency assumes that the distribution of weighted yearly vehicle miles traveled (VMT) is an appropriate proxy measure for the distribution of such crashes over the vehicle's lifetime. This measure takes into account both vehicle survival rates and changes over time in annual average VMT. Multiplying the percent of a vehicle's total lifetime mileage that occurs in each year by the discount factor and summing these percentages over the years of the vehicle's operating life, results in the discount factor at that discount rate. Table VI-1 shows the process of deriving the 3-percent and 7-percent discount factors for truck tractors. In these tables, columns c, d, e, and f are derived separately using the formulas: c = a * b, d = $\frac{\text{c}}{\text{total of c}}$, e = $\frac{1}{(1+\text{discount rate})^{\text{age}-0.5}}$, and f = d * e.

As shown, a 3-percent discount factor is 0.8087 and a 7-percent discount factor is 0.6421. These multipliers are applied to the estimated number of equivalent fatalities prevented to give the present values of estimated safety benefits for the respective discount rates. For example, the present value of the benefits of the proposal at the 3 percent discounted rate is equivalent to a 0.8087 of the initial estimates.

Note that VMT data in the tables are based on the Census Bureau's 2002 Vehicle Inventory and Use Survey (VIUS)[52]. Survivability is based on 1991 to 2008 R. L. Polk Registration data. A detailed description of the process for deriving the discount factors can be found in the agency report on vehicle survivability and travel mileage schedules[53]. For truck tractors specifically, the process is explained in a 2009 NHTSA report "An In-Service Analysis of Maintenance and Repair Expenses for Tractors and Trailers" by Kirk Allen[54].

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[52] U.S. Census Bureau, Service Sector Statistics Division; http://www.census.gov/svsd/www/vius/products.html

[53] Lu, S., "Vehicle Survivability and Travel Mileage Schedules", NHTSA Technical Report, January 2006, DOT 809 952

[54] Allen, K., An In-Service Analysis of Maintenance and Repair Expenses for the Anti-Lock Brake System and Underride Guard for Tractors and Trailers, March 2009, DOT HS 811 109

Table VI-1
Mid-Year Discount Factors, Truck Tractors

Age	Total Annual Miles Traveled (a)	Surviva-bility (b)	Weighted Miles Traveled (c)	Percent of Total Weighted Miles (d)	Raw Discount Factors (e)		Weighted Discount Factors (f)	
					3%	**7%**	**3%**	**7%**
1	240,737	1.0000	240,737	9.90	0.9853	0.9667	0.0975	0.0957
2	226,110	0.9930	224,535	9.20	0.9566	0.9035	0.0880	0.0831
3	212,378	0.9810	208,351	8.60	0.9288	0.8444	0.0799	0.0726
4	199,486	0.9642	192,351	7.90	0.9017	0.7891	0.0712	0.0623
5	187,381	0.9432	176,733	7.30	0.8755	0.7375	0.0639	0.0538
6	176,017	0.9181	161,599	6.70	0.8500	0.6893	0.0570	0.0462
7	165,346	0.8894	147,061	6.10	0.8252	0.6442	0.0503	0.0393
8	155,327	0.8575	133,198	5.50	0.8012	0.6020	0.0441	0.0331
9	145,919	0.8230	120,085	4.90	0.7778	0.5626	0.0381	0.0276
10	137,085	0.7860	107,748	4.40	0.7552	0.5258	0.0332	0.0231
11	128,789	0.7473	96,239	4.00	0.7332	0.4914	0.0293	0.0197
12	120,999	0.7071	85,559	3.50	0.7118	0.4593	0.0249	0.0161
13	113,683	0.6660	75,708	3.10	0.6911	0.4292	0.0214	0.0133
14	106,813	0.6244	66,689	2.70	0.6710	0.4012	0.0181	0.0108
15	100,360	0.5826	58,471	2.40	0.6514	0.3749	0.0156	0.0090
16	94,300	0.5411	51,028	2.10	0.6324	0.3504	0.0133	0.0074
17	88,609	0.5003	44,332	1.80	0.6140	0.3275	0.0111	0.0059
18	83,263	0.4604	38,338	1.60	0.5961	0.3060	0.0095	0.0049
19	78,242	0.4217	32,998	1.40	0.5788	0.2860	0.0081	0.0040
20	73,526	0.3845	28,273	1.20	0.5619	0.2673	0.0067	0.0032
21	69,096	0.3490	24,112	1.00	0.5456	0.2498	0.0055	0.0025
22	64,935	0.3152	20,470	0.80	0.5297	0.2335	0.0042	0.0019
23	61,026	0.2835	17,300	0.70	0.5142	0.2182	0.0036	0.0015
24	57,354	0.2537	14,552	0.60	0.4993	0.2039	0.0030	0.0012
25	53,905	0.2260	12,180	0.50	0.4847	0.1906	0.0024	0.0010
26	50,664	0.2004	10,155	0.40	0.4706	0.1781	0.0019	0.0007
27	47,620	0.1769	8,424	0.30	0.4569	0.1665	0.0014	0.0005
28	44,759	0.1554	6,957	0.30	0.4436	0.1556	0.0013	0.0005
29	42,072	0.1359	5,718	0.20	0.4307	0.1454	0.0009	0.0003
30	39,547	0.1183	4,677	0.20	0.4181	0.1359	0.0008	0.0003
31	37,175	0.1025	3,809	0.20	0.4059	0.1270	0.0008	0.0003
32	34,945	0.0884	3,090	0.10	0.3941	0.1187	0.0004	0.0001
33	32,851	0.0759	2,493	0.10	0.3826	0.1109	0.0004	0.0001
34	30,883	0.0649	2,004	0.10	0.3715	0.1037	0.0004	0.0001
35	29,033	0.0552	1,602	0.10	0.3607	0.0969	0.0004	0.0001
Total	3,530,235		2,427,576					
Lifetime Discount Factor							0.8087	0.6421

c = a*b; d = c/total miles; $e = \left(\frac{1}{1+\text{Discount Rate}}\right)^{age-0.5}$; f = d * e

A. Fatal Equivalents

To calculate a cost per equivalent fatality, nonfatal injuries must be expressed in terms of fatalities. This is done by comparing the values of preventing nonfatal injuries to the value of preventing a fatality. Comprehensive values, which include both economic impacts and loss of quality (or value) of life considerations, will be used to determine the relative value of nonfatal injuries to fatalities. Value-of-life measurements inherently include a value for lost quality of life plus a valuation of lost material consumption that is represented by measuring consumers' after-tax lost productivity. In addition to these factors, preventing a motor vehicle fatality will reduce costs for medical care, emergency services, insurance administrative costs, workplace costs, and legal costs. If the countermeasure is one that also prevents a crash from occurring, such as ESC and RSC, property damage and travel delay would be prevented as well. The sum of both value-of-life and economic cost impacts is referred to as the comprehensive cost savings from reducing fatalities. However, travel delay and property damage were measured separately in this analysis, and are thus not included in the calculations of the comprehensive ratio for injuries.

