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**National Highway
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PRELIMINARY REGULATORY IMPACT ANALYSIS

PROPOSED FMVSS No. 126
Electronic Stability Control Systems

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. 126, Electronic Stability Control Systems (ESC). ESC has been found to be highly effective in preventing single-vehicle loss-of-control, run-off-the road crashes, of which a significant portion are rollover crashes. ESC has also been found to reduce some multi-vehicle crashes. Based on this analysis, the proposal is highly cost-effective.

Proposed Requirements

The proposal would require passenger cars, multipurpose passenger vehicles (MPVs), trucks, and buses that have a gross vehicle weight rating (GVWR) of 4,536 kg (10,000 pounds) or less to be equipped with an ESC system. We assume throughout this analysis that an ESC system combines two basic technologies: Anti-lock Brakes (ABS) and Electronic Stability Control. The proposal would require an ESC system to meet a definition, as well as meet the functional and performance requirements specified in FMVSS No. 126. The proposal would require manufacturers to install an ESC malfunction telltale and would allow manufacturers to provide an optional ESC Off switch (and associated telltale) to temporarily disable the ESC system. In addition, the proposal would require specific symbols to be used for the malfunction telltale and ESC Off switch.

Technical Feasibility/Baseline

ESC is increasingly being offered as standard or optional equipment in new model year passenger vehicles. An estimated 29 percent of the 2006 model year (MY) passenger vehicles will be equipped with ESC, compared to 10 percent in MY 2003 vehicles. Based on manufacturers' product plans submitted to the agency, 71 percent of the MY 2011 light vehicles will be equipped with ESC. The agency believes that these ESC systems will meet the proposed definition since the vast majority of the 2006 ESC systems already met the proposed performance test. The projected MY 2011 installation rates serve as the baseline voluntary compliance rates. The analysis estimates the incremental benefits and costs of the proposal, which would require manufacturers to increase ESC installations from 71 percent of the fleet to 100 percent of the fleet.

Benefits[1]

Based upon our analysis, we estimate that the proposal would save 1,536 – 2,211 lives and reduce 50,594 – 69,630 MAIS 1-5 injuries annually once all passenger vehicles have ESC. Fatalities and injuries associated with rollovers are a significant portion of this total; we estimate that the proposal would reduce 1,161 to 1,445 fatalities and 43,901 to 49,010 MAIS 1-5 injuries associated with single-vehicle rollovers.

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[1] Benefits of the proposal are measured from a baseline of 71% ESC installation to 100% installation. However, the overall benefits of ESC could be measured from "no ESC" to 100% penetration rate. Overall, ESC would save a total of 5,252 – 10,292 lives and eliminate 167,949 – 251,566 MAIS 1-5 injuries annually. Of these benefits, 4,194 – 5,425 lives and 155,849 – 178,062 MAIS 1-5 injuries would be associated with single-vehicle rollovers.

	Low Range of Benefits			**High Range of Benefits**		
	Single Vehicle Crashes	**Multi-Vehicle Crashes**	**Total**	**Single Vehicle Crashes**	**Multi-Vehicle Crashes**	**Total**
Fatalities	1,536	0	1,536	2,066	145	2,211
Injuries (AIS 1-5)	50,594	0	50,594	62,212	7,418	69,630

Technology Costs

Vehicle costs are estimated to be $368 (in 2005 dollars) for anti-lock brakes and an additional $111 for electronic stability control for a total system cost of $479 per vehicle. The total incremental cost of the proposal (over the MY 2011 installation rates and assuming 17 million passenger vehicles sold per year) are estimated to be $985 million to install antilock brakes, electronic stability control, and malfunction lights. The average incremental cost per passenger vehicle is estimated to be $58 ($90 for the average passenger car and $29 for the average light truck), a figure which reflects the fact that many baseline MY 2011 vehicles are projected to already come equipped with ESC components (particularly ABS).

Summary of Vehicle Costs
($2005)

	Average Vehicle Costs	Total Costs
Passenger Cars	$ 90.3	$ 722.5 mill.
Light Trucks	$ 29.2	$ 262.7 mill.
Total	$ 58.0	$ 985.2 mill.

Other Impacts

Property Damage and Travel Delay

The proposal would prevent crashes and thus reduce property damage costs and travel delay associated with those crashes avoided. The proposal would save $453 million at a 3 percent discount rate to $260 million at a 7 percent discount rate in property damage and travel delay.

Fuel Economy

The proposal would add weight to vehicles and consequently would increase their lifetime use of fuel. Most of the added weight is for ABS components and very little is for the ESC components. Since 99 percent of the light trucks are predicted to have ABS in MY 2011, the weight increase for light trucks is less than one pound and is considered negligible. The average weight gain for a passenger car is estimated to be 2.1 pounds, resulting in 2.6 more gallons of fuel being used over their lifetime. The present discounted value of the added fuel cost over the lifetime of the average passenger car is estimated to be $3.35 at a 3 percent discount rate and $2.73 at a 7 percent discount rate.

Net Cost Per Equivalent Life Saved

The net cost per equivalent life saved, discounted at a 3 percent and 7 percent discount rate, is less than $450,000.

Cost Per Equivalent Life Saved
(2005 dollars)

	3% Discount Rate		7% Discount Rate	
	Low	High	Low	High
Net Cost per Equivalent Life Saved	$188,014	$315,051	$272,742	$427,665

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 high end of the net benefits is $10.6 billion using a 3 percent discount rate and the low end is $5.8 billion using a 7 percent discount rate. Both of these are based on a $3.75 million comprehensive value for preventing a fatality.

Net Benefits
With $3.75 M Cost Per Life
(in billions of 2005 dollars)

	At 3% Discount		At 7% Discount	
	Low	High	Low	High
Net Benefits	$7.5 Bill.	$10.6 Bill.	$5.8 Bill.	$8.2 Bill.

Leadtime

The agency is proposing a phase-in requirement for vehicle manufacturers excluding multi-stage manufacturers, alterers, and small volume manufacturers (*i.e.*, manufacturers producing less than 5,000 vehicles for sale in the U.S. market in one year). Vehicle manufacturers are permitted to use carryover credits. The phase-in schedule for vehicle manufacturers is:

Model Year	Production Beginning Date	Requirement
2009	September 1, 2008	30% with carryover credit
2010	September 1, 2009	60% with carryover credit
2011	September 1, 2010	90% with carryover credit
2012	September 1, 2011	Fully effective

Instead of complying with the proposed phase-in requirement, the proposal would allow multi-stage manufacturers and alterers to fully comply with the standard on September 1, 2012, which is a one-year extension from full compliance of the phase-in schedule. The proposal would also permit small volume manufacturers to be excluded from the phase-in but to fully comply with the standard on September 1, 2011.

CHAPTER I. INTRODUCTION

This preliminary regulatory impact analysis (PRIA) accompanies NHTSA's proposal to establish Federal Motor Vehicle Safety Standard (FMVSS) No. 126, Electronic Stability Control Systems, which would require passenger cars, multipurpose passenger vehicles (MPVs), trucks, and buses that have a gross vehicle weight rating (GVWR) of 4,536 kg (10,000 pounds) or less to be equipped with an electronic stability control (ESC) system. An ESC system is an active-safety technology designed to proactively help drivers to maintain control of their vehicles in situations where the vehicle is beginning to lose directional stability. Typically, an ESC system intervenes by utilizing computers to control individual wheel brakes, thereby keeping the vehicle headed in the direction intended by drivers. Keeping the vehicle on the road prevents run-off-road crashes, which are the circumstances that lead to most single-vehicle rollovers.

Several studies from Europe and Japan have shown significant reduction in crashes by ESC, specifically in single-vehicle crashes (see Chapter III). The agency's studies and a study by the Insurance Institute for Highway Safety (IIHS) also concluded that the ESC systems would eliminate a substantial number of crashes. Based on 2004 Fatality Analysis Reporting Systems (FARS) and 2000-2004 National Automotive Sampling System (NASS) Crashworthiness Data System (CDS), the agency estimates that there were 34,314 police-reported passenger vehicle fatal crashes[2] and over 2.5 million serious non-fatal crashes (defined as at least one involved passenger vehicle was towed away) annually. About 33,907 passenger vehicle occupant fatalities and 2,182,460 non-fatal injuries were associated with these crashes. Single-vehicle crashes, which frequently include roadway departure, accounted for about 53 percent (18,321

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[2] Not all passenger vehicle fatal crashes result in fatalities to passenger vehicle occupants, some result in fatalities to pedestrians, motorcyclists, etc.

fatal crashes) of the fatal crashes and 33 percent (820,218 crashes) of the towaway crashes. A total of 15,611 occupant fatalities and 516,500 non-fatal injuries were associated with these single-vehicle crashes. Rollovers comprised a large share of these single-vehicle crashes and were responsible for a disproportionate number of fatalities. Rollovers accounted for 42 percent (or 7,734 crashes) of the single-vehicle fatal crashes and 56 percent (8,487 fatalities) of the occupant fatalities[3]. ESC would potentially prevent many of these crashes from occurring and thus would reduce associated fatalities and injuries. Based on the agency's ESC effectiveness study, which found that ESC is highly effective against rollovers (Chapter III), a large portion of these benefits would be from rollovers.

Since the early 1990's, the agency has been actively engaged in finding ways to address the rollover safety problem. The agency has explored several options. However, due to feasibility and practicability issues, the agency ultimately chose a consumer-information-based-approach to the rollover problem. In 2001, the agency added a rollover resistance rating to our New Car Assessment Program (NCAP) consumer information. The rollover resistance rating, based on the height of the center of gravity and the track width of a vehicle, measures the likelihood of a vehicle would rollover in a crash. The agency believes that the NCAP rollover resistance rating information allows consumers to make an informed decision when they purchase a new vehicle. In addition, the agency believes that the NCAP rollover information also encourages vehicle manufacturers to increase their vehicles' geometric stability and rollover resistance through market-based incentives.

In response to NCAP rollover resistance information, vehicle manufacturers have modified many of their new model vehicles, especially those with a higher center of gravity such as SUVs and

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[3] An additional 1,971 rollover occupant fatalities were recorded in multi-vehicle crashes.

trucks. Examples of their changes include utilizing a wider track platform for newer sport utility vehicles (SUVs) and/or equipping SUVs with roll stability control technology. However, the impact of this consumer-information-based-approach has been offset by a continuous demand from consumers for vehicles with a greater carrying capacity and a higher ground clearance.

In recent years, the maturation of ESC technologies has created an opportunity to establish performance criteria and reduce the occurrence of rollovers in new vehicles. This opportunity led to today's proposal. This proposal is consistent with recent congressional legislation contained in section 10301 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users of 2005 (SAFETEA-LU).[4] The provision requires the Secretary of Transportation to "establish performance criteria to reduce the occurrence of rollovers consistent with stability enhancing technology" and to "issue a proposed rule … by October 1, 2006, and a final rule by April 1, 2009."

This PRIA estimates the benefits, cost, cost-effectiveness, benefit-cost of the proposal, and the following outlines the structure of the balance of this document. The PRIA first describes the proposed requirements in Chapter II. After describing the proposal, the PRIA discusses current ESC systems, their functional capability, and their effectiveness in Chapter III. Chapter IV of the PRIA estimates the benefits. Chapter V discusses the costs and leadtime. Chapter VI provides cost-effectiveness and benefit-cost analysis. Chapter VII discusses alternatives. Chapter VIII provides the uncertainty analysis to address variations of the estimated benefits. And finally, Chapter IX examines the impacts of the rule on small business entities

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

CHAPTER II. PROPOSED REQUIREMENTS

The proposal would establish Federal Motor Vehicle Safety Standard (FMVSS) No. 126, Electronic Stability Control System, which would require passenger cars, multipurpose passenger vehicles (MPVs), light trucks and buses that have a gross vehicle weight rating (GVWR) of 4,536 kg (10,000 pounds) or less to be equipped with an ESC system that meets the requirements of the standard. The proposed standard specifies: (a) the Definition of ESC, (b) the Functional Requirements of ESC, (c) the Performance Requirements of ESC, (d) ESC Malfunction Telltale and Symbol Requirements, and (e) ESC Off Switch, Telltale and Symbol Requirements (if provided). The following sections summarize these requirements. Interested parties should consult the preamble of the notice of proposed rulemaking (NPRM) for the detailed proposal. Comprehensive technical background for deriving the proposed requirements can be found in the following agency research reports:

a. Forkenbrock, G.J., Elsasser, D.H., O'Harra, B., and Jones, R.E., "Development of Criteria for Electronic Stability Control Performance Evaluation," DOT HS 809 974, December 2005

b. Mazzae, E.N., Papelis, Y.E., Watson, G.S., and Ahmad, O., "The Effectiveness of ESC and Related Telltales: NADS Wet Pavement Study," DOT HS 809 978, December 2005

A. DEFINITION OF ESC

The agency proposes to adopt the ESC definition based on the Society of Automotive Engineers (SAE) Surface Vehicle Information Report J2564 (revised June 2004). The ESC is defined as a system that has all of the following attributes:

(a) ESC augments vehicle directional stability by applying and adjusting the vehicle brakes individually to induce correcting yaw torques to the vehicle.

(b) ESC is a computer-controlled system, which uses a close-loop algorithm to limit understeer and oversteer of the vehicle when appropriate. [The close-loop algorithm is a cycle of operations followed by a computer that includes automatic adjustments based on the result of previous operations or other changing conditions.]

(c) ESC has a means to determine vehicle yaw rate and to estimate its sideslip. [Yaw rate means the rate of change of the vehicle's heading angle about a vertical axis through the vehicle center of gravity. Sideslip is the arctangent of the ratio of the lateral velocity to the longitudinal velocity of the center of gravity.]

(d) ESC has a means to monitor driver steering input.

(e) ESC is operational over the full speed range of the vehicle (except below a low –speed threshold where loss of control is unlikely).

B. FUNCTIONAL REQUIREMENTS

The proposed ESC is required to comply with following functional requirements:

(a) The ESC system must have the means to apply all four brakes individually and a control algorithm that utilizes this capability.

(b) The ESC must be operational during all phases of driving including acceleration, coasting, and deceleration (including braking).

(c) The ESC system must stay operational when the antilock brake system (ABS) or Traction Control is activated.

With the ESC definition and the functional requirements, the agency basically adopts the SAE definition and attributes for the 4-wheel ESC system without engine control[5]. This system would have oversteering and understeering intervention capabilities. Oversteering and understeering are typically cases of loss-of-control where vehicles move in a direction different from the driver's intended direction. Oversteering is a situation where a vehicle turns more than driver's input because the rear end of the vehicle is spinning out or sliding out. Understeering is a situation where a vehicle turns less than the driver's input and departs from its intended course because the front wheels do not have sufficient traction. Chapter III details how ESC functions during these situations. The agency proposed this ESC standard to balance the necessary ESC intervention capabilities and the complexity of the technologies, which generally are associated with significant costs. Also, the proposed standard does not conflict with the 4-wheel ESC system with engine control. An ESC system with engine control may control the throttle and

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[5] Engine control refers to the ability of the vehicle's ESC to remove or apply driver torque to one or more wheels. Such intervention is intended to augment, but not replace, the benefits offered by brake intervention.

reduce the amount of fuel going into the engine to slow the vehicle down, in addition to braking one wheel.

Furthermore, the proposed ESC definition and functional requirements would require manufacturers to implement an ABS-equivalent braking technology in their vehicles. If manufacturers choose to equip their vehicles with the ABS technology, the ABS would be required to comply with FMVSS No. 135.

C. PERFORMANCE REQUIREMENTS

As proposed, the ESC-equipped vehicle must satisfy a performance test criteria to ensure sufficient oversteer intervention (i.e., mitigate the tendency for the vehicle to spinout). A "spinout" is defined as vehicle final heading angle of more than 90 degrees from the initial heading after a symmetric steering maneuver in which the amount of right and left steering is equal. During the proposed test, the vehicle is not permitted to lose lateral stability. A quantifiable definition of lateral stability is proposed and is discussed later in this chapter.

In addition to being required to satisfy the standard's lateral stability criteria, the standard proposes an ESC-equipped vehicle also must satisfy a responsiveness criterion to preserve the ability of the vehicle to adequately respond to a driver's steering inputs during ESC intervention. These criteria ensure that an ESC achieves an optimal stability performance, but not at the expense of responsiveness. Note that the agency is still conducting research to establish an appropriate understeering intervention test.

Oversteering Test Maneuver

The proposed performance test uses a maneuver based on a modified 0.7 Hz sinusoidal steering input to assess ESC oversteer intervention performance. The maneuver, known as the 0.7 Hz Sine with Dwell maneuver, is depicted in Figure II-1. The performance test uses a steering machine that delivers the proposed maneuver to the steering wheel to assess vehicle stability during the ESC oversteer intervention. Steering is initiated at 80 kmph (50 mph). Two series of tests are conducted: one with right-to-left steering maneuver and the other one with left-to-right steering maneuver. Each series of tests begins with a test run with a moderate steering wheel angle. The initial steering wheel angle is increased from test run-to-test run in a series until a termination criterion is attained.

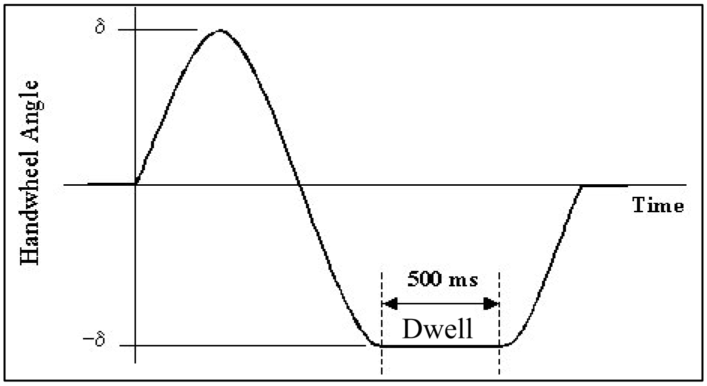

Figure II-1. Sine with Dwell Handwheel Inputs

Initially, the agency examined 12 maneuvers with 12 steering combinations. After three phases of maneuver reduction research, the agency identified the top four possible maneuvers.[6] The

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[6] Sine with Dwell, Increasing Amplitude Sine Steer, Yaw Acceleration Steering Reversal (YASR), and YASR with Pause.

proposed Sine with Dwell maneuver was selected over three other maneuvers due to its objectivity, practicability, repeatability, and representativeness.

The proposed maneuver is highly objective because it will initiate oversteer intervention for every tested ESC system and because it will discriminate strongly between vehicles with and without ESC (or ESC disabled). The maneuver is practicable because it can easily be programmed into the steering machine and because it simplifies the instrumentation required to perform the test due to its lack of acceleration feedback. It is repeatable due to the use of a steering machine thereby minimizing drive effects. In addition, the maneuver is representative of steering inputs produced by human drivers in an emergency obstacle avoidance situation.

The agency also explored the possibility of using a Sine with Dwell curve with a different frequency (i.e., the 0.5 Hz curve) as the steering maneuver. However, the Alliance of Automobile Manufacturers (Alliance) presented data, which cast doubt on the practicability of this approach, as discussed in their presentation to the agency on December 3, 2004 (Docketed at NHTSA-2004-19951-1). Specifically, the Alliance reported that the 0.5 Hz Sine with Dwell did not correlate as well with the responsiveness versus controllability ratings made by its professional test drivers in a subjective evaluation (the same vehicles evaluated with the Sine with Dwell maneuvers were also driven by the test drivers), and it provided less input energy than the 0.7 Hz Sine with Dwell.

Lateral Stability Criteria

"Lateral stability" is defined as the ratio of vehicle yaw rate at a specified time and the peak yaw rate generated by the 0.7 Hz Sine with Dwell steering reversal. The performance limit (i.e., the maximum value of the ratio) establishes a 5 percent spinout threshold when ESC intervenes. In other words, an ESC-equipped vehicle has a less than 5 percent probability of spinout if the vehicle meets the proposed lateral criteria. Under the proposed performance test, ESC would be required to meet the following two lateral stability criteria:

(1) One second after completion of the steering input for the 0.7 Hz Sine with Dwell maneuver, the yaw rate of the vehicle has to be less than or equal to 35 percent of the peak yaw rate (Criterion #1).

(2) 1.75 seconds after completion of the steering input, the yaw rate of the vehicle has to be less than or equal to 20 percent of the peak yaw rate (Criterion #2).

The lateral stability criteria can be represented in the mathematical notations as follows:

$$\frac{\dot{\psi}_{(t_0+1.00)}}{\dot{\psi}_{Peak}} \times 100 <= 35\% \text{ (Criterion \#1), and}$$

$$\frac{\dot{\psi}_{(t_0+1.75)}}{\dot{\psi}_{Peak}} \times 100 <= 20\% \text{ (Criterion \#2)}$$

Where,

$\dot{\psi}_t$ = Yaw rate at time t (in seconds)

$\dot{\psi}_{Peak}$ = Peak yaw rate generated by the 0.7 Hz Sine with Dwell sterring recersal

t_0 = time to completion of steering input

Based on the agency's analysis, we anticipate that an ESC system meeting these lateral stability criteria would have at least a 95 percent probability of preventing a spinout.

Responsiveness Criterion

The proposed responsiveness criterion would be used to measure the ability of a vehicle to respond to the driver's inputs during an ESC intervention. The proposed criterion is defined as the lateral displacement of the vehicle's center of gravity with respect to its initial straight path during the portion of the sine with dwell maneuver prior to the beginning of the steering dwell. The proposed criterion performance limit establishes the displacement threshold to ensure that the ESC intervention used to achieve acceptable lateral ability does not compromise the ability of the vehicle to response to the driver's input. The proposal would require that an ESC-equipped vehicle would have a lateral displacement of at least 1.83 meters (6 feet) at 1.07 seconds after the initiation of steering. The lateral displacement at 1.07 seconds after initiation of the steering inputs (or the 1.07-seconds-lateral-displacement) can be calculated using the following double integration formula:

$$\text{Lateral Displacement} = \int_{t_0}^{t_0+1.07} \int_{t_0}^{t_0+1.07} Ay_{C.G.}(t)dt \geq 1.83 \text{ m}$$

Where,

t_0 = Steering wheel input starting time
$A_{C.G}$ = Lateral acceleration, corrected for the effect of roll angle.

The following discussion explains how the agency arrived at the proposed responsiveness criterion for lateral displacement.

The 1.07 seconds is chosen because it is the starting point of the dwell period and can easily be identified. Most importantly, 1.07 seconds is short enough to assure accuracy of the double integration and long enough to induce a discernable lateral displacement.

The 1.83 meters (6 feet) is based on the responsiveness, measured by the 1.07-seconds-lateral-displacement, of 61 vehicles tested by the agency and eleven vehicle manufacturers using the 0.7 Hz Sine with Dwell maneuver with steering angles of 180 degrees or greater. These 61 vehicles include passenger cars (PCs), sport utility vehicles (SUVs), pick-up trucks, and vans and range from high performance sports cars to 15-passenger vans. All of the 61 vehicles but one achieved the 1.83 meters (6 feet) lateral displacement at 1.07 seconds.

The double integration technique for deriving the lateral displacement was presented by the Alliance on September 7, 2005.[7] The technique is an indefinite double integral. Strictly speaking, it means $Ay_{C.G.}$ (the vehicle's lateral acceleration data) analytically is integrated twice; first to obtain lateral velocity, and a second time to produce lateral displacement from the vehicle's initial heading. The result is an approximation for lateral displacement as a function of time. The technique was adapted after the agency validated the integration displacement results and concluded that they are in good agreement with the global positioning sensor (GPS) measurements for vehicles tested by the agency, provided there is no offset to the lateral acceleration data channel and calculated data no longer than 1.07 seconds after initiation of the Sine with Dwell steering inputs are considered. The Alliance stated that there would be a

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[7] Docket Number NHTSA-2005-19951

substantial cost savings to the industry with no loss of technical validity if double integration was used instead of GPS measurements.

During the development of the responsiveness criterion, the agency also considered several other metrics, such as lateral speed and lateral acceleration, to measure the responsiveness of the vehicle. However, the agency concluded that the lateral displacement and maximum displacement are the most obvious and relevant responsiveness measurements. The 1.07-seconds-lateral-displacement was chosen over the maximum lateral displacement for several reasons. The maximum displacement occurs later in the steering maneuver and at different times for different vehicles. Therefore, the maximum displacement is subject to greater measurement error from the double integration process. Such errors could be systematically greater for certain type of vehicles than others. Most importantly, the 1.07-seconds-lateral-displacement establishes a standardized baseline for every vehicle since it is measured uniformly at the same traveling distance from the initiation of steering.

