U.S. Department
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National Highway
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Administration

NHTSA
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Final Regulatory Impact Analysis

FMVSS No. 121
Air Brake Systems
Amending Stopping Distance

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

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TABLE OF CONTENTS

Appendix

EXECUTIVE SUMMARY

This final regulatory impact analysis analyzes the potential impacts of amending the performance requirements for truck tractor stopping distance. The intent of this final rule is to reduce the number and severity of crashes involving tractor trucks and the resulting fatalities, injuries, and related property damage.

A. Test Requirements

The final rule requires a 30% reduction in stopping distance specified in FMVSS No. 121 Air Brake Systems. According to the current standard, when stopped six times at an initial braking speed of 60 mph, each truck tractor must stop at least once in not more than 355 ft, measured from the point at which movement of the service brake control begins, without any part of the vehicle leaving the roadway. With the final rule, the vehicle must stop within 250 ft.[1,2]

B. Countermeasures

The agency believes that larger S-cam drum brakes or disc brakes at all wheel positions, or alternatively disc brakes on the steer axle and larger drum brakes on the drive axle(s), could be used to meet the test requirements. We believe most of the current truck tractor manufacturers will have to modify their current brake systems to pass the 30% reduction in stopping distance. We analyzed the costs and benefits of three countermeasures: (1) larger S-cam drum brake systems at all wheel positions, (2) disc brake systems at all wheel positions, (3) front disc and larger rear S-cam drum brake systems.

[1] The change from the 30% reduced distance of 248.5 ft to the 250 ft value in the final rule is due to rounding 355 x 0.7 = 248.5 and is not considered to be a change of any significance.

[2] A small number of tractors with high Gross Vehicle Weight Ratings (GVWRs) will be permitted to stop within 310 ft.

The analysis shows that the three systems could meet the 30% reduction in stopping distance. The larger S-cam brake system at all wheel positions is the least expensive of the countermeasures examined. An estimated three (3) percent of tractor trucks currently meet the 30% (250 ft) reduction in stopping distance.

C. Target Population

For tractor trucks, estimates of the number of property damage only (PDO) vehicle involvements, crashes, and injuries were derived from the agency's 2004-2006 GES database and the number of fatalities was determined from the agency's 2004-2006 FARS database. The injury estimates are presented at various levels of injury severity using the "KABCO" injury severity scale. For the analysis, the "KABCO" injury severity scale was converted to the AIS injury severity scale. The conversion was necessary to estimate the property damage savings that would result from the final rule and also to calculate the "equivalent fatalities" that these injury estimates represent. The results from the conversion of the "KABCO" injuries are shown below. We estimate there are 864 fatalities, 15,614 non-fatal injuries and 17,621 property damage only crashes occurring annually when the front of a braked truck tractor strikes others.

Estimated Number of Occupant Injuries in
Braked Truck Tractor Crashes
Front of Truck to Others
(Truck and Non-Truck Occupants)

AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
45,678	12,896	1,855	709	101	53	864

D. Estimated Safety Benefits

The agency estimates that the 30% improved brake performance would save 227 fatalities and prevent 300 MAIS 3-5 injuries among occupants in truck tractor crashes.

Estimated Annual Benefits

Percent Reduction in Stopping Distance	Fatalities Reduced	Serious Injuries Reduced
30%	227	300

E. Property Damage Savings

The reduction in stopping distance would significantly reduce property damage by reducing the number of crashes and also severity of crashes when every vehicle meets the 30% reduction in stopping distance. Using a 3% discount rate, the agency believes that $205 million of property damage would be prevented (present value of property damage savings over the lifetime of these vehicles) with the required 30% reduction in stopping distance, as shown below:

Property Damage Prevented
(in millions)

Percent Reduction In Stopping Distance	3% Discount	7% Discount
30%	$205	$169

F. Consumer Costs

Potential compliance costs for the 30% reduction in stopping distance requirement vary considerably and are dependent upon the types of the brake systems chosen by the manufacturers. Although disc brakes at all wheel positions would be most effective in reducing stopping distance, the analysis assumed that all countermeasures could meet the required 30% reduction in stopping distance. The costs do not include increased fuel and maintenance costs. In addition, the cost estimate does not include potential costs for changes to the suspension and frame. For the required 30% reduction in stopping distance, given the level of compliance, the agency believes that the average incremental cost to meet the requirement with the larger S-cam drum brakes at all wheel positions is estimated to be $211 per vehicle and with the disc brakes at all wheel positions is estimated to be $1,475 per vehicle (2007 dollars). The combination of these brake systems, front disc and larger rear S-cam drum brakes, is estimated to be $613 per vehicle. Total incremental costs for the 130,000 tractor trucks manufactured annually are estimated to range between $27 and $192 million, depending upon which countermeasures are chosen by the manufacturers.

Incremental Costs
(2007 Dollars)

30% Percent Reduction in Stopping Distance	Larger S-cam Drum at all Wheel Positions	Disc Brakes at All Wheel Positions	Front Disc and Larger Rear S-cam Drum	Most Likely Combination[3]
Total Cost	$27M	$192M	$80M	$54M
Cost Per Vehicle	$211	$1,475	$613	$413

G. Costs per Equivalent Life Saved

When the estimated costs are reduced by the amount of discounted property damage prevented, it results in net costs (or in some cases net benefits). For the required 30% reduction in stopping distance, the analysis shows that the disc brake system would result in net costs, but the larger S-cam brake system and the front disc & larger rear S-cam brake system would result in net benefits (the property damage saved is greater than the vehicle cost). In addition, the most likely combination brake system would result in net benefits.

A cost per equivalent life saved was computed using the annual cost figures and the discounted equivalent lives saved for those cases resulting in net costs. The net cost figures were divided by the discounted equivalent lives saved. The derived cost per equivalent life saved shows that the

[3] Assumes that typical 3-axle tractors will use larger S-cam drum brakes and 2-axle and severe service tractors will use disc brakes front and rear.

cost would be much lower than the $5.8 million per statistical life used in valuing reduction in premature fatalities.

Net Cost per Equivalent Life Saved
(For the 30% Reduction in Stopping Distance, in millions)

Brake System	3 Percent	7 Percent
Larger S-Cam Brake	NB	NB
All Disc Brake	NB	$0.108
Front Disc and Larger Rear S-Cam Drum	NB	NB
Most Likely Combination	NB	NB

NB = Net Benefits (Property damage benefits exceed the costs).

H. Net Benefits (Valuing Injuries and Fatalities)

For the net benefits analysis, injury and fatality benefits were assigned a monetary value of $6.1 million comprehensive cost per statistical life. These values were added to property damage benefits and were compared to the monetary value of costs to derive a net benefit. For the required 30% reduction in stopping distance, the high end of the net benefits is $1,751 million for the larger S-cam drum brakes at all wheel positions using a 3 percent discount rate and the lower end is $1,271 million for the disc brakes at all wheel positions, using a 7 percent discount rate.

Net Benefits
With $6.1M Cost Per Life
(in millions)

Brake System	Net Benefit for 30% Reduction	
	3% discount	7% discount
Larger S-cam Drum at all Wheel Positions	$1,751	$1,436
Disc Brakes at all Wheel Positions	$1,587	$1,271
Front Disc and Larger Rear S-cam Drum	$1,699	$1,384
Most Likely Combination	$1,725	$1,410

G. Lead-time

The agency is requiring an effective date that is two years from the date of publication of the final rule for typical three-axle tractors. Typical tractors are defined as having three axles and a

GVWR less than or equal to 59,600 pounds, and will have a two-year lead time for the effective date. The lead time for all two-axle tractors, and severe service tractors with a GVWR greater than 59,600 pounds, is four years from the date of publication of the final rule.

I Introduction

Crash data indicate that the incompatibility of passenger vehicles and heavy trucks on U.S. highways results in large numbers of passenger vehicle occupants being injured and killed in collisions with heavy trucks. The incompatibility includes crashworthiness factors such as a large difference in mass between the passenger vehicle and the heavy truck, which results in greater damage to the passenger vehicle in collisions between these vehicles. The incompatibility also includes the crash avoidance capability of the two vehicle types, with heavy trucks sometimes taking twice as long to stop as passenger cars. While it would not be practical to reduce the mass of large trucks used to transport goods and provide services across the U.S., recent developments in brake systems have demonstrated that stopping distance reductions are possible. Thus, if heavy trucks can be provided with better performing brakes, many collisions with passenger vehicles may be avoided or reduced in severity by reducing stopping distances and lowering collision speeds.

The crash data indicate that combination trucks, typically tractors and trailers equipped with air brakes, have the greatest exposure in fatal crashes among all medium and heavy vehicle types. The agency is requiring a 30% reduction in stopping distance for heavy-duty tractor trucks equipped with air brakes and regulated under Federal Motor Vehicle Safety Standard (FMVSS) No. 121, Air Brake Systems.