In the past, these values were adopted from the most recent study of vehicle crash-related economic impacts published by NHTSA in 2000[55]. The adopted costs were then adjusted to a present value using an appropriate consumer price index[56]. In 2008, the DOT issued new guidelines on the value of a statistical life (VSL) and raised the VSL from $3.0 million to $5.8

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[55] Blincoe, L., *et al.*, The Economic Impact of Motor Vehicle Crashes 2000, Washington, DC, DOT HS 809 446, May 2002.

[56] Gross Domestic Product – Implicit Price Deflators, for example

million. In late 2009, the DOT again revised the guideline and raised the VSL to $6.0 million. In response to the new guideline, the agency updated all relative values for non-fatal MAIS injuries as well. Currently, the agency is conducting research to revise these relative values and will publish these estimates when they become available. In the interim, the agency adjusted the comprehensive costs for MAIS injuries by preserving the relative injury/fatal rations as estimated in the 2000 report. Appendix B describes the process to derive these costs in 2008 economics. These 2008 dollars were further adjusted to 2010 dollars by using the GDP deflator of 1.01906 (= 110.668/108.598)[57]. Table VI-4 shows the adjusted comprehensive costs excluding travel delay and property damage in 2010 economics for each MAIS injury level and the relative fatality ratios.

Table VI-4
Calculation of Fatal Equivalents

Injury Severity	Comprehensive Cost* (2010 $)	Relative Fatality Ratio
MAIS 1	$17,706	0.0028
MAIS 2	$280,378	0.0436
MAIS 3	$516,883	0.0803
MAIS 4	$1,286,378	0.1999
MAIS 5	$4,282,726	0.6655
Fatality	$6,435,237	1.00000

* Excluding traffic delay and property damage

Fatal equivalents are derived by applying the relative fatality ratios (Table VI-4) to the estimated MAIS 1-5 injury benefits (Table IV-8-A). As discussed earlier, benefits are realized throughout a vehicle's life. Thus, fatal equivalents are required to be discounted at 3 and 7 percent. Table VI-5 shows the undiscounted and discounted fatal equivalents. Undiscounted, the proposal

[57] National Income and Product Account Table, Price Indexes for Gross Domestic Product as of January 28, 2011

would save 63 to 78 fatal equivalents. Of these, 38 - 53 were from rollover crashes and 25 were from LOC crashes. At a 3 percent discount, 51 – 63 equivalent lives would be saved, 31 – 43 were from rollover crashes and 20 were from LOC crashes. At a 7 discount rate, 40 – 50 equivalent lives would be saved, 24 – 34 were saving from rollover crashes and 16 were from LOC crashes.

Table VI-5
Injury Benefits of the Proposal in Fatal Equivalents

	Rollovers	LOC	Total
Undiscounted	38 - 53	25	63 – 78
3% Discount	31 - 43	20	51 – 63
7% Discount	24 – 34	16	40 – 50

B. Net Costs

The net cost is the difference between the cost to implement the technology and the savings from reduced travel delay and property damage. The total technology cost of the rule as estimated in the cost chapter is $113.6 million. The technology cost represents the investment paid at the time of vehicle purchase for future benefits and thus no discounting is needed.

By contrast, travel delay and property damage savings are realized throughout the vehicle's life, and thus must be discounted. At a 3 percent discount rate, the travel delay and property damage savings range from $13.9 to $17.8 million. At a 7 percent discount rate, the savings are estimated to range from $11.0 to $14.1 million. Subtracting the travel delay and property damage savings from the vehicle technology cost derives the net cost. The net cost is estimated to range from $95.8 to $99.7 million at a 3 percent discount rate and $99.4 to $102.6 million at a 7 percent discount rate.

C. Cost-Effectiveness

The cost-effectiveness analysis derives the cost per equivalent life saved (i.e., cost per equivalent fatality), which is equal to the net cost divided by the fatal equivalents. The net cost per equivalent fatality would range from $1.5 to $2.0 million at a 3 percent discount rate, and $2.0 to $2.6 million at a 7 percent discount rate.

D. Net Benefits

The benefit-cost analysis derives the net benefits which is the difference between the injury benefits and the net costs of the rule in monetary terms. Thus, the benefit-cost analysis differs from cost-effectiveness analysis in that it requires that the benefits be assigned a monetary value, and that this value be compared to the monetary value of costs to derive the net benefits. As shown in Table VI-4, a fatality was valued at $6.44 million in 2010 dollars. Multiplying this unit cost by the total fatal equivalents (Table VI-5) derives the monetary values for the injury benefits of the rule. The value of injury benefits is estimated to range from $328 to $405 million at a 3 percent discount rate and $257 to $322 million at a 7 percent discount rate.

After translating the injury benefits into monetary values and deriving the net cost annually, the net benefits simply is the difference of these values. The net benefits of the proposal would range from $228 to $310 million at a 3 percent discount rate and $155 to $222 million at a 7 percent discount rate.

E. Summary

In summary, this proposal would prevent 1,807 to 2,329 crashes. By eliminating these crashes, the proposal would save 49 to 60 lives and eliminate 649 to 858 MAIS 1-5 injuries. The proposal would also eliminate 1,187 to 1,499 PDOVs. These fatalities and injuries translate to a total of 63 to 78 undiscounted fatal equivalents, 51 to 63 fatal equivalents at a 3 percent discount, 40 to 50 fatal equivalents at a 7 percent discount rate.

The cost per equivalent life saved would range from $1.5 to $2.0 million at a 3 percent discount rate and $2.0 to $2.6 million at a 7 percent discount rate. The net benefit is estimated to range from $228 to $310 million at a 3 percent discount rate and $155 to $222 million at a 7 percent discount rate. Table VI-6 summarizes the fatal equivalents, cost-effectiveness, and net benefit statistics. The low and high figures correspond to the low and high bounds of the injury benefits. Based on these cost/benefit statistics, the proposal is considered to be cost-effective compared to a $6.44 million comprehensive value per life. The net cost per equivalent life saved, at both 3 and 7 discount rates, is estimated to be less than $3.0 million. At both 3 and 7 discount rates, the rule would generate over $150 million in net benefits.