D. ESC Malfunction Telltale and Symbol

The proposal would require a yellow ESC malfunction telltale identified by the following symbol:

We propose to include this symbol in Table 1 of FMVSS No. 101, Controls and Displays. The malfunction telltale would be required to be mounted inside the occupant compartment in front of and in clear view of the driver. The malfunction telltale would be required to illuminate not more than two minutes after the occurrence of one or more ESC malfunctions. Such telltale would be required to remain continuously illuminated for as long as the malfunction exists, whenever the ignition locking system in "On" ("Run") position. The ESC malfunction telltale is permitted to flash in order to indicate ESC operation. A flashing telltale can not be used to indicate a malfunction.

E. ESC Off Switch, Telltale and Symbol

The proposal would permit (but not require) vehicle manufacturers to install a driver-selectable switch to temporarily disable or limit the ESC functions. This would allow drivers to disengage ESC or limit the ESC intervention capability in certain circumstances when the full ESC intervention might not be appropriate. Examples include circumstances such as when a vehicle is stuck in sand/gravel or when the vehicle is being operated within the controlled confines of a racetrack for maximum performance.

If vehicles manufacturers choose this option, the proposal would require that the ESC system return to a mode that satisfies the requirements of the standard at the initiation of each new ignition cycle. In addition, vehicle manufacturers would be required to provide a yellow "ESC OFF" telltale identified by the following symbol:

We propose to include this symbol in Table 1 of FMVSS No 101, Controls and Displays. The telltale would be required to be mounted inside the occupant compartment in front of and in clear view of the driver. Such telltales must remain continuously illuminated for as long as the ESC is in a mode that makes it unable to meet the performance requirements of the standard, whenever the ignition locking system is in the “On” (“Run”) position.

CHAPTER III. HOW ESC WORKS

A. ESC SYSTEMS

ESC is known by many different trade names such as AdvanceTrac, Dynamic Stability Control (DSC), Dynamic Stability and Traction Control (DSTC), Electronic Stability Program (ESP), Vehicle Dynamic Control (VDC), Vehicle Stability Assist (VSA), Vehicle Stability Control (VSC), Vehicle Skid Control (VSC), Vehicle Stability Enhancement (VSE), StabiliTrak, and Porsche Stability Management (PSM). An ESC system utilizes computers to control individual wheel brakes 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.

When a driver attempts a sudden maneuver (for example, to avoid a crash or because he misjudged the severity of a curve), he may lose control if the vehicle responds differently as it nears the limits of road traction than it does in ordinary driving. The driver’s loss of control can result in either the rear of the vehicle “spinning out" or the front of the vehicle "plowing out." As long as there is sufficient road traction, a professional race driver could maintain control in many spinout or plowout conditions by using countersteering (momentarily turning away from the intended direction) and other techniques. However, in a panic situation with the vehicle beginning to spin out, for example, average drivers would be unlikely to countersteer like a race driver and regain control.

In contrast, ESC uses automatic braking of individual wheels to adjust the vehicle's heading if it departs from the direction the driver is steering. Thus, it prevents the heading from changing too quickly (spinning out) or not quickly enough (plowing out). Although it cannot increase the available traction, ESC affords the driver the maximum possibility of keeping the vehicle under control and on the road in an emergency maneuver using just the natural reaction of steering in the intended direction.

Keeping the vehicle on the road prevents single-vehicle crashes, which are the circumstances that lead to most rollovers. However, if the speed is simply too great for the available road traction, the vehicle will unavoidably drift (without spinning) off the road. And, of course, ESC cannot prevent road departures due to driver inattention or drowsiness rather than loss of control.

B. How ESC Prevents Loss of Control

The following explanation of ESC systems illustrates the basic principle of yaw stability control, but actual systems include countless refinements and proprietary algorithms that make them practical for the range of circumstances and roadway conditions encountered by drivers. For example, actual ESC systems augment the yaw rate control strategy described below with the consideration of vehicle sideslip (lateral sliding that may not alter yaw rate) to determine the optimal intervention.

An ESC system maintains what is known as "yaw" (or heading) control by determining the driver's intended heading, measuring the vehicle's actual response, and automatically turning the vehicle if its response does not match the driver's intention. However, with ESC, turning is accomplished by counter torques from the braking system 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 yaw rate will be in balance with the speed and lateral acceleration.

The concept of "yaw rate" can be illustrated by imagining the view from above of a car 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 car 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 car is constantly rotating at a rate of 18 deg/sec around a vertical axis that can be imagined as piercing its roof. If the speed is doubled, the yaw rate increases to 36 deg/sec.

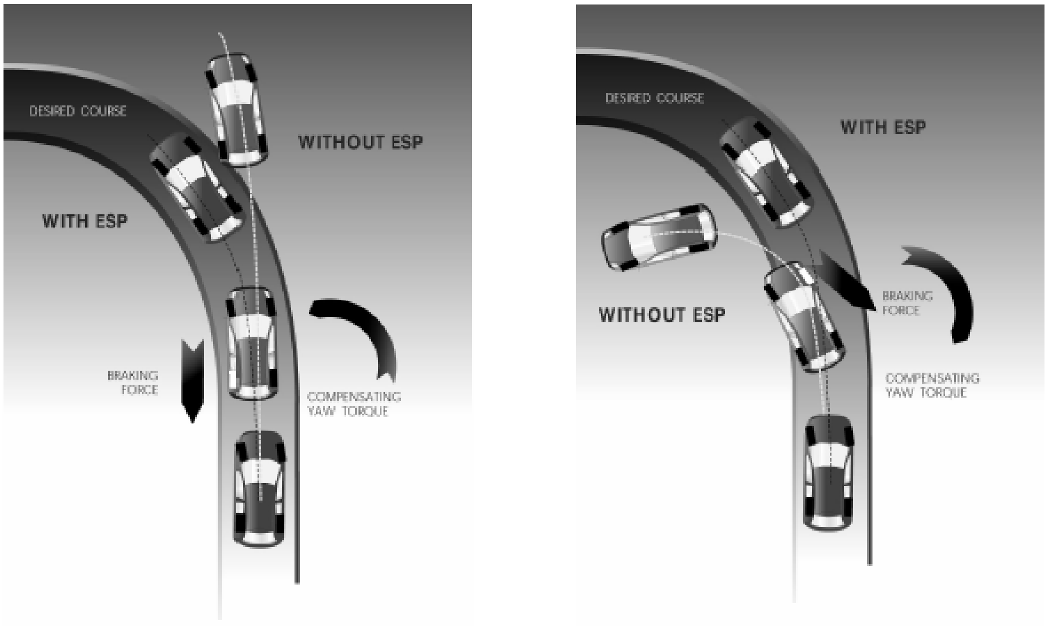
While driving in a circle, the driver notices that he must hold the steering wheel tightly to avoid sliding toward the passenger seat. The bracing force is necessary to overcome the lateral acceleration that is caused by the car following the curve. The lateral acceleration is also measured by the ESC system. When the speed is doubled, the lateral acceleration increases by a factor of four if the vehicle follows the same circle. There is a fixed physical relationship between the car's speed, the radius of its circular path, and its lateral acceleration. Since the ESC system measures the car's speed and its lateral acceleration, it can compute the radius of the circle. Since it then has the radius of the circle and the car's speed, the ESC system can compute the correct yaw rate for a car following the path. Of course, the system includes a yaw rate sensor, and it compares the actual measured yaw rate of the car to that computed for the path the car is following. If the computed and measured yaw rates begin to diverge as the car that is trying to follow the circle speeds up, it means the driver is beginning to lose control, even if he cannot yet sense it. Soon, an unassisted vehicle would have a heading significantly different from the desired path and would be out of control either by oversteering (spinning out) or understeering.

When the ESC system detects an imbalance between the measured yaw rate of a vehicle and the path defined by its speed and lateral acceleration (as measured by the steering angle), it automatically intervenes to turn the vehicle. The automatic turning of the vehicle is accomplished by uneven brake application rather than by steering wheel movement. If only one wheel is braked, the uneven brake force will cause the vehicle's heading to change. Figure III-1 shows the action of ESC using single wheel braking to correct the onset of oversteering or understeering.

- <u>Oversteering</u>. In Figure III-1 to the right, the vehicle has entered a left curve that is extreme for the speed it is traveling. The rear of the vehicle begins to slide which would lead to a non-ESC vehicle turning sideways (or "spinning out") unless the driver expertly countersteers. In a vehicle equipped with ESC, the system immediately detects that the vehicle's heading is changing more quickly than appropriate for the driver's intended path (the yaw rate is too high). It momentarily applies the right front brake to turn the heading of the vehicle back to the correct path. The intervention action happens quickly and smoothly and thus most of the time will go undetected by the drivers. Even if the driver brakes because the curve is sharper than anticipated, the system is still capable of generating uneven braking if necessary to correct the heading.

- <u>Understeering</u>. Figure III-1 to the left shows a similar situation faced by a vehicle whose response as it nears the limits of road traction is first sliding at the front ("plowing out" or understeering) rather than oversteering. In this vehicle, ESC rapidly detects that the vehicle's heading is changing less quickly than appropriate for the driver's intended path (the yaw rate is too low). It momentarily applies the left rear brake to turn the heading of the vehicle back to the correct path.

While Figure III-1 may suggest that particular vehicles go out of control due to either oversteer or vehicles prone to understeer, it is quite possible a vehicle could require both understeer and oversteer interventions during progressive phases of a complex avoidance maneuver like a double lane change.



Understeering (“plowing out”) Oversteering (“spinning out”)

Figure III-1. ESC Interventions for Understeering and Oversteering

Although ESC cannot change the tire/road friction conditions the driver is confronted with in a critical situation, there are clear reasons to expect it can reduce loss-of-control crashes.

In vehicles without ESC, the response of the vehicle to steering inputs changes as the vehicle nears the limits of road traction. Generally speaking, most drivers operate with their “linear range” skills, the range of lateral acceleration in which a given steering wheel movement produces a proportional change in the vehicle’s heading. The driver merely turns the wheel the expected amount to produce the desired heading. Adjustments in heading are easy to achieve because the vehicle’s response is proportional to the driver’s steering input, and there is very little lag time between input and response. The car is traveling in the direction it is pointed, and the driver feels in control. However, at lateral accelerations above about one half g on dry pavement for ordinary vehicles, the relationship between the driver’s steering input and the vehicle’s response changes (oversteer or understeer), and the lag time of the vehicle response can lengthen. When a driver encounters these changes during a panic situation, it adds to the likelihood that the driver will lose control and crash because the familiar actions learned by driving in the linear range would not be correct.

However, ordinary linear range driving skills are much more likely to be adequate for a driver of a vehicle with ESC to avoid loss of control in a panic situation. By monitoring yaw rate and sideslip, ESC can intervene early in the impending loss-of–control situation with the appropriate brake forces to restore yaw stability *before* the driver would attempt an over-correction or other error. The net effect of ESC is that the driver’s ordinary driving actions learned in linear range driving are the correct actions to control the vehicle in an emergency. Also, the vehicle will not change its heading from the desired path in a way that would induce further panic in a driver facing a critical situation. Studies using a driving simulator, discussed in Section III, demonstrate that ordinary drivers are much less likely to lose control of a vehicle with ESC when faced with a critical situation.

Besides allowing drivers to cope with potentially dangerous situations and slippery pavement using only “linear range” skills, ESC provides more complete control interventions than those available to expert drivers of non-ESC vehicles. For all practical purposes, the yaw control actions with non-ESC vehicles are limited to steering. However, as the tires approach the maximum lateral force sustainable under the available pavement friction, the yaw moment generated by a given increment of steering angle is much less than at the low lateral forces occurring in regular driving[8]. This means that as the vehicle approaches its maximum cornering capability, the ability of the steering system to turn the vehicle is greatly diminished even in the hands of an expert. ESC creates the yaw moment to turn the vehicle using braking at an individual wheel rather than the steering system. This intervention remains powerful even at limits of tire traction because both the braking force of the individual tire and the reduction of lateral force that accompanies the braking force act to create the desired yaw moment. Therefore, ESC can be especially beneficial on slippery surfaces. The possibility of a vehicle staying on the road in any maneuver is ultimately limited by the tire/pavement friction. ESC maximizes an ordinary driver's ability to use the tire/pavement friction available.

C. Additional Features of Some ESC Systems

In addition to the basic operation of "yaw stability control", many systems include additional features. Most ESC systems reduce engine power during intervention to slow the vehicle and to give it a better chance of being able to stay on the intended path after its heading has been corrected.

Other ESC systems may go beyond reducing engine power to slow the vehicle by performing high deceleration automatic braking at all four wheels. Of course, the braking would be performed unevenly side to side so that the same net yaw torque or "turning force" would be applied to the vehicle as in the basic case of single wheel braking.

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[8] Liebemann *et al*, Safety and Performance Enhancement: The Bosch Electronic Stability Control (ESP), 2005 ESV Conference, Washington, DC

Some ESC systems used on vehicles with a high center of gravity (c.g.), such as SUVs, are programmed for an additional function known as roll stability control. Roll stability control is a direct countermeasure for on-pavement rollover crashes of high c.g. vehicles. Some systems measure the roll angle of the vehicle using an additional roll rate sensor to determine if the vehicle is in danger of tipping up. Other systems rely on the existing ESC sensors for steering angle, speed, and lateral acceleration along with knowledge of vehicle-specific characteristics to estimate whether the vehicle is in danger of tipping up.

Regardless of the method of detecting the risk of tip-up, the various types of roll stability control intervene in the same way. They intervene by reducing the lateral acceleration that is causing the roll motion of the vehicle on its suspension and preventing the possibility of it rolling so much that the inside wheels lift off the pavement. The principal way of accomplishing this intervention is by applying hard braking to either the outside front wheel or to both outside front wheels. In either case, the braking force generated must be large enough to cause high longitudinal wheel slip for the outside front wheel(s). This dramatically reduces the lateral forces being produced by the outside front tire(s) and straightens the path of the vehicle. Greatly reducing the lateral forces being produced by the outside front tire(s) lowers the lateral acceleration of the vehicle. Since lateral acceleration is the driving force that causes untripped rollover, greatly reducing it makes untripped rollover less likely to happen. Also, whereas the primary objective of conventional ESC intervention is increased path-following capability, the roll stability control endeavors to prevent on-road untripped rollver; often at the expense of path-following.

Another difference between a roll stability control intervention and oversteer intervention by the ESC system operating in the basic yaw stability control mode is the triggering circumstance. The oversteer intervention occurs when the vehicle's excessive yaw rate indicates that its heading is departing from the driver's intended path, but the roll stability control intervention occurs when there is an appreciable risk the vehicle could roll over. The roll stability control intervention may occur when the vehicle is still following the driver's intended path. The obvious trade-off of roll stability control is that the vehicle must depart to some extent from the driver's intended path in order to reduce the lateral acceleration from the level that could cause rollover.

If the determination of impending rollover that triggers the roll stability intervention is very certain, then the possibility of the vehicle leaving the roadway as a result of the roll stability intervention represents a lower relative risk to the driver. Obviously, systems that intervene only when absolutely necessary and produce the minimum loss of lateral acceleration to prevent rollover are the most effective. However, roll stability control is a new technology that is still evolving. Roll stability control is not a subject of this rulemaking because there are not enough vehicles with roll stability for actual crash statistics to demonstrate its practical effect on crash reduction.

D. ESC Effectiveness

The Agency's Real World Crash Data Analysis

In 2004, an agency study found that ESC is approximately 30 percent effective in preventing fatal single-vehicle crashes for passenger cars (PCs) and 63 percent for sport utility vehicles (SUVs). For all single-vehicle crashes, the corresponding effectiveness rates are 35 and 67 percent.[9] These results were statistically significant at the 0.05 level. The 2004 study deployed a before-after, case-control approach to derive these effectiveness rates. The approach attempted to control factors other than presence and absence of ESCs that could be associated with crash scenarios. Basically, the approach compared the number of case crashes (and control crashes) involving make-models equipped with ESCs (after) to their earlier models without ESCs (before). The case crashes contain crashes that would be affected by ESCs and the control crashes would not. In the agency approach, the case crashes were single-vehicle crashes excluding pedestrians, pedalcyclists, and animals, and the control crashes were multi-vehicle crashes. The effectiveness of ESC was derived by the following formula:

$$1 - \frac{f_{\text{ESC, Case}} / f_{\text{No ESC, Case}}}{f_{\text{ESC, Control}} / f_{\text{No ESC, Control}}}$$

Where,

$f_{\text{ESC, Case}} =$ the number of case crashes (i.e., single vehicle) involving vehicles with ESCs,

$f_{\text{No ESC, Case}} =$ the number of case crashes (i.e., single vehicle) involving vehicles without ESCs,

$f_{\text{ESC, Control}} =$ the number of control crashes (i.e., multi-vehicle crashes) involving

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[9] Dang, J., Preliminary Results Analyzing Effectiveness of Electronic Stability Control (ESC) Systems, September 2004, DOT HS 809 790

vehicles with ESCs, and
$f_{\text{No ESC, Control}}$ = the number of control crashes (i.e., multi-vehicle crashes) involving vehicles without ESCs.

Data from 1997 to 2003 FARS were used to examine the effectiveness of ESCs in reducing fatal single vehicle crashes. For nonfatal single-vehicle crashes, 1997 to 2002 State data from five States were used. The five States are Florida, Illinois, Maryland, Missouri, and Utah. These five States were chosen because they consistently have a high percentage of Vehicle Identification Numbers (VINs), which were used to identify vehicle make/models with ESCs. A high percentage of VIN coded among these five States allowed the agency to establish a larger sample and minimize variations among States.

We acknowledge that the NHTSA study was not without it limitations. Since ESC is considered a fairly new technology in the U.S. market, only specific make/models were equipped with ESC each year. Vehicle make/models that offered ESC as optional equipment were excluded from the sample in order to clearly differentiate vehicles with ESC and without. Thus, the passenger car sample included mainly Mercedes-Benz, BMW, and GM luxury models. The SUV sample included certain Mercedes-Benz, Toyota, and Lexus models. Since vehicles included were from a few manufacturers and were mostly high-end luxury models, the estimated effectiveness of ESC derived from these vehicles might not be representative of an overall fleet of vehicles. Furthermore, the effectiveness of ESC for SUVs was derived from a small sample, so a large estimation error is expected. In addition, vehicle type obviously is a factor that influences the effectiveness of ESC. Thus, the effectiveness of ESC for SUVs might not be comparable to that of pick-up trucks and vans.

The 2004 study also used logistic regression to verify the effect of passenger car ESC on crash involvements by controlling factors such as vehicle age, make/model, driver age, and gender. The produced effectiveness estimates are similar to those derived from the before-after comparison approach.

Recently, the agency extended the 2004 study to examine ESC effectiveness on multi-vehicle crashes (publication pending).[10] There were three major changes in the updated study. First, the updated study included one more year of newly available crash data, i.e., 2004 FARS and 2003 State Data, in the analysis. In addition, a total of 7 State data[11] were used as apposed to 5 States used in the 2004 study. Second, the updated study refined the control crashes. It used a set of ESC-insensitive multi-vehicle crashes on dry roadways as the control crashes, as opposed to all multi-vehicle crashes used in the 2004 study. The refined control crashes were called the non-culpable crashes on <u>dry</u> roadways. These crashes included, for example, a vehicle rear-ended by the front of another vehicle. Third, the updated study examined the effect of ESC on several types of case crashes including: (a) single-vehicle crashes excluding pedestrians/cyclists/animals, (b) single-vehicle rollover crashes, (c) culpable multi-vehicle crashes, and (d) non-culpable multi-vehicle crashes on <u>wet</u> roadways. Culpable multi-vehicle crashes include, for example, head-on crashes involving a vehicle that failed to stop or yield or crashes where the driver was charged with reckless driving or where the driver was inattentive.

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[10] Dang, J., Statistical Analysis of the Effectiveness of Electronic Stability Control (ESC) Systems, --- 2006, DOT HS --- --- (currently under external peer review)

[11] California, Florida, Illinois, Kentucky, Missouri, Pennsylvania, and Wisconsin

The updated study found that ESC is effective in preventing single-vehicle crashes including rollovers and culpable multi-vehicle crashes. The results are statistically significant, except for the passenger car (PC) effectiveness rate against culpable multi-vehicle crashes. Table III-1 lists these ESC effectiveness rates by crash types (single vs. multi-vehicle) and vehicle types [PCs vs. light trucks/vans (LTVs)]. These effectiveness rates, if statistically significant, are used later to derive the benefits of the proposal. ESC effectiveness rates that are not statistically significant are treated as zero, i.e., no effect. For example, the ESC effectiveness rates in preventing non-culpable crashes on wet roadways are very small (not shown in Table III-1) and not statistically significant. Therefore, this analysis assumes that ESC has no effect on these non-culpable multi-vehicle crashes regardless of the roadway surface conditions on which they occurred. Also, the effectiveness rates for PCs in preventing culpable multi-vehicle crashes are not statistically significant, and thus are also treated as zero.

As shown in Table III-1, for fatal crashes, ESC is 35 percent effective in preventing single-vehicle crashes (excluding pedestrians, cyclists, and animals) for PCs and 67 percent for LTVs. If limited to single vehicle rollovers, the ESC effectiveness rates are generally higher than those assessed for fatal single-vehicle crashes as a whole. ESC is 69 percent effective in preventing single-vehicle PC rollover crashes and 88 percent for single-vehicle LTV rollover crashes. For culpable multi-vehicle crashes, the corresponding effectiveness rates are 19 and 38 percent for PCs and LTVs, respectively. The 19 percent effectiveness for PCs in multi-vehicle crashes is not statistically significant.

For all crash severity levels, ESC is 34 percent effective against single-vehicle crashes for PCs and 59 percent for LTVs. For rollovers, ESC is 71 percent effective in preventing single-vehicle passenger car rollover crashes and 84 percent for single-vehicle LTV rollover crashes. For culpable multi-vehicle crashes, the ESC effectiveness rate is 11 percent for PCs (not statistically significant) and 16 percent for LTVs. Note that these ESC effectiveness rates are the mean results among the seven States.

Table III-1
Effectiveness of ESC by Crash Type and Vehicle Type

Fatal Crashes	PCs	LTVs
Single Vehicle Excluding Pedestrians, Bicyclist, and Animal	35 (20 – 51)	67 (55 – 78)
Rollover	69 (52 – 87)	88 (81 – 95)
Culpable Multi-Vehicle	19* (-2 – 39)	38 (16 – 60)
All Fatal Crashes	14 (3 – 25)	29 (21 – 38)
All Crash Severity Levels		
Single Vehicle Excluding Pedestrians, Bicyclist, and Animal	34 (20 – 46)	59 (47 – 68)
Rollover	71 (60 – 78)	84 (75 – 90)
Culpable Multi-Vehicle	11* (4 – 18)	16 (7 – 24)
All Crashes	8 (5 – 11)	13 (9 – 16)

*not statistically significant
PC: passenger cars, LTV: light trucks and vans
Note: numbers in parentheses represent the 90 percent confidence bounds for the mean

Overall, the updated study found that ESC is estimated to reduce all fatal crashes by 14 percent for PCs and 29 percent for LTVs. When considering all police-reported crash involvements based on the seven State data, ESC is estimated to reduce all crashes by 8 percent for passenger cars and 13 percent for LTVs. These effectiveness rates are statistically significant.

The updated study further examined the effectiveness for two types of ESC systems that have been installed in vehicles: 2-wheel and 4-wheel systems. The 2-wheel systems are no longer being produced by any manufacturer. The 2-wheel ESC system is designed to apply an intervention force only to the two front wheels of a vehicle, while the 4-wheel ESC system is capable of intervening by applying braking force individually to all four wheels. The updated study used a chi-square statistic to test the difference between their effectiveness rates. Due to small sample sizes and no LTVs in the sample were equipped with a 2-wheel system, the updated study only examined single-PC run-off-road crashes.

For <u>fatal</u> single-PC run-off-road crashes, the updated study found that the effectiveness rate for each individual system compared to no ESC is statistically significant. However, the vehicle sample with ESC systems in FARS was too small to test the difference in these two effectiveness rates for 2-wheel and 4-wheel ESC systems.

For <u>all crash severity levels</u>, based on means of the reductions in crashes in six states[12], the 4-wheel system was found to be 46 percent effective in preventing single-PC run-off-road crashes; while for the 2-wheel system, the effectiveness rate was 32 percent. The difference between these two systems was found to be statistically significant at the 0.05 level. In addition, if all the state crash data were treated as one sample, the 4-wheel system was found to be 48 percent effective in preventing single-PC run-off-road crashes; while for the 2-wheel system, the effectiveness rate was 33 percent. The difference was also statistically significant at the 0.05 level.

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[12] California (CA) was excluded from the 2- v.s. 4-channel analysis since Mercedes-Benz was the only manufacturer included in the California crash data and all the Mercedes-Benz models, if equipped, were equipped with a 4-channel ESC.