This Final Regulatory Impact Analysis presents the agency's estimation of the potential benefits and costs of brake systems that could meet the required 30% reduction in stopping distance.

II Background

Background:

On March 15, 1995, the agency published three final rules as a part of a comprehensive effort to improve the braking ability of medium and heavy vehicles[4] (60 FR 13216 and 60 FR 13287). The major focus of that effort was to improve the directional stability and control of heavy vehicles during braking through antilock brake system (ABS) requirements. However, the 1995 effort also reinstated stopping distance requirements for air-braked vehicles, and established different stopping distances for different types of heavy vehicles. Previous stopping distance requirements for medium and heavy vehicles had been invalidated in 1978 by the United States Court of Appeals for the 9th Circuit because of issues with the reliability of ABS then in use. See, PACCAR v. NHTSA, 573 F.2d 632 (9th Cir. 1978) cert. denied, 439 U.S. 862 (1978).

The current stopping distance requirements under Federal Motor Vehicle Safety Standard No. 121, Air brake systems, as established under the 1995 final rule, are determined according to vehicle type. Under the loaded-to-GVWR-60-mph stopping distance requirements of FMVSS No. 121, air-braked buses must comply with a stopping distance of 280 feet, air-braked single-unit trucks must comply with a stopping distance of 310 feet, and air-braked tractor trucks must comply with a stopping distance requirement of 355 feet.[5]

[4] Medium and heavy weight vehicles are hydraulic-braked vehicles over 10,000 pounds gross vehicle weight rating (GVWR), and all vehicles equipped with air brake systems; hereafter referred to collectively as heavy vehicles.

[5] For heavy tractor trucks (tractors), the current stopping distance test at GVWR is conducted with the tractor coupled to an un-braked control trailer, with weight placed over the fifth wheel of the tractor, and a 4,500 pound load on the single axle of the trailer. This test method isolates the braking performance of the tractor so that only the performance of the tractor is evaluated.

The stopping distance requirements adopted in the 1995 final rule are generally less stringent than those invalidated by the PACCAR decision. In adopting the requirements, the agency estimated that half of the air-braked truck tractor vehicles and a quarter of the air-braked single-unit trucks would meet the stopping distance requirements without modification. However, the stopping distance requirements were an enhancement to the overall braking performance of air-braked vehicles given the newly adopted ABS requirements. The agency determined that the stability and control during braking requirements would result in a majority of the benefits, but estimated that the new stopping distance requirements would prevent annually about 3 vehicle occupant fatalities, 84 vehicle occupant injuries, and $3.24 million in property damage.

Safety Issues:

Since the agency established the stability control and stopping distance requirements for heavy vehicles almost ten years ago, data indicate that the involvement of heavy vehicles in fatal and injury producing crashes has slightly declined while vehicle-miles-traveled has increased. However, because the number of registered heavy vehicles has increased, the total number of crashes remains high. In 2006:

- 385,000 heavy vehicles were involved in traffic crashes in the U.S.
- 4,732 heavy vehicles were involved in fatal crashes, resulting in 4,995 fatalities (12 percent of all fatalities reported in 2006). 75 percent of the fatalities were occupants of another vehicle, 16 percent were truck occupants, and 8 percent were nonoccupants.

- 106,000 people were injured in crashes involving heavy vehicles. 76 percent of the injuries were occupants of another vehicle, 22 percent were truck occupants, and 2 percent were nonoccupants.[6]

According to Large Truck Crash Facts 2005 (report number FMCSA-RI-07-046) published by the Analysis Division of the Federal Motor Carrier Safety Administration (FMCSA), the heavy vehicle fatality rate remained 60 percent higher than for passenger vehicles (defined as a car or light truck) in 2005. When the FMCSA report considered combination trucks (e.g., tractor and trailer combinations) separately, the fatality rate was nearly double that of passenger vehicles. Conversely, the fatality rate for single-unit trucks was approximately 15 to 20 percent higher than the fatality rate for passenger vehicles.

The FMCSA data indicate that the heavier weight classes of large trucks (over 26,000 pounds GVWR) are by far, the most involved in all types of crashes involving large trucks. Retail sales data, averaged for 2006 and 2007, indicate that annual sales of trucks between 10,001 and 26,000 pounds GVWR were approximately 317,000 units and annual sales of heavy-duty trucks over 26,000 pounds GVWR were approximately 298,000 units. While data indicate that medium-duty trucks make up a sizable portion of the population of large trucks in the U.S. truck fleet, the crash data indicate that the majority of crashes involve heavy-duty trucks with GVWRs over 26,000 pounds, as shown in Table II-1. Almost all of the heavy-duty trucks with a GVWR greater than 26,000 pounds are air-braked, and over half of those are tractor trucks.

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[6] See Traffic Safety Facts 2006 - Large Trucks, National Center for Statistics and Analysis (NCSA), report number DOT HS 810 805. The NCSA report uses the term “large trucks,” which in practical terms describes the same segment of the vehicle population as “heavy vehicles.”

Table II-1
Large Trucks in Crashes by Gross Vehicle Weight Rating
(FMCSA-RI-02-011, January 2003).

Gross Vehicle Weight Rating	Fatal		Injury		Towaway	
	Number	Percent	Number	Percent	Number	Percent
≤ 10,000 lbs	2	*	449	1.2%	592	1.4%
10,001 - 26,000 lbs	519	10.8%	3,772	9.9%	4,931	11.7%
≥ 26,001 lbs	4,246	88.6%	26,736	70.2%	29,941	70.9%
Unknown	26	0.6%	7,104	18.7%	6,795	16.1%
Total	4,793	100.0%	38,061	100.0%	42,259	100.0%

* Less than 0.05 percent.

One factor contributing to this discrepancy is that, in general, the heavier a vehicle is, the longer it requires to stop. While large trucks operate on the same roadway as significantly lighter passenger vehicles, large trucks may take twice as long to stop in instances of full-effort braking. The difference in mass between large trucks and passenger cars also contributes to passenger cars incurring greater damage in collisions between such vehicles. While it would not be practical to reduce the mass of large trucks, recent developments in brake systems indicate that stopping distance reductions are possible.

Based on the crash data from the NCSA and FMCSA reports, the crash geometries (and the percentage of total passenger car occupant fatalities) that might be mitigated through improvements in stopping distance are: rear-end, truck striking passenger vehicle (4 percent of total passenger car occupant fatalities); passenger vehicle turned across path of truck (8 percent); straight path, truck into passenger vehicle (generally side-impact crashes at roadway junctions; 14 percent). The total percentage of all passenger vehicle occupant fatalities for these crash types was 26 percent. In addition, it is possible that some of the head-on collisions could be reduced in severity, since improvements in the braking capability of large trucks could reduce impact speeds.

Under normal driving conditions, drivers would keep a safe distance between their vehicles and the vehicles they are following. The perceived safe distance would be a threshold at which the vehicle would stop without striking the other vehicles, if the driver applies the brakes. Theoretically, if drivers believe that stopping distance is shortened by improved braking systems, and that benefit is confirmed by the vehicle stopping sooner during braking in normal driving over time, they could follow other vehicles closer when compared to vehicles with unmodified brake systems. Although this risk compensation behavior may occur with improved braking systems, it would only affect occupants and vehicles in rear-end crashes (truck striking other vehicles). According to the NCSA and FMCSA reports, about 15%[7] of all passenger vehicle occupant fatalities for truck striking passenger vehicle crashes were rear-end crashes, where following distance might be an issue. The other crashes are intersection crashes, head-on crashes, angular crashes, or sideswipes, where following distance is not a factor in the crash. Even in the rear-end crashes, there will be cases where another vehicle cut in front of the truck and was struck in the rear. So, in some of the rear-end crashes, risk compensation will not be a factor. Therefore, a reduction in stopping distance would benefit the majority of fatal and nonfatal injuries and property damage crashes, regardless of the risk compensation behavior. We have not made adjustments to the benefit estimates for the risk compensation theory.

Selected Comments on PRIA:

The agency's preliminary regulatory impact analysis (PRIA) estimated that greater safety benefits would be attained with a 30-percent reduction in stopping distance requirements compared to the benefits estimated for a 20-percent reduction. It estimated that more than twice

[7] As discussed previously, 26% of total passenger car occupant fatalities could be mitigated through improvements in stopping distance. Among the total fatalities, 4% were rear-end, truck striking passenger vehicle crashes. The rear-end fatalities were 15% (4%/26% = 15.4%) of the fatalities that could be mitigated through improved brakes.

as many benefits in fatalities and serious injuries prevented are projected for the 30-percent case versus the 20-percent case. The differential in estimated property damage reductions is even greater, with approximately five times the property damage prevented for the 30-percent case versus the 20-percent case.