Table VI-6
Summary of Cost-Effectiveness and Net Benefits by Discount Rate
(2010 $)

	3% Discount		**7% Discount**	
	Low	High	Low	High
Fatal Equivalents	51	63	40	50
Injury Benefits (1)	$328,197,087	$405,419,931	$257,409,480	$321,761,850
PD&TD Savings	$13,862,581	$17,778,541	$11,006,756	$14,115,990
Vehicle Costs*	$113,562,400	$113,562,400	$113,562,400	$113,562,400
Net Costs (2)	$99,699,819	$95,783,859	$102,555,644	$99,446,410
Net Cost Per Fatal Equivalent (3)	$1,954,898	$1,520,379	$2,563,891	$1,988,928
Net Benefits (4)	$228,497,268	$309,636,072	$154,853,836	$222,315,440

PD&TD: property damage and travel delay
* Vehicle costs are not discounted, since they occur when the vehicle is purchased, whereas benefits occur over the vehicle's lifetime and are discounted back to the time of purchase.
(1) = $6,435,237 * Fatal Equivalents
(2) = Vehicle Costs - PD&TD
(3) = Net Costs/Fatal Equivalents
(4) = Injury Benefits – Net Costs

CHAPTER VII. ALTERNATIVES

The agency considered two alternatives to the proposal. These alternatives would require the less-expensive RSC technology. Alternative 1 would require only RSC for all applicable vehicles, i.e., all truck tractors and large buses that have a gross vehicle weight rating (GVWR) greater than 11,793 kg (26,000 pounds). Alternative 2 would require trailer-RSC for all new trailers.   The cost-effectiveness and net benefit analysis conducted for these two alternatives are based on the assumption that the current RSC and trailer-RSC systems would comply with the proposed tests for roll stability, but not necessarily for vehicle yaw control. Also for clarification, ESC and RSC are technologies specifically for truck tractors. Trailer-RSC as the name implied is for trailers.

Cost and benefit estimates for these alternatives follow the same approach that was used for the proposal. Therefore, the detailed processes for deriving these measures are not repeated here. Only critical information that has not previously presented (mostly relating to trailers for Alternative 2) is discussed in depth here. The critical information includes:

(1) Effectiveness of trailer-RSC

(2) Unit cost per trailer-RSC

(3) Average annual trailer output

(4) Baseline trailer-RSC installation rate (i.e., for 2012 MY new trailers)

A. Alternative 1 – RSC for All Applicable Vehicles

RSC is designed primarily to mitigate on-road, un-tripped rollovers and thus has minimal impact on LOC. As described in Chapter IV, RSC is estimated to be 37 to 53 percent effective against the target rollover crashes and 3 percent effective against LOC crashes. Applying these effectiveness rates to Base 1 of the projected target population (Table IV-7) derives the benefits of this alternative.

RSC is estimated to cost $640 per unit, which is based on confidential industry submissions in response to the agency's request for RSC/ESC product plans and costs in 2009. As provided in the earlier Chapters, about 57.8 percent of truck tractors and 20 percent of large buses would be required to install RSC if this Alternative were proposed. Assuming an annual production of 150,000 truck tractors and 2,200 large buses, the total affected applicable vehicles for this Alternative are estimated to be 87,140 units (86,700 truck tractors and 440 large buses). Applying the unit cost to the affected vehicles derives the costs of Alternative 1. Similarly, applying the travel delay and property damage unit costs to the corresponding benefit units derives the associated travel delay and property damage savings. Table VII-1 summarizes the undiscounted benefits and costs of the alternative. Table VII-2 summarizes cost-effectiveness and net benefits of Alternative 1 for the two discount rates.

Comparing these benefit measures to those of the proposal, Alternative 1 is slightly more cost-effective than the proposal. However, Alternative 1 would save fewer lives and accrue less net benefits than the proposal. Furthermore, Alternative 1 would have significantly less impact on

LOC crashes, a sizeable safety population that the agency intends to address. Therefore, Alternative 1 was not proposed.

Table VII-1
Summary of Undiscounted Benefits
Alternative 1

Benefit Category	Low	High
Crashes Prevented	1,291	1,813
Lives Saved	28	39
MAIS 1-5 Injuries Eliminated	505	715
Equivalent Lives Saved	38	53
PDOV Reduced	790	1,103
PD & TD Savings	$12,012,344	$16,878,401

PDOV: property damage only vehicles
PD & TD: property damage and travel delay

Table VII-2
Summary of Cost-Effectiveness and Net Benefits by Discount Rate
Alternative 1
(2010 $)

	3% Discount		**7% Discount**	
	Low	High	Low	High
Fatal Equivalents	31	43	24	34
Injury Benefits (1)	$199,492,347	$276,715,191	$154,445,688	$218,798,058
PD&TD Savings	$9,714,383	$13,649,563	$7,713,126	$10,837,621
Vehicle Costs*	$55,769,600	$55,769,600	$55,769,600	$55,769,600
Net Costs (2)	$46,055,217	$42,120,037	$48,056,474	$44,931,979
Net Cost Per Fatal Equivalent (3)	$1,485,652	$979,536	$2,002,353	$1,321,529
Net Benefits (4)	$153,437,130	$234,595,154	$106,389,214	$173,866,079

PD&TD: property damage and travel delay
* Vehicle costs are not discounted, since they occur when the vehicle is purchased, whereas benefits occur over the vehicle's lifetime and are discounted back to the time of purchase.
(1) = $6,435,237 * Fatal Equivalents
(2) = Vehicle Costs - PD&TD
(3) = Net Costs/Fatal Equivalents
(4) = Injury Benefits – Net Costs

B. Alternative 2 – Trailer-RSC for All New Trailers

This alternative would require a trailer-RSC on all new models of trailers. The design of trailer-RSC is expected to impact only the target rollover crashes, and as described below would be less effective in preventing rollovers than a tractor-based RSC. Based on 2006-2008 GES, about 98 percent of target rollovers involved a truck-tractor towing one or more trailers. Therefore, the base population for the benefit estimate of Alternative 2 is 98 percent of projected target rollovers for the proposal, i.e., only the rollover potion of the Base 1 population shown in Table IV-7.

For effectiveness, the agency conducted tests on trailer-RSC under the 150-foot J-turn maneuver with three different trailer loadings. The 150-foot J-turn maneuver is one of the maneuvers that the agency has investigated. The maneuver can adequately differentiate the performance of ESC and trailer-RSC. Table VII-3 presents these test results which were used to derive the effectiveness of trailer-RSC. Interested readers can consult the agency technical report for detailed test conditions and test results[58]. As shown in the table, under the High-CG condition, the truck tractor (Volvo) wheel-lifted at 36 mph when trailer-RSC was off and ESC was off. Wheel-lift was used as proxy for rollovers. The 33 mph serves as the baseline performance (ESC off, Trailer-RSC off). When ESC is on and the trailer-RSC is off (ESC on, Trailer-RSC off), the truck tractor completed the test run (noted as TC in the table) up to 50 mph. When ESC is off, and trailer-RSC is on (ESC off, Trailer-RSC On) the truck tractors wheel-lifted occurred at 36 mph. Therefore, for ESC the speed difference between with and without the technology is 17 mph (= 50 – 33). For trailer-RSC, the speed difference for possible rollovers with the technology and without is 3 mph (= 36 – 33). Therefore, trailer-RSC effectiveness against target rollovers is

[58] NHTSA's Class 8 Truck-Tractor Stability Control Test Track Effectiveness, 2009 ESV paper, No. 09-0552

estimated to be 17.6 percent (= 3/17) of that of tractor-based ESC systems. Applying this percentage to the effectiveness of ESC against target rollovers results the effectiveness estimates of trailer-RSC. Thus, the effective of trailer-RSC against target rollovers ranges from 7 to 10 percent. The relatively low effectiveness of trailer-RSC to that of ESC and RSC are expected since trailer- RSC applies only the trailer brakes while ESC and RSC apply both the tractor brakes and the trailer brakes. Furthermore, ESC and RSC intervene earlier in a near-rollover event and allow tractor-trailers to decelerate more rapidly than did trailer-RSC.