Global Studies of ESC Effectiveness

Several studies from Europe and Japan concluded that ESC is highly effective in preventing crashes. In the U.S., the IIHS's 2004 study also confirmed that ESC is effective. The following summarizes some results from these global studies:

- Germany: ESC would prevent 80 percent of skidding crashes (Volkswagen and Audi ESP) and 35 percent of all vehicle fatalities (Rieger *et al*, 2005).[13]
- Sweden: ESC would prevent 16.7 percent of all injury crashes excluding rear-end and 21.6 percent of serious and fatal crashes (Lie *et al*, 2005).[14]
- Japan: ESC would prevent 35 percent of single-vehicle crashes and 50 percent of fatal single-vehicle crashes. In addition, ESC would prevent 30 percent of head-on crashes and 40 percent of fatal head-on crashes (Aga, 2003).[15]
- U.S., IIHS: ESC would prevent 41 percent of the single vehicle crashes and 56 percent of the fatal single vehicle crashes (Farmer, 2004).[16] The study also found a small but not statistically significant reduction in multi-vehicle crashes.
- U.S., University of Michigan: ESC would reduce the odds of fatal single-SUV crashes by 50 percent and fatal single-PC crashes by 30 percent. Corresponding reductions for non-

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[13] Rieger, G., Scheef, J., Becker, H., Stanzel, M., Zobel, R., Active Safety Systems Change Accident Environment of Vehicles Significantly – A Challenge for Vehicle Design, Paper Number 05-0052, Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicle (CD-ROM), National Highway Traffic Safety Administration, Washington DC, 2005

[14] Lie A., Tingvall, C., Krafft, M., Kullgren, A., The Effectiveness of ESC (Electronic Stability Control) in Reducing Real Life Crashes and Injuries, Paper Number 05-0135, Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicle (CD-ROM), National Highway Traffic Safety Administration, Washington DC, 2005

[15] Aga, M, Okada, A., Analysis of Vehicle Stability Control (VSC)'s Effectiveness from Accident Data, paper Number 541, Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicle (CD-ROM), National Highway Traffic Safety Administration, Washington DC, 2003

[16] Farmer, C., Effect of Electronic Stability Control on Automobile Crash Risk, Traffic Injury Prevention, 5:317-325, 2004

fatal single-vehicle crashes are 70 percent for SUVs and 55 percent for PCs (UMTRI, 2006).[17]

Note that the summary serves only as a reference in assessing ESC global effects. It is not meant to be comprehensive. Interested parties can consult Bosch's 2005 review[18] for a more complete list of studies on ESC effectiveness.

Laboratory Studies of ESC

The University of Iowa has performed two studies looking at the effectiveness of ESC in assisting drivers to maintain control of their vehicle in certain critical situations. For both of these studies, the University used the National Advanced Driving Simulator (NADS) to simulate real world driving conditions. A variety of critical events were simulated and driver/vehicle reactions studied.

The first study[19] examined drivers' ability to avoid crashes with ESC versus without ESC on a dry pavement. This experiment had five factors: critical event, ESC presence (between-subjects), vehicle type (mid-size sedan versus SUV, between-subjects), gender (male/female), and participant age. Three driver age groups: Younger (18-25), Middle (30-40), and Older (55-65) were included to assess effects of ESC on loss of control by age group. A total of 120 drivers were used in this study. Each participant drove a single vehicle with ESC either "On" or

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[17] Green, P., Woodrooffe, J. , The Effect of Electronic Stability Control on Motor Vehicle Crash Prevention, UMTRI-2006-12, Transportation Research Institute, University of Michigan, April 2006

[18] Bosch, 2005, 10 Years of ESP® from Bosch: More Driving Safety with the Electronic Stability Program, http://www.bosch-press.de, February 2005.

[19] Papelis, Y.E., Brown, T., Watson, G.S., Holz, D., and Pan, W., "Study of ESC Assisted Driver Performance Using a Driver Simulator," University of Iowa, March 2004

"Off" in three critical event scenarios: an intersection incursion from the right, a deceptively decreasing radius curve, and a sudden lateral wind gust. A total of 360 data points were collected during this testing, 180 each for "ESC On" and for "ESC Off." This study found that drivers lost control in 6 out of 180 cases with "ESC On" compared to 50 out of 180 cases for "ESC Off." This study demonstrated that, for these three maneuvers, ESC is 88 percent effective in assisting drivers in maintaining control of their vehicles.

The second study[20] examined drivers' ability to avoid crashes with ESC versus without ESC on a wet, slippery pavement and assessed the effects of alerting the driver of ESC operation. Alerting the driver of ESC activation may not be advisable, since it could divert the attention of the driver away from the event at a critical time. Such an alert might also startle the driver. The study used the ISO J.14 icon with the text "ACTIVE" beneath it.

The experiment focused on the effects of ESC presence/icon (between-subjects) and participant age. One fifth of participants drove with ESC off and the remaining participants drove with ESC on. To assess whether presentation of a visual indication of ESC activation affects the outcome of a crash-imminent event, some participants were presented with an ESC icon during ESC activation. Participants in the "ESC on" condition were broken into four groups: one receiving visual ESC activation indication via a steadily illuminated telltale, one receiving visual ESC activation indication via a flashing telltale, another receiving no visual ESC activation indication, and lastly a group that received an auditory only indication of ESC operation. Four age groups [between-subjects; Novice (16-17, licensed 1-6 months), Younger (18-25), Middle (30-45), and

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[20] Mazzae, E.N., Papelis, Y.E., Watson, G.S., and Ahmad, O., "The Effectiveness of ESC and Related Telltales: NADS Wet Pavement Study," DOT HS 809 978, December 2005

Older (50-60)] were included to assess effects of ESC on crashes, loss of control, and road departures by age group. In addition to the three critical events used in the first study, two additional events, an oncoming vehicle incursion and an object-in-the-lane avoidance were added for this study.

To achieve the most direct comparison of event outcome as a function of ESC presence, the results of participants in the "no ESC" condition were compared to participants in the ESC condition that were not presented with an ESC activation indication. Participants in the ESC condition that did not receive an activation indication experienced loss of control significantly (χ^2 (1) = 84.06, p<.0001) less frequently (2%) across all five of the scenarios than those without ESC (38%). For road departures, participants in the ESC condition that did not receive an activation indication were found to have had significantly fewer overall road departures than those without ESC (p=0.0071). The number of crashes did not differ significantly as a function of ESC. However, it should be noted that scenarios were designed such that with the proper timing and magnitude of steering inputs, participants could steer around any obstacles present. The trend of fewer loss of control incidents for participants with ESC continued to be evident when examining all ESC icon conditions combined for individual scenario events.

Participants in the ESC condition that received a notification of ESC activation did not lose control of the vehicle or depart the roadway significantly less than those that did not receive a notification. In fact, participants in the condition in which only auditory ESC activation indications were presented experienced significantly more road departures (15%) than participants receiving visual only (steady 8%, flashing 8%) or no ESC activation indications

(7%). Results suggest that providing the driver with a visual indication of ESC activation does not improve the outcome of a critical, loss of control situation. While this study did not provide statistically significant results that would justify requiring or forbidding the presentation of a telltale during ESC activation, glance results suggest that presenting a flashing telltale during ESC activation may draw the drivers' eyes away from the roadway. Presentation of an auditory indication of ESC activation was shown to increase the likelihood of road departure, particularly for older drivers. As a result, use of an auditory indication of ESC activation that is presented during the ESC activation is not recommended.

When examining road departure results by age group, the finding of increased departures for participants in the auditory indication condition was revealed to be most evident for the older driver group who experienced significantly more road departure events with the auditory ESC indication than with the other three conditions ($p<0.0001$). Younger drivers also showed an increased road departure rate with the auditory ESC indication, although not at a statistically significant level ($p=0.071$). Other age groups' results with respect to road departures were unremarkable.

CHAPTER IV. BENEFITS

This chapter estimates the benefits of the proposal. ESC is a crash avoidance countermeasure that would prevent crashes from occurring. Preventing a crash not only would save lives and reduce injuries, it also would alleviate 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 eliminated by the proposal. The non-injury benefits include the travel delay and property damage savings from crashes that were avoided by ESC.

Basically, the size of the benefits depends on two elements: (1) target population (P) and (2) the ESC effectiveness (e) against that population. The overall injury 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 proposal

P = Target population, and

e = Effectiveness of ESC.

The following three sections discuss these two elements and the benefit estimation process, specifically for the injury benefits. The non-injury benefits are estimated by MAIS level and property damage only (PDO) crashes and are discussed in Section D following the injury benefits.

The element "e", the effectiveness of ESC, was discussed in detail in Chapter III and thus is not repeated here. For clarity, this chapter only provides a table summarizing the ESC effectiveness rates that are used for the benefit assessment.

Table IV-1 lists the effectiveness rates of ESC, which are used for deriving benefits. The analysis uses a range of ESC effectiveness for LTVs, with the effectiveness derived from SUVs as the upper bound and PCs as the lower bound. The range is used to address the uncertainties inherent in the ESC effectiveness estimate for LTVs. For instance, the data sample used in deriving the effectiveness for LTVs contains mostly SUVs. The effectiveness of SUVs might not be comparable to that of all LTVs, including minivans and pickup trucks. Furthermore, the sample size with ESC is very small, so a large estimation error for LTV effectiveness is expected. In any case, the lower bound provides a conservative benefit estimate. Note that the analysis uses only the statistically significant effectiveness rates and treats those non-statistically significant results as zero as shown in Table IV-1. In other words, the analysis assumes that ESC has no effect against a population, such as culpable multi-vehicle crashes for passenger cars, against which the impact of ESC was not measured to be statistically significant.

Table IV-1
Effectiveness of ESC by Crash Type and Vehicle Type

Fatal Crashes	PCs	LTVs*
Single Vehicle Excluding Pedestrians, Bicyclist, and Animal (Rollover)	35 (69)	35 – 67 (69 – 88)
Culpable Multi-Vehicle	0**	0 – 38
All Crash Severity Levels		
Single Vehicle Excluding Pedestrians, Bicyclist, and Animal (Rollover)	34 (71)	34 – 59 (71 – 84)
Culpable Multi-Vehicle	0**	0 – 16

*Lower bound effectiveness = effectiveness of PCs
** Treated as 0 since it was not statistically significant
PC: passenger cars, LTV: light trucks and vans

A. Target Population

The target population is derived in a manner consistent with the crash population that was used in deriving effectiveness. Accordingly, the base target population for benefit estimates includes all occupant fatalities and MAIS 1+ non-fatal injuries[21] in: (a) single vehicles crashes excluding crashes involving pedestrians, pedalcyclists, and animals and (b) multi-vehicle crashes that 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 the at-fault vehicle or striking vehicle. The inclusion criteria for these single- and multi-vehicle crashes are consistent with or comparable to that used by the agency in deriving the effectiveness of ESCs.[22,23] The target

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[21] 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).

[22] Dang, J., Preliminary Results Analyzing Effectiveness of Electronic Stability Control (ESC) Systems, September 2004, DOT HS 809 790

[23] Dang, J., Statistical Analysis of the Effectiveness of Electronic Stability Control (ESC) Systems, --- 2006, DOT HS --- --- (currently under external peer review)

single vehicle crashes were further segregated by rollover status to identify the target rollover population.

The base target fatalities and non-fatal injuries were limited to crashes where ESC was not already a standard safety device in any of the involved subject vehicles. In other words, fatalities and injuries that occurred in ESC-equipped vehicles were excluded from the target population. Some of these ESC systems were 2-wheel systems that did not meet the proposal. However, the numbers are too small to make a significant impact. In addition, the industry is already moving towards more advanced ESC technologies.

The 2004 Fatality Analysis Reporting System (FARS) and 2000 – 2004 Crashworthiness Data System (CDS) were used to derive the base target population. FARS is a census of fatalities that occurred in fatal crashes. Therefore, FARS was used to derive the incidence of fatal crashes and associated fatalities and non-fatal injuries. CDS is a sampling system limited to the police-reported passenger vehicle towaway crashes. CDS was used to derive the MAIS 1+ injuries in non-fatal passenger vehicle crashes. MAIS injuries in the CDS-based fatal crashes were also used but only as a tool to translate KABCO[24]-based, non-fatal injuries in FARS to MAIS injuries. We chose CDS over the nationally representative sample, General Estimates System (GES), for its in-depth crash information, its use of the MAIS injury scale, and its applicability. In-depth crash information allows crashes to be categorized more accurately. We also believe that crashes collected in CDS are more applicable to ESC, since under its tow-away crash conditions ESC would likely intervene. Nevertheless, CDS might underestimate the injuries and

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[24] KABCO is a policed-reported injury severity scale. K: fatal injury, A: incapacitating injury, B: non-incapacitating injury, C: possible injury, O: no injury.

provide a conservative estimate of target non-fatal injuries since in the past GES has estimated consistently more than CDS on an annual basis.

FARS is the crash data source used in deriving the ESC effectiveness against fatal crashes. Thus, the definition used to derive the target fatal population, which is based on FARS, is consistent with that used in the agency's ESC effectiveness studies. CDS data, on the other hand, were not the source for deriving ESC effectiveness. Besides, variables and structures in CDS are different from those in the FARS and State Data (the other data source used in the ESC effectiveness analysis). Therefore, the analysis cannot define the crashes as precisely as defined in FARS and State Data. Instead, the analysis derives a comparable definition by mapping the CDS-variables closely to those in the FARS and State Data. The CDS variables used to define the target multi-vehicle crashes include accident type, driver distraction, roadway condition, roadway alignment, weather condition, pre-crash stability, pre-crash movement, crash avoidance maneuver, rollover type, rollover initiation objects contacted, and crash event sequence. The accident type variable defined single-vehicle or multi-vehicle crashes. This variable was also used to identify pedestrian/cyclist/animal-related single-vehicle crashes. The remaining chosen variables were used to further refine certain aspects of multi-vehicle crashes such as driver inattention (the driver distraction variable), crashes on wet roadway (roadway condition and weather), or curved roadway (roadway alignment), or loss-of-control not due to flat tires and vehicle mechanical failure (pre-crash stability), or with certain pre-crash movement (e.g., negotiating a curve), or with certain steering or braking input (avoidance maneuver). They are also used to identify the subject vehicles.

For rollovers, rollover occurrence sequence is the factor used for establishing a rollover population comparable to that used in generating the ESC effectiveness rates against rollover. CDS does not have a specific code to indicate whether the rollover is the first harmful event or a subsequent event as does FARS. Therefore, the analysis uses three variables to identify the first event and subsequent event rollovers: (1) rollover type, (2) rollover initiation objects contacted, and (3) crash event sequence. The first event rollover crashes in CDS are those for which the rollover crash event sequence is the initial event, and no rollover initiation objects were coded other than “turn-over”, “end-to-end”, “jackknife”, or “ground”.

In total, there were 25,365 target fatal crashes (13,711 single-vehicle crashes; 11,594 multi-vehicle crashes) and 1,374,119 target non-fatal crashes (662,877 single-vehicle crashes; 711,242 multi-vehicle crashes). About 28,252[25] fatalities (15,007 in single-vehicle crashes; 13,234 in multi-vehicle crashes) and 1,088,977 MAIS1-5 injuries (493,670 in single-vehicle crashes; 595,307 in multi-vehicle crashes) were associated with these target crashes. Table IV-2 shows these base target crashes by crash type (single, multi-vehicles), crash severity (fatal, nonfatal), and subject vehicle type (PCs, LTVs). A parallel table, Table IV-3, shows the associated target fatalities and MAIS 1-5 injuries.

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[25] Compared to the 33,907 passenger vehicle occupant fatalities in 2004, this estimate excludes fatalities in (1) single-vehicle crashes where drivers were involved with or were avoiding pedestrians/cyclists/animals and a passenger vehicle occupant died (2) multi-vehicle crashes such as rear-end crashes, back-up crashes, etc., where ESC could not have been a factor, and (3) crashes where the subject vehicle, striking vehicle, was not a light passenger vehicle, but a passenger vehicle occupant died.

Table IV-2
Base **Target Crashes**
by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

All Target Crashes

Crash	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
Type	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
Single	7,147	6,624	13,771	419,099	243,788	662,877	426,246	250,402	676,648
Rollover	*3,306*	*4,401*	*7,707*	*97,857*	*100,334*	*198,209*	*101,181*	*104,735*	*205,916*
Multi	6,341	5,253	11,594	470,914	240,328	711,242	477,255	245,581	722,836
Total	13,488	11,877	25,365	890,013	484,106	1,374,119	903,501	495,983	1,399,484

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans
Single: single vehicle crashes, Multi: multi-vehicle crashes.

Note that the target crashes and injuries (fatalities and MAIS 1-5 injuries) were organized by subject vehicle type instead of the actual vehicle type where injuries occurred. This categorization corresponds to how the effectiveness rates should apply. For example, in a multi-vehicle crash, if the subject vehicle is a PC and if it were equipped with an ESC, the crash might be prevented. The chance that this crash would be prevented depends on its ESC effectiveness for the subject vehicle, not the partner vehicle. In this case, ESC effectiveness for PCs would apply to all associated injuries, including those in the partner vehicle.

Table IV-3

Base **Target Fatalities and Non-Fatal Injuries**

by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

Target Single Vehicle Crashes

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	1,863	2,815	4,678	235,484	159,254	394,738	237,347	162,069	399,416
2	884	861	1,745	28,077	23,788	51,865	28,961	24,649	53,610
3	982	1,445	2,427	16,415	8,396	24,811	17,397	9,841	27,238
4	408	429	837	6,617	2,731	9,348	7,025	3,160	10,185
5	260	144	404	2,191	626	2,817	2,451	770	3,221
Fatalities	7,807	7,200	15,007	0	0	0	7,807	7,200	15,007
1-5	4,397	5,694	10,091	288,784	194,795	483,579	293,181	200,489	493,670

Target Multi-Vehicle Crashes

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	6,769	5,071	11,840	347,737	166,302	514,039	354,506	171,373	525,879
2	2,417	1,152	3,569	26,487	15,166	41,653	28,904	16,318	45,222
3	3,048	1,683	4,731	8,046	4,946	12,992	11,094	6,629	17,723
4	1,241	527	1,768	1,289	931	2,220	2,530	1,458	3,988
5	687	121	808	1,058	629	1,687	1,745	750	2,495
Fatalities	8,220	5,025	13,245	0	0	0	8,220	5,025	13,245
1-5	14,162	8,554	22,716	384,617	187,974	572,591	398,779	196,528	595,307

Total Target Crashes (Single and Multi-Vehicle Crashes Combined)

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	8,632	7,886	16,518	583,221	325,556	908,777	591,853	333,442	925,295
2	3,301	2,013	5,314	54,564	38,954	93,518	57,865	40,967	98,832
3	4,030	3,128	7,158	24,461	13,342	37,803	28,491	16,470	44,961
4	1,649	956	2,605	7,906	3,662	11,568	9,555	4,618	14,173
5	947	265	1,212	3,249	1,255	4,504	4,196	1,520	5,716
Fatalities	16,027	12,225	28,252	0	0	0	16,027	12,225	28,252
1-5	18,559	14,248	32,807	673,401	382,769	1,056,170	691,960	397,017	1,088,977

Source: 2004 FARS, 2000-2004 CDS

PC: passenger cars, LTV: light trucks/vans

Target Single-Vehicle Crashes

As shown in Tables IV-2 and IV-3, there were a total of 676,648 target single-vehicle crashes, of which, 13,771 were fatal crashes and 662,877 were non-fatal crashes. A total of 15,007 fatalities and 493,670 MAIS 1-5 injuries were associated with these crashes. Of the 15,007 fatalities, about 52 percent (7,807 fatalities) were PC occupants and 48 percent (7,200 fatalities) were LTV occupants. While for MAIS 1-5 injuries, 59 percent (293,181 MAIS 1-5 injuries) were PC occupants and 41 percent (200,489) were LTV occupants.

Target Multi-Vehicle Crashes

Based also on Tables IV-2 and IV-3, there were a total of 722,836 target multi-vehicle crashes, of which 11,594 were fatal crashes and 711,242 were non-fatal crashes. About 13,245 fatalities and 595,307 MAIS 1-5 injuries were associated with these target multi-vehicle crashes. Of these 13,245 fatalities, 62 percent (8,220 fatalities) occurred in crashes where PC is the subject vehicle (i.e., at fault or striking vehicle) and 38 percent (5,025 fatalities) where the LTV is the subject vehicle. While for MAIS 1-5 injuries, 67 percent (398,779 MAIS 1-5 injuries) occurred in crashes where a PC is the subject vehicle, while 33 percent (196,528 MAIS 1-5 injuries) were in crashes where a LTV was the subject vehicle.

Single-Vehicle Rollovers

Among the 676,648 target single vehicle crashes, 205,916 were rollovers. Of these rollovers, 7,707 were fatal rollover crashes (3,306 – PCs; 4,401 – LTVs), and 198,209 were non-fatal rollover crashes (97,875 – PCs; 100,334 - LTVs). Overall, rollovers comprised 56 percent of the target fatal single-vehicle crashes and 30 percent of the all target single-vehicle crashes.

Rollover crashes were further segregated by rollover occurrence sequence (i.e., the first harmful event vs. a subsequent event). Table IV-4 shows rollover crashes by rollover occurrence sequence. As shown in Table IV-4, 3,254 of the target rollover fatal crashes and 156,585 of the non-fatal crashes were first event rollovers.

Table IV-4
Base Target Single Vehicle **Rollover** Crashes*
by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

Rollover	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
Type	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
First	1,034	2,220	3,254	77,321	79,264	156,585	78,355	81,484	159,839
Sub	2,272	2,181	4,453	20,554	21,070	41,624	22,826	23,251	46,077
Total	3,306	4,401	7,707	97,875	100,334	198,206	101,181	104,735	205,916

* Part of the target single vehicle crashes
Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans
First: first harmful event, Sub: the subsequent event.

As discussed previously, rollover occurrence sequence was used to establish a rollover population comparable to that used to generate the ESC effectiveness rates. These first event rollovers are equivalent to those used to derive the ESC effectiveness against rollovers. Thus, the rollover effectiveness would apply directly to these first event rollovers. The ESC effectiveness rate for single-vehicle crashes would apply to the remaining rollovers, i.e., the subsequent event rollovers.

Table IV-5 shows the target rollover fatalities and non-fatal injuries. As shown in Table IV-5, there were about 8,460 rollover fatalities[26], which account for about 56 percent (=8,460/15,007 from Table IV-2) of the fatalities in single-vehicle crashes. There were 247,498 rollover MAIS 1-5 injuries, which account for 24 percent (=247,498/1,016,858) of MAIS 1+ injuries in target single-vehicle crashes. About 3,624 fatalities and 193,897 MAIS 1-5 injuries were associated with the first-event rollovers. The remaining 4,836 fatalities and 53,601 MAIS 1-5 injuries were associated with the subsequent rollovers. Similar to crashes, the rollover effectiveness rate would be applied to fatalities and non-fatal injuries in the first-event rollovers while ESC effectiveness for single-vehicle crashes would be applied to the subsequent-event rollovers to derive the overall rollover benefits.

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[26] In 2004, there were 10,458 rollover fatalities in PCs and LTVs. Of these, 1,998 fatalities were excluded from our base target population: 27 were in vehicles already equipped with ESC and 1,971 were in multi-vehicle crashes.

Table IV-5
Based Target Fatalities and Non-Fatal Injuries in **Single-Vehicle Rollover** Crashes by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

The First-Event Rollovers

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	403	1,549	1,952	69,102	89,207	158,309	69,505	90,756	160,261
2	179	424	603	8,048	12,216	20,264	8,227	12,640	20,867
3	113	643	756	3,445	4,109	7,554	3,558	4,752	8,310
4	71	108	179	1,568	1,697	3,265	1,639	1,805	3,444
5	36	78	114	373	528	901	409	606	1,015
Fatalities	1,116	2,508	3,624	0	0	0	1,116	2,508	3,624
1-5	802	2,802	3,604	82,536	107,757	190,293	83,338	110,559	193,897

The Subsequent-Event Rollovers

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	712	884	1,596	18,369	23,712	42,081	19,081	24,596	43,677
2	317	242	559	2,139	3,247	5,386	2,456	3,489	5,945
3	200	367	567	915	1,092	2,007	1,115	1,459	2,574
4	125	62	187	417	451	868	542	513	1,055
5	64	45	109	100	141	241	164	186	350
Fatalities	2,476	2,360	4,836	0	0	0	2,476	2,360	4,836
1-5	1,418	1,600	3,018	21,940	28,643	50,583	23,358	30,243	53,601

Rollovers Total

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	1,115	2,433	3,548	87,471	112,919	200,390	88,586	115,352	203,938
2	496	666	1,162	10,187	15,463	25,650	10,683	16,129	26,812
3	313	1,010	1,323	4,360	5,201	9,561	4,673	6,211	10,884
4	196	170	366	1,985	2,148	4,133	2,181	2,318	4,499
5	100	123	223	473	669	1,142	573	792	1,365
Fatalities	3,592	4,868	8,460	0	0	0	3,592	4,868	8,460
1-5	2,220	4,402	6,622	104,476	136,400	240,876	106,696	140,802	247,498

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans

B. Projected Target Population

The base target population is derived from a crash population for a fleet of vehicles where most of them were equipped without ESC. There is a difference between the percent of the on-road fleet in our crash data with ESC and the percent of the MY 2011 new vehicle fleet with ESC (see Chapter V for a discussion of using MY 2011 as the baseline). For example, less than 0.5 percent of the vehicles involved in the target fatal crashes were equipped with ESC. However, the agency estimates that about 71 percent of the MY 2011 vehicles will be equipped with ESC. Thus, using the base target population shown in Tables IV-2 and IV-3 would overestimate the benefit of ESC. To overcome this, the analysis adjusts the base target population to a level that reflects the penetration rate of the 2011 model vehicles. This adjustment is appropriate to derive the projected target population for benefit estimates. The following discussion leads to a projected target population.