Because the agency could not accurately predict the precise methods that truck manufacturers would use to upgrade tractor brake systems to meet the new requirements, the agency used an array of foundation brake upgrades to estimate increased costs for the brake system improvements. The highest cost of complying with shorter stopping distance requirements would be realized if all tractors were equipped with disc brakes rather than the current S-cam drum brakes, and the lowest cost would be realized if all tractors could meet the new requirements if they were equipped with enhanced (larger) S-cam drum brakes. Both methods have been demonstrated to provide sufficient improvements in braking performance for typical three-axle tractors, while agency testing and data completed after the publication of the NPRM show that the disc brake approach was required to meet the 30-percent reduction for less common configurations of tractors (severe service and two-axle tractors) where improved drum brakes could not achieve the full 30-percent reduction, plus a 10-percent margin of compliance (margin of compliance is discussed in additional detail below).

To refine the cost-benefits analysis for this final rule, the agency requested additional data primarily on the cost portion of the NPRM from truck manufacturers and manufacturers of heavy vehicle brake systems and components. An important issue was whether the seven tests of the three-axle tractor conducted by Radlinski, Inc., and the two tractor test programs from VRTC, which were submitted to the docket by NHTSA for public review, are representative of the potential braking performance improvements for the current tractor fleet. The NPRM included this question in Section VII, Request for Comments, where specific questions were asked for technical information and cost data related to the rulemaking. The agency wanted to determine, for example, if typical three-axle tractors, representing a majority of tractor production, would be able to meet a 30 percent reduction in stopping distance using larger drum brakes, as the Radlinski data indicate was readily achieved, and what the cost of the larger drum brakes would be.

Selected comments related to the PRIA are shown below:

- TMA and Freightliner stated that typical three-axle tractors (similar to the tractors from the Radlinski and VRTC tests) comprise 82 percent of annual tractor production and ATA stated that such tractors comprise 81 percent of production. Haldex stated that the test data in the docket primarily covers standard three-axle tractors, but does not represent other configurations, such as 4x2 (two-axle) or severe service tractors. Thus, the agency concludes that the tests conducted, by VRTC and Radlinksi on typical three-axle tractors, represent approximately 82 percent of annual tractor production. Freightliner commented that 4x2 tractors comprise ten percent of tractor production, and severe service tractors comprise seven percent of tractor production (though there may be rounding error as Freightliner’s statements on total production for the three types of tractors adds to 99 percent rather than 100 percent).

The agency’s cost estimates in the PRIA for improved brake systems on a three-axle tractor to achieve the 30 percent reduction ranged from a low estimate of $153 (for larger S-cam drum brakes at all wheel positions) to a high estimate of $1,308 (for air disc brakes at all wheel positions).

- Freightliner was the only commenter providing cost information on improved tractor brake systems. It stated that its cost to purchase enhanced drum brake components for a three-axle tractor is $222,[8] and its cost to purchase all disc brakes is $1,627. Freightliner stated that these costs do not include development and manufacturing costs, but it did not elaborate on what these costs might be. Freightliner stated that all two-axle tractors will need to be redesigned for enhanced brake systems, and would most likely require disc brakes at a cost of $963, not including development and manufacturing costs.

The NPRM Request for Comments section also asked for information on tractor components other than the foundation brakes (e.g., frames and suspensions) that may need to be modified to meet shorter stopping distance requirements of 20 to 30 percent. In this request, the agency was seeking to identify additional costs or weight penalties that might be required to meet the new stopping distance requirements. The commenters provided little specific information on the vehicle modifications that may be required to reliably equip tractors with more powerful foundation brakes.

- TMA cited chassis structural analysis, design, and validation, but did not elaborate on the costs or scope of these issues. For example, validation might refer to endurance testing or it might refer to FMVSS No. 121 compliance testing.
- Freightliner stated that if two-axle tractors are fitted with disc brakes, electronic stability control systems may be needed to reduce instability during hard braking events.

[8] In the PRIA, we estimated that large drum brakes at wheel positions would be $153. Freightliner commented that their cost was $222. They did not break out steer vs. driver brakes. In the PRIA, we used $75 for steer and $50 for drive, but for this analysis, the updated estimate of $85 for larger steer S-cam and $65 for larger drive S-cam.

- Haldex stated that necessary vehicle modifications such as tires, suspensions, chassis structure, etc., would be most effectively addressed by the vehicle manufacturers.

On the issue of weight penalties for improved brake systems, Bendix provided data on drum brake versus disc brake weights. It stated that the heaviest drum brakes weigh more than the lightest disc brakes, while the heaviest disc brakes weigh more than the lightest drum brakes. It stated that for a three-axle tractor equipped with all disc brakes, total vehicle weight could increase by 212 pounds, or decrease by 134 pounds (compared to a tractor equipped with current-sized all drum brakes), depending upon which disc or drum brakes are used for comparison.

The agency concludes that the cost-benefits analysis provided in the PRIA cannot be significantly refined at this point, nor is it necessary to do so.[9] As described in the section below, it appears that a small percentage of tractors, perhaps no more than 18 percent of tractors (4x2 and severe service tractors), will need to have disc brakes installed at all wheel positions. Some of the typical three-axle tractors may need disc brakes on the steer axle only, and many of these tractors may be able to comply by upgrading to enhanced drum brakes (the lowest-cost option). Thus, it is unlikely that the total cost to implement the requirements in this final rule would be close to the high-end cost estimate in the PRIA (which was to install disc brakes on all tractors). These upgrades will be developmental and require validation testing (as mentioned by several tractor manufacturers), and possibly incur weight increases (that cannot be determined from the

[9] The agency contracted with Ludtke and Associates to perform a cost and weight analysis of improved tractor brake components. However, the findings will not be available for the FRIA. In addition, we have not received any significant information on costs associated with the new rule.

available data) that would result in slight fuel consumption increases and possible loss of revenue by displacing cargo-carrying capacity. Such per-vehicle costs cannot be specifically estimated, but these are believed to be a tiny fraction of the cost of better brakes.

III Test Data

The agency has been conducting brake research as part of an ongoing effort to enhance the crash avoidance capabilities of medium and heavy trucks. Most of the recent braking research in this area has been directed towards air-braked heavy trucks and in particular combination vehicles that, as the crash data show, have the most exposure in truck-related fatal crashes.

In general terms, all of the information provided to the agency show that air disc brakes installed on all wheel positions of a tractor would enable typical three-axle tractors to exceed a 30% reduction of the stopping distance requirements currently stated in FMVSS No. 121. Similar results were also indicated for three tests of larger, enhanced S-cam drum brakes, when installed on all positions of typical three-axle tractors.

The air disc and larger S-cam based brake configurations tested by the agency, as described below, were experimental in nature. While the results are believed to reflect what effect the installing of such brakes may have on reducing stopping distances, the truck manufacturers did not design their vehicles with the knowledge that such brakes would be installed.

(A) NHTSA Test Results:

At the agency's Vehicle Research and Test Center (VRTC) in East Liberty Ohio, research was initiated in 2002 to compare the performance of S-cam drum brakes, larger S-cam steer axle drum brakes, and disc brakes, for air-braked tractors and trailers. The tractors tested included a 1991 Volvo 6x4 tractor and a 1996 Peterbilt 6x4 tractor, both of which had 12,000 pounds gross axle weight rating (GAWR) steer axles, 19,000 pounds GAWR drive axles, and 50,000 pound

GVWRs. Both tractors were fitted with ABS. Trailers in the test program included a 1998 48 ft Dorsey flatbed trailer with tandem axles rated at 20,000 pounds GAWR each and a 72,837 pound GVWR, and a 2001 53 ft Fruehauf van trailer with tandem axles rated at 20,000 pounds GAWR each and a 68,000 pound GVWR.[10] Also a FMVSS No. 121 un-braked control trailer was used for 121-type tests, equipped with a single axle loaded to 4,500 pounds for all tests.

(1) S-Cam Drum Brakes:

Both tractors were originally equipped with conventional S-cam drum brakes (16.5” x 7” for drive axles, 15” x 4” on steer axles), but were converted to vented air disc brakes (16.93”x1.77” on Peterbilt and 16.54”x1.77” on Volvo) at all wheel positions. Both tractors were additionally converted to two different hybrid brake configurations, each using conventional S-cam drum brakes on the drive axles. The first hybrid configuration was equipped with the air disc brakes on the steer axle, and the second configuration was equipped with larger S-cam drum brakes (16.5”x6” on Peterbilt and 16.5”x5” on Volvo) on the steer axles. The two production trailers were cycled between being fitted with standard S-cam drum brakes (16.5” x 7”) or with vented air disc brakes (16.93”x 1.77” on Dorsey and 16.54”x1.77” on Fruehauf). Tests were conducted in various combinations of vehicles and foundation brake configurations to provide comparative data on the performance of the brakes, and these tests included bobtail tractor service and failed system tests, braking-in-a-curve tests on a low-friction surface, parking brake tests, and also tests with the conventional (S-cam) and disc trailer brakes.