Table VII-3
Wheel Lift Speed within the Speed Test Limit
150-foot J-turn maneuver

	Speed (MPH) at Wheel Lift					
	LLVW		**Load Condition**			
			Low CG		**High CG**	
	Trailer RSC		**Trailer RSC**		**Trailer RSC**	
	OFF	**ON**	**OFF**	**ON**	**OFF**	**ON**
Freightliner						
ESC OFF	50^	X	38*	X	31*	X
ESC ON	TC	TC	TC	TC	TC	TC
Volvo						
ESC OFF	48*	TC	40*	TC	33*	36*
ESC ON	TC	TC	TC	TC	TC	TC

* - Denotes wheel lift.
^ - Denotes no wheel lift, but severe understeer
X – Denotes not tested.
TC – Test complete up to the maximum speed of 50 mph

As described earlier, the target rollover population of this alternative is about 98 percent of that of the proposal. The effectiveness of trailer-RSC is about 17.6 percent of that of ESC. Therefore, the benefit of this alternative basically is about 17.2 percent (= 0.98 * 0.176) of that of the proposal. Tables VII-4 summarizes the <u>undiscounted</u> benefits.

Table VII-4
Summary of Undiscounted Benefits
Alternative 2

Benefit Category	Low	High
Crashes Prevented	229	319
Lives Saved	5	7
MAIS 1-5 Injuries Eliminated	92	129
Equivalent Lives Saved	7	10
PDOV Reduced	137	191
PD&TD Savings	$2,137,258	$2,985,898

PDOV: property damage only vehicles
PD&TD: property damage and travel delay

The agency estimates that about 203,000 new trailers are produced annually. This annual production estimate is based on 2000-2010 trailer production data that were posted on the Trailer-Body Builders website[59]. Over the 10 year period, the top 30 producers manufactured an average of 184,531 new trailers. The agency estimated that the top 30 producers had 90 percent of the market share, therefore, the estimated total annual trailer output would be 202,985 which rounds up to 203,000 units.

The agency estimates that a trailer-RSC would cost $400 per trailer based on the industry's input and expert judgment within the agency. The agency believes that the current trailer-RSC installation rate on new trailers is extremely low, and is likely to be less than 0.2 percent of the annual production. Therefore, the analysis assumes that the current trailer-RSC installation rate is zero percent. In other words, all 203,000 new trailers produced annually, all of them would be affected by this Alternative. The cost of this Alternative thus is estimated to be $81.2 million (=$400 * 203,000).

[59] http://trailer-bodybuilders.com/trailer-output

For the cost-effectiveness and net benefit measures, the estimated benefits shown in Table VII-4 are first discounted at 3 and 7 percent. As described earlier, vehicle survival probability and VMT are essential elements for deriving adjustment factors. However, due to lack of VMT and historic registration data for trailers, survival probabilities of trailers cannot be established as rigorously as was done for truck tractors. The survival probabilities of trailers were established by considering the relationship between the average annual production and the average number of operational truck-trailers and comparing this relationship to that of truck tractors. Based on the annual new trailer production of 203,000 units and the total annual number of operational truck-trailers of 5.24 million units, it would take 26 production years to reach the annual operational level if there was no scrappage for those models. By contrast, it would take about 12 years for truck tractors to reach the average annual operational level. In addition, by the nature of usage of trailers, the operational life of a trailer is expected to be much longer than that of a truck tractor and the scrappage rate for trailers is expected to be more gradual than that for truck tractors.

In this analysis, the operational life of a trailer is assumed to be 45 years. The survival probabilities reflect a smooth, gradual reduction over 45 years and are constrained by the condition that the total survival trailers of various ages would be close to the 5.24 million. The rate of reduction in survivability modulated with that of truck tractors but with a slower pace. The weighted survival rate at a specific age for trailer is the percentage of survival trailers at that age among an operational fleet of trailers. These weighted survival rates serve as the surrogate for VMT adjusted survival rates as shown in the discount factor for truck tractors in Table VI-I to derive discount factors for trailers. Table VII-5 shows the process of deriving discount factors for trailers. As shown in the table, the discount factor for the 3 percent discount rate is 68.26 percent and for the 7 percent discount rate it is 49.95 percent. Therefore, the lifetime benefits of the alternative are 68.26 percent of the initial undiscounted estimates using a 3 percent discount rate. At 7 percent, the lifetime benefits are 49.95 percent of the initial estimates.

Table VII-6 presents cost-effectiveness and net benefits of Alternative 2 by discount rate. As shown, Alternative 2 would save 5 to 7 lives, even fewer than Alternative 1. In addition, this Alternative would have no impact on LOC crashes. Moreover, not only is Alternative 2 significantly less cost-effective than both the proposal and Alternative 1, it would also produce negative net benefits. Therefore, Alternative 2 is not proposed.