The projected target population essentially is equal to the potential target population multiplied by the non-penetration portion (No-ESC portion), i.e., discounting the ESC penetration portion from the potential target population. The potential target population is an estimated population for a fleet of vehicles without ESCs, which contains two subpopulations: (1) base target population (i.e., No-ESC portion) and (2) all injuries in ESC-portion including those saved by ESC (i.e., ESC portion plus saved population). The potential target population is derived by the following formula:

$$P_t = P_b + \frac{P_{ESC}}{1 - e}$$

Where, P_t = Potential target population

P_b = Base Target Population (No-ESC portion)

P_{ESC} = Population in crashes with subject vehicles equipped with ESCs,

e = ESC effectiveness rate of the subject vehicle

If the potential target population were impacted by ESC at the 2011 penetration level (i.e., the ESC portion), this portion of crashes, even if they could not be prevented by ESC, would not benefit by a further increased penetration of ESCs. Thus, the ESC portion is completely excluded from the projected population. The projected target population can be mathematically expressed as follows:

$$\begin{aligned} P_p &= \text{potential target population} * (1 - \%_p) \\ &= P_t * (1 - \%_b) \\ &= (P_b + \frac{P_{ESC}}{1 - e}) * (1 - \%_p) \end{aligned}$$

Where, P_p = Projected Target Population

P_b = Base Target Population

P_{ESCs} = Population in crashes with subject vehicles with ESCs

$\%_p$ = Projected ESC rate in crash data base

e = ESC effectiveness of the subject vehicle

As mentioned previously, the analysis uses a range of effectiveness for LTVs. Using the range produces two sets of projected population. The sizes of these two projected target populations are very similar and they are very close to the base target population due to the following reasons:

1) Less than 0.5 percent of fatalities were in ESC-equipped vehicles, i.e., P_{ESC} is relatively small for fatal crashes,
2) All vehicles in CDS were non-ESC equipped vehicles, i.e., $P_{ESC} = 0$ for MAIS 1-5 injuries in non-fatal crashes, and
3) The majority of the crashes were multi-vehicle crashes against which ESC had a lower effectiveness than against single-vehicle crashes.

Therefore, for simplicity, this analysis uses the base target population, instead of the potential target population, for adjustment. The above formula for the projected target population formula can be simplified as:

$$P_p = P_b(1 - \%_p)$$

The impact of this simplified approach on target population is minimal (less than 0.01 percent of overall target population and less than 0.5 percent of the fatalities). In addition, using the simplified formula generally produces a smaller projected population than the original formula because the base target crash population is smaller than the potential crash population.

The agency estimates that about 65 percent of PCs and 77 percent of LTVs in model year 2011 vehicles will be equipped with ESCs. Thus, $\%_p = 0.65$ for PCs and $\%_p = 0.77$ for LTVs. The projected target population for PC is the product of the base target population for PCs (Tables IV-2 and IV-3) and 0.35 (1-0.65). Similarly, the projected target population for LTVs is the product of the base target population for LTVs and 0.23. Tables IV-6 and IV-7 list the projected target crashes and injuries separately for benefit estimates. Tables IV-8 and IV-9 show the projected rollover crashes and associated injuries. Note that the analysis does not adjust the projected baseline population further to account for the effects of current finalized safety regulations and those that have not been fully phased in. Current finalized safety regulations or consumer information that the agency anticipates will have an influence on fatalities from run-off-the-road crashes include FMVSS No. 208 advanced air bags and rear-center seat lap/shoulder belt requirements, FMVSS No. 138 Tire Pressure Monitoring Systems, FMVSS No. 139, New Pneumatic Tires for Light Vehicles, and the Static Stability Ratings for new vehicles. The agency believes that the impact of these safety standards on the proposed ESC rule is not significant enough to make specific adjustments. Similarly, the analysis does not adjust the baseline to account for possible increases in vehicle miles traveled (VMT) that could increase the target population of fatalities and injuries.

As shown in Tables IV-6 and IV-7, the proposal would impact 430,301 crashes and the associated 5,725 fatalities and 330,571 MAIS 1-5 injuries. For rollovers, the proposal would impact 59,503 rollover crashes and the 2,378 fatalities and 69,730 MAIS 1-5 injuries that were associated with rollovers (Tables IV-8 and IV-9).

Table IV-6
Projected Target **Crashes** for MY 2011 ESC Level
by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

Crash	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
Type	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
Single	2,501	1,524	4,025	146,685	56,069	202,754	149,186	57,593	206,779
Rollover	1,157	1,013	2,170	34,256	23,077	57,333	35,413	24,090	59,503
Multi	2,219	1,208	3,427	164,820	55,275	220,095	167,039	56,483	223,522
Total	4,720	2,732	7,452	311,505	111,344	422,849	316,225	114,076	430,301

Source: 2004 FARS, 2000-2004 CDS;
PC: passenger cars, LTV: light trucks/vans
Single: single vehicle crashes, Multi: multi-vehicle crashes.

Table IV-7
Projected Target **Fatalities and Injuries** for MY 2011 ESC Level
by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

Target Single Vehicle Crashes

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	652	647	1,299	82,419	36,628	119,047	83,071	37,275	120,346
2	309	198	507	9,827	5,471	15,298	10,136	5,669	15,805
3	344	332	676	5,745	1,931	7,676	6,089	2,263	8,352
4	143	99	242	2,316	628	2,944	2,459	727	3,186
5	91	33	124	767	144	911	858	177	1,035
Fatalities	2,732	1,656	4,388	0	0	0	2,732	1,656	4,388
1-5	1,539	1,309	2,848	101,074	44,802	145,876	102,613	46,111	148,724

Target Multi-Vehicle Crashes

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	2,369	1,166	3,535	121,708	38,249	159,957	124,077	39,415	163,492
2	108	46	154	9,270	3,488	12,758	9,378	3,534	12,912
3	120	76	196	2,816	1,138	3,954	2,936	1,214	4,150
4	50	23	73	451	214	665	501	237	738
5	32	8	40	370	145	515	402	153	555
Fatalities	956	381	1,337	0	0	0	956	381	1,337
1-5	2,679	1,319	3,998	134,615	43,234	177,849	137,294	44,553	181,847

Total Target Crashes (Single and Multi-Vehicle Crashes Combined)

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	3,021	1,813	4,834	204,127	74,877	279,004	207,148	76,690	283,838
2	417	244	661	19,097	8,959	28,056	19,514	9,203	28,717
3	464	408	872	8,561	3,069	11,630	9,025	3,477	12,502
4	193	122	315	2,767	842	3,609	2,960	964	3,924
5	123	41	164	1,137	289	1,426	1,260	330	1,590
Fatalities	3,688	2,037	5,725	0	0	0	3,688	2,037	5,725
1-5	4,218	2,628	6,846	235,689	88,036	323,725	239,907	90,664	330,571

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans

Table IV-8
Projected Target Single-Vehicle **Rollover Crashes** for MY 2011 ESC Level
by Rollover Type, Crash Severity, Injury Severity, and Vehicle Type

Rollover Type	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
First	362	511	873	27,062	18,231	45,293	27,424	18,742	46,166
Sub	795	502	1,297	7,194	4,846	12,040	7,989	5,348	13,337
Total	1,157	1,013	2,170	34,256	23,077	57,333	35,413	24,090	59,503

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans
First: the first-event rollovers, Sub: the subsequent-event rollovers

C. Benefits

Applying the effectiveness rates of ESCs (Table IV-1) to the projected target population (crashes and injuries) derived in the previous section provides the benefits of the proposal. Table IV-10 lists the crashes that would be prevented by the proposal. Table IV-11-A shows the estimated overall benefits for the proposal by crash severity (fatal and non-fatal), injury severity level (MAIS), and vehicle type (PCs and LTVs). As shown in Tables IV-10, the proposal would prevent 70,344 – 90,153 crashes (1,408 – 2,355 fatal crashes, 68,936 – 91,798 non-fatal crashes). As a result, the proposal would save 1,536 – 2,211 fatalities and reduce 50,594 – 69,630 MAIS 1-5 injuries (Table IV-11-A).

Table IV-9
Projected Target **Fatalities and Injuries** in
Single-Vehicle Rollover Crashes for MY 2011 ESC Level
by Rollover Type, Crash Severity, Injury Severity, and Vehicle Type

First Event Rollovers

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	141	356	497	24,186	20,518	44,704	24,327	20,874	45,201
2	63	98	161	2,817	2,810	5,627	2,880	2,908	5,788
3	40	148	188	1,206	945	2,151	1,246	1,093	2,339
4	25	25	50	549	390	939	574	415	989
5	13	18	31	131	121	252	144	139	283
Fatalities	391	577	968	0	0	0	391	577	968
1-5	282	645	927	28,889	24,784	53,673	29,171	25,429	54,600

Subsequent Event Rollovers

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	249	203	452	6,429	5,454	11,883	6,678	5,657	12,335
2	111	56	167	749	747	1,496	860	803	1,663
3	70	84	154	320	251	571	390	335	725
4	44	14	58	146	104	250	190	118	308
5	22	10	32	35	32	67	57	42	99
Fatalities	867	543	1,410	0	0	0	867	543	1,410
1-5	496	367	863	7,679	6,588	14,267	8,175	6,955	15,130

Rollovers Total

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	390	559	949	30,615	25,972	56,587	31,005	26,531	57,536
2	174	154	328	3,566	3,557	7,123	3,740	3,711	7,451
3	110	232	342	1,526	1,196	2,722	1,636	1,428	3,064
4	69	39	108	695	494	1,189	764	533	1,297
5	35	28	63	166	153	319	201	181	382
Fatalities	1,258	1,120	2,378	0	0	0	1,258	1,120	2,378
1-5	778	1,012	1,790	36,568	31,372	67,940	37,346	32,384	69,730

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans

Table IV-10

Estimated Crashes Prevented

by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

Lower Bound*

Crash	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
Type	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
Single	875	533	1,408	49,873	19,063	68,936	50,748	19,596	70,344
Rollover	*528*	*529*	*1,057*	*21,660*	*14,592*	*36,252*	*22,188*	*15,121*	*37,309*
Multi	0	0	0	0	0	0	0	0	0
Total	875	533	1,408	49,873	19,063	68,936	50,748	19,596	70,344

Higher Bound

Crash	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
Type	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
Single	875	1,021	1,896	49,873	33,081	82,954	50,748	34,102	84,850
Rollover	*528*	*786*	*1,314*	*21,660*	*18,173*	*39,833*	*22,188*	*18,959*	*41,147*
Multi	0	459	459	0	8,844	8,844	0	9,303	9,303
Total	875	1,480	2,355	49,873	41,925	91,798	50,748	43,405	94,153

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans
Single: single-vehicle crashes, Multi: multi-vehicle crashes
* Assuming ESC effectiveness of LTVs = PCs

Table IV-11-B also shows the overall benefits for the proposal but benefits are tabulated by crash type (single-vehicle, multi-vehicles crashes) instead of by crash severity as are shown in Table IV-11-A. As shown in Table IV-11-B, of the 1,536 – 2,211 estimated fatalities saved by the proposal, 1,536 – 2,066 are from the prevention of single-vehicle crashes and up to 145 are from the reduction of multi-vehicle crashes. The proposal would eliminate 50,594 to 62,212 MAIS 1-5 injuries from single-vehicle crashes and up to 7,418 MAIS 1-5 injuries from multi-vehicle crashes.

Table IV-11-A
Estimated Benefits of the Proposal
Occupant Fatalities and Injuries Reduced
by **Crash Severity**, Injury Severity, and Vehicle Type

Lower Bound*

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	228	226	454	28,022	12,454	40,476	28,250	12,680	40,930
2	108	69	177	3,341	1,860	5,201	3,449	1,929	5,378
3	120	116	236	1,953	657	2,610	2,073	773	2,846
4	50	35	85	787	214	1,001	837	249	1,086
5	32	12	44	261	49	310	293	61	354
Fatalities	956	580	1,536	0	0	0	956	580	1,536
1-5	538	458	996	34,364	15,234	49,598	34,902	15,692	50,594

Higher Bound

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	228	876	1,104	28,022	27,731	55,753	28,250	28,607	56,857
2	108	150	258	3,341	3,786	7,127	3,449	3,936	7,385
3	120	251	371	1,953	1,321	3,274	2,073	1,572	3,645
4	50	75	125	787	405	1,192	837	480	1,317
5	32	25	57	261	108	369	293	133	426
Fatalities	956	1,255	2,211	0	0	0	956	1,255	2,211
1-5	538	1,377	1,915	34,364	33,351	67,715	34,902	34,728	69,630

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans
* Assuming ESC effectiveness of LTVs = PCs

Table IV-11-B
Estimated Benefits of the Proposal
Occupant Fatalities and Injuries Reduced
by **Crash Type**, Injury Severity, and Vehicle Type

Lower Bound*

Injury Severity	Single-Vehicle Crashes			Multi-Vehicle Crashes			Single- + Multi-Vehicle Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	28,250	12,680	40,930	0	0	0	28,250	12,680	40,930
2	3,449	1,929	5,378	0	0	0	3,449	1,929	5,378
3	2,073	773	2,846	0	0	0	2,073	773	2,846
4	837	249	1,086	0	0	0	837	249	1,086
5	293	61	354	0	0	0	293	61	354
Fatalities	956	580	1,536	0	0	0	956	580	1,536
1-5	34,902	15,692	50,594	0	0	0	34,902	15,692	50,594

Higher Bound

Injury Severity	Single-Vehicle Crashes			Multi-Vehicle Crashes			Single- + Multi-Vehicle Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	28,250	22,044	50,294	0	6,563	6,563	28,250	28,607	56,857
2	3,449	3,361	6,810	0	575	575	3,449	3,936	7,385
3	2,073	1,361	3,434	0	211	211	2,073	1,572	3,645
4	837	437	1,274	0	43	43	837	480	1,317
5	293	107	400	0	26	26	293	133	426
Fatalities	956	1,110	2,066	0	145	145	956	1,255	2,211
1-5	34,902	27,310	62,212	0	7,418	7,418	34,902	34,728	69,630

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans
* Assuming ESC effectiveness of LTVs = PCs

Similarly, applying the projected rollover population to its corresponding ESC effectiveness rates derives the rollover portion of benefits. Tables IV-12 and IV-13 list the rollover crashes that would be prevented and injuries that would be eliminated separately by this proposal. As shown in these two tables, the proposal would prevent 37,309 to 41,147 single-vehicle rollover crashes, including 1,057 – 1,314 fatal crashes and 36,252 – 39,833 non-fatal single-vehicle rollover crashes. In preventing these rollover crashes, the proposal would save 1,161 to 1,445 lives and eliminate 43,901 – 49,010 MAIS 1-5 injuries.

Note that the range of benefits basically is a reflection of the range of effectiveness rates that were used for LTVs in the analysis. The lower range of the benefits was derived by assuming that the ESC effectiveness rates for LTVs are equal to those of the PCs. ESC is designed to prevent loss-of-control crashes including rollovers. Logically, ESC would be expected to be more beneficial to LTVs specifically for rollover crashes. However, the agency also acknowledges that ESC effectiveness estimates for LTVs might have a greater estimating variation due to the small sample size of LTVs with an ESC and the predominance of SUVs within the sample. Therefore, the analysis provides the lower bound estimates as a conservative benefit estimate.

The rollover benefits were derived using different ESC effectiveness estimates based on whether the rollover is the first or subsequent harmful event. For first-event rollovers, the ESC effectiveness rates against rollovers were used. For the subsequent event rollovers, the ESC effectiveness rates against all crashes were used. The differentiation is made to ensure that the rollover target population is consistent with or comparable to that used in deriving the rollover effectiveness rates.

Although the effectiveness rates are crash-based (i.e., against crashes), these rates are applied directly to fatalities and injuries to derive benefits. The effectiveness rates for fatal crashes are applied to the fatalities and nonfatal injuries associated with the fatal target crashes. Similarly, the effectiveness rates for nonfatal crashes are uniformly applied to those nonfatal injuries associated with the nonfatal target crashes, regardless of MAIS severity levels. This approach is appropriate since preventing a crash would prevent all injuries that resulted from that crash.

Table IV-12
Single-Vehicle Rollover Crashes Prevented
by Rollover Type, Crash Severity, Injury Severity, and Vehicle Type

Lower Bound*

Rollover	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
Type	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
First	250	353	603	19,214	12,944	32,158	19,464	13,297	32,761
Sub	278	176	454	2,446	1,648	4,094	2,724	1,824	4,548
Total	528	529	1,057	21,660	14,592	36,252	22,188	15,121	37,309

Higher Bound*

Rollover	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
Type	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
First	250	450	700	19,214	15,314	34,528	19,464	15,764	35,228
Sub	278	336	614	2,446	2,859	5,305	2,724	3,195	5,919
Total	528	786	1,314	21,660	18,173	39,833	22,188	18,959	41,147

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans
First: the first-event rollovers, Sub: the subsequent-event rollovers
* Assuming ESC effectiveness of LTVs = PCs

Table IV-13
Estimated **Single-Vehicle Rollover** Benefits of the Proposal
Occupant Fatalities and Injuries Reduced
by Crash Type, Crash Severity, Injury Severity, and Vehicle Type

Lower Bound*

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	184	317	501	19,358	16,422	35,780	19,542	16,739	36,281
2	82	88	170	2,255	2,249	4,504	2,337	2,337	4,674
3	53	131	184	965	756	1,721	1,018	887	1,905
4	32	22	54	440	312	752	472	334	806
5	17	16	33	105	97	202	122	113	235
Fatalities	573	588	1,161	0	0	0	573	588	1,161
1-5	368	574	942	23,123	19,836	42,959	23,491	20,410	43,901

Higher Bound

Injury Severity	Fatal Crashes			Nonfatal Crashes			Fatal + Nonfatal Crashes		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	184	449	633	19,358	20,453	39,811	19,542	20,902	40,444
2	82	124	206	2,255	2,801	5,056	2,337	2,925	5,262
3	53	186	239	965	942	1,907	1,018	1,128	2,146
4	32	31	63	440	389	829	472	420	892
5	17	23	40	105	121	226	122	144	266
Fatalities	573	872	1,445	0	0	0	573	872	1,445
1-5	368	813	1,181	23,123	24,706	47,829	23,491	25,519	49,010

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans (pickups, vans, and sport-utility vehicles)
* Assuming ESC effectiveness of LTVs = PCs

D. Travel Delay and Property Damage Savings

The non-injury component of benefits includes savings from the elimination of crash-related travel delays and vehicle property damage. Unit costs for both travel delay and property damage are represented on a per person basis for all MAIS injury levels, and per vehicle basis for property damage only (PDO) crashes. These unit costs were developed from a 2002 NHTSA report[27] based on 2000 economics. These costs were adjusted to 2005 dollars using a factor of 1.121 (=112.145/100), which was derived using the implicit price deflator for gross domestic product[28].

The total travel delay and property damage cost for each MAIS and PDO level is equal to the product of the individual unit cost and the corresponding incidences that would be prevented by the proposal. The MAIS incidences prevented by the proposal were estimated previously in this section (Tables IV-11 and IV-13). For PDO crashes, the incidence is the total number of PDO vehicles for which crashes were eliminated. At this time, there is no available ESC effectiveness rate against PDO crashes for us to precisely estimate the PDO crashes that would be prevented by ESC. As an alternative, the number of PDO crashes was prorated from the total non-fatal crashes prevented according to their proportion reported in the 2000-2004 CDS.

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[27] 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

[28] Published by Bureau of Economic Analysis, U.S. Department of Commerce, December 2005.

Based on 2000-2004 CDS, PDO crashes accounted for about 43 percent of the target single-vehicle crashes and 49 percent of the target multi-vehicle crashes. Therefore, 43 percent of the single-vehicle crashes and 49 percent of the multi-vehicle crashes prevented by the proposal would be PDO crashes, i.e.,

$PDO_s = 0.43 * C_s$, and

$PDO_m = 0.49 * C_m$

Where, PDO_s = Single vehicle PDO crashes prevented

PDO_m = Multi-vehicle PDO crashes prevented

C_s = Single vehicle non-fatal crashes prevented, and

C_m = Multi-vehicle non-fatal crashes prevented.

C_s and C_m can be found in Table IV-10 for all non-fatal crashes and in Table IV-12 for rollovers.

Also, based on 2000-2004 CDS, on average, about 2.2 vehicles were involved in a multi-vehicle crash. Thus, the total number of vehicles in prevented PDO crashes is equal to the sum of the total single-vehicle PDO crashes prevented and 2.2 times the multi-vehicle PDO crashes, i.e.,

$$PDOV = PDO_s + 2.2 * PDO_m$$

$$= 0.43 * C_s + 2.2 * 0.49 * C_m$$

Where, PDOV = Property-damage-only-vehicles in PDO crashes prevented

PDO_s = Single-vehicle PDO crashes prevented

PDO_m = Multi-vehicle PDO crashes prevented

C_s = Single-vehicle non-fatal crashes prevented, and

C_m = Multi-vehicle non-fatal crashes prevented.

Table IV-14 lists the travel delay and property damage unit costs, MAIS and PDO incidences, and the total costs. All the costs reported in Table IV-14 are in 2005 dollars. As shown in Table IV-14, the proposal would save undiscounted \$396 to \$555 million from travel delay and property damage associated with the crashes that would be prevented by the proposal.

Table IV-14
Total Travel Delay and Property Damage Savings
(Undiscounted 2005 $)

Lower Bound*

	Unit Cost			Total Costs		Total
MAIS	Travel Delay	Property Damage	Incidents Prevented	Travel Delay	Property Damage	Travel Delay +Property Damage
1	$871	$4,309	40,930	$35,650,030	$176,367,370	$212,017,400
2	$948	$4,432	5,378	$5,098,344	$23,835,296	$28,933,640
3	$1,054	$7,622	2,846	$2,999,684	$21,692,212	$24,691,896
4	$1,120	$11,023	1,086	$1,216,320	$11,970,978	$13,187,298
5	$10,255	$10,589	354	$3,630,270	$3,748,506	$7,378,776
Fatal	$10,255	$11,516	1,536	$15,751,680	$17,688,576	$33,440,256
PDO**	$900	$1,664	29,642	$26,677,800	$49,324,288	$76,002,088
Total				$91,024,128	$304,627,226	$395,651,354

Higher Bound

	Unit Cost			Total Costs		Total
MAIS	Travel Delay	Property Damage	Incidents Prevented	Travel Delay	Property Damage	Travel Delay +Property Damage
1	$871	$4,309	56,857	$49,522,447	$244,996,813	$294,519,260
2	$948	$4,432	7,385	$7,000,980	$32,730,320	$39,731,300
3	$1,054	$7,622	3,645	$3,841,830	$27,782,190	$31,624,020
4	$1,120	$11,023	1,317	$1,475,040	$14,517,291	$15,992,331
5	$10,255	$10,589	426	$4,368,630	$4,510,914	$8,879,544
Fatal	$10,255	$11,516	2,211	$22,673,805	$25,461,876	$48,135,681
PDO**	$900	$1,664	45,205	$40,684,320	$75,220,787	$115,905,107
Total				$129,567,052	$425,220,191	$554,787,243

Source: Table 2 of “The Economic Impact of Motor Vehicle Crashes 2000”, NHTSA Report; 2004 FARS, 2000-2004 CDS

PDO: property damage only

*Assuming ESC effectiveness of LTVs = PCs; ** PDO vehicles

Table IV-15 shows the total travel delay and property damage savings specifically for single-vehicle rollovers. The proposal would save an undiscounted $310 to $348 million for rollovers.