Figures III-1 and -2 below show data from VRTC for the two tractors tested from 60 mph on high friction pavement, loaded to the lightly loaded vehicle weight (LLVW) and GVWR using

[10] The detailed test results are presented in SAE paper, No. 2005-01-3614.

the FMVSS No. 121 un-braked control trailer. Two tractor trucks, Peterbilt (i.e., NHTSA Peterbilt) and Volvo (i.e., NHTSA Volvo), were equipped with different types of brakes for the tests. Both the Peterbilt and Volvo were equipped with larger steer drum brakes, disc brakes on the steer axle only, conventional S-cam drum brakes at all wheel positions, and disc brakes at all wheel positions, when braked using a FMVSS No. 121 un-braked control trailer. Figure III-1 shows results for the LLVW[11] test condition and Figure III-2 shows results for the GVWR test condition. The results in Figure III-1 show that the tested vehicles would achieve a 30% reduction in stopping performance when tested in LLVW test condition.

For the GVWR test condition, the Peterbilt data show that with either larger drum brakes or disc brakes on the steer axles, the vehicle is close to achieving a 30% reduction in stopping distance performance. With disc brakes at all wheel positions, the vehicle meets the 249-foot distance consistently with this brake system configuration. For the Volvo tractor, it is notable that this vehicle equipped with conventional S-cam drum brakes had a large margin of compliance (an average of 26 percent) against the FMVSS No. 121 requirement of 355 feet. With either the larger S-cam drum brakes or the air disc brakes installed on the steer axle, the stopping performance did not change appreciably compared to the baseline vehicle. However, when equipped with disc brakes at all wheel positions, the vehicle surpassed a 249-foot, 30 percent reduction in stopping distance compared to current FMVSS No. 121 requirements, with an average margin of compliance of eight feet or three percent.

[11] Lightly loaded vehicle weight (LLVW) is unloaded truck weight plus a small allowance (unloaded weight plus up to 500 lbs for test driver and instrumentation, plus at the vehicle manufacturer's option, not more than an additional 1,000 lbs for a roll bar structure on the vehicle). See FMVSS No. 121, S5.3.1.1(b) or S5.3.6.2(b) for additional information.

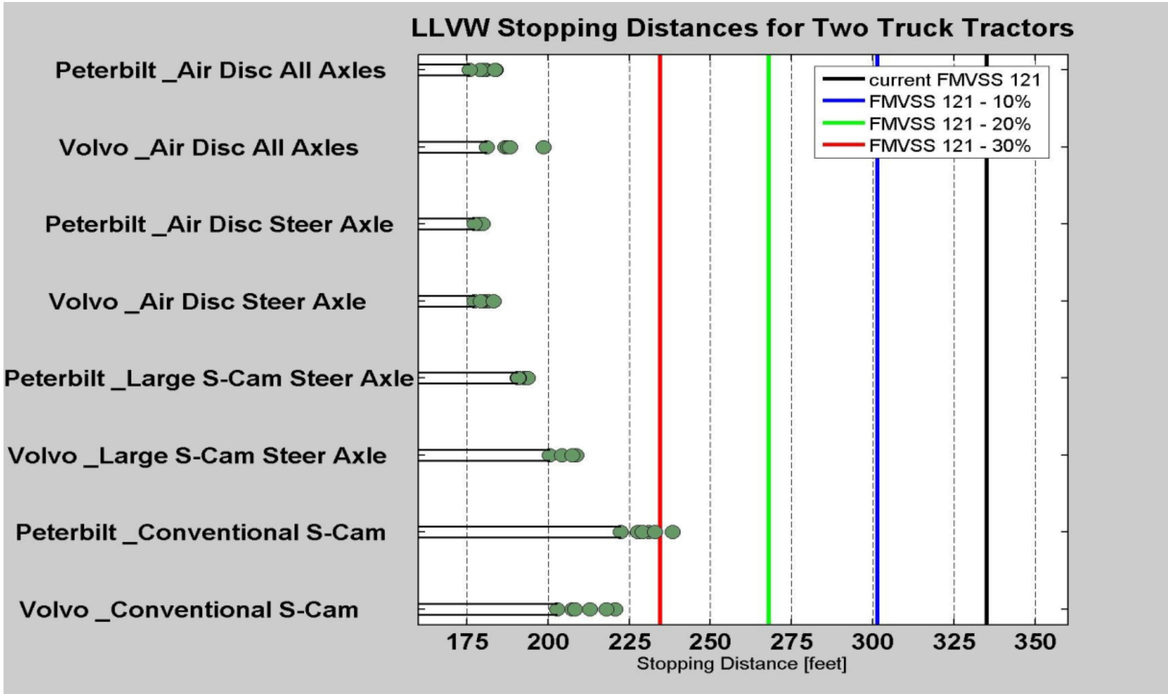

Figure III-1. LLVW Stopping Distance

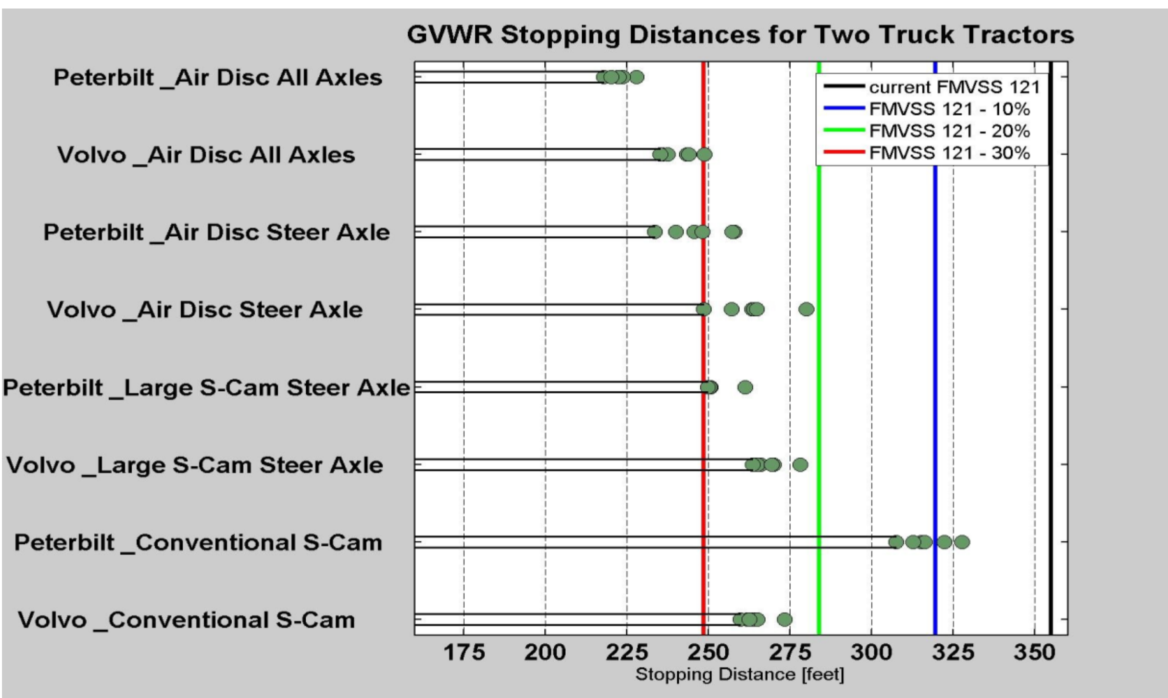

Figure III-2. GVWR Stopping Distance

(2) Disc Brakes at All Wheel Positions:

Over the past three years, NHTSA has been made aware of recent developments in air brake systems through meetings and vehicle demonstrations provided by the major suppliers of air brake systems and components in the U.S. Developments include air disc brakes, and enhanced S-cam drum brakes, electronically controlled brake systems (ECBS), and advanced ABS.

The disc brake systems tested at VRTC for the two tractors tested from 60 mph on high friction pavement, loaded to GVWR using the FMVSS No. 121 un-braked control trailer show that trucks equipped with disc brakes could meet the required stopping distance with a high margin of compliance. With the NHTSA Peterbilt, the disc system produced an average stopping distance of 222 ft. With the NHTSA Volvo, the average stopping distance was 241 ft. These stopping distances measured are shorter than the required 250 ft[12].

(3) Disc Brakes on Front Axle and Larger S-cam Drum Brakes on Drive Axle(s)

The results in Figure III-1 and III-2 show that air disc brakes installed on all wheel positions of a tractor could meet the required 30% reduction in stopping distance. Although such tests have not been performed by NHTSA, the larger S-cam drum brake data indicate that a truck equipped with larger S-cam drum brakes at all wheel positions could also meet the required 30% reduction in stopping distance. Furthermore, a truck equipped with disc brakes on the steer axle and larger S-cam drum brakes on the drive axle(s) might meet the required reduction requirements, although the agency has not actually tested this configuration.

[12] Although the stopping distance is shorter than the proposed requirements, for the benefits analysis, the 249 ft was used.