Table VII-5
Mid-Year Discount Factors for Trailers

Age	Survival Rate (a)	# of Trailers (b)	Weighted Survival Rate (%) (c)	Raw Discount Factors (d)		Weighted Discounted Factors (e)	
				3%	7%	3%	7%
1	1.0000	203,000	3.99	0.9853	0.9667	0.0393	0.0386
2	1.0000	203,000	3.99	0.9566	0.9035	0.0382	0.0360
3	1.0000	203,000	3.99	0.9288	0.8444	0.0371	0.0337
4	1.0000	203,000	3.99	0.9017	0.7891	0.0360	0.0315
5	1.0000	203,000	3.99	0.8755	0.7375	0.0349	0.0294
6	0.9950	201,985	3.97	0.8500	0.6893	0.0337	0.0274
7	0.9900	200,970	3.95	0.8252	0.6442	0.0326	0.0254
8	0.9850	199,955	3.93	0.8012	0.6020	0.0315	0.0237
9	0.9800	198,940	3.91	0.7778	0.5626	0.0304	0.0220
10	0.9750	197,925	3.89	0.7552	0.5258	0.0294	0.0205
11	0.9530	193,459	3.80	0.7332	0.4914	0.0279	0.0187
12	0.9310	188,993	3.71	0.7118	0.4593	0.0264	0.0170
13	0.9090	184,527	3.62	0.6911	0.4292	0.0250	0.0155
14	0.8870	180,061	3.54	0.6710	0.4012	0.0238	0.0142
15	0.8650	175,595	3.45	0.6514	0.3749	0.0225	0.0129
16	0.8330	169,099	3.32	0.6324	0.3504	0.0210	0.0116
17	0.8010	162,603	3.19	0.6140	0.3275	0.0196	0.0104
18	0.7690	156,107	3.06	0.5961	0.3060	0.0182	0.0094
19	0.7370	149,611	2.94	0.5788	0.2860	0.0170	0.0084
20	0.7050	143,115	2.81	0.5619	0.2673	0.0158	0.0075
21	0.6630	134,589	2.64	0.5456	0.2498	0.0144	0.0066
22	0.6210	126,063	2.48	0.5297	0.2335	0.0131	0.0058
23	0.5790	117,537	2.31	0.5142	0.2182	0.0119	0.0050
24	0.5370	109,011	2.14	0.4993	0.2039	0.0107	0.0044
25	0.4950	100,485	1.97	0.4847	0.1906	0.0095	0.0038
26	0.4630	93,989	1.85	0.4706	0.1781	0.0087	0.0033
27	0.4310	87,493	1.72	0.4569	0.1665	0.0079	0.0029
28	0.3990	80,997	1.59	0.4436	0.1556	0.0071	0.0025
29	0.3670	74,501	1.46	0.4307	0.1454	0.0063	0.0021
30	0.3350	68,005	1.34	0.4181	0.1359	0.0056	0.0018
31	0.3030	61,509	1.21	0.4059	0.1270	0.0049	0.0015
32	0.2710	55,013	1.08	0.3941	0.1187	0.0043	0.0013
33	0.2390	48,517	0.95	0.3826	0.1109	0.0036	0.0011
34	0.2070	42,021	0.83	0.3715	0.1037	0.0031	0.0009
35	0.1750	35,525	0.70	0.3607	0.0969	0.0025	0.0007
36	0.1530	31,059	0.61	0.3502	0.0905	0.0021	0.0006
37	0.1310	26,593	0.52	0.3400	0.0846	0.0018	0.0004
38	0.1090	22,127	0.43	0.3301	0.0791	0.0014	0.0003
39	0.0870	17,661	0.35	0.3205	0.0739	0.0011	0.0003
40	0.0650	13,195	0.26	0.3111	0.0691	0.0008	0.0002
41	0.0530	10,759	0.21	0.3021	0.0646	0.0006	0.0001
42	0.0410	8,323	0.16	0.2933	0.0603	0.0005	0.0001
43	0.0290	5,887	0.12	0.2847	0.0564	0.0003	0.0001
44	0.0170	3,451	0.07	0.2764	0.0527	0.0002	0.0000
45	0.0050	1,015	0.02	0.2684	0.0493	0.0001	0.0000
Total		5,093,270					
Lifetime Discount Factor						0.6827	0.4595

b = a*203,000; c = b/total units; $d = \frac{1}{1+\text{Discount Rate}}^{\text{age}-0.5}$; e = c * d

Table VII-6
Summary of Cost-Effectiveness and Net Benefits by Discount Rate
Alternative 2
(2010 $)

	At 3% Discount		At 7% Discount	
	Low	High	Low	High
Fatal Equivalents	5	7	3	5
Injury Benefits (1)	$30,754,672	$43,935,246	$20,700,937	$29,572,767
PD&TD Savings	$1,459,169	$2,038,560	$982,165	$1,372,153
Vehicle Costs*	$81,200,000	$81,200,000	$81,200,000	$81,200,000
Net Costs (2)	$79,740,831	$79,161,440	$80,217,835	$79,827,847
Net Cost Per Fatal Equivalent (3)	$15,948,166	$11,308,777	$26,739,278	$15,965,569
Net Benefits (4)	-$48,986,159	-$35,226,194	-$59,516,898	-$50,255,080

PD&TD: property damage and travel delay
* Vehicle costs are not discounted, since they occur when the vehicle is purchased, whereas benefits occur over the vehicle's lifetime and are discounted back to the time of purchase.
(1) = $6,435,237 * Fatal Equivalents
(2) = Vehicle Costs - PD&TD
(3) = Net Costs/Fatal Equivalents
(4) = Injury Benefits – Net Costs

CHAPTER VIII. REGULATORY FLEXIBILITY ACT AND UNFUNDED MANDATES REFORM ACT

A. Regulatory Flexibility Act

The Regulatory Flexibility Act of 1980 (5 U.S.C. § 601 et seq.), as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996, requires agencies to evaluate the potential effects of their proposed and final rules on small businesses, small organizations, and small governmental jurisdictions in the United States.

5 U.S.C. § 603 requires agencies to prepare and make available for public comment an initial and a final regulatory flexibility analysis (RFA) describing the impact of proposed and final rules on small entities if the agency decides that the rule may have a significant economic impact on a substantial number of small entities. Each RFA must contain:

(1) A description of the reasons why action by the agency is being considered;

(2) A succinct statement of the objectives of, and legal basis for, a proposal or final rule;

(3) A description of and, where feasible, an estimate of the number of small entities to which the proposal or final rule will apply;

(4) A description of the projected reporting, record keeping and other compliance requirements of a proposal or final rule including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record;

(5) An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the proposal or final rule;

(6) Each final regulatory flexibility analysis shall also contain a description of any significant alternatives to the final rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities.

1. Description of the reasons why action by the agency is being considered

NHTSA is considering this action to require an ESC system in truck tractors and large buses in order to reduce the number of rollover and loss-of-control crashes and associated fatalities and injuries. ESC has been found to be effective in reducing these two types of crashes which account for 13 percent of the fatal truck tractor and large bus crashes.

2. Objectives of, and legal basis for, the proposal or final rule

Under 49 U.S.C. 322(a), the Secretary of Transportation (the "Secretary") has authority to prescribe regulations to carry out the duties and powers of the Secretary. One of the duties of the Secretary is to administer the National Traffic and Motor Vehicle Safety Act, as amended (49 U.S.C. 30101 et seq.). The Secretary is authorized to issue Federal motor vehicle safety standards (FMVSS) that are practicable, meet the need for motor vehicle safety, and are stated in objective terms[60]. The Secretary has delegated the responsibility for carrying out the National Traffic and Motor Vehicle Safety Act to NHTSA[61]. NHTSA is adopting this rule under the Authority of 49 U.S.C. 322, 30111, 30115, 30117, and 30166; delegation of authority at 49 CFR 1.50.

[60] 49 U.S.C. 30111(a)

[61] 49 U.S.C. 105 and 322; delegation of authority at 49 CFR 1.50.

Furthermore, this final rule satisfies the congressional mandate in Section 10301 of the Safe, Accountable, Flexible, Efficient, Transportation Equity Act: A Legacy for Users of 2005 (SAFETEA-LU).[62] Under that provision, the Secretary of Transportation must conduct a rulemaking to "establish performance criteria to reduce the occurrence of rollovers consistent with stability enhancing technologies" and issue "a final rule by April 1, 2009." This responsibility was subsequently delegated to NHTSA.