Table IV-15
Total Travel Delay and Property Damage Savings for **Single-Vehicle Rollovers**
(Undiscounted 2005 $)

Lower Bound*

	Unit Cost			Total Costs		Total
MAIS	Travel Delay	Property Damage	Incidents Prevented	Travel Delay	Property Damage	Travel Delay +Property Damage
1	$871	$4,309	36,281	$31,600,751	$156,334,829	$187,935,580
2	$948	$4,432	4,674	$4,430,952	$20,715,168	$25,146,120
3	$1,054	$7,622	1,905	$2,007,870	$14,519,910	$16,527,780
4	$1,120	$11,023	806	$902,720	$8,884,538	$9,787,258
5	$10,255	$10,589	235	$2,409,925	$2,488,415	$4,898,340
Fatal	$10,255	$11,516	1,161	$11,906,055	$13,370,076	$25,276,131
PDO**	$900	$1,664	15,589	$14,030,100	$25,940,096	$39,970,196
Total				$67,288,373	$242,253,032	$309,541,405

Higher Bound

	Unit Cost			Total Costs		Total
MAIS	Travel Delay	Property Damage	Incidents Prevented	Travel Delay	Property Damage	Travel Delay +Property Damage
1	$871	$4,309	40,444	$35,226,724	$174,273,196	$209,499,920
2	$948	$4,432	5,262	$4,988,376	$23,321,184	$28,309,560
3	$1,054	$7,622	2,146	$2,261,884	$16,356,812	$18,618,696
4	$1,120	$11,023	892	$999,040	$9,832,516	$10,831,556
5	$10,255	$10,589	266	$2,727,830	$2,816,674	$5,544,504
Fatal	$10,255	$11,516	1,445	$14,818,475	$16,640,620	$31,459,095
PDO**	$900	$1,664	17,128	$15,415,200	$28,500,992	$43,916,192
Total				$76,437,529	$271,741,994	$348,179,523

Source: Table 2 of "The Economic Impact of Motor Vehicle Crashes 2000", NHTSA Report; 2004 FARS, 2000-2004 CDS
PDO: property damage only
*Assuming ESC effectiveness of LTVs = PCs; ** PDO vehicles

E. Summary

The following summarizes the estimated benefits of the proposal. These are incremental benefits over a projected baseline of 71 percent ESC installations in the model year 2011 fleet. These are the annual benefits that would accrue once all vehicles in the fleet are equipped with ESC.

<u>Overall Benefits of the Proposal</u>

- Prevent 70,344 – 95,153 crashes
    - 1,408 – 2,355 fatal crashes
    - 68,936 – 91,798 non-fatal crashes
- Save 1,536 – 2,211 lives
- Eliminate 50,594 – 69,630 MAIS 1-5 injuries
- Save $396 – $555 million (undiscounted) from travel delay and property damage.

<u>Single-Vehicle Rollover Benefits</u> (these are included in the overall benefits above)

- Prevent 37,309 – 41,147 rollover crashes
    - 1,057 – 1,314 fatal crashes
    - 36,252 – 39,833 non-fatal crashes
- Save 1,161 – 1,445 lives
- Eliminate 43,901 – 49,010 MAIS 1-5 injuries.
- Save $310 – $348 million (undiscounted) from travel delay and property damage.

Note that the estimated injury benefits and property damage and travel delay savings of the proposal are measured from a baseline of 71 percent ESC installation rate to 100 percent installation. The benefits of the ESC system itself, which are measured from a baseline of no ESC installation to 100 percent installation, are summarized below.

ESC Benefits (0% to 100% ESC Installation)

- Prevent 230,198 – 333,710 crashes
    - 4,819 – 8,935 fatal crashes
    - 225,379 – 324,775 non-fatal crashes
- Save 5,252 – 10,292 lives
- Eliminate 167,949 – 251,566 MAIS 1-5 injuries
- Save $1,310 – $2,056 million (undiscounted) from travel delay and property damage.

ESC Benefits for Single-Vehicle Rollovers (these are included in the ESC benefits above)

- Prevent 129,130 – 145,822 rollover crashes
    - 3,803 – 4,923 fatal crashes
    - 125,327 – 140,899 non-fatal crashes
- Save 4,194 – 5,425 lives
- Eliminate 155,849 – 178,062 MAIS 1-5 injuries.
- Save $1,096 – $1,264 million (undiscounted) from travel delay and property damage.

CHAPTER V. ESC COSTS

The cost of the proposal comprises technology costs and fuel economy impacts. The components add weight to vehicles and increase fuel consumption over the lifetime of the vehicles. The analysis examines the economic and environmental impacts resulting from increases in fuel consumption. These future impacts are discounted to represent their present value, using a 3 and 7 percent discount rate.

A. Technology Costs

A contractor did a tear-down study of the incremental technology cost and weight to equip vehicles with ABS, traction control, ESC, and a telltale light. Ten different make/models were analyzed. In addition, a cost tear-down study of a 2-channel system was completed in order to be able to compare it to a 4-channel system in the same make/model. In order to estimate the cost of the additional components required to equip every vehicle in future model years with an ESC system, a determination had to be made about the relationship between equipment found in anti-lock brake systems (ABS), traction control, and ESC systems. Almost every ESC system in production today has ABS, traction control, and ESC. We assumed that ABS is a prerequisite for an ESC system. However, we assumed that traction control is a convenience feature and is not a safety feature required to provide the safety benefits found in ESC systems. Thus, the cost of traction control is not included in the cost of an ESC system. Thus, if a passenger car or light truck had none of those systems, it would require the cost of an ABS plus the additional incremental costs of ESC to comply with an ESC standard. We estimated a future annual production volume of 17 million light vehicles, consisting of 9 million light trucks and 8 million passenger cars.

The Baseline for ESC compliance

The installation rate for ESC in the new model year fleet has been rapidly increasing (from 10 percent in MY 2003, to 16 percent in MY 2004, to 19 percent in MY 2005, to 29 percent in MY 2006)[29]. In order to get a better estimate of the market penetration of ESC with a requirement, the agency requested product plan information from seven manufacturers to establish a baseline voluntary installation rate of ABS and ESC. From these product plans and the current MY 2006 installation rates of ABS and ESC for those manufacturers that were not asked for production plans, estimates were made of the planned progress of ABS and ESC. MY 2011 was chosen as the baseline voluntary installation rate for ESC, because it was the last year for which available data indicated changes in the planned percentages of ESC. MY 2011 serves as the baseline against which both costs and benefits are measured. In other words, the ESC penetration rate for each new model of vehicles beyond MY 2011 is assumed to be at the MY 2011 level of 71 percent. Thus, the cost of the standard is the incremental cost of going from the MY 2011 planned installations to 100 percent installation of ABS and ESC. The estimated model year (MY) planned installation rates are shown in Table V-1. The weighted average reflects the relative unit sales of passenger cars and light trucks noted above.

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[29] Based on NHTSA estimates.

Table V-1
Estimated Installations
(% of the fleet)

	MY 2007	MY 2008	MY 2009	MY 2010	MY 2011
Neither ABS nor ESC					
Passenger Cars	22	18	16	14	14
Light Trucks	4	1	2	1	1
Weighted Ave	12	9	8	7	7
ABS alone					
Passenger Cars	49	46	39	33	21
Light Trucks	42	35	27	25	22
Weighted Ave	45	40	32	29	22
ABS + ESC					
Passenger Cars	29	36	44	52	65
Light Trucks	54	64	72	74	77
Weighted Ave	42	52	60	64	71

Based on the assumptions above and the data provided in Table V-1, the percent of the MY 2011 fleet that needs these specific technologies in order to reach 100 percent of the fleet with ESC are shown in the Table V-2.

Table V-2
Percent of Fleet Needing Technology to Achieve 100% ESC

	None	ABS + ESC	ESC only
Passenger Cars	65	14	21
Light Trucks	77	1	22
Weighted Ave.	71	7	22

The cost estimates developed for this analysis were taken from tear down studies that a contractor has performed for NHTSA[30]. The total average incremental cost for ABS and ESC in these vehicles is estimated at $479 (see Table V-3). This process resulted in estimates of the consumer cost of ABS at $368, and the incremental cost of ESC at $111, for a total cost of $479.

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[30] In order to abide with our confidentiality agreements with the manufacturers, the particular make/models will not be disclosed. However, a representative sample of passenger cars, light trucks, vans, and SUVs designed in the U.S., Europe, and Japan were analyzed.

Table V-3
Incremental Cost and Weights for ABS and ESC

	ABS	ESC	ABS/ESC Combined
Costs	$368	$111	$479
Weights	4.85 kg. 10.7 lbs.	0.82 kg. 1.8 lbs.	5.67 kg. 12.5 lbs.

We included, in these costs above, the costs and weights for two malfunction warning telltales, one for ABS and one for ESC systems, at $2.52 per telltale (which includes the malfunction electronics) and 0.02 pounds. We assumed that existing ABS systems and existing ESC systems already had a malfunction warning telltale.

The agency and its contractor had a very difficult time determining the parts that made up the ABS and ESC systems, and separating out the traction control systems. Each manufacturer provided the contractor with a confidential list of parts that comprised their systems. However, some manufacturers included everything in the brake system (down to the nuts and bolts), including parts from the non-ABS hydraulic brake systems, and other manufacturers provided only the new big ticket items (new sensors and integrated control unit). Each manufacturer has different names for their systems, uses different parts, and the systems are quickly changing. The agency took the contractor's data and tried to make a consistent set of incremental parts for each manufacturer and averaged these data, as shown in Table V-4. Costs and weights were very similar between passenger cars and light trucks and are assumed to be the same for all vehicles. Further complicating the task was changing technology. For example, when we compared some ABS systems to ABS/ESC systems for the same make/models, we found that the integrated control unit doing both functions (ABS and ESC) was cheaper than the previous integrated control unit handling only ABS. In this case we assumed that the ABS integrated control unit could have been made less expensive if it were redesigned after the learning curve of technology costs. In essence, we have a cost estimate from a slice in time (MY 2005).

Table V-4
Average Incremental Costs and Weights
($2005 and lbs.)

ABS System Components	Incremental Costs	Incremental Weight
Speed Sensors	$60.32	3.22 lbs.
Integrated Control Unit/Hydraulic Control Unit	290.03	6.78
Wires/Telltale/Hardware	17.52	0.70
Subtotal	$367.87	10.70
ESC System Components		
Yaw Rate/Lateral Acceleration Sensors	$60.24	0.78
Steering Wheel Sensor	27.55	0.35
Integrated Control Unit (over ABS)	17.58	0.61
Wires/Telltale	5.52	0.08
Subtotal	$110.89	1.82
Total	$478.76	12.52 lbs.

Note: Most ESC systems include a manual Off switch to allow the driver to turn off the ESC in some situations. The contractor's estimate of the cost of an Off switch averaged $5.93 and weighed 0.08 lbs. An Off switch is not required by the standard and has not been included in the average cost of the rule.

Combining the technology needs in Table V-2 with the cost above and the assumed production volume yields the cost in Table V-5 for the proposed standard.

Table V-5
Total Costs for the Proposal
($2005)

Passenger Cars	None	ABS + ESC	ESC only
% Needing Improvements	65%	14%	21%
8 million sales estimated		1.12 M	1.68 M
Costs per vehicle	0	$479	$111
Total costs	0	$536 M	$186 M
Light Trucks			
% Needing Improvements	77%	1%	22%
9 million sales estimated		0.09 M	1.98 M
Costs per vehicle	0	$479	$111
Total costs	0	$43 M	$ 220 M

M: million

Table V-6
Summary of Vehicle Costs
($2005)

	Average Vehicle Costs	Total Costs
Passenger Cars	$ 90.3	$ 722.5 mill.
Light Trucks	$ 29.2	$ 262.7 mill.
Total	$ 58.0	$ 985.2 mill.

In summary, Table V-6 shows that the incremental vehicle costs of providing electronic stability control and antilock brakes compared to manufacturer's planned production for MY 2011 fleet will add $985 million to new light vehicles at a cost averaging $58 per vehicle.

Predicting MY 2011 Installations for Manufacturers without their production plans

Because we have different effectiveness estimates for SUVs versus passenger cars, we broke out sales estimates into light trucks (pickups, vans, and SUVs) and passenger cars separately. At this time, our tear-down costs data do not indicate that an ABS or ESC system costs more or less for a light truck than for a passenger car. We assume they are the same cost. The basis for predicting MY 2011 installations for manufacturers without their production plans starts with data provided in the 2005 Wards Automotive Yearbook. This provides sales of MY 2004 vehicles by make/model, which includes actual rates of installations for standard equipment as well as factory-installed optional equipment.

From these MY 2004 sales data, and from make/model data provided in “Buying a Safer Car” by NHTSA for MY 2006, which provides information as to whether such equipment is provided as standard equipment or optional equipment, an estimate was made regarding predicted installations of ESC-related equipment for MY 2006. Assumptions made in the analysis included:

1) That the optional equipment installation rate for a specific make/model in MY 2004 would be the same optional equipment installation rate for that make/model in MY 2006. (This may well be a conservative assumption, given the level of media coverage of the benefits of ESC over this time period.)
2) When a MY 2004 make/model was replaced by another make/model by MY 2006, and both had optional equipment, the optional equipment installation rate would be the same for the new MY 2006 make/model.
3) When a totally new make/model was introduced by MY 2006 that had optional equipment, the sales level and the optional equipment installation rate from a similar vehicle in its class were used to estimate the sales and optional equipment installation rates for the new make/model.

Obviously, there are a number of assumptions that must be made in this estimation process for MY 2006; however, this will give us a closer estimate of current compliance with the ESC proposal than if we just relied on known MY 2006 installation rates.

B. Fuel Economy Impacts

Going through the same averaging technique we used for costs in Tables V-5 and V-6 and applying it to weights, we find that the proposal would add an additional 2.13 pounds to an average PC and 0.52 pounds to a LTV. The added weight would reduce vehicle fuel economy [measured by miles per gallon (mpg)] and consequently increase vehicle lifetime gasoline consumption and fuel economy costs. Lifetime fuel economy cost is the cost of additional gasoline used over the vehicles' life and is estimated on a per vehicle basis. Applying the estimated lifetime fuel economy cost per vehicle to every vehicle derives the fuel economy cost of the proposal. The cost is accrued throughout the vehicles' life and is discounted to reflect its present value (2005 $ value). The analysis uses a 3 percent and a 7 percent discount rate. The discounting procedures for future benefits and costs in regulatory impact analyses are based on the guidelines published in Appendix V of the "Regulatory Program of the United States Government", April 1, 1990 - March 31, 1991.

The process of deriving the lifetime fuel economy cost per vehicle can be represented by the following generic formula:

$$\mathrm{LFEV}_j = \sum_{i=1}^{N} \mathrm{FC}_i * \mathrm{G}_i(j) * \mathrm{d}_i$$

Where, LFEV_j = lifetime fuel economy cost per vehicle

j = added weight

N = vehicle life

FC_i = fuel price per gallon

$G_i(j)$ = additional gallons used per vehicle

d_i = discount factors at 3 or 7 percent

Within this formula, Vehicle life, N, is determined by the age at which 98 percent of the vehicles originally produced in a model year are no longer registered using Polk data (mainly because they have been scrapped). Based on this criterion and the vehicle operation data in the National Vehicle Population Profile (NVPP)[31], the agency concludes that PCs are expected to last an average of about 25 years and LTVs will last 36 years. Therefore, N = 25 for PCs and N=36 for LTVs.

Fuel prices per gallon, FC_i, are adapted from those (in 2003 dollar) published in the 2006 final rule for corporate average fuel economy (CAFE) standards for light trucks[32], but are presented in 2005 dollars. The adjustment factor from 2003 dollars to 2005 dollars is 1.055 (=112.145/106.305), which is the ratio of 2005 and 2003 gross domestic product (GDP) implicit price deflector[33]. Fuel taxes of $0.40 are already excluded from these unit prices since taxes are transfer payments and not a cost to society. These fuel prices are further adjusted to account for externalities that are associated with U.S. oil consumption but not reflected in the projected

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[31] Annual census of passenger cars and light trucks vans in operation, as July 1 of each year, compiled by R.L. Polk and Company.

[32] Final Regulatory Impact Analysis, Corporate Average Fuel Economy and CAFE Reform for MY 2008-2011 Light Trucks, March 2006

[33] Published by U.S. Department of Commerce, Bureau of Economic Analysis, May 25, 2006

market oil price. Externalities considered here include the monopsony effect of the oil market, oil price shock impacts, environmental impacts, and other impacts from rebound effects. Costs for these externalities are also adopted from those published in the 2006 CAFE final rule or revisions derived after the publication of the final rule. Detailed discussions about these external economic costs are available in the 2006 CAFE final rule.

Monopsony costs are related to oil supplier-demand and the anticompetitive nature of the global oil market. For the supplier side, the Organization of Petroleum Exporting Countries (OPEC) operates as a cartel that restricts oil production to escalate the price of oil far above its marginal cost. For the demand side, an increase in U.S. petroleum demand also can cause the world oil price to rise. Since the higher oil price is applied to all oil imported to the U.S., not just limited to the increased oil use, the actual cost for purchasing the increased amount would exceed their market payment. In addition, an increase in monopsony payment to foreign oil suppliers represents a net loss to U.S. oil purchasers and thus has a downward impact on the U.S. economy. Overall, the monopsony cost is estimated to be $0.142 per gallon[34].

The effects of oil price shocks account for the impacts on oil price that were triggered by a disruption in world oil supplies. The increased oil price reduces the level of U.S. economic output using its available resource. Also, a sudden disruption requires a rapid adjustment in oil use and the use of other energy sources and would impose an additional societal cost. The agency estimates that the cost is about $0.047 per gallon[35].

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[34] Derived from a revised value of $0.135 (2003 $) which is slightly different from $0.122 that was published in the 2006 CAFÉ final rule for light trucks.

[35] Adjusted from the $0.045 (2003 $) published in the 2006 CAFE final rule.

Environmental impacts include the economic and environmental consequence of increased emissions directly from vehicles (combustion emissions) and emissions associated with fuel's exploration, production, processing, and distribution (pre-combustion emissions). These emissions include carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrous oxides nitrogen (NO_x) and other airborne particulates. At this moment, the administration has not taken a position on combustion emission related costs. Also, the cost on a per vehicle basis is extremely small if based on estimates in the literature. Thus the cost for combustion emissions is not included in the analysis. As for pre-combustion emission related cost, the agency estimates its marginal cost is $0.084 per gallon[36].

This cost is adjusted downward to account for the emission impact due to the rebound effect. Rebound effect refers to drivers' compensatory behavior in response to the rising cost of driving due to lower fuel economy and increased oil prices. Drivers might reduce their driving by combining short trips and/or driving less to control the rising cost of driving. Driving less miles reduces emissions. The estimated emission impact due to the rebound effect is $0.030 per gallon[37]. Overall, the economic and environmental impact is estimated to be $0.054 per gallon (= $0.084 - $0.030)

Furthermore, the compensatory behavior due to the rebound effect, in turn, would generate other benefits to drivers and society such as reducing traffic congestion, motor vehicle crashes, and noise. The agency estimates that the combined benefit is about $0.07 per gallon, of which

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[36] Adjusted from the $0.080 (2003 $) estimated in the 2006 CAFE final rule

[37] Adjusted form the $0.028 (2003 $) estimated in the 2006 CAFE final rule

$0.045 is from the mitigation of traffic congestion, $0.024 from the reduction of crashes, and $0.001 from the elimination of noise[38].

Collectively, the net cost for these externalities is $0.173 per gallon (= $0.042 + 0.047 + $0.054 - $0.070). Note that the real impact of relatively small increase in vehicle weight on these externalities is unclear. The inclusion of estimates for these externalities nevertheless provides a comprehensive assessment of the costs and produces relatively conservative cost-effectiveness and net benefit estimates.

Additional gasoline use per vehicle, $G_i(j)$, is the difference in fuel consumption (in gallons) between an average baseline vehicle (i.e., 2011 MY) with added weight and without. Fuel consumption of a vehicle generally is a function of average vehicle miles traveled, the survival probability of the vehicle, its fuel economy, and vehicle weight. Specifically, some vehicles are gradually scrapped or retired each year after their initial production. As vehicles age, the actual miles traveled tend to decline. Therefore, the average vehicle miles traveled are discounted by the vehicle's survival probability to reflect the actual average miles traveled in each year. Dividing the actually vehicle miles traveled by the fuel economy derives the total gallons of fuel used. Fuel economy is determined according to procedures established by the Environmental Protection Agency (EPA). However, the EPA estimates that actual on-road fuel economy is overall 15 percent less than the EPA's derived fuel economy. Therefore, the EPA fuel economy values are discounted by 15 percent.

In essence, $G_i(j)$ can be noted as:

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[38] Adjusted separately from the $0.043 (traffic congestion), $0.023 (crashes), and $0.001 (noise) estimated in the 2006 CAFÉ final rule

$$G_i(j) = \frac{VMT_i * Suv_i}{0.85 * MPG_{w0+j}} - \frac{VMT_i * Suv_i}{0.85 * MPG_{w0}}$$

$$= \frac{VMT_i * Suv_i}{0.85} \left(\frac{1}{MPG_{w0+j}} - \frac{1}{MPG_{w0}} \right)$$

Where G_i = gasoline use per vehicle

j = added weigh

VMT_i = average miles traveled

Suv_i = vehicle survival probability

MPG_{w0} = fuel economy that is associated with vehicle test weight w0

0.85 = EPA factor to reflect the on-road driving fuel economy

The average vehicle miles traveled and survival probability are derived from the agency report on vehicle survivability and travel mileage schedules[39]. Fuel economy value for PCs is based on EPA fuel economy of 29.50 mpg achieved by the 2006 model year PCs[40]. The 2006 level CAFE standard of 22.50 mpg is used for the fuel economy value for LTVs. These fuel economy values are associated with their base vehicle test weights: 3,564 pounds for PCs and 4,750 pounds for LTVs. In other words, $MPG_{w0} = MPG_{3,564} = 29.50$ mpg for PCs and $MPG_{w0} = MPG_{4,750} = 22.50$ mpg for LTVs.

Furthermore, j represents the added weight, i.e., j = 2.13 pounds for PCs and j = 0.52 pounds for LTVs. A study by the National Research Council projected a fuel consumption of 3 to 4 percent

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

[40] Current the CAFE standard for PCs is 27.5 mpg.

for each 5 percent weight reduction while maintaining the same acceleration performance[41]. If an average is used, the projection means that every 1 percent reduction (or increase) in vehicle weight would reduce (or increase) fuel consumption by 0.7 percent (=3.5/5). Based in this projection, the new fuel consumption per mile, i.e., $\frac{1}{MPG_{w0+j}}$, can be transformed to be a function of base weight (w0), added weight (j pounds), and base fuel consumption $\frac{1}{MPG_{w0}}$:

$$\begin{aligned}\frac{1}{MPG_{w0+j}} &= (1+\frac{0.7j}{w0})\frac{1}{MPG_{w0}}\\ &= \frac{w0+0.7j}{w0}\frac{1}{MPG_{w0}}\end{aligned}$$

Substituting this formula to that in $G_i(j)$, $G_i(j)$ can be rewritten as

$$\begin{aligned}G_i(j) &= \frac{VMT_i * Suv_i}{0.85}(\frac{1}{MPG_{w0+j}} - \frac{1}{MPG_{w0}})\\ &= \frac{VMT_i * Suv_i}{0.85}(\frac{w0+0.7j}{w0}\frac{1}{MPG_{w0}} - \frac{1}{MPG_{w0}})\\ &= \frac{VMT_i * Suv_i}{0.85} * \frac{0.7j}{w0} * \frac{1}{MPG_{w0}}\end{aligned}$$

Lastly, <u>the discount factors (d_i)</u> are factors corresponding to mid-year 3 and 7 discount rates. The discount factors (d_i) corresponding a discount rate can be represented as:

$$d_i = \frac{1}{(1+d)^{i-0.5}}$$

Where, d = 3 percent or 7 percent

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[41] Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, National Research Council, National Academy Press, Washington DC, 2002

Substitute the above detailed formulas back into the generic LFEV_j, the LFEV_j can be refined as:

$$
\begin{aligned}
\text{LFE}_j &= \sum_{i=1}^{N} \text{FC}_i * \text{G}_i(j) * d_i \\
&= \sum_{i=1}^{N} \text{FC}_i * (\text{VMT}_i * \text{Suv}_i * \frac{0.7j}{0.85 * \text{MPG}_{w0}}) * \frac{1}{(1+d)^{i-0.5}} \\
&= \frac{0.7j}{0.85 * \text{MPG}_{w0}} \sum_{i=1}^{N} \text{FC}_i * \text{VMT}_i * \text{Suv}_i * \frac{1}{(1+d)^{i-0.5}}
\end{aligned}
$$

Tables V-7 to V-10 illustrate the process of deriving LFEV_i. These tables list the unit fuel prices, vehicle miles traveled, survival probability, fuel consumption in gallons, and present discounted values of fuel costs by vehicle age. Tables V-7 and V-8 show the present discounted values of fuel costs at 3 percent discount for PCs and LTVs, respectively. In parallel, Tables V-9 and V-10 show the present discounted values of the fuel costs at 7 percent discount.

As shown, the average weight gain of 2.13 pounds for every PC results in an additional 2.6 gallons of fuel being used over its lifetime. The present discounted value of the added fuel cost over the lifetime of an average passenger car is estimated to be \$3.35 at a 3 percent discount rate and \$2.73 at a 7 percent discount rate. The average weight increase for every light truck is estimated to be 0.52 pounds. The incremental fuel cost for LTVs is negligible.