(B) Test Results Provided by Brake Suppliers

(1) Larger S-Cam Drum Brakes

The performance of larger S-cam drum brakes on both steer and drive axles (16.5” x 5” and 16.5” x 8 5/8”, respectively) for a typical three-axle tractor were provided to NHTSA by two suppliers of heavy truck brake linings, Federal Mogul Corporation and Motion Control Industries, Inc. The results show that for the vehicle tested, enhanced S-cam drum brakes performed equal to or better than NHTSA’s tests of tractors equipped with air disc brakes at all wheel positions.

The tests were conducted on a Freightliner Century 6x4 (three-axle) tractor that was taken from regular fleet service and subjected to FMVSS No. 121-type test requirements by Radlinski and Associates in East Liberty, Ohio. Three test reports were provided, showing results for various brake linings and tractor test weights. Test numbers RAI-FM-20 and RAI-MC-04 compared two front and two rear brake linings on the tractors when tested at 12,000 lbs for the steer axle and 34,000 lbs for the drive axles (this represents testing by de-rating the drive axles which were fully rated at 40,000 lbs.). Additional comparisons were made between Type 20 and Type 24 steer axle brake chambers.[13] One additional test was also made with the tractor drive axles at their full rating of 40,000 lbs.

The third test, RAI-FM-21, was tested at 12,000 lbs on the steer axle and 40,000 lbs on the drive axles, and provided a comparison of two slack adjuster lengths on the drive axles, 5 ½ inch and 6

[13] The 20 and 24 referring to the nominal square inches of brake actuator surface area, with Type 24 generating more force and consuming more air than Type 20.

inch. The 6 inch slack adjuster typically can provide higher brake torque than the 5 ½ inch slack adjuster for a given air pressure. The test results are summarized in Table III-1.

Table III-1
Average Stopping Distance for 60-mph Service Brake Stops of
Three-axle Tractor Using Enhanced S-Cam Drum Brakes
(The Trailer is an Un-Braked Control Trailer as Specified in FMVSS No. 121)

Report No.	Nominal Axle weights (lb)			Brake Chamber Size/Type (in^2)		Slack Adjuster Length (in)		Average Stopping Distance (ft)
	Steer	Drive	Trailer	Steer	Drive	Steer	Drive	
RAI-FM-20	12,000	34,000	4,500	24	30	5 1/2	5 1/2	208
	12,000	34,000	4,500	20	30	5 1/2	5 1/2	219
RAI-MC-04	12,000	34,000	4,500	24	30	5 1/2	5 1/2	206
	12,000	34,000	4,500	20	30	5 1/2	5 1/2	209
	12,000	40,000	4,500	24	30	5 1/2	5 1/2	215
RAI-FM-21	12,000	40,000	4,500	24	30	5 1/2	5 1/2	216
	12,000	40,000	4,500	24	30	5 1/2	6	206

A review of the variability among the six stops for each test condition shows that stop-to-stop variability was minimal. On average, the difference between the shortest stop and the longest stop for the seven test conditions was 10 feet. Thus, the stopping distance performance for each test condition is observed to have little variation from stop-to-stop.

The performance exhibited by the enhanced S-cam drum brakes on this vehicle, for each test condition, indicates that this vehicle could easily meet the required 30 percent reduction in stopping distance when tested according to the procedures specified in FMVSS No. 121. In fact, the performance of this vehicle, in any of the seven brake configurations, actually met or exceed NHTSA's own tractor service brake test using air disc brakes at all wheel positions. When tested at the full gross axle weight rating of 40,000 lbs for the drive axles, as shown for three test conditions, the average stopping distances were 215, 216, and 206 feet. The tests with the drive axles at a de-rated[14] weight rating of 34,000 lbs showed slightly better service brake stopping performance (except for the test using smaller Type 20 brake chambers on the steer axle), but the differences were not significant.

On November 19, 2007, the agency received a letter of explanation from Link-Radlinski (the successor organization to Radlinski and Associates) describing that it was aware of possible variations in their instrumentation during the time frame of the three RAI reports[15]. The estimated error that typically may have been introduced into measurement of stopping distance during these tests is no more than nine feet, which could be added or subtracted to the measured stopping distance to arrive at the true stopping distance. However, Link-Radlinski is not able to determine if any particular testing was inaccurate by that amount. Nevertheless, even if the stopping distance results indicated in Table III-1 were increased by nine feet, the margin of compliance to a 250-foot stopping distance would still be ten percent in five out of seven test configurations, and the remaining two would have still have a nine percent margin of compliance.

In summary, the test data appear to indicate that to meet a 30% reduction in stopping distance, <u>most</u> vehicles will need to improve their brakes on all axles, both steering and drive. Based on

[14] De-rating of axles is one potential method that vehicle manufacturers could use to achieve improvements in stopping performance. While a typical drive axle tandem might be rated at 38,000 or 40,000 lbs gross weight rating, typical tandem drive axle state roadway weight limits for on-road truck operation are 34,000 lbs. Fleets often purchase higher rated drive axles for increased durability. There are potentially negative consequences of de-rating of axles that may discourage this practice. The brake burnish conducted with the tractor at GVWR, is not considered particularly severe. Thus, running the burnish at reduced weight could result in less conditioning of the brake linings, and this could affect the ability of the tractor to meet the parking brake requirements. However, reviewing the results from the three tests shows mixed results with regard to parking brake drawbar force.

[15] Docket No. NHTSA-2005-21462-0041, Letter from Link-Radlinski

the available data, it appears that both technologies used to improve braking performance (larger S-cam drum or disc brakes) may be able to achieve either goal.

(C) Baseline Fleet Brake Performance:

The agency has very limited information on fleet baseline brake performance. According to the current fleet brake type and size data (as shown in Table IV-24), about 3% of the trucks are currently equipped with the enhanced drum brakes (i.e., larger S-cam drums) and could meet the required 30% reduction in stopping distance requirement without modification.[16] For the analysis, therefore, we assumed that NHTSA Peterbilt, NHTSA Volvo and the Radlinski Freightliner represent 66%, 31% and 3% of the current fleets, respectively. Based on the percent distribution, the results from the NHTSA's and Brake Suppliers' tests were weighted, as shown in Table III-2.

Table III-2
Weighted Stopping Distance with respect to
Percent of Annual Truck Production that Could be Represented by Trucks Tested

Vehicle Tested	% of annual Production[17]	Brake Type		Average Stopping Distance (ft)	Weighted Stopping Distance (ft)
		Steer Axle	Drive Axle		
NHTSA Peterbilt	66%	S-cam Drums	S-cam Drums	317	
NHTSA Volvo	31%	S-cam Drums	S-cam Drums	264	
Radlinski Freightliner	3%	X-Large Drum	X-Large Drum	216	298

When the 298 ft weighted baseline stopping distance was compared to the 250 ft minimum stopping distance (i.e., a 30% reduction in stopping distance), it results in a 16% reduction in stopping distance.

[16] The agency does not have information on the number of tractors equipped with disc brakes.
[17] As discussed, the percentages were estimated.

(D) Braking Performance of Two-Axle Tractors:

In their comments on the NPRM, Freightliner stated that two-axle tractors (4x2 tractors) represent ten percent of air-braked tractors produced annually. Freightliner and TMA stated that 4x2 tractors are only involved in 3.4 percent of fatal crashes involving tractors, and because of this low fatality involvement rate, these vehicles should not be included in the agency's rulemaking to require shorter stopping distances. International also commented that it believes 4x2 tractors should be excluded from the rulemaking, and although it did not cite the fatality involvement rates in its comments, it stated that it was an active participant in the preparation of TMA's comments[18]. Freightliner stated that two-axle tractors are used in diverse applications ranging from intra-city beverage delivery vehicles to over-the-road combination vehicles with two or three trailers.[19]

[18] TMA included in its comments a report on Class 8 truck tractor crash statistics performed by the University of Michigan Transportation Research Institute (UMTRI) using its Trucks Involved in Fatal Accidents database for the years 1999 through 2003. Table 7 of the report shows the road type (interstate, U.S. route, state route, county road, etc.) on which Class 8 tractor fatal involvements occurred. Two-axle tractor crash data regarding road type for Class 8 tractors were quite similar to those for typical three-axle tractors. Only slightly fewer fatal crashes occurred among two-axle tractors on interstates (29 percent) compared to three-axle tractor fatal crashes occurring on interstates (34 percent). Crashes among the two vehicle configurations were nearly the same for U.S. and state routes, and slightly higher for two-axle tractor crashes on county roads (7 percent) versus typical three-axle tractors (5 percent).

[19] Referring to TMA's UMTRI report, Figure 1 shows that the frequency distribution of the gross combination weight (total weight of the combination at the time of the crash, and not the gross combination weight rating) for the three types of tractors (two-axle, typical three-axle, and severe service) was highly concentrated in the 20,000 to 40,000 pounds range for the two-axle tractors. There were many fewer two-axle tractors involved in fatal crashes that were being operated in excess of 45,000 pounds gross combination weight in comparison with tractors having three or more axles.