3. <u>Description and estimate of the number of small entities to which the proposal or final rule will apply</u>

The proposal applies to truck tractor and large bus manufacturers who produce these types of vehicles with a GVWR greater than 11,793 kg (26,000 pounds). The proposal also will impact manufacturers of ESC systems. Business entities are defined as small businesses using the North American Industry Classification System (NAICS 2007) code[63], for the purposes of receiving Small Business Administration assistance. One of the criteria for determining size, as stated in 13 CFR 121.201[64], is the number of employees in the firm. Affected business categories include: (a) To qualify as a small business in Heavy Duty Truck Manufacturing (NAICS 336120), the firm must have fewer than 1000 employees, (b) In Truck Trailer Manufacturing (NAICS 336212), the firm must have fewer than 500 employees, (c) In Other Motor Vehicle Electronic and Electronic Equipment Manufacturing (NAICS 336322), the firm must have fewer than 750 employees, (d) In Motor Vehicle Brake System Manufacturing (NAICS 336340), the

[62] Pub. L. 109-59, 119 Stat. 1144 (2005)

[63] The latest version modified by the Office of Management and Budget in 2007

[64] Effectiveness August 22, 2008

firm must have fewer than 750 employees, and (e) In All Other Motor Vehicle Parts Manufacturing (NAICS 336399), the firm must have fewer than 750 employees.

Small volume truck tractor and large bus manufacturers

The heavy truck industry is highly concentrated with large manufacturers, including Daimler Trucks North America (Freightliner, Western Star), Navistar International, Mack Trucks Inc., PACCAR (Peterbilt and Kenworth), and Volvo Trucks North America, accounting for more than 99% of the annual productions. The remaining heavy truck manufacturers with a collective production less than 1 percent of annual heavy truck output are mostly likely small business.

The agency believes there are approximately 37 bus manufacturers in the United States. Of these, ten manufacturers can be classified as small business, with fewer than 1,000 employees. They are Advanced Bus Industries, Ebus Inc., Enova Systems, Gillig Corporation, Krystal Koach[65] Inc., Liberty Bus, Sunliner Coach Group LLC[66], TMC Group Inc., TMC Group Inc., Transportation Collaborative, Inc.[67], and Van-Con, Inc.

However, most of these companies do not manufacture large buses. A review of online product information indicates that only Sunliner Coach Group LLC specifically includes a bus in its product offering, but it is primarily a producer of travel trailers, campers, shuttle buses, and service buses. Other companies either manufacture other types of buses (school buses, transit buses, etc.) or perform a variety of bus related modifications. One company, Liberty Coach,

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[65] owned by Krystal Enterprises; $175M revenue; 800 employees

[66] Its parent holding company is Stallion Bus Industries, LLC, which is the distribution arm of the organization.

[67] employs 140

manufacturers "bus homes", which, although based on a bus body, would typically not include the 16 designated seating positions, including 8 forward facing seating positions rearward of the driver, that would define the final product as a bus. The agency thus concludes that this standard would not have a significant impact on a significant number of small businesses.

Small ESC system manufacturers

No ESC system manufacturers would qualify as a small business under the definition (c) Other Motor Vehicle Electronic and Electronic Equipment Manufacturing, (d) Motor Vehicle Brake System Manufacturing, and (e) In All Other Motor Vehicle Parts Manufacturing above. Nevertheless, the proposal is expected to have positive economic impacts on ESC manufacturers.

4. Description of the projected reporting, record keeping and other compliance requirements for small entities

The rule requires manufacturers to equip their vehicles with ESC and to certify that their products comply with the standard. There is no record keeping for this proposal.

5. Duplication with other Federal rules

There are no relevant Federal regulations that duplicate, overlap, or conflict with the final rule.

6. Description of any significant alternatives to the proposed rule

The agency considered one alternative based on the development and the implementation of the stability control technologies and cost. The alternative was to require RSC for proposed applicable truck tractors and large buses. In essence, the alternative focuses on reducing rollover crashes and cost. The agency decided not to adopt this alternative since (1) the alternative is slightly less cost-effective than the proposal, (2) significant benefits from loss-of-control crashes would be lost, and (3) the industry trend is moving towards equipping their truck tractors and large buses with ESC.

B. Unfunded Mandates Reform Act

The Unfunded Mandates Reform Act of 1995 (Public Law 104-4) requires agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditures by State, local or tribal governments, in the aggregate, or by the private sector, of more than $100 million annually (adjusted annually for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for the year 2010 results in $136 million (110.668/81.533 = 1.36). The assessment may be included in conjunction with other assessments, as it is here.

This proposed rule is not estimated to result in expenditures by State, local or tribal governments of more than $136 million annually. It also would not result in an expenditure of much more than that magnitude by the automobile manufacturers and/or their suppliers. The estimated annual cost would be $115 million annually. These effects have been discussed previously in this Preliminary Regulatory Impact Analysis (see Chapter V, Costs).

APPENDIX A. RETROFITTING

The agency examined the practicability of retrofitting ESC, RSC, and trailer-RSC for in-service truck tractors, large buses, and trailers. To retrofit in-service truck tractors and large buses with ESC and RSC would be complex because it involves the integration between these systems with vehicle's chassis, engine, braking, other stability related systems (e.g., traction control), vehicle local network communication systems, and electronic control units. Changes necessary to originally manufactured vehicles include but are not limited to plumbing for new air brake valves, adding wires and sensors, and implementing a new electronic control unit for a revised antilock brake system. The ESC/RSC modules and required sensors need to be calibrated using special tools. Therefore, it does not appear feasible to retrofit ESC and RSC. Furthermore, the component costs and associated labor costs is expected to be very high and would not be cost-effective. Specially, retrofitting in-service large buses with ESC or RSC would not be cost-effective due to the small safety target population that would be impacted by retrofitting (about 1 rollover and 1 LOC crashes annually). In addition, retrofitting would impact 80 percent of large bus operators with a large bus fleet size of less than the 10 vehicles[68]. For these reasons, the agency has determined that it is not practical to retrofit applicable vehicles with ESC or RSC.

For trailer-RSC on the other hand, retrofitting service and equipment is already available. Retrofitting trailer-RSC involves installing few additional components. The integration of a trailer-RSC with an operational trailer includes replacing the ABS ECU/valve assembly with a trailer-RSC ECU valve assembly, mounting an electronic sensor to measure the deflection of the

[68] Motorcoach Facts, 2009, American Bus Association, www.buses.org

suspension springs or to sense the air pressure in an air suspension system, and possibly installing wheel-speed sensors and cables (if the trailer is not already equipped with ABS). Based on industry information, retrofitting trailer-RSC would cost $1,200 per unit plus four to six hours of labor[69].

The costs and benefits of retrofitting would depend on the retrofitting schedule of existing trailers in the fleet, and the trailer-RSC installation rate in new models of trailers, and the effectiveness of the technology in preventing rollovers. Therefore, the cost and benefit of retrofitting trailer-RSC were estimated under the following assumptions:

(1) Retrofitting cost is estimated to be $1,305 which includes $1,200 for parts and five hours of labor at a labor rate of $21 per hour. The five hours is the average of four and six hours quoted above.