Applying the per vehicle based fuel costs and fuel consumption to the total vehicles derives the total fuel impacts of the proposal. Table V-11 summarizes the estimated fuel economy impact of the proposal. As shown, the proposal would increase the lifetime fuel consumption by a total of 20.8 million gallons. The estimated added fuel consumption cost is estimated to be \$26.8 million at 3 percent discount and $21.8 million at 7 percent discount. Fuel consumption costs for PCs contribute to almost all the fuel economy impacts of the proposal.

Table V-7
Present Discounted Value @3% of Lifetime Fuel Economy Impact Per Passenger Car* (2005 Dollars)

Vehicle Age	Vehicle Miles Traveled	Survival Prob-ability	Actual Vehicle Miles Traveled	Fuel Price**	Fuel Consumption (gallon)		Present Value of Fuel Consumption ($)	
					Base	New	Base	New
1	14,231	0.990	14,089	1.65	561.7	562	$913.18	$913.67
2	13,961	0.983	13,725	1.58	547.2	547.5	$827.05	$827.51
3	13,669	0.973	13,300	1.49	530.3	530.5	$733.89	$734.17
4	13,357	0.959	12,813	1.49	510.9	511.1	$686.41	$686.68
5	13,028	0.941	12,262	1.48	488.9	489.1	$633.49	$633.75
6	12,683	0.919	11,652	1.48	464.6	464.8	$584.47	$584.72
7	12,325	0.892	10,991	1.46	438.2	438.4	$527.94	$528.18
8	11,956	0.860	10,287	1.48	410.2	410.3	$486.41	$486.52
9	11,578	0.825	9,554	1.49	380.9	381.1	$441.43	$441.67
10	11,193	0.787	8,804	1.51	351.1	351.2	$400.38	$400.49
11	10,804	0.717	7,746	1.53	308.9	309	$346.52	$346.63
12	10,413	0.612	6,378	1.55	254.3	254.4	$280.57	$280.68
13	10,022	0.509	5,105	1.58	203.5	203.6	$222.21	$222.32
14	9,633	0.414	3,990	1.60	159.1	159.2	$170.81	$170.92
15	9,249	0.331	3,060	1.61	122	122	$127.95	$127.95
16	8,871	0.260	2,310	1.63	92.1	92.2	$94.94	$95.04
17	8,502	0.203	1,724	1.64	68.7	68.8	$69.18	$69.28
18	8,144	0.157	1,275	1.66	50.8	50.8	$50.27	$50.27
19	7,799	0.120	936	1.67	37.3	37.3	$36.05	$36.05
20	7,469	0.092	684	1.68	27.3	27.3	$25.77	$25.77
21	7,157	0.070	498	1.69	19.9	19.9	$18.35	$18.35
22	6,866	0.053	362	1.70	14.4	14.4	$12.97	$12.97
23	6,596	0.040	263	1.71	10.5	10.5	$9.23	$9.23
24	6,350	0.030	191	1.72	7.6	7.6	$6.53	$6.53
25	6,131	0.023	139	1.74	5.5	5.5	$4.64	$4.64
Total			152,137		6065.9	6068.5	$7,710.64	$7,713.99
Difference Between New and Base						2.6		$3.35

*Average vehicle test weight = 3,564 pounds; ** Excluded $0.40 for taxes and $0.173 for externalities

Table V-8
Present Discounted Value @3% of Lifetime Fuel Economy Impact Per Light Truck/Van* (2005 Dollars)

Vehicle Age	Vehicle Miles Traveled	Survival Prob-ability	Actual Vehicle Miles Traveled	Fuel Price**	Fuel Consumption (gallon)		Present Value of Fuel Consumption ($)	
					Base	New	Base	New
1	16,085	0.974	15,668	1.65	819.0	819.0	$1,331.49	$1,331.49
2	15,782	0.960	15,155	1.58	792.2	792.2	$1,197.35	$1,197.35
3	15,442	0.942	14,547	1.49	760.4	760.4	$1,052.33	$1,052.33
4	15,069	0.919	13,849	1.49	723.9	723.9	$972.58	$972.58
5	14,667	0.891	13,072	1.48	683.3	683.3	$885.38	$885.38
6	14,239	0.859	12,230	1.48	639.3	639.3	$804.24	$804.24
7	13,790	0.823	11,343	1.46	592.9	592.9	$714.32	$714.32
8	13,323	0.783	10,428	1.48	545.1	545.1	$646.37	$646.37
9	12,844	0.740	9,506	1.49	496.9	496.9	$575.87	$575.87
10	12,356	0.696	8,595	1.51	449.3	449.3	$512.36	$512.36
11	11,863	0.650	7,712	1.53	403.1	403.1	$452.20	$452.20
12	11,369	0.604	6,870	1.55	359.1	359.1	$396.19	$396.19
13	10,879	0.552	6,002	1.58	313.7	313.7	$342.54	$342.54
14	10,396	0.501	5,207	1.60	272.2	272.2	$292.23	$292.23
15	9,924	0.452	4,488	1.61	234.6	234.6	$246.04	$246.04
16	9,468	0.406	3,846	1.63	201.1	201.1	$207.30	$207.30
17	9,032	0.363	3,281	1.64	171.5	171.5	$172.69	$172.69
18	8,619	0.324	2,790	1.66	145.8	145.8	$144.27	$144.27
19	8,234	0.287	2,366	1.67	123.7	123.7	$119.57	$119.57
20	7,881	0.254	2,004	1.68	104.7	104.7	$98.84	$98.84
21	7,565	0.224	1,697	1.69	88.7	88.7	$81.79	$81.79
22	7,288	0.198	1,440	1.70	75.2	75.2	$67.72	$67.72
23	7,055	0.174	1,224	1.71	64.0	64.0	$56.27	$56.27
24	6,871	0.152	1,046	1.72	54.7	54.7	$46.98	$46.98
25	6,739	0.133	898	1.74	46.9	46.9	$39.55	$39.55
26	6663	0.116	776	1.75	40.6	40.6	$33.44	$33.44
27	6648	0.102	676	1.77	35.3	35.3	$28.55	$28.55
28	6648	0.089	590	1.78	30.8	30.8	$24.32	$24.32
29	6648	0.077	514	1.79	26.9	26.9	$20.74	$20.74
30	6648	0.067	448	1.81	23.4	23.4	$17.71	$17.71
31	6648	0.059	389	1.82	20.4	20.4	$15.07	$15.07
32	6648	0.051	339	1.84	17.7	17.7	$12.84	$12.84
33	6648	0.044	294	1.85	15.4	15.4	$10.90	$10.90
34	6648	0.038	256	1.86	13.4	13.4	$9.26	$9.26
35	6648	0.033	222	1.88	11.6	11.6	$7.87	$7.87
36	6648	0.029	193	1.89	10.1	10.1	$6.68	$6.68
Total			179,957		9,406.9	9,406.9	$11,643.85	$11,643.85
Difference Between New and Base						0.00***		$0.00***

*Average vehicle test weight = 4,750 pounds; ** Excluded $0.40 for taxes and $0.173 for externalities;
*** Insignificant difference

Table V-9
Present Discounted Value @7% of Lifetime Fuel Economy Impact Per Passenger Car* (2005 Dollars)

Vehicle Age	Vehicle Miles Traveled	Survival Prob-ability	Actual Vehicle Miles Traveled	Fuel Price**	Fuel Consumption (gallon)		Present Value of Fuel Consumption ($)	
					Base	New	Base	New
1	14,231	0.990	14,089	1.65	561.7	562	$895.94	$896.42
2	13,961	0.983	13,725	1.58	547.2	547.5	$781.14	$781.57
3	13,669	0.973	13,300	1.49	530.3	530.5	$667.20	$667.45
4	13,357	0.959	12,813	1.49	510.9	511.1	$600.70	$600.93
5	13,028	0.941	12,262	1.48	488.9	489.1	$533.63	$533.85
6	12,683	0.919	11,652	1.48	464.6	464.8	$473.97	$474.17
7	12,325	0.892	10,991	1.46	438.2	438.4	$412.14	$412.33
8	11,956	0.860	10,287	1.48	410.2	410.3	$365.47	$365.56
9	11,578	0.825	9,554	1.49	380.9	381.1	$319.30	$319.47
10	11,193	0.787	8,804	1.51	351.1	351.2	$278.76	$278.84
11	10,804	0.717	7,746	1.53	308.9	309	$232.24	$232.32
12	10,413	0.612	6,378	1.55	254.3	254.4	$181.04	$181.11
13	10,022	0.509	5,105	1.58	203.5	203.6	$138.00	$138.07
14	9,633	0.414	3,990	1.60	159.1	159.2	$102.13	$102.19
15	9,249	0.331	3,060	1.61	122	122	$73.64	$73.64
16	8,871	0.260	2,310	1.63	92.1	92.2	$52.60	$52.66
17	8,502	0.203	1,724	1.64	68.7	68.8	$36.90	$36.95
18	8,144	0.157	1,275	1.66	50.8	50.8	$25.80	$25.80
19	7,799	0.120	936	1.67	37.3	37.3	$17.82	$17.82
20	7,469	0.092	684	1.68	27.3	27.3	$12.26	$12.26
21	7,157	0.070	498	1.69	19.9	19.9	$8.40	$8.40
22	6,866	0.053	362	1.70	14.4	14.4	$5.72	$5.72
23	6,596	0.040	263	1.71	10.5	10.5	$3.92	$3.92
24	6,350	0.030	191	1.72	7.6	7.6	$2.67	$2.67
25	6,131	0.023	139	1.74	5.5	5.5	$1.82	$1.82
Total			152,137		6065.9	6068.5	$6,223.21	$6,225.94
Difference Between New and Base						2.6		$2.73

*Average vehicle test weight = 3,564 pounds; ** Excluded 0.40 taxes and $0.173 for externalities

Table V-10
Present Discounted Value @7% of Lifetime Fuel Economy Impact Per Light Truck/Van* (2005 Dollars)

Vehicle Age	Vehicle Miles Traveled	Survival Prob-ability	Actual Vehicle Miles Traveled	Fuel Price**	Fuel Consumption (gallon)		Present Value of Fuel Consumption ($)	
					Base	New	Base	New
1	16,085	0.974	15,668	1.65	819.0	819.0	$1,306.35	$1,306.35
2	15,782	0.960	15,155	1.58	792.2	792.2	$1,130.89	$1,130.89
3	15,442	0.942	14,547	1.49	760.4	760.4	$956.70	$956.70
4	15,069	0.919	13,849	1.49	723.9	723.9	$851.13	$851.13
5	14,667	0.891	13,072	1.48	683.3	683.3	$745.82	$745.82
6	14,239	0.859	12,230	1.48	639.3	639.3	$652.19	$652.19
7	13,790	0.823	11,343	1.46	592.9	592.9	$557.64	$557.64
8	13,323	0.783	10,428	1.48	545.1	545.1	$485.66	$485.66
9	12,844	0.740	9,506	1.49	496.9	496.9	$416.54	$416.54
10	12,356	0.696	8,595	1.51	449.3	449.3	$356.73	$356.73
11	11,863	0.650	7,712	1.53	403.1	403.1	$303.07	$303.07
12	11,369	0.604	6,870	1.55	359.1	359.1	$255.65	$255.65
13	10,879	0.552	6,002	1.58	313.7	313.7	$212.73	$212.73
14	10,396	0.501	5,207	1.60	272.2	272.2	$174.73	$174.73
15	9,924	0.452	4,488	1.61	234.6	234.6	$141.60	$141.60
16	9,468	0.406	3,846	1.63	201.1	201.1	$114.86	$114.86
17	9,032	0.363	3,281	1.64	171.5	171.5	$92.11	$92.11
18	8,619	0.324	2,790	1.66	145.8	145.8	$74.06	$74.06
19	8,234	0.287	2,366	1.67	123.7	123.7	$59.08	$59.08
20	7,881	0.254	2,004	1.68	104.7	104.7	$47.02	$47.02
21	7,565	0.224	1,697	1.69	88.7	88.7	$37.45	$37.45
22	7,288	0.198	1,440	1.70	75.2	75.2	$29.85	$29.85
23	7,055	0.174	1,224	1.71	64.0	64.0	$23.88	$23.88
24	6,871	0.152	1,046	1.72	54.7	54.7	$19.18	$19.18
25	6,739	0.133	898	1.74	46.9	46.9	$15.55	$15.55
26	6663	0.116	776	1.75	40.6	40.6	$12.65	$12.65
27	6648	0.102	676	1.77	35.3	35.3	$10.40	$10.40
28	6648	0.089	590	1.78	30.8	30.8	$8.53	$8.53
29	6648	0.077	514	1.79	26.9	26.9	$7.00	$7.00
30	6648	0.067	448	1.81	23.4	23.4	$5.76	$5.76
31	6648	0.059	389	1.82	20.4	20.4	$4.72	$4.72
32	6648	0.051	339	1.84	17.7	17.7	$3.87	$3.87
33	6648	0.044	294	1.85	15.4	15.4	$3.16	$3.16
34	6648	0.038	256	1.86	13.4	13.4	$2.58	$2.58
35	6648	0.033	222	1.88	11.6	11.6	$2.11	$2.11
36	6648	0.029	193	1.89	10.1	10.1	$1.73	$1.73
Total			179,957		9,406.9	9,406.9	$9,122.98	$9,122.98
Difference Between New and Base						0.00***		$0.00***

*Average vehicle test weight = 4,750 pounds; ** Excluded $0.40 for taxes and $0.173 for externalities;
*** Insignificant difference

Table V-11
Fuel Economy Impacts
by Vehicle Type and Discount Rate
(2005 Dollars)

At 3% Discount

	Added Weights Per Vehicle (pounds)	Total Vehicles	Additional Fuel Use Per Vehicle (gallon)	Fuel Economy Per Vehicle ($)	Total Additional Fuel Use (gallon)	Present Value of Total Fuel Economy ($)
PCs	2.13	8,000,000	2.6	$3.35	20,800,000	$26,800,000
LTVs	0.52	9,000,000	0.0*	$0.00*	0*	$0*
Total		17,000,000			20,800,000	$26,800,000

At 7% Discount

	Added Weights Per Vehicle (pounds)	Total Vehicles	Additional Fuel Use Per Vehicle (gallon)	Fuel Economy Per Vehicle ($)	Total Additional Fuel Use (gallon)	Present Value of Total Fuel Economy ($)
PCs	2.13	8,000,000	2.6	$2.73	20,800,000	$21,840,000
LTVs	0.52	9,000,000	0.0*	$0.00*	0*	$0*
Total		17,000,000			20,800,000	$21,840,000

* Extremely small numbers

C. Summary

The following summarizes the estimated cost and fuel economy impacts of the proposal:

- Technology cost: $985 million
    - Cost per vehicle: $58.0 ($90.3 per PC; $29.2 per LTV)
    - Number of vehicles: 17 million (8 million PCs and 9 million LTVs)
- Fuel economy impacts
    - Added weight per vehicle: 2.13 lbs per PC; 0.52 lbs per LTV
    - Additional fuel consumption per vehicle: 2.6 gallons per PC; < 0.001 gallons per LTV
    - Total additional fuel consumption: 20.8 million gallons
    - Fuel cost: $26.8 million at 3 percent; $21.8 million at 7 percent

CHAPTER VI. COST-EFFECTIVENESS AND BENEFIT-COST

This chapter provides cost-effectiveness and benefit-cost analysis for the ESC proposal. The Office of Management and Budget (OMB) requires all agencies to perform both analyses in support of rules, effective January 1, 2004.[42]

The cost-effectiveness measures the net cost per equivalent life saved (i.e., per equivalent fatality), while the benefit-cost measures the net benefit which is the difference between benefits and net costs in monetary values. The net cost is equal to the technology and fuel costs for the vehicles minus the savings from the prevention of crash-related travel delays and property damage. Thus, these two analyses require four primary components: injury benefits, travel delays and property damage savings, vehicle costs, and fuel costs. Injury benefits are expressed in fatal equivalents in cost-effectiveness analysis and are further translated into monetary value in benefit-cost analysis. Fatal equivalents and travel delays and property damage savings represent the savings throughout the vehicle life and are discounted to reflect their present values (2005 $ value). The discounting procedures for future benefits and costs in regulatory impact analyses are based on the guidelines published in Appendix V of the "Regulatory Program of the United States Government", April 1, 1990 - March 31, 1991. The guidelines state, "An attempt should be made to quantify all potential real incremental benefits to society in monetary terms to the maximum extent possible."

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

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[42] See OMB Circular A-4.

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 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[43] 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[44] put the rate at between one and five percent, based on returns to stocks and three-month Treasury bills. Moore and Viscusi[45] 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 agencies use both 3 percent and 7 percent as the “social rate of time preference.”

Safety benefits can occur at any time during the vehicle's lifetime. For this analysis, the agency assumes that the distribution of weighted yearly vehicle miles traveled is an appropriate proxy

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[43] 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.).

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

[45] 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.

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 vehicle miles traveled (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 a factor of 0.8304 for PCs and 0.8022 for LTVs under a 3 percent discounted rate. For the 7 percent discounted rate, these factors are 0.6700 and 0.6300 for PCs and LTVs, respectively. For example, the present value of the benefits for PCs at the 3 percent discounted rate is equivalent to a 0.8304 of the initial estimates.

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, 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.

These values were taken from the most recent study of vehicle crash-related economic impacts published by NHTSA[46]. Because travel delay and property damage were netted out from cost, they were taken out from these comprehensive values. The reported costs were in 2000 dollars. These dollars were adjusted to 2005 dollars by a factor of 1.121 (the same factor used in the benefit chapter). Table VI-1 shows the comprehensive costs for each MAIS injury level. Note the adjustment did not affect the relative fatality ratio since the factor 1.121 was applied to each unit.

Table VI-1
Calculation of Fatal Equivalents

Injury Severity	Comprehensive Cost (2000 $)	Comprehensive Cost* (2005 $)	Relative Fatality Ratio
MAIS 1	$10,396	$11,654	0.00311
MAIS 2	$153,157	$171,689	0.04576
MAIS 3	$306,465	$343,547	0.09156
MAIS 4	$720,747	$807,957	0.21534
MAIS 5	$2,384,403	$2,672,916	0.71241
Fatality	$3,346,966	$3,751,949	1.00000

Source: Table VIII-9 of "The Economic Impact of Motor Vehicle Crashes 2000"
* Adjusted from 2000 $ by a factor of 1.121

Fatal equivalents are derived by applying the relative fatality ratios to the estimated MAIS 1-5 injury benefits. As discussed earlier, benefits are realized through a vehicle's life. Thus, fatal equivalents are required to be discounted at 3 and 7 percent. Table VI-2 shows the undiscounted and discounted fatal equivalents. As shown, undiscounted the proposal would save 2,656 – 3,647 fatal equivalents. At a 3 percent discount rate, 2,180 – 2,974 would be saved. At a 7 percent discount rate, 1,746 – 2,370 would be saved.

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

Table VI-2

Fatal Equivalents

Lower Bound*

Injury Severity	No Discount			At 3 Percent Discount			At 7 Percent Discount		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	88	39	127	73	31	104	59	25	84
2	158	88	246	131	71	202	106	55	161
3	190	71	261	158	57	215	127	45	172
4	180	54	234	149	43	192	121	34	155
5	209	43	252	174	34	208	140	27	167
Fatalities	956	580	1,536	794	465	1,259	641	366	1,007
Total	1,781	875	2,656	1,479	701	2,180	1,194	552	1,746

Higher Bound

Injury Severity	No Discount			At 3 Percent Discount			At 7 Percent Discount		
MAIS	PC	LTV	Total	PC	LTV	Total	PC	LTV	Total
1	88	89	177	73	71	144	59	56	115
2	158	180	338	131	145	276	106	113	219
3	190	144	334	158	115	273	127	91	218
4	180	103	283	149	82	231	121	65	186
5	209	95	304	174	76	250	140	60	200
Fatalities	956	1,255	2,211	794	1,006	1,800	641	791	1,432
Total	1,781	1,866	3,647	1,479	1,495	2,974	1,194	1,176	2,370

PC: passenger cars, LTV: light trucks/vans

* Assuming the effectiveness of LTVs = PCs

B. Net Costs

The net cost is the difference between the technology and fuel economy costs and the savings from travel delays and property damage. The total technology cost of the proposal as estimated in the cost chapter is $985 million. The technology cost represents the investments paid now for future benefits and thus no discounting is needed.

By contrast, the travel delay and property damage savings and fuel economy costs are realized through vehicle's life, thus are required to be discounted at 3 and 7 percent. At a 3 percent discount, the travel delay and property damage savings range from $325 to $453 million. At a 7 percent discount, the savings are estimated to range $260 to $361 million. The fuel economy costs are estimated be $26.8 and $21.8 million at 3 percent and 7 percent discount, respectively. Subtracting the travel delay and property damage savings from vehicle technology and fuel economy costs derives the net cost. The net cost is estimated to range from $559 to $687 million at a 3 percent discount and $646 to $747 million at a 7 percent discount. Table VI-3 lists the vehicle technology cost, travel delays and property damage savings, fuel economy costs, and the net costs by discount rate,

Table VI-3
Net Costs by Discount Rate
(2005 $)

	At 3% Discount	At 7% Discount
Vehicle Cost (a)*	$985 M	$985 M
Savings from Property Damage and Travel Delay (b)	$325 - $453 M	$260 - $361 M
Fuel Economy Impact (c)	$26.8 M	$21.8 M
Net Costs (= a – b + c)	$559 -$687 M	$646 - $747 M

* 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.
M: million

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. As show in Table VI-3, the net cost is estimated to be \$559 to \$687 million at a 3 percent discount and \$646 to \$747 million at a 7 percent discount. Dividing these costs to the responding fatal equivalents derives the net cost per equivalent fatality. The net cost per equivalent fatality would range from \$0.19 to \$0.32 million at a 3 percent discount, and \$0.27 - \$0.43 million at a 7 percent discount.

D. Net Benefits

Benefit-cost analysis derives the net benefits which is the difference between the injury benefits and the net costs of the proposal in monetary values. Thus, benefit-cost analysis differs from cost-effectiveness analysis in that it requires that benefits be assigned a monetary value, and that this value be compared to the monetary value of costs to derive a net benefit. As shown in Table VI-5, a fatality was valued at \$3,751,949 in 2005 dollars. Multiplying this unit cost by the total fatal equivalents (Table VI-2) derives the monetary values for the injury benefits of the proposal. As results, the <u>injury benefit</u> is estimated to range from \$8.2 to \$11.2 billion at a 3 percent discount and \$6.6 to \$8.9 billion at a 7 percent discount.

After translating the injury benefits into monetary values and deriving the net cost (Table VI-3), the net benefits simply is the difference of these values. Table IV-4 shows the discounted injury benefits, net costs, and net benefits. As shown, the net benefits would range from $7.5 to $10.6 billion at a 3 percent discount rate and $5.8 to $8.2 billion at a 7 percent discount rate.

E. Summary

In summary, this proposal would save 1,536 to 2,211 lives and eliminate 50,594 to 69,630 MAIS 1-5 injuries. These fatalities and injuries translate to a total of 2,656 to 3,467 undiscounted fatal equivalents, 2,180 to 2,974 fatal equivalent at a 3 percent discount, and 1,746 to 2,730 fatal equivalents at a 7 percent discount rate.

The cost per equivalent life saved would range from $0.19 to $0.32 million at a 3 percent discount and $0.27 to $0.43 million at a 7 percent discount. The net benefit is estimated to range from $7.5 to $10.6 billion at a 3 percent discount and $5.8 to $8.2 billion at a 7 percent discount. Table VI-4 summarizes the fatal equivalents, cost-effectiveness, and net benefit statistics. The low and high figures correspond to the low and high bounds of injury benefits. Based on these cost/benefit statistics, the proposal is extremely cost-effective. The cost per life saved, at both 3 and 7 discount, is estimated to be less than a $450,000. At both 3 and 7 discount, the proposal would generate over $5.5 billion in net benefits.

Table VI-5
Cost-Effectiveness and Net Benefits by Discount Rate
(2005 $)

	3% Discount		7% Discount	
	Low	High	Low	High
Fatal Equivalents	2,180	2,974	1,746	2,370
Injury Benefits (1)	$8,179,248,820	$11,158,296,326	$6,550,902,954	$8,892,119,130
PD&TD Savings	$325,144,966	$452,803,776	$260,294,366	$360,597,716
Vehicle Costs*	$985,157,000	$985,157,000	$985,157,000	$985,157,000
Fuel Costs	$26,800,000	$26,800,000	$21,840,000	$21,840,000
Net Costs (2)	$686,812,034	$559,153,224	$746,702,634	$646,399,284
Net Cost Per Fatal Equivalent (3)	$188,014	$315,051	$272,742	$427,665
Net Benefits (4)	$7,492,436,786	$10,599,143,102	$5,804,200,320	$8,245,719,846

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) = $3,751,949 * Fatal Equivalents
(2) = Vehicle Costs - PD&TD + Fuel Economy Costs
(3) = Net Costs/Fatal Equivalents
(4) = Injury Benefits – Net Costs

CHAPTER VII. ALTERNATIVES

The agency considered two alternatives to the proposal. The first was to limit the ESC standard's applicability only to LTVs. The second alternative was to not require a 4-wheel system, which would allow a 2-wheel system to be used by manufacturers.