Table 3 of the UMTRI report indicated that there were 724 Class 3 through 7 tractors in the sample (most if not all of these would be Class 7 tractors with a GVWR between 26,001 and 33,000 pounds, and would be in the lower combination weight applications such as beverage delivery), compared to the 534 crashes of Class 8, two-axle tractors (GVWR greater than 33,000 pounds) in the sample that were used in its analysis. Thus, more than half of the two-axle tractors involved in fatal crashes are missing from UMTRI's analysis because they were not Class 8 tractors (the report states that only Class 8 tractors were used in the analysis). Therefore, the agency does not agree with TMA that two-axle tractors should be excluded from this final rule. The agency does not agree that two-axle tractors are under-represented in fatal crashes to a degree that would warrant them being excluded from this final rule.

The agency did not include test data on two-axle tractors when the NPRM was published. However, since that time, the agency has completed a foundation brake study at VRTC on a typical two-axle tractor. The tractor was purchased new and was originally equipped with larger steer axle S-cam drum brakes of 16.5" diameter by 5" lining width, and standard S-cam drum brakes of 16.5" x 7" on the drive axle. In the as-received state (approximately 1,000 miles of normal road use, but only in the bobtail condition), the average stopping distance (six stops) was 241 feet from 60 mph at GVWR plus 4,500 pounds of weight on the single axle, unbraked control trailer as specified in FMVSS No. 121. However, when the foundation brakes were replaced with all new components and subjected to a complete FMVSS No. 121 burnish, the average stopping performance increased to 322 feet. Further investigation of this problem indicated that the replacement brake linings generated less torque than the original linings.

In the second test configuration, the tractor was equipped with disc brakes on the steer axle and the standard S-cam drum brakes on the drive axle (hybrid brake configuration), and again subjected to an FMVSS No. 121 burnish. The average loaded-to-GVWR stopping distance was 223 feet, although there was incomplete burnishing of the drive axle brakes. However, the proposed 250-foot stopping distance requirement was met with a margin of compliance of eleven percent. In the final test configuration, the tractor was equipped with disc brakes on both the steer axle and drive axle, and after an FMVSS No. 121 burnish, the average loaded-to-GVWR stopping distance was 200 feet. The performance with all disc brakes therefore met the 250-foot stopping distance requirement and had a margin of compliance of 20 percent.

TMA data submitted in response to the NPRM indicated that among regular-service 4x2 tractors ("regular service" versus "severe service" definitions for two-axle tractors were not clearly defined in TMA's comments), the hybrid brake configuration (one test; disc front and standard 16.5" x 7" S-cam drum brakes on the drive axle) met a 250-foot stopping distance with a margin of compliance of approximately 12 percent. TMA data on another hybrid brake configuration with disc brakes on the steer axle and enhanced S-cam drum brakes of 16.5" x 8 5/8" on the drive axle (two tests) indicated that both test vehicles met a 250-foot stopping distance, with one having a margin of compliance of approximately 15 percent and the other having a margin of compliance of approximately two percent. In the all-disc brake configuration (one test), the vehicle met the proposed 250-foot requirement with an approximate margin of compliance of 22 percent.

TMA comments submitted in October 2006 provided additional data on the performance of two-axle tractors with improved foundation brakes. Tests of three tractors with all disc brakes indicated that the best-of-six stops ranged from approximately 206 to 221 feet, meeting a 30-percent reduction in stopping distance with margins of compliance ranging from 18 to 12 percent. A fourth tractor with larger S-cam drum brakes had a shortest stop of approximately 248 feet and thus had marginal compliance to a 30-percent stopping distance reduction. Three of the tractors with standard drum brakes could not meet a 250-foot stopping distance (one of the four tractors did not have data describing its drum brake sizes).

Bendix provided test data on the disc/drum hybrid configuration (two tests; drive axle drum brake size not specified) and the average stopping distance (three stops for one test and six stops for the other test) for both tractors would meet the proposed 250-foot requirement with a margin of compliance of 12 percent for one vehicle and nine percent for the other. Using the best stopping distance of 225 feet (rather than the average stopping distance of 228 feet) for the poorer-performing tractor yields a margin of compliance of 10 percent. Bendix test data on all-disc braked 4x2 tractors (two tests) indicated that both vehicles would meet a 250-foot stopping distance and the margins of compliance were 19 percent and 14 percent based upon the average of six stops in each case. The GAWRs for all 4x2 tractor tests were 22,999 pounds or less on the drive axle and 12,000 pounds or less on the steer axle (i.e., standard service and not severe service).

Based on this data, the agency concludes that meeting a 30-percent reduction in stopping distance is achievable for two axle tractors with at least a 10 percent margin of compliance with all-disc brake configurations. To a lesser extent, the hybrid disc/drum configuration (one test with a good margin of compliance and another with a poor margin of compliance) may also be able to achieve the 30-percent reduction in stopping distance.

(E) Performance of Severe Service Tractors with Improved Brake Systems:

In its comments, TMA described a severe service tractor as having three axles with either a steer axle GAWR greater than 14,600 pounds or tandem drive axles with a total GAWR greater than 45,000 pounds. In addition, severe service tractors include those tractors with twin steer axles, auxiliary axles (e.g., lift axles), and/or tridem drive axles. Chassis configurations include 6x4, 8x4, 8x6, 10x6 and 14x4 layouts. Based on comments from TMA and Freightliner, the GVWR of severe service tractors is greater than 60,000 pounds and can exceed 100,000 pounds. Severe service tractors are used in special purpose applications such as oil field service, extreme heavy hauling, transporting earth moving equipment, and logging. Operation is both on- and off-road and in some cases on-road use is at very slow speeds with the tractor-trailer combination being accompanied by escort vehicles.

Freightliner stated that severe service tractors comprise seven percent of tractor production and are involved in 5.6 percent of fatal tractor crashes, according to the UMTRI report on Class 8 tractors involved in fatal crashes that was included with TMA's comments. Based upon the comments received it appears that on-road mileage exposure for severe service tractors is lower than for typical three-axle or two-axle tractors, and thus the 5.6 percent fatality involvement rate does not necessarily indicate that severe-service tractors are underrepresented in fatal crashes.

TMA, in its original comments submitted in response to the NPRM, provided test data for one severe-service 4x2 tractor with 16.5" x 5" S-cam drum brakes on the steer axle and 16.5" x 7" S-cam drum brakes on the drive axle. The indicated stopping distance was approximately 315 feet so this brake configuration was not close to meeting a 250-foot stopping distance requirement. However, a 4x2 tractor is not a typical severe-service tractor because it does not have a GVWR in excess of 60,000 pounds. A typical severe-service tractor would have three or more axles to be able to carry heavy loads. In addition, the 4x2 severe service tractor in question would need to be tested with disc brakes that have been demonstrated to typically provide the shortest stopping distance before any definitive statements could be made about its potential braking performance capabilities. The agency declines to use the TMA data on this severe service 4x2 tractor in formulating the requirements for severe service tractors in the final rule.

Recently (after publication of the NPRM) the agency conducted testing on a severe service truck, a 6x4 Peterbilt Model 357 with a steer axle GAWR of 18,000 pounds and a tandem drive axle GAWR of 44,000 pounds. The GVWR was 62,000 pounds, and the wheelbase was 275 inches. The vehicle was purchased as a chassis-cab and manufactured as a single-unit truck, and a load frame was attached to the frame rails for test loading purposes. Although this particular truck was a single-unit truck, the agency believes, as discussed in further detail below, that it exhibited similar service braking characteristics as would a tractor of similar size and weight dimensions.

A study performed by VRTC in August 2006, *Vehicle Modeling Research: Study of Longitudinal Dynamic Load Transfer During Braking* compared the weight transfer characteristics of single-unit trucks and tractor-trailer combinations and found that under moderately hard braking (0.45 g), as the wheelbase increases (from 150 inches to 200 or 300 inches) the differences in dynamic load transfer on drive and steer axles between trucks and tractors becomes small. However, in each case, the steer axle of the single-unit truck still had higher dynamic load transfer than for the comparison tractor with the same wheelbase. Thus, in this respect, the VRTC tests on the Peterbilt Model 357 were likely to be more severe in terms of steer axle load transfer than if the vehicle had actually been tested as a tractor.

On the other hand, the difference in loading methods of single-unit trucks and tractors under FMVSS No. 121 test conditions means that the VRTC tests on the Peterbilt Model 357 were less severe than if it had been tested as a tractor. Single-unit trucks are tested at GVWR by ballasting the load frame attached to the chassis cab frame rails, while a tractor is tested in the fully-loaded condition by attaching a FMVSS No. 121-specific unbraked control trailer, so that the tractor is loaded to its GVWR and the semitrailer's single axle weighs 4,500 pounds measured at its tires on the ground. Thus, when tested as a tractor, there would be an additional weight demand on the tractor, amounting to a seven percent weight increase over this particular truck's GVWR. The net difference of the effects of dynamic weight transfer (favoring tractors) and loading scheme (favoring trucks) may have an effect on the tests of the Peterbilt being representative of a tractor. However, the agency was not able to quantify the net effect of the two factors that were considered.