(2) The unit cost cited above is for trailers that are already equipped with ABS. Therefore, only trailers manufactured after September 1998, the effective date for requiring ABS, would be retrofitted. Retrofitting older, non-ABS trailers would likely be cost-prohibitive since the wheel hubs and axles would need to be replaced or modified.

(3) The timeframe for retrofitting and the retrofitting schedule within that timeframe would impact the cost and benefit estimates. For simplicity, the timeframe is set to be 10 years starting 2014. The analysis examines two retrofitting schedules. One is the maximum benefit scenario which assumes retrofitting would be completed within the first year. The other one is the least cost scenario which assumes that retrofitting would be completed by the last year of the 10 years period, i.e., 2023.

[69]http://www.todaystrucking.com/

(4) All 2015 trailers and newer would have trailer-RSC. The number of trailers older than the 2015 model year that would have the factory -installed trailer-RSC is believed to be extremely small relatively to their annual production. Thus, the trailer-RSC installation rates for trailers older than 2015 were assumed to be zero percent.

(5) Trailers operate in tandem with truck tractors. Therefore, the benefits from retrofitting trailer-RSC would also be impacted by the ESC and RSC installation rates in truck tractors. ESC and RSC installation rates for truck tractors newer than 2012 model are assumed at the 2012 level. Their installation rates for tractor models up to 2012 were estimated from industry's historic data and future product plans that were submitted in response to the agency's request in 2009.

(6) The retrofitted trailer-RSC is assumed to be as effective as the factory installed trailer-RSC. Thus, the effectiveness of trailer-RSC against target rollovers ranges from 7 to 10 percent.

Table A-1 provides the ESC, RSC, and trailer-RSC installation rates by retrofitting scenario and model year based on the above assumptions. For a given technology, its installation rates were weighted by the appropriate survival probabilities (Table VII-4 for trailers and Table VI-1 for truck tractors) to derive an overall installation rate for that technology among the in-service vehicles (i.e., truck tractors for ESC/RSC, trailers for trailer-RSC). The overall installation rates were used to estimate adjustment factors to discount the initial target population in order to account for the impacts of the increasing installation of these stability technologies on future crashes. The process of deriving an overall installation rate for a given technology can be expressed as:

$$OI = \sum_{i=1}^{OL} S_i * I_i$$

Where:

OI = an overall installation rate of a technology among a operational fleet

i = age of the vehicles

S_i = survival probability at age i

OL = operational life, 45 years for trailers and 35 years for truck tractors

I_i = installation rate of a technology for year i model vehicles.

Table A-1
ESC, RSC, and Trailer-RSC Installation Percentage
by Retrofitting Scenario and Applicable Vehicle Model Year*

	Maximum Benefit Scenario				Least Cost Scenario			
Age	Model Year	ESC	RSC	Trailer-RSC	Model Year	ESC	RSC	Trailer-RSC
1	2014	26.2	16.0		2023	26.2	16.0	100.0
2	2013	26.2	16.0		2022	26.2	16.0	100.0
3	**2012**	**26.2**	**16.0**		2021	26.2	16.0	100.0
4	2011	23.3	14.8		2020	26.2	16.0	100.0
5	2010	21.8	12.3		2019	26.2	16.0	100.0
6	2009	13.8	17.0		2018	26.2	16.0	100.0
7	2008	12.1	12.0		2017	26.2	16.0	100.0
8	2007	7.4	10.5		2016	26.2	16.0	100.0
9	2006	3.2	6.4		2015	26.2	16.0	100.0
10	2005	0.2	5.4		2014	26.2	16.0	
11	2004				2013	26.2	16.0	
12	2003				**2012**	**26.2**	**16.0**	
13	2002				2011	23.3	14.8	
14	2001				2010	21.8	12.3	
15	2000				2009	13.8	17.0	
16	1999				2008	12.1	12.0	
17					2007	7.4	10.5	
18					2006	3.2	6.4	
19					2005	0.2	5.4	
20					2004			
21					2003			
22					2002			
23					2001			
24					2000			
15					1999			

*1999 and newer
Bold-faced model year is the latest model information submitted by the manufacturers

Adjustment factors for ESC and RSC can be derived using the f_1 formula that was previously presented in the Chapter IV. The adjustment factor to account for the impact of trailer-RSC installation among new trailers during the retrofitting period is merely one minus the overall trailer-RSC installation rate.

The trailer-RSC installation rates shown in Table A-1 and trailers' survival probabilities (Table VII-5) are also used to derive the percent of operational trailers that would be retrofitted. Applying this percentage to the total of 5.24 million in-service trailer units derives the number of affected trailers. Table A-2 presents all the measures mentioned above, i.e., the total number of affected trailers, the overall ESC, RSC, and trailer-RSC installation rates, and adjustment factors.

Table A-2
Affected Trailers, Technology Installation Rates, and
Target Population Adjustment Factors by Retrofitting Scenarios

	Maximum Benefit	Least Cost
Affected Percent of Trailers	61.0%	48.9%
Total Affected Trailers (1)	3,199,918	2,561,926
Installation Rate (%)		
ESC	12.3%	22.3%
RSC	9.4%	14.3%
Trailer-RSC	0.0%	35.7%
Adjustment Factors		
Account for ESC and RSC	80.3%	65.0%
Account for Trailer-RSC	100.0%	64.3%
Final Adjustment Factor (2)	80.3%	41.8%

(1) = affected percent * 5.24 million
(2) = ESC/RSC factor * Trailer-RSC factor

The following tables, A-3 to A-5, separately represent the adjusted baseline population, undiscounted benefits, the summary cost-effectiveness and net benefits by retrofitting scenario. As shown in Table A-5, retrofitting trailer-RSC would cost $3.3 to $4.2 billion. Retrofitting trailer-RSC is extremely non cost-effective. The cost per equivalent live saved would range from $463 million to $1.7 billion. Therefore, the agency has determined that it is impractical to consider retrofitting trailer-RSC.