Alternative 1, Limiting the Applicability to LTVs

The agency considered this alternative for two reasons: (a) the ESC effectiveness rates for LTVs against single-vehicle crashes were almost twice as high of the effectiveness rates for passenger cars (PCs), and (b) LTVs generally had a higher propensity for rollover than PCs. The alternative would address the core rollover issue and target the high-risk rollover vehicle population. However, after examining the safety impact and the cost-effectiveness of the alternative, the agency determined that an excellent opportunity to reduce passenger car crashes would be lost if PCs were excluded from the proposal.

We examined this alternative by looking at the impacts of requiring ESC for passenger cars. Requiring ESC for passenger cars would save 956 lives and reduce 34,902 non-fatal injuries. Following this analysis through the cost-effectiveness equations, the cost-effectiveness analysis shows that ESC is highly cost-effective for PCs alone. For PCs, the cost per equivalent life saved is estimated to be $0.35 million at a 3 percent discount rate and $0.47 million at a 7 percent discount rate. The net benefit would be $4.8 billion at a 3 percent discount rate and $3.8 billion at a 7 percent discount rate.

Given the fact that ESC is highly cost-effective and that extending the ESC applicability to PCs would save a large number of additional lives (956) and reduce a large number of additional injuries (34,902), the agency is not proposing this alternative.

Alternative 2, Two-Wheel System

2-Wheel vs. 4-Wheel systems

General Motors utilized a 2-wheel ESC system in most of its ESC-equipped passenger cars through MY 2005, but has changed over to a 4-wheel system in MY 2006. All other manufacturers have utilized a 4-wheel ESC system in their vehicles. The agency's tests on the track indicate that the 4-wheel systems tend to exhibit more oversteer mitigation capability than GM's earlier 2-wheel systems.

Statistical analyses comparing 2-wheel to 4-wheel ESC systems were shown in Chapter III. The effectiveness estimates show a potentially enhanced benefit of 4-wheel ESC systems over 2-wheel ESC systems in reducing single-vehicle run-off-road crashes (significant at the 0.05 level), although the benefit could not be shown in a separate analysis of fatal-only crashes, likely due to the small sample size.

The agency's contractor has performed a teardown study to determine the difference in costs between a 2-wheel and 4-wheel system, and the 2-wheel system is about $10.00 less expensive. However, it is not intuitively obvious that the difference need be this much, and with a sample of one, it is possible that other changes in design for other reasons may be affecting this estimate.

Since the industry has moved away from the 2-wheel system on its own, and it appears that the difference in cost of $10 or less will be insignificant as compared to the additional benefits achieved with 4-wheel ESC, we are not providing a full analysis of this alternative at this time.

Based on the available information, the agency is proposing the 4-wheel system. The agency's decision is based on our and the industry's engineering judgment that the 4-wheel system is more effective, the effectiveness study showing that the 4-wheel system is more effective than the 2-wheel system in reducing crashes, the industry trend towards installing the 4-wheel system in their vehicles, and the estimated cost differences between 2-wheel and 4-wheel ESC systems.

VIII. PROBABILISTIC UNCERTAINTY ANALYSIS

This chapter identifies and quantifies the major uncertainties in the cost-effectiveness and net benefit (benefit-cost) analyses and examines the impacts of these uncertainties. Throughout the course of these analyses, many assumptions were made, diverse data sources were used, and different statistical processes were applied. The variability of these assumptions, data sources, and statistical processes potentially would influence the estimated regulatory outcomes. Thus, all these assumptions, data sources, and derived statistics can be considered as uncertainty factors for the regulatory analysis. The purpose of this uncertainty analysis is to identify the uncertainty factors with appreciable variability, quantify these uncertainty factors by appropriate probability distributions, and induce the probabilistic outcomes accompanied with degrees of probability or plausibility. This facilitates a more informed decision-making process.

A Monte Carlo statistical simulation technique[47] is used to accomplish the process. The technique is to first randomly select values for those uncertainty factors from their pre-established probability distributions. The selected values then are fed back to the cost-effectiveness and net benefit analysis process to generate all possible outcomes. The process is run repeatedly. Each complete run is a trial. Crystal Ball®[48], a spreadsheet-based risk analysis and forecasting software package which includes the Monte Carlo simulation technique tool, was chosen to automate the process. In addition to simulation results, Crystal Ball® also provides

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[47] a: Robert, C.P. & Casella, G., *Monte Carlo Statistical Methods*, Springer-Verlag New York, Inc., 1999
b: Liu, J.S., *Monte Carlo Strategies in Scientific Computing*, Springer-Verlag New York, Inc., 2001
(Or any statistics books describing the Monte Carlo simulation theory are good references for understanding the technique.)

[48] A registered trademark of Decisioneering, Inc.

the degree of certainty (or confidence, or credibility) that is associated with the simulated results. The degree of certainty provides the decision-makers an additional piece of important information to evaluate the outcomes.

The analysis starts by establishing mathematical models that imitate the actual processes in deriving cost-effectiveness and net benefits, as shown in previous chapters. The formulation of the models also allows analysts to conveniently identify and categorize uncertainty factors. In the mathematical model, each variable (e.g., cost of technology) represents an uncertainty factor that would potentially alter the model outcomes if its value were changed. Variations of these uncertainty factors are described by appropriate probability distribution functions. These probability distributions are established based on available data. If data are not sufficient or not available, professional judgments are used to estimate the distribution of these uncertainty factors.

After defining and quantifying the uncertainty factors, the next step is to simulate the model to obtain probabilistic results rather than single-value estimates. The simulation repeats the trials until certain pre-defined criteria[49] are met and a probability distribution of results is generated.

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[49] The pre-defined criteria may change with each uncertainty analysis. In this case, we require a 99 percent precision in mean for each simulated outcome such as total costs, cost-effectiveness, and net benefits as described later.

A. Simulation Models

Mathematical models were built to imitate the process used in deriving cost-effectiveness and net benefits as developed in previous chapters. Both the cost-effectiveness and net benefit models comprise four principal components: injury benefits, travel delay and property damage savings, vehicle technology costs, and fuel economy cost. These four components are discussed separately in the following sections.

A.1 Benefit Component

In the cost-effectiveness model, injury benefits are represented by fatal equivalents (FEs) reduced. In the net benefit model, injury benefits are represented by their monetary value, which is the product of comprehensive cost per life saved and FEs. Since benefits (fatalities and injuries reduced) were already expressed as FEs in the cost-effectiveness model, the net benefit model is just one step removed from the cost-effectiveness model. Therefore, the FE model is discussed first.

The overall FEs are derived from eight mutually exclusive target crash populations that were categorized by three attributes: crash type (single vehicle crashes, multi-vehicle crashes), crash severity (non-fatal, fatal), and vehicle type (PC, LTV). For example, one crash type is single-vehicle, non-fatal PC crashes. Each of these FEs is derived through the following steps:

(1) estimating initial crash benefits (i.e., crashes avoided by ESC)

(2) deriving corresponding injury benefits (i.e., fatalities and MAIS 1-5 injuries eliminated by ESC),

(3) deriving FEs by multiplying the injury benefits by their corresponding injury-to-fatality ratios, and

(4) discounting FEs to derive the discounted net benefits over the vehicle's life.

Therefore, FEs can be represented by the following mathematical formula:

$$\text{FEs} = \left(\sum_{i=1}^{8}\sum_{j=1}^{6} \text{TC}_i * e_i * p_{ij} * r_j\right) * d$$

Where TC_i= target crash population

e_i = effectiveness of ESC against the i^{th} target crash population

p_{ij} = MAIS j injuries per crash for i^{th} target crash population, with j=6 as fatalities

r_j = MAIS j injury-to-fatality ratio with j=6 as fatalities.

d = cumulative lifetime discount factor, either at 3 or 7 percent discount rate.

Of the notation and processes, the product of the i^{th} target crash (TC_i) and the corresponding ESC effectiveness rate (e_i) represents the crash benefits from the i^{th} target crash population (= TC_i*e_i). The product of the resulted crash benefits and severity j injuries per crash (p_{ij}) represents the injury benefits for severity j injuries (= $\text{TC}_i*e_i * p_{ij}$). Multiplying the injury severity j benefits by its corresponding injury-to-fatality ratio (= $\text{TC}_i*e_i * p_{ij} *r_j$) derives its FEs. Summed over the injury severity (indexed by j) and target crash population (indexed by i) thus will derive the total FEs. Finally, the total FEs are discounted either at a 3 or 7 percent rate to reflect the net benefits of the proposal over a vehicle's life.

As described, FEs is the basic benefit measurement for estimating cost-effectiveness. For net benefits, FEs is translated into monetary value. If M denotes the cost per fatality, benefit in the net benefit calculation is equal to M*FEs. Hence, the benefit component for net benefits is:

$$M * FEs = M * (\sum_{i=1}^{8} \sum_{j=1}^{6} TC_i * e_i * p_{ij} * r_j) * d$$

A.2 Traveling Delay and Property Damage Savings

Travel delay and property damage savings (S) can be represented by the following mathematical formula:

$$S = (\sum_{j=1}^{7} u_j * o_j) * d$$

Where,

u_j= unit cost for travel delays and property damage by MAIS injury severity levels and PDOV, with j=6 as fatalities and j=7 as PDOV

o_j = incidents by MAIS severity levels and PDOV

d = cumulative lifetime discount factors, either at 3 or 7 percent discount rate.

Incidents, o_i, represent injuries, fatalities, and PDOV that would be prevented by ESC. As described in the FE model and the benefit chapter, these incidents can be derived from target crashes avoided. Injuries and fatalities were derived by multiplying injuries per crash (noted as p_{ij} in the FE model) by the number of corresponding target crashes avoided (i.e., TC_i*e_i).

Similarly, PDOV is the product of PDOV per crash and the number of corresponding target crashes avoided. Thus, the S model can be further expanded as:

$$S = \left(\sum_{i=1}^{8}\sum_{j=1}^{7} u_i * TC_i * e_i * p_{ij}\right) * d$$

Note that p_{ij} represents severity j injuries per crash with $j \leq 6$ and PDOV per crash for $j = 7$.

A.3 Vehicle Technology Cost Component

Vehicle technology cost (VC) is the product of technology cost per vehicle and the number of vehicles. The technology cost per vehicle varies depending upon whether vehicles are required to install ABS and ESC or just ESC. As discussed in the cost chapter, the manufacturers' product plan for PCs is different from that of LTVs. Thus, the vehicle technology cost per vehicle differs between these two groups of vehicles. The vehicle technology cost of the proposal can be represented as:

$$VC = \sum_{i=1}^{2} c_i * v_i$$

Where, VC = vehicle technology cost

c_i = technology cost per vehicle, i=1 for PCs and i=2 for LTVs

v_i = vehicle population corresponding to c_i.

A.4 Fuel Economy Cost Component

The total lifetime fuel economic cost (LFE) model of the proposal can be represented by the following simplified formula:

$$\mathrm{LFE} = \sum_{i=1}^{2} \mathrm{LFEV}_i * v_i$$

Where, LFEV_i = present value of lifetime fuel economy per vehicle at 3 or 7 percent discount, with i=1 for PCs and i=2 for LTVs

v_i = number of vehicles

A.5 Cost-Effectiveness Model and Net Benefit Model

After the fatal equivalent, travel delay and property damage savings, vehicle technology cost, and fuel economy cost models were established, the cost-effectiveness model (CE) is calculated as the ratio of net costs (NC) to fatal equivalents (FEs) where net cost is equal to vehicle technology cost (VC) plus lifetime fuel economy cost (LFE) minus savings from travel delay and property damage (S). The cost-effectiveness model (CE) has the format:

$$\begin{aligned} \mathrm{CE} &= \frac{\mathrm{NC}}{\mathrm{FEs}} \\ &= \frac{\mathrm{VC} + \mathrm{LFE} - \mathrm{S}}{\mathrm{FEs}} \\ &= \frac{\sum_{i=1}^{2} (c_i + \mathrm{LFEV}_i) * v_i - (\sum_{i=1}^{8} \sum_{j=1}^{7} u_j * \mathrm{TC}_i * e_i * p_{ij}) * d}{(\sum_{i=1}^{8} \sum_{j=1}^{6} \mathrm{TC}_i * e_i * p_{ij} * r_i) * d} \end{aligned}$$

The net benefit is the difference between benefits expressed in monetary value and the net cost. The net benefit model (NB) has the format:

$$
\begin{aligned}
\mathrm{NB} &= \mathrm{M} * \mathrm{FEs} - \mathrm{NC} \\
&= \mathrm{M} * \mathrm{FEs} + \mathrm{S} - \mathrm{VC} - \mathrm{LFE} \\
&= \mathrm{M} * \left(\sum_{i=1}^{8} \sum_{j=1}^{6} \mathrm{TC}_i * e_i * p_{ij} * r_j\right) * d + \left(\sum_{i=1}^{8} \sum_{j=1}^{7} u_j * \mathrm{TC}_i * e_i * p_{ij}\right) * d - \sum_{i=1}^{2} (c_i + \mathrm{LFEV}_i) * v_i
\end{aligned}
$$

Where, M is the cost per fatality.

B. Uncertainty Factors

Each parameter in the above cost-effectiveness and net benefit model represents a major category of uncertainty factors. Therefore, there are nine categories of uncertainty factors that would impact the cost-effectiveness: (1) target crash population, TC_i, (2) effectiveness, e_i, (3) injuries or PDOV per crash, p_{ij}, (4) injury-to-fatality ratios, r_i, (5) cumulative lifetime discount factors, d, (6) unit costs for travel delays and property damage, u_i, (7) cost per vehicle, c_i, (8) lifetime fuel economic cost per vehicle, LEFV_i, and (9) number of vehicles, v_i. The net benefit model has one additional uncertainty factor (10) cost per life, M, in addition to those eight for the cost-effectiveness model.

Target crash population, TC_i, is important to benefit estimates because it defines the crash population of risk without the rule. The major uncertainties in this factor arise from sources such as demographic projections, driver/occupant behavioral changes (e.g., shifts in safety belt use), increased roadway travel, new Government safety regulations, and survey errors in NHTSA's data sampling system NASS-CDS.

The impact of demographic and driver/occupant behavior changes, roadway traveling, and new automobile safety regulations are reflected in the crash database. Thus, the analysis examined the historic FARS and CDS to determine whether variations resulting from these uncertainty sources would warrant further adjustment to the future target crash population. Based on 1995 to 2004 FARS, there is no definitive trend in total incidents for this period of time. The changes in fatal crashes and fatalities among years were small with a variation within ±2.0 percent. Data from 1995-2004 CDS yields a similar result for non-fatal crashes and MAIS 1-5 injuries. Therefore, the analysis does not further adjust the target crash population to account for variations associated with these uncertainty sources. Only survey errors from CDS are considered here. In other words, fatal crashes (and fatalities) are treated as constants. In contrast, non-fatal crashes (and MAIS 1-5 injuries) have variations and are treated as normally distributed. Survey errors for CDS are used as the proxy for standard deviation to establish the normal distribution for non-fatal target population. Standard errors (SE) form CDS were derived using SUDAAN[50].

Effectiveness of countermeasures, e_i, is by far the parameter with the greatest uncertainty. The sources of its uncertainty include the estimation errors inherent in the statistical processes, the variability of the data systems (i.e., FARS and State Data Systems), and the representativeness of the data samples (i.e., SUVs representing LTVs). Two types of probability distributions are used to describe the variations for these effectiveness rates. For PCs, the ESC effectiveness rates are treated as normally distributed. Their confidence bounds are used as the proxy for standard deviations for establishing the normal distribution. For LTVs, the ESC effectiveness rates are

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[50] Software for the Statistical Analysis of Correlated Data, Release 9.0.1, Research Triangle Institute, NC

treated as minimum extreme value distribution (also known as the Gumbel distribution) with its initial confidence bounds as the proxy for standard deviations. As described in the benefit chapter, the lower range of the ESC effectiveness for LTVs is bounded by the mean effectiveness for PCs. Due to this constraint, distributions for ESC in LTVs tend to be negatively skewed if its mean is preserved, i.e., a distribution with a longer tail towards the lower end of values. Therefore, a minimum extreme value distribution, a skewed distribution bounded by its minimum and maximum values, is more appropriate to describe the effectiveness for LTVs than a normal distribution with a similar mean and standard deviation.

MAIS injuries and PDOV per crash, p_{ij}, is obviously important to benefit estimates because it is used to derive the at-risk injury and PDOV population. The major uncertainties for these factors arise from sources similar to those for crash population. Similarly, only survey errors from CDS are considered. However, variations for these factors are highly correlated with those of crash population and are already described by the probability distributions for crash population (TC_i). Furthermore, based on 1995-2004 FARS and CDS, no specific trend existed in number of occupants per vehicle and in injury profile (i.e., the make-up of all injury severity levels or the relative proportion of each injury severity) would influence these factors. Based on these historic data, the fatalities per crash fluctuated between 1.12 and 1.13. Injuries per crash range from 0.8 to 1.0 over the years with the majority at a constant level of 0.9. These statistics indicate that changes in number of occupants per vehicle and injury profile are insignificant and are not considered here. Similarly, the number of PDOV per crash stays almost constant over the same period. Therefore, these factors are not described by separate distributions and are treated as constants.

Injury-to-fatality ratios, r_i, reflect the relative economic impact of injuries compared to fatalities based on their estimated comprehensive unit costs. They were derived based on the most current 2002 crash cost assessment[51]. The crash cost assessment itself is a complex analysis with an associated degree of uncertainty. At this time, these uncertainties are also unknowns. Thus, the variation in these ratios is unknown and the analysis treats these ratios as constants.

Cumulative lifetime discount factors, d, represent the present discount factor over the vehicle's life. These factors are derived based on the agency study on vehicle miles traveled and vehicle survivability[52]. Variation of these factors comes from vehicle mileage surveys, national vehicle population, and statistical process. These uncertainties cannot be quantified at this time. Thus, the analysis treats these factors as constants.

Technology cost per vehicle, c_i, is a concern. The sources of cost uncertainties arise from, but are not limited to, maturity of the technologies/countermeasures and potential fluctuation in labor and material costs (e.g., due to economics from production volume). According to professional judgments of NHTSA cost analysts and contractors, the cost (for MY 2005 designs) will fall within 10 percent of the point estimate shown in the cost chapter. Any cost in this range would have equal chance to be the true cost. Thus, the analysis treats the cost is uniformly distributed.

Lifetime fuel economy cost per vehicle, $LFEV_i$, is expected to have certain level of variability. Its variation comes from many sources: fuel price projections, vehicle lifespan, annual vehicle

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[51] The Economic Impact of Motor Vehicle Crashes 2000, NHTSA DOT HS 809 446, May 2002

[52] Vehicle Survivability and Travel Mileage Schedules, Technical Report, DOT HS 809 952, January 2006 (Docket No. 22223-2218)

miles traveled, survival probability, and discount rate. Variations for these sources are unknown at this time. Therefore, the uncertainty for $LFEV_i$ is also unknown. However, due to the importance of the fuel economy impacts, the analysis treats $LFEV_i$ as normally distributed to monitor the potential fuel economic impact of the proposal. The standard deviation is set to be 10 percent of the mean cost.

Number of vehicles, v_i, is an uncertainty factor that would impact the cost estimates. Although, vehicle sales have gradually increased over time, they are subject to annual variation due to changes in economic conditions, which are difficult to predict. Thus, the number of vehicles (v_i) is treated as a constant.

The nine factors discussed above would impact the cost-effectiveness outcome. The net benefit model has an additional factor, cost of statistical life, M.

Cost per statistical life, M, is an uncertainty factor for net benefits. The cost is based on recent meta-analyses of the wage-risk value of statistical life (VSL). These meta-analyses deployed different statistical methodologies and assumptions. But, generally, these studies show that an individual's willingness-to-pay (WTP) for reduction in premature fatalities is from \$1 million to \$10 million[53]. Thus, the agency uses this as the range for M and assumes the value of M is normally distributed.

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[53] a: Mrozek, J.R. and L.O. Taylor, What determines the value of a life? A Meta Analysis, Journal of Policy Analysis and Management 21 (2), pp. 253-270.

b: Viscusi , W. K., The Value of Life: Estimates with Risks by Occupation and Industry, Economic Inquiry, Oxford University Press, vol. 42(1), pages 29-48, January, 2004.

C. Quantifying the Uncertainty Factors

This section establishes the appropriate probability distributions for the uncertainty factors that come with appreciable variations (i.e., target crash population and effectiveness) and quantifies the constant values for other factors.

Target Crashes, TC_j. As discussed in the previous section, the size of the target fatal crashes is treated as constant and the size of the target non-fatal crashes is treated as normally distributed. Means and standard deviations are provided here to establish the normal distributions. The standard deviation for the target non-fatal crashes is set to be equivalent to the survey errors of the CDS. PROC CROSSTAB[54] procedure in SUDAAN is used to derive the survey errors for the base target crash population. Then, standard errors for the projected crash population (e.g., 2011 based adjustment) are prorated from the overall standard errors based on its size relative to the base population. In other words, if SE_{BC} represents the standard errors for the base crash population BC, the standard errors for the individual projected target population (i.e., 2011 adjusted crash population) $TC_{j,}$, j = 1 to 8, is equal to SE_{IC} * TC_j / BC. Figure VIII-1 depicts the probability distribution for projected target crash population by crash type, crash severity, and subject vehicle type. Note that target fatal crashes are treated as constants.

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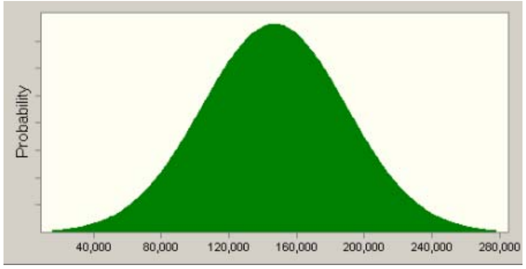
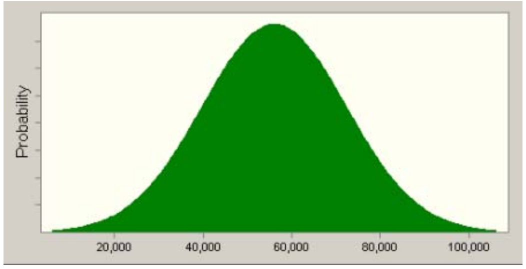
c: Viscusi, W. K. & Aldy, J.E., The Value of a Statistical Life: A Critical Review of Market Estimates through Out the World, Journal of Risk and Uncertainty, Kluwer Academic Publishers, vol. 27(1), pages 5-76, August, 2003.

[54] SUDAAN User’s Manual, Research Triangle Institute

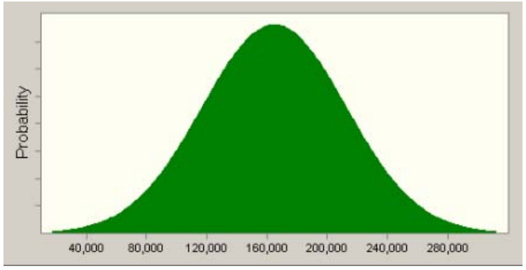
Single-Vehicle Crashes

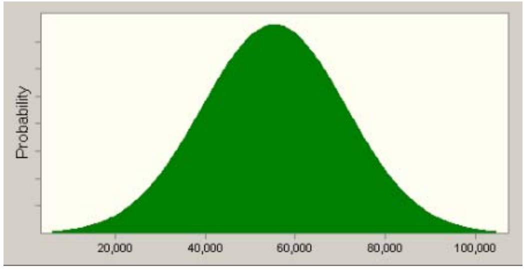
<table>
<tr><th colspan="2">Fatal</th></tr>
<tr><th>PC</th><th>LTV</th></tr>
<tr><td>(TC_1)
Constant: 2,501</td><td>(TC_2)
Constant: 1,524</td></tr>
<tr><th colspan="2">Non-Fatal</th></tr>
<tr><td>

(TC_3)
Mean: 146,685
SD: 42,479</td><td>

(TC_4)
Mean: 56,069
SD: 16,237</td></tr>
</table>

Multi-Vehicle Crashes

<table>
<tr><th colspan="2">Fatal</th></tr>
<tr><th>PC</th><th>LTV</th></tr>
<tr><td>(TC_5)
Constant: 2,219</td><td>(TC_6)
Constant: 1,208</td></tr>
<tr><th colspan="2">Non-Fatal</th></tr>
<tr><td>

(TC_7)
Mean: 164,820
SD: 47,731</td><td>

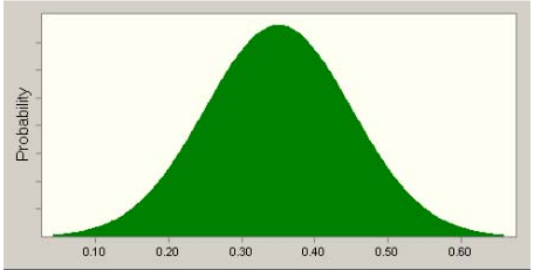
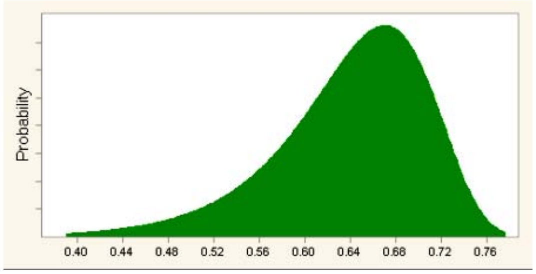
(TC_8)
Mean: 55,275
SD: 16,007</td></tr>
</table>

Source: 2004 FARS, 2000-2004 CDS
PC: passenger cars, LTV: light trucks/vans

Figure VIII-1
Probability Distributions for **Target** Crashes

ESC Effectiveness, e_i. The analysis treats ESC effectiveness for PCs as normally distributed with its standard errors as the proxy for standard deviation. The effectiveness for LTVs is described by a minimum extreme value distribution with the standard deviation set to be equal to the standard error derived from the statistical process. Two parameters, mode and scale, are also required to establish the minimum extreme value distribution. Figures VIII-2-A and Figure VIII-2-B depict these two types of distributions against single-vehicle and multi-vehicle crashes, respectively. Note that mean and standard deviation are required for establishing the normal distributions. Mode and scale are required for minimum extreme value distributions.