The substantial differences in braking performance for this vehicle in the truck versus tractor configuration would be apparent in emergency braking performance for which the truck configuration would likely need to utilize spring brake modulation to meet the stopping distance requirement at GVWR (there is no equivalent test requirement for tractors, since emergency brake requirements only apply in the unloaded condition), and there are also differences in parking brake performance requirements for single-unit trucks and tractors. However, neither of these brake system differences were factors during the normal service brake tests of the Peterbilt.

The baseline VRTC truck was originally manufactured with large 16.5" x 6" steer axle S-cam drum brakes, and drive axle S-cam drum brakes of 16.5" x 7" (the drive axles were not equipped with the wider 8" or 8 5/8" enhanced S-cam brakes). It was also equipped with a 6S/6M ABS system that should provide the highest braking efficiency because the braking forces are modulated individually at each wheel position. With the OEM S-cam drum brakes, the average loaded-to-GVWR, 60 mph stopping distance was 280 feet, which does not meet a 250-foot, 30-

percent reduction stopping distance requirement. In a hybrid configuration with disc brakes on the steer axle and the standard S-cam drum brakes on the drive axles, the average stopping distance was 251 feet which is close to the 250-foot target stopping distance. However, when this truck was equipped with disc brakes at all wheel positions the average stopping distance was 224 feet which meets the 30-percent target stopping distance and had an additional 10 percent margin of compliance.

A computer simulation study performed by VRTC in July 2006 based on this truck investigated what its service brake performance might be if this truck were tested at a higher GVWR of 80,000 pounds. This study used the Truck Sim vehicle dynamics modeling software with which the VRTC staff has extensive experience, including validation of many modules (such as foundation brakes and ABS control systems) used in the program. This simulation study determined that with the same all-disc-brake configuration, but with the GVWR increased to 80,000 pounds, the estimated stopping distance would be 280 feet. By increasing the brake torque on the steer axle (using type 30 brake chambers in place of type 24 chambers) the estimated stopping distance was 262 feet at 80,000 pounds GVWR. Additional parametric studies (by modeling further increases in brake torque at all wheel positions) showed that if brake torque could be increased sufficiently to utilize the available tire-road friction, stopping distances as low as 227 feet could be achieved (meeting a 30-percent reduction with a nine percent margin of compliance). However, the agency is not aware that there are any available disc brakes currently capable of generating that much torque, which would be able to be packaged within the available wheel envelope.

Data submitted by TMA in its October 2006 supplemental comments included additional information on severe service tractor stopping performance with six drum and disc brake configurations and three drive axle GAWRs. TMA stated that the disc brakes used in these tests were prototype models that have not been fully tested for production (dynamometer and other test data not were not yet available) but the agency assumes they would be the largest practical disc brakes that would work within the available wheel and suspension envelope.

When tested at a steer axle weight of 20,000 pounds and a tandem drive axle weight of 46,000 pounds yielding a GVWR of 66,000 pounds, the baseline all-drum brake configuration (unspecified sizes) had a stopping distance of 262 feet. With a hybrid configuration using the prototype disc brakes on the steer axle and drum brakes on the drive axles, the stopping distance was 229 feet which meets a 30-percent reduction in stopping distance and has an eight percent margin of compliance. When tested with disc brakes at all wheel positions, the stopping distance was 223 feet which meets a 30-percent reduction in stopping distance with an eleven percent margin of compliance. The data for the all-disc brake test is similar to the performance obtained by VRTC in its tests of the 6x4 truck with a 62,000 pound GVWR using all disc brakes.

The remaining test data provided by TMA for hybrid and all-disc brake foundation brake configurations were based upon (unspecified) simulations, presumably similar to the Truck Sim work performed by VRTC. A footnote indicates that one all-drum-brake configuration at 72,000 pounds GVWR was verified by actual vehicle testing.

The simulation results for a 72,000-pound GVWR tractor with a 20,000-pound steer axle load and 52,000-pound tandem drive axle load estimated that for the hybrid configuration with disc brakes on the steer axle and drum brakes on the drive axles, the stopping distance would be 248 feet which would marginally meet a 30-percent reduction in stopping distance. When tested at this weight with all disc brakes, the stopping distance was estimated at 242 feet which meets a 30-percent reduction in stopping distance with a three percent margin of compliance. The all-drum-brake configuration was road tested at 72,000 pounds GVWR and had a stopping distance of 285 feet that does not meet a 250-foot target stopping distance.

The final simulated test condition was at 78,000 pounds GVWR with a 20,000-pound steer axle load and 58,000-pound tandem drive axle load. For the hybrid disc/drum configuration the stopping distance was estimated at 268 feet, and for the all-disc-brake configuration the stopping distance was estimated at 261 feet. Neither of these would meet a target stopping distance of 250 feet. In the all-drum-brake configuration, the estimated stopping distance was 307 feet. The agency notes that a 58,000-pound tandem drive axle rating (or 29,000 pounds per axle) is exempt from FMVSS No. 121 under Section S3, Application, paragraph (b). That paragraph states that any vehicle with a GAWR of 29,000 pounds or more is not subject to the requirements in FMVSS No. 121.

TMA's supplemental comments also stated that among all severe service vehicles, those at the upper end of the weight range (single axle weight ratings of 26,000 pounds or more, or tandem axle weight ratings of 52,000 pounds or more) represent less than one percent of annual tractor production. Furthermore, TMA believes that it is unclear as to what technology would be needed to achieve high levels of braking performance improvements.

We previously noted that severe service tractors constitute approximately 7 to 8 percent of annual tractor production and these vehicles are not underrepresented in fatal crash involvements, so improvements in stopping distance performance should be pursued. The agency does not have annual production details on severe service tractors by front and rear axle ratings and total GVWR, but believes that those at the lower end of the severe service weight category make up the majority of production in the severe service tractor category (i.e., those severe service tractors with very high GVWRs, according to supplemental TMA comments, make up less than one percent of the severe service vehicles produced).

The agency refers to two photographs of severe service tractors shown on page 12 of TMA's original comments. The first example is a 6x4 tractor shown towing double trailers. The second example is a 10x6, twin-steer tractor with tridem-drive axles. Although TMA did not state the axle ratings for these two tractors, presumably the 6x4 example falls into the lower range of severe service tractors with drive axles in the 46,000 to 52,000-pound GAWR range and the steer axle in the 13,000 to 14,500-pound range for an estimated GVWR range of 59,000 to 66,500 pounds, which is similar to the 6x4 truck tested at VRTC (62,000 pounds GVWR) and is also at the lower end of the GVWR range for severe service tractors. The available test data show that this type of severe service vehicle is capable of meeting a 250-foot stopping distance requirement with improved foundation brakes and can also achieve a 10 percent margin of compliance.

Typical weights for the second example, based upon information provided to the agency in several ex-parte meetings that have been held since the publication of the NPRM[20], would be 14,500 pounds GAWR for each steer axle and 20,000 pounds for each of the tridem drive axles, yielding a GVWR of 89,000 pounds. Another described configuration of a twin-steer tractor is an 8x4 with a 20,000-pound GAWR for each steer axle and a 26,000-pound GAWR for each of the tandem drive axles, yielding a GVWR of 96,000 pounds. Neither of these tractors would be exempt from FMVSS No. 121 based on these axle ratings. The agency agrees with TMA that, based on all available information, foundation brakes that could provide loaded-to-GVWR stopping distance performance in the 250-foot range are not available for these tractors, although there are no test data available for such tractors fitted with the largest available disc brakes to confirm this (noted in the TMA supplemental comments citing tests of prototype disc brakes that have not been tested extensively). However, the agency believes that they could meet the stopping distance requirements for similar vehicles that are configured as single-unit trucks rather than tractors, because similarly-configured single unit trucks are currently being manufactured[21] in compliance with FMVSS No. 121. The service brake stopping distance requirement for single-unit trucks is 310 feet in the loaded-to-GVWR condition.

Based on the limited amount of test data that are available for severe service tractors, the agency concludes that for lower-GVWR three-axle severe service tractors, a 250-foot stopping distance and a ten percent margin of compliance has been demonstrated for 6x4, all disc brake tractors of 62,000 and 66,000 pounds GVWR. For higher weight GVWR 6x4 severe service tractors, a 72,000 pound GVWR tractor equipped with all disc brakes only achieved a three percent margin

[20] Memorandums of ex-parte meetings provided in Docket No. NHTSA-2005-21462
[21] See Docket No. NHTSA-2003-15227 for additional information on severe-service single unit trucks that are offered in the marketplace.

of compliance which the agency does not consider to be enough margin of compliance for manufacturers to reliably manufacture tractors with assured compliance to FMVSS No. 121. A 78,000-pound GVWR 6x4 tractor equipped with all disc brakes stopped in 261 feet thus it did not meet a 250-foot stopping distance requirement. The agency therefore concludes that three-axle tractors with a GVWR greater than 70,000 pounds should be provided with a longer stopping distance requirement of 310 feet.