Table A-3
Target Population by Retrofitting Scenarios

	Maximum Benefits	**Least Cost**
Crashes	4,336	2,257
MAIS Injuries		
1	1,368	712
2	236	123
3	105	55
4	26	14
5	9	5
MAIS 1-5	1,744	909
Fatality	87	45
PDOV	2,595	1,350

PDOV: property damage only vehicles

Table A-4
Undiscounted Benefits by Retrofitting Scenarios

	Maximum Benefits		**Least Cost**	
	Low	High	Low	High
Crashes	304	434	158	226
MAIS Injuries				
1	96	137	50	71
2	17	24	9	12
3	7	11	4	6
4	2	3	1	1
5	1	1	0	1
MAIS 1-5	123	176	64	91
Fatality	6	9	3	5
PDOV	182	260	95	135

PDOV: property damage only vehicles

Table A-5
Summary of Cost-Effectiveness and Net Benefits by Retrofitting Scenarios
(2010 $)

At 3 Percent

	Maximum Benefits		Least Cost	
	Low	High	Low	High
Fatal Equivalents	6	9	3	5
Injury Benefits (1)	$39,541,721	$57,115,820	$17,574,098	$30,754,672
PD&TD Savings	$1,928,133	$2,768,177	$1,001,121	$1,442,234
Vehicle Costs*	$4,175,892,990	$4,175,892,990	$3,343,313,430	$3,343,313,430
Net Costs (2)	$4,173,964,857	$4,173,124,813	$3,342,312,309	$3,341,871,196
Net Cost Per Fatal Equivalent (3)	$695,660,810	$463,680,535	$1,114,104,103	$668,374,239
Net Benefits (4)	-$4,134,423,136	-$4,116,008,993	-$3,324,738,211	-$3,311,116,524

At 7 Percent

	Maximum Benefits		Least Cost	
	Low	High	Low	High
Fatal Equivalents	4	6	2	3
Injury Benefits (1)	$26,615,491	$38,444,598	$11,829,107	$20,700,937
PD&TD Savings	$1,297,824	$1,863,257	$673,854	$970,766
Vehicle Costs*	$4,175,892,990	$4,175,892,990	$3,343,313,430	$3,343,313,430
Net Costs (2)	$4,174,595,166	$4,174,029,733	$3,342,639,576	$3,342,342,664
Net Cost Per Fatal Equivalent (3)	$1,043,648,792	$695,671,622	$1,671,319,788	$1,114,114,221
Net Benefits (4)	-$4,147,979,675	-$4,135,585,135	-$3,330,810,469	-$3,321,641,727

PD&TD: property damage and travel delay
* Vehicle costs are not discounted, since they occur when the vehicle is purchased, whereas benefits occur over the vehicle's lifetime and are discounted back to the time of purchase.
(1) = $6,435,237 * Fatal Equivalents
(2) = Vehicle Costs - PD&TD
(3) = Net Costs/Fatal Equivalents
(4) = Injury Benefits – Net Costs

APPENDIX B. REVISED COMPREHENSIVE COSTS

Comprehensive costs which include both economic impacts and lost quality (or value) are used in the cost-effectiveness and net benefit analyses. The agency develops the comprehensive costs for fatalities and MAIS injuries periodically by thoroughly surveying all cost components that are associated with automobile accidents. Cost components include costs for medical care, emergency service (EMS), market productivity, household productivity, insurance administration, workplace loss, legal costs, travel delay, property damage, and lost quality of life (QALYs). The most recent estimates were developed in 2000[70]. Table B-1 shows estimated costs by injury severity levels for both crash avoidance and crashworthiness countermeasures. The difference between these two sets of costs is that travel delay and property damage costs which were typically associated with crash avoidance countermeasures were excluded from the costs for crashworthiness countermeasures.

Table B-1
Comprehensive Costs
(2000 $)

Injury Severity	Comprehensive Cost (for Crash Avoidance)	Comprehensive Cost* (for Crashworthiness)
MAIS 1	$15,017	$10,396
MAIS 2	$157,958	$153,157
MAIS 3	$314,204	$306,465
MAIS 4	$731,580	$720,747
MAIS 5	$2,402,997	$2,384,403
Fatality	$3,366,388	$3,346,966

Source: Table VIII-9 of “The Economic Impact of Motor Vehicle Crashes 2000”
* Excluding traffic delay and property damage

[70] Blincoe, L., *et al.*, The Economic Impact of Motor Vehicle Crashes 2000, Washington, DC, DOT HS 809 446, May 2002.

In the 2002 report, the comprehensive costs were derived using an earlier DOT guideline on the value of a statistical life (VSL) of $3.0 million. In 2007, the DOT revised this guideline and raised the VSL from $3.0 million to $5.8 million. In 2009, the DOT revised the VSL again to $6.0 million. VSL includes QALYs, household productivity, and the after-tax portion of market productivity. In response to the new guideline, the agency needs to revise all relative costs for non-fatal MAIS injuries. Currently, the agency is conducting research to estimate the relative values for injuries. The revised estimates will be published when they become available. In the interim, the agency has adjusted the unit comprehensive costs first by adjusting each of the cost components to the 2008 value using an appropriate consumer price index. Then, QALYs for MAIS injuries were adjusted further to reflect the revised VSL but the relative injury-to-fatal ratios of QALYs were maintained as estimated in the 200 report. Table B-2 shows the adjusted unit cost estimates in 2008 values by cost category. As shown, the revised comprehensive cost for a fatality is now estimated to be $6.34 million for crash avoidance countermeasures and $6.31 million for crashworthiness countermeasure. The QALYs for a fatality is estimated to be $5.1 million. QALYs for MAIS injuries were derived by applying QALY injury-to-fatal ratios published in the 2000 report to the $5.1 million. The relative injury/fatal ratios under “comprehensive cost” are used to derive fatal equivalents for benefits accrued from crash avoidance countermeasures and ratios under “injury comprehensive cost” are used for crashworthiness countermeasures.

Table B-2
Unit Costs Reflecting the $6.0 Million Value of a Statistical Life (VSL)
(2008 $)

CPI	Cost Item	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
1.395955	Medical	$3,322	$21,812	$64,905	$183,297	$464,095	$30,844
1.250308	EMS	$121	$265	$460	$1,038	$1,065	$1,042
1.309809	Market Productivity	$2,291	$32,767	$93,591	$139,415	$574,620	$779,805
1.309809	Household Produce	$749	$9,590	$27,604	$36,686	$195,565	$250,882
1.250308	Insurance. Admin.	$926	$8,638	$23,622	$40,429	$85,267	$46,411
1.309809	Workplace Cost	$330	$2,558	$5,588	$6,153	$10,729	$11,398
1.250308	Legal Costs	$188	$6,228	$19,765	$42,117	$99,845	$127,704
1.309809	Travel Delay	$1,018	$1,108	$1,231	$1,308	$11,982	$11,982
1.250308	Property Damage	$4,806	$4,944	$8,501	$12,294	$11,810	$12,844
1.309809	QALYs	$9,448	$193,276	$271,680	$813,183	$2,771,438	$5,066,789
Revised Comprehensive Costs		$23,199	$281,186	$516,947	$1,275,920	$4,226,416	$6,339,701
Injury Subtotal*		$17,375	$275,134	$507,215	$1,262,318	$4,202,624	$6,314,875
Relative Injury-To-Fatal Ratios							
QALYs		0.0019	0.0381	0.0536	0.1605	0.5470	1.0000
Comprehensive Cost		0.0037	0.0444	0.0815	0.2013	0.6667	1.0000
Injury Comprehensive Cost*		0.0028	0.0436	0.0803	0.1999	0.6655	1.0000

QALYs: Quality-Adjusted Life Years
* Excluding travel delay and property damage and specifically used for crashworthiness countermeasures