Fatal Single-Vehicle Crashes

PC	LTV
 (e$_1$) Mean: 35% SD: 10%	 (e$_2$) Mode: 67% Scale: 6%

Non-Fatal Single-Vehicle Crashes

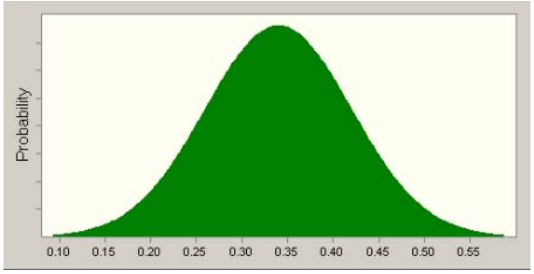
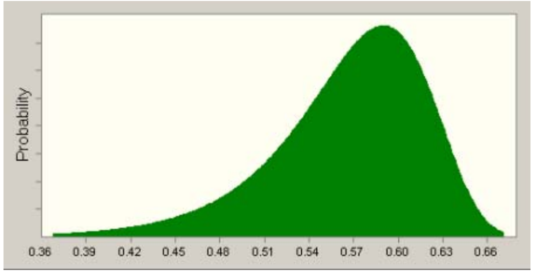
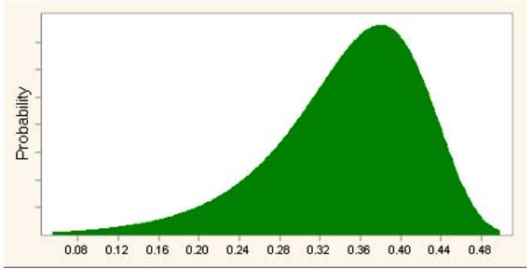
PC	LTV
 (e$_3$) Mean: 34% SD: 8%	 (e$_4$) Mode: 59% Scale: 4%

Figure VIII-2-A
Parameters for Probability Distributions
ESC Effectiveness (in Percent) Against **Single-Vehicle** Crashes

Fatal Multi-Vehicle Crashes

PC	LTV
(e_5) Constant: 0%	 (e_6) Mode: 38% Scale: 6%

Non-Fatal Multi-Vehicle Crashes

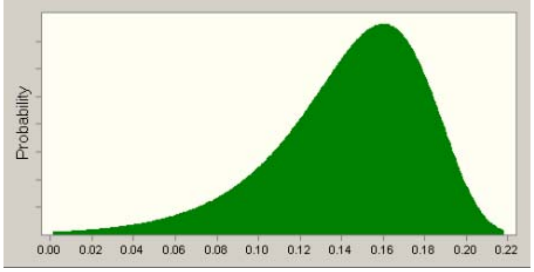
PC	LTV
(e_7) Constant: 0%	 (e_8) Mode: 16% Scale: 3%

Figure VIII-2-B
Parameters for Probability Distributions
ESC Effectiveness (in Percent) Against **Multi-Vehicle** Crashes

Injuries and PDOV Per Crash ($p_{i,j}$). The index j of these factors represents injury severity with j=1 as MAIS 1 injuries, j=6 as fatalities, and j=7 as PDOV. The index i represents the eight target crash types that were defined by crash type (single vehicle crashes, multi-vehicle crashes), crash severity (fatal, non-fatal), and vehicle type (PCs, LTVs). These factors are treated as constants. For injuries, i.e., p_{ij}, $j \leq 6$, their values are represented by the mean injuries per crash that is derived from the FARS and CDS. Basically, their values are equal to the number of injuries shown in Table IV-3 (mean injuries) divided by the number of corresponding crashes shown in Table IV-2 (mean crashes). For example, fatalities per single fatal PC crash ($p_{1,6}$) is equal to 1.0924 which is equal to 2,732/2,501.

As for PDOVs per crash, p_{ij}, j=7, it is equal to 0.43 per single-vehicle crash (= 1 PDOV per single-vehicle PDO crash * 0.43 of the single-vehicle crashes) and 1.08 per multi-vehicle crash (= 2.2 PDOV per multi-vehicle PDO crash * 0.49 of the multi-vehicle crashes). In other words,

p_{i7} = 0.43 for $1 \leq i \leq 4$ (single-vehicle crash types)

= 1.08 for $5 \leq i \leq 8$ (multi-vehicle crash types)

Table VIII-1 summarizes these constants for p_{ij}.

Table VIII-1

Constant Values for Injuries per Crash (p_{ij})

Injury Severity	Fatal Crashes		Non-Fatal Crashes	
By Crash Type	PC	LTV	PC	LTV
Single Vehicle	(i=1)	(i=2)	(i=3)	(i=4)
MAIS 1 (j=1)	0.2607	0.4245	0.5619	0.6533
MAIS 2 (j=2)	0.1236	0.1299	0.0670	0.0976
MAIS 3 (j=3)	0.1375	0.2178	0.0392	0.0344
MAIS 4 (j=4)	0.0572	0.0650	0.0158	0.0112
MAIS 5 (j=5)	0.0364	0.0217	0.0052	0.0026
Fatality (j=6)	1.0924	1.0866	0.0000	0.0000
PDOV (j=7)	0.4300	0.4300	0.4300	0.4300
Multi-Vehicle	(i=5)	(i=6)	(i=7)	(i=8)
MAIS 1 (j=1)	1.0676	0.9652	0.7384	0.6920
MAIS 2 (j=2)	0.0487	0.0381	0.0562	0.0631
MAIS 3 (j=3)	0.0541	0.0629	0.0171	0.0206
MAIS 4 (j=4)	0.0225	0.0190	0.0027	0.0039
MAIS 5 (j=5)	0.0144	0.0066	0.0022	0.0026
Fatality (j=6)	0.4308	0.3154	0.0000	0.0000
PDOV (j=7)	1.0800	1.0800	1.0800	1.0800

Source: 2004 FARS, 2000-2004 CDS

PC: passenger cars, LTV: light trucks/vans, PDOV: property damage only vehicles

Injury-to-fatality equivalent ratios (r_i). These factors are treated as constants. Table VIII-2 lists the injury-to-fatality equivalent ratios which are used to translate non-fatal injuries to fatal equivalents.

Table VIII-2
Injury-To-Fatality Equivalence Ratios*

	Injury-To-Fatality Equivalence Ratios
MAIS 1 (r_1)	0.0031
MAIS 2 (r_2)	0.0458
MAIS 3 (r_3)	0.0916
MAIS 4 (r_4)	0.2153
MAIS 5 (r_5)	0.7124
Fatality (r_6)	1.0000

Cumulative lifetime discount factors (d). These factors are treated as constants. At a 3 percent discount, d = 0.8304 for PCs and d = 0.8022 for LTVs. A at 7 percent discount, d = 0.6700 for PCs and d = 6303 for LTVs.

Unit costs for travel delays and property damage, u_j, are represented as per person based for all MAIS injury levels, and per vehicle based for PDO crashes. Same as injury-to-fatality ratios, these unit costs were also developed from the NHTSA 2000 crash cost report. Similarly, uncertainties associated with these unit costs are unknown. These unit costs are treated as constants. Table VIII-3 lists these unit costs in 2005 dollar. The combined cost of travel delay and property damage is used for u_j.

Table VIII-3
Unit Costs for Travel Delays and Property Damage
(2005 $)

	Travel Delays	Property Damage	Combined (u_j)
MAIS 1	$871	$4,309	$5,180
MAIS 2	$948	$4,432	$5,380
MAIS 3	$1,054	$7,622	$8,676
MAIS 4	$1,120	$11,023	$12,143
MAIS 5	$10,255	$10,589	$20,844
Fatality	$10,255	$11,516	$21,771
PDOV	$900	$1,664	$2,564

PDOV: property damage only vehicles

Cost per vehicle, c_i. The analysis assumes the cost is uniformly distributed. The uniform distribution for C would be established by two parameters: maximum (C_{max}) and minimum (C_{min}) costs, i.e.,

$$\begin{aligned} C(x) &= \frac{1}{C_{Max} - C_{Min}}, C_{min} \leq x \leq C_{max} \\ &= 0, \text{otherwise} \end{aligned}$$

Table VIII-4 lists these costs per vehicle. These costs vary by vehicle type due to difference in technology implementation and the size of each vehicle type. These costs represent the investments paid now for future benefits and thus no discounting is needed.

Table VIII-4
Cost Parameters for Uniform Distribution by Equipments Needed
(2005 Dollar)

	PCs	LTVs
The Most Likely Cost (point estimate)	$90.31	$29.18
Minimum Cost (C_{min})	$81.28	$26.26
Maximum Cost (C_{max})	$99.34	$32.10

Lifetime fuel economy per vehicle, $LFEV_i$. The factor is treated as normally distributed. Table VIII-5 lists the mean and standard deviation the two parameters required for establishing its normal distribution.

Table VIII-5
Lifetime Fuel Economy Cost Per Vehicle
Parameters for Normal Distribution by Vehicle Type and Discount Rate
(2005 Dollar)

		At 3% Discount	At 7 Percent Discount
PC ($LFEV_1$)	Mean SD	\$3.35 \$0.34	\$2.73 \$0.27
LTV ($LFEV_2$)	Mean SD	\$0.00*	\$0.00*

* extremely small numbers

Number of Vehicles, v_i,. These factors are constant. The total number of passenger vehicles is 17 million. Of these, 8,000,000 are PCs and 9,000,000 are LTVs.

Cost per statistical life, M. Recent meta-analysis of the wage-risk value of statistical life (VSL) shows that an individual's willingness-to-pay (WTP) for reduction in premature fatalities is from \$1 million to \$10 million[55]. Thus, the agency uses this as the range for M and assumes the value of M is normally distributed with its mean equal to \$5.5 million. This value of \$5.5 million represents a central value consistent with a range of values from \$1 to \$10 million.

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[55] a: Mrozek, J.R. and L.O. Taylor, What determines the value of a life? A Meta Analysis, Journal of Policy Analysis and Management 21 (2), pp. 253-270.

b: Viscusi , W. K., The Value of Life: Estimates with Risks by Occupation and Industry, Economic Inquiry, Oxford University Press, vol. 42(1), pages 29-48, January, 2004.

c: Viscusi, W. K. & Aldy, J.E., The Value of a Statistical Life: A Critical Review of Market Estimates through Out the World, Journal of Risk and Uncertainty, Kluwer Academic Publishers, vol. 27(1), pages 5-76, August, 2003.

D. Simulation Results

The Monte Carlo simulation first randomly selects a value for each of the significant factors based on their probability distributions. Then, the selected values are fed into the model to forecast the results. Each process is a trial. The simulation repeats the process until a pre-defined accuracy has been accomplished. Since Crystal Ball is a spreadsheet based simulation software, the simulation model actually is a step-wise process, i.e., the simulation estimates gross benefits, the net benefits (after redistribution of gross benefits through the injury redistribution process), fatal equivalents, cost-effectiveness, and net benefits. Therefore, each of these forecasted results had certainty bounds. This uncertainty analysis conducted a total of 10,000 trials before the forecasted mean results reached 99 percent precision. Even if the later criterion was reached first, the trial numbers generally are very close to 10,000. These criteria were chosen to ensure the simulation errors ($\approx \frac{1}{10{,}000}$) would be very close to 0. Therefore, the results would truly reflect the probabilistic nature of the uncertainty factors.

Table VIII-6 summarizes the simulated injury benefit results including travel delay and property damage savings at no discount level after about 10,000 trials. As shown, <u>undiscounted</u>, the proposal would prevent 28,405 to 207,207 crashes. Reducing theses crashes results in eliminating 922 to 3,201 fatalities and 21,068 to 150,851 MAIS 1-5 injuries. These fatalities and injuries equate to 1,808 – 5,590 equivalent lives.

TABLE VIII-6
Simulated Injury Benefits

	No Discount
Crashes Prevented	
Mean	91,822
Range	28,405 – 207,207
90% Certainty	58,712 – 129,493
Fatalities Reduced	
Mean	2,146
Range	922 – 3,201
90% Certainty	1,644 – 2,633
MAIS Injuries Eliminated	
Mean	67,754
Range	21,068 – 150,851
90% Certainty	44,017 – 94,456
Equivalent Lives Saved	
Mean	3,551
Range	1,808 – 5,590
90% Certainty	2,807 – 4,310

Table VIII-7 summarizes the simulated cost-effectiveness and net benefit results at 3 and 7 percent discount. As shown, at a 3 percent discount rate, the proposal rule would save 2,285 – 3,529 equivalent lives with a 90 percent certainty. In addition, with the same 90 percent certainty, the proposal would save $299 - $599 million from travel delay and property damage that is associated with the crashes that would be prevented by the proposal. However, the proposal would increase fuel economy cost by $22.4 - $31.3 million. Nevertheless, the proposal is extremely cost effective. At this discount level, the proposal would produce a cost per equivalent fatality of no more than $3.75 million and a positive net benefit with a 100 percent certainty. At a 90 percent certainty, the net benefits would range from $8.2 to $23.4 billion.

<u>At a 7 percent discount rate</u>, the proposal rule would save 1,816 – 2,815 equivalent lives and $237 - $477 million from travel delay and property damage with a 90 percent certainty. The fuel economy cost would be increased by $18.3 - $25.5 million with a 90 percent certainty. At this discount level, the proposal would produce a cost per equivalent fatality of no more than $3.75 million and a positive net benefit with a 100 percent certainty. At a 90 percent certainty, the net benefits would range from $6.3 to $18.5 billion

Table VIII-7
Simulated Cost-Effectiveness and Net Benefits by Discount Rate

(2005 Dollar)

	Discount Rate	
Costs*	**At 3%**	**At 7%**
Mean	$985 M	$985 M
Total Range	$889 – $1,082 M	$889 – $1,082 M
90% Certainty Range	$914 – $1,056 M	$914 – $1,056 M
Equivalent Lives Saved		
Mean	2,899	2,309
Total Range	1,468 – 4,579	1,164 – 3,656
90% Certainty Range	2,285 – 3,529	1,816 – 2,815
Property Damage and Travel Delay Savings		
Mean	$440 M	$351 M
Total Range	$175 – $938 M	$139 – $749 M
90% Certainty Range	$299 – $599 M	$237 – $477 M
Fuel Economy		
Mean	$26.8 M	$21.9 M
Total Range	$16.3 – $37.2 M	$12.8 – $30.9 M
90% Certainty Range	$22.4 – $31.3 M	$18.3 – $25.5 M
Cost-Effectiveness (CE)		
Mean	$0.20 M	$0.29 M
Total Range	$0.02 – $0.52 M	$0.07 – $0.69 M
90% Certainty Range	$0.12 – $0.31 M	$0.19 – $0.42 M
Certainty that CE ≤ $3.75 M	100%	100%
Certainty that CE ≤ $5.5 M	100%	100%
Net Benefit (NB)		
Mean	$15.4 B	$12.0 B
Total Range	$2.3 – $38.9 B	$1.7 – $30.8 B
90% Certainty Range	$8.2 – $23.4 B	$6.3 – $18.5 B
Certainty that NB > $0	100%	100%

B: billion; M: million
* same for all discount rates

CHAPTER IX. REGULATORY FLEXIBILITY ACT AND UNFUNDED MANDATES REFORM ACT ANALYSIS

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 proposal 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. <u>Description of the reasons why action by the agency is being considered</u>

NHTSA is considering this action to require an ESC system in light vehicles in order to reduce the number of automobile crashes and associated fatalities and injuries. ESC has been found to be highly effective in reducing single-vehicle run-off-road crashes, a large percentage of which involve vehicle rollover.

2. <u>Objectives of, and legal basis for, the proposal or final rule</u>

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[56]. The Secretary has delegated the responsibility for carrying out the National Traffic and Motor Vehicle Safety Act to NHTSA[57]. NHTSA is proposing this rule under the Authority of 49 U.S.C. 322, 30111, 30115, 30117, and 30166; delegation of authority at 49 CFR 1.50.

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[56] 49 U.S.C. 30111(a).

[57] 49 U.S.C. 105 and 322; delegation of authority at 49 CFR 1.50.

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

The proposal would apply to motor vehicle manufacturers, second-stage or final-stage manufacturers and alterers, and manufacturers of ESC systems. Business entities are defined as small businesses using the North American Industry Classification System (NAICS) code, for the purposes of receiving Small Business Administration assistance. One of the criteria for determining size, as stated in 13 CFR 121.201, is the number of employees in the firm. Affected business categories include: (a) To qualify as a small business in Automotive Manufacturing (NAICS 336111), the firm must have fewer than 1000 employees, (b) In Light Truck and Utility Vehicle Manufacturing (NAICS 336112), the firm must have fewer than 1000 employees, (c) In Motor Vehicle Body Manufacturing (NAICS 336211), the firm must have fewer than 1000 employees, and (d) In All Other Motor Vehicle Parts Manufacturing (NAICS 336399), the firm must have fewer than 750 employees.

Small volume motor vehicle manufacturers

There are four vehicle manufacturers that would qualify as a small business under the definitions of (a), (b), and (c) above. Table IX-1 provides information about the 4 small domestic manufacturers in MY 2005.

Table IX-1
Small Vehicle Manufacturers

Manufacturer	Employees	Estimated Sales	Sale Price Range	Est. Revenues*
Avanti	22	150	$75,000 to $125,000	$15,000,000
Panoz	50	150	$90,000 to $130,000	$16,500,000
Saleen	150	1,300	$42,000 to $75,000	$76,000,000
Shelby	44	60	$42,000 to $135,000	$5,310,000

* Assuming an average sales price from the sales price range

Based on information available at various web sites[58], Table IX-2 shows the current status of compliance with the proposal.

Table IX-2
Small Volume Vehicle Manufacturer Compliance Status

	ABS	Traction Control	ESC
Avanti	Yes	Yes	No
Panoz	Yes	Yes	No
Saleen S7	?	?	No
Saleen Mustang and Focus Based Models	Optional	Optional	No
Shelby	Optional	Optional	No

ESC would cost at least $111 for the models that need only ESC and $479 for the models that need ABS and ESC. Consumer costs for the more exotic models may be much higher than this. Compared to the least expensive vehicle in Table IX-1, the cost could range from less than one-half of one percent ($111/$42,000 = .0026) to 1.1 percent ($479/42,000 = .0114). Compared to a weighted average sales price ($68,000), the cost could range from less than two tenths of one percent ($111/$68,000 = .0016) to 0.7 percent ($479/$68,000 = .0070).

We believe that the market for the products of these small manufacturers is highly inelastic. Purchasers of these products are enticed by the desire to have an unusual vehicle. Furthermore, the price of competitor's models will also need to be raised by a similar amount, since all light vehicles must pass the standards. Thus, we do not believe that raising the price to include the value of ESC will have much, if any, affect on sales of these vehicle. We expect that these price increases will be passed on to the final customer. Based on this analysis, the agency believes that the proposal will not have a significant economic impact on these four small domestic vehicle manufacturers.

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[58] Avantimotors.com, panozauto.com, saleen.com, shelbyamerican.com, Edmunds.com

Final-stage manufacturers and alterers

There are a significant number (several hundred) of second-stage or final-stage manufacturers and alterers that could be impacted by the proposed rule. Some of these manufacturers buy incomplete vehicles. Many of these vehicles are van conversions, but there are a variety of vehicle types affected. Typically, none of these second-stage manufacturers or alterers changes the brake system of the vehicle. Even the incomplete vehicles typically are delivered with brakes. The brake system contains the central components for the ESC system. Thus, the original manufacturer's certification should apply for all of these vehicles as long as the brake system is not disturbed. Thus, while there are a significant number of second-stage and final stage manufacturers impacted by the proposed rule, we do not believe the impact will be economically significant, since a pass-through certification process should apply to these manufacturers.

Based on this analysis, although the proposal will impact about 100 percent of the small vehicle manufacturers, final-stage manufacturers, and alterers, the proposal is not anticipated to have a significant economic impact on these entities.

Small ESC system manufacturers

There are no ESC system manufacturers that would qualify as a small business under the definition (d) above (i.e., all other motor vehicle parts manufacturing). ESC manufacturers include Bosch, TRW, Continental-Teves, FTE, Automotive GmbH, Delphi, Mando America Corp (Korean), Advics Co. Ltd (was Denso Japan), Nissin Kogyo Co., Ltd, Hitachi, and AISIN

SEIKI Co., LTD. All of these are large corporations. 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 proposed rule would require manufacturers to equip their vehicles with ESC and to certify that their products comply with the standard. There are record keeping requirements for those manufacturers that comply using the phase-in schedule. However, the proposal would require the multi-stage manufacturers, alterers, and small volume manufacturers to fully comply with the standard on September 1, 2012, which is a one-year extension from full compliance of the phase-in schedule. Thus, for these manufacturers there are no new reporting or record keeping requirements, because they are not required to report during the phase-in period.

5. Duplication with other Federal rules

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

6. Description of any significant alternatives to the proposed rule

The agency considered two alternatives. One alternative was to limit applicability of the standard to just light trucks, since ESC effectiveness for SUVs was much higher than ESC effectiveness for passenger cars. The agency decided not to propose this alternative since there were significant benefits from equipping passenger cars with ESC and requiring ESC for passenger cars was very cost-effective. Extending the ESC applicability to PCs would save an additional 956 lives and reduce an additional 34,902 injuries.

The other alternative is to require a 2-wheel ESC system. A 2-wheel system is a less complex system than the proposed ESC system. Based on an agency study, the 2-wheel ESC system is less effective in preventing crashes than the proposed system. Thus, the proposed system would potentially save more lives and reduce more injuries than the 2-wheel system. In addition, the industry is already moving towards the proposed system for many of its vehicles. The agency believes that all the 2011ESC systems will meet the proposed performance test.

In summary, the proposal requires for vehicle manufacturers to install ESC in their light vehicles. There are 18 vehicle manufacturers. Four of them are considered to be small businesses. However, purchasers of these high-end products are enticed by the desire to have an unusual vehicle. These price increases will be passed on to the final customers. Most importantly, many vehicles produced by these four companies already are equipped with ABS. The cost increase per vehicle would be less than three tenths to 0.7 percent of their average sales price. We believe this price increase will not affect their vehicle sales, given that all other vehicles will be required to provide the same equipment.

As for the final stage manufacturers and alterers, typically these small businesses adhere to original equipment manufacturers' instructions in manufacturing modified and altered vehicles. Based on our knowledge, original equipment manufacturers do not permit a final stage manufacturer or alterer to modify or alter sophisticated devices such as air bags, event-data recorders (EDRs), or ESC. Therefore, multistage manufacturers and alterers would be able to rely on the certification and information provided by the original equipment manufacturer. For the above reasons, we have concluded that this proposal would not result in a significant economic impact on small business, small organizations, or small governmental units.

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 2005 results in $122 million (112.145/92.106 = 1.22). The assessment may be included in conjunction with other assessments, as it is here.

This proposal is not estimated to result in expenditures by State, local or tribal governments of more than $122 million annually. However, it would result in an expenditure of much more than that magnitude by the automobile manufacturers and/or their suppliers. The estimated annual cost would be $985 million annually. These effects have been discussed previously in this Preliminary Regulatory Impact Analysis (see Chapter V, Costs).