Based upon a 310-foot requirement (representing a 13-percent reduction in stopping distance from the existing 355-foot requirement) for the above examples, and assuming a 10 percent margin of compliance, the 78,000 pound GVWR 6x4 tractor with its standard, all-drum brake configuration would not provide acceptable performance (307-foot stopping distance). At a minimum the steer axle would need to be equipped with disc brakes to achieve a 10 percent margin of compliance. For the 72,000-pound GVWR 6x4 tractor in its standard, all-drum brake configuration, the margin of compliance would be eight percent, so either slight improvements in the drum brakes would need to be made or disc brakes would need to be installed on the steer axle to achieve a full 10 percent margin of compliance. The agency believes that in both cases safety benefits will be obtained because of these improvements, but whether these benefits would be the same or smaller than for typical (non-severe service) 6x4 tractors is unknown. Also, note that the 78,000-pound GVWR example cited is already exempt from FMVSS No. 121 requirements because of its 29,000 pound GAWR drive axles, so the longer, 310-foot stopping distance would only be applicable to three-axle tractors in the GVWR range of 70,000 to 78,000 pounds (typical).

For severe service tractors with more than three axles, the agency considered tractor configurations that, even though they are in the severe service category, should be able to comply with a 250-foot stopping distance when most or all of the brakes are upgraded to disc brakes. One example of this is a severe service 6x4 tractor that has an auxiliary axle installed by either the truck manufacturer or by a vehicle alterer (e.g., body builder or truck shop). Using the VRTC 6x4 as a guideline, which had GAWRs of 18,000 pounds for the steer axle and 44,000 pounds for the tandem drive axles and a GVWR of 62,000 pounds, we considered the installation of a lift axle placed in front of the drive axles with a GAWR of 20,000 pounds (on the upper end of axle weight ratings for lift axles; many lower GAWR ratings for lift axles are also available). The GVWR would now be increased to 82,000 pounds, and although the agency has no full vehicle test data, the loaded-to-GVWR service braking performance of the tractor would not be expected to decrease substantially from the performance in the original three-axle configuration (this vehicle when tested with three axles at 62,000 pounds GVWR demonstrated good compliance to a 250-foot stopping distance requirement when equipped with all disc brakes, or in the hybrid disc/drum brake configuration). This is because of the dynamometer requirements in FMVSS No. 121 that requires the brakes on auxiliary axles (and all other axles as well) to meet the brake fade resistance and hot stop requirements in S5.4.2 and recovery requirements in S5.4.3. Furthermore, reviewing the TMA supplemental data for the 66,000-pound GVWR 6x4 severe service tractor, a stopping distance of 229 feet was obtained with drum brakes on the drive axles (disc brakes on the steer axle only) that were rated at 23,000 pounds each, so adequately-performing drum brakes that are typically installed on auxiliary axles should be available for a 20,000-pound auxiliary axle (i.e., it is not expected that disc brakes would need to be installed on auxiliary axles).

Severe service tractors with four or more axles (such as the twin-steer examples described) above 85,000 pounds GVWR may have high levels of dynamic weight transfer onto the steer axle(s). Using a 20,000 pound steer axle GAWR as an example, the agency believes there is not an adequate installation envelope to install a large enough disc brake to be able to meet a 250-foot stopping distance requirement for these vehicles. The envelope has several factors to consider including the articulation of the spindle and foundation brakes needed for adequate steering cut, vertical clearance with chassis components during dynamic steer axle loading (suspension jounce [compression] during hard braking), and the size of the wheels that limits the diameter of the disc rotor and caliper assembly that can be fit within the inside diameter of the wheel rim.

Several comments received in response to the NPRM stated that there are some severe service 4x2 tractors that are defined as having a drive axle GAWR of 23,000 pounds or more. TMA provided test data for one such tractor, equipped with 16.5" x 5" steer axle S-cam drum brakes and 16.5" x 7" drive axle S-cam drum brakes. The stopping distance for this vehicle was approximately 315 feet. Presumably this could be improved by the addition of disc brakes on the steer and/or drive axle. The agency could not find any further information on severe service 4x2 tractors in the comments. The agency is not providing a longer stopping distance requirement for these vehicles at this time, but is providing a longer lead time for the effective date because very little is known about what levels of performance are practically attainable.

Based upon this analysis, the agency is setting the loaded-to-GVWR stopping distance requirements for severe service tractors as follow:

Table III-3
Stopping Distance Requirements for Severe Service Tractors

Tractor	GVWR (lb)	Required Stopping Distance
Three axles	70,000 or less	250 ft
Three axles	greater than 70,000	310 ft
Four or more axles	85,000 or less	250 ft
Four or more axles	greater than 85,000	310 ft

The agency believes that these requirements will ensure that the vast majority of tractors, estimated to be approximately 99 percent of annual tractor production, will be required to meet the 30-percent reduction in stopping distance. The remaining one percent of tractors which are high-GVWR severe service tractors will be required to meet a 13-percent reduction in stopping distance that is equal to the required performance for single unit trucks, and those tractors with any axle with a GAWR of 29,000 pounds or greater will continue to be exempt from FMVSS No. 121 requirements.

IV Benefits Analysis

The following sections discuss the techniques used and the results of the benefit estimation analysis. This analysis developed estimates of the reductions in the numbers of crashes, injuries and fatalities, and the amount of property damage that would result from implementing the 30% reduction in stopping distance discussed in the final rule. The property damage benefit estimates were based on the property damage per injury or fatality associated with injury and fatality producing crashes and on the property damage per involved vehicle associated with property damage only (PDO) crashes. In order to estimate this latter category of benefit, it was necessary to determine the numbers of vehicles involved in PDO crashes. The numbers of vehicles involved in PDO crashes are later referred to as "PDO vehicle involvements" or "PDO vehicles."

Benefit Estimation Methodology

The basic methodology used here is similar to the one used and described for the reduction in stopping distance in the Tire Pressure Monitoring System FEA[22]. For each area of vehicle stopping distance performance improvement, an estimation of the crash, PDO vehicle involvement, injury and fatality benefit effectiveness rate is made. These estimated benefit effectiveness rates are then applied to the number of "unable-to-stop-in-time" crashes (i.e., non-preventable crashes) and some preventable crashes, and the resulting PDO vehicle involvements, injuries (at various levels of severity) and fatalities. These benefit effectiveness rates are later referred to simply as effectiveness rates.

For the analysis, the following assumptions were used:

[22] Final Economic Assessment, Tire Pressure Monitoring System, FMVSS No. 138, dated March 2002.

1. Due to limited data, all road surface conditions (including wet, snow and ice) are treated the same as dry condition.
2. The effectiveness rates and benefits are applicable for all vehicle configuration/brake type/load condition categories including fully loaded air-braked tractor trucks.
3. All vehicles involved in crashes are equipped with ABS and there is no sliding (i.e., wheel lock-up) during stopping.
4. A peak braking force is applied in "unable-to-stop-in-time" crashes, regardless of initial braking speed. The driver performs a full brake application stop without modulation of the pedal.
5. The friction coefficient (between the brake disc or drum and the brake pad/shoe) and the force acting on the brake disc or drum are assumed to be constant. Accordingly, the corresponding deceleration is assumed to be constant for a given brake system[23,24].
6. All other factors that would affect stopping distance remain unchanged. The factors include, but are not limited to, tire pressure, road surface condition, and driver behavior in braking.

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[23] According to NHTSA Report (draft) DOT HS 809 722, "Light and Medium Truck Hydraulic ABS Brake Performance Test," the constant deceleration method resulted in a percent error of less than 2%, as shown below:

Vehicle	Initial Braking Speed	Measured Distance	Calculated Distance	% Error
F-450	30 mph	45.7 ft	45.9 ft	0.43%
@ GVWR	60 mph	183.5 ft	183.5 ft	N/A
load condition	70 mph	254.3 ft	249.8 ft	1.77%

[24] In a report titled "Heavy Single-Unit Truck Original Equipment and Aftermarket Brake Performance Characterization in Field, Test-Track and Laboratory Environments, (draft), August 2006, the authors reported that a constant deceleration rate for a constant braking pressure during the stopping distance tests for most of the runs conducted at TRC.

Target population

For tractor trucks, the estimates of the number of PDO vehicle involvements, crashes, and injuries were derived from the agency's 2004-2006 GES database and the number of fatalities were determined from the agency's 2004-2006 FARS database.[25] The injury estimates are presented at various levels of injury severity using the "KABCO" injury severity scale. These estimates appear in Tables IV-1, 2, and 3, which represent the crash data estimated for tractor trucks.

Table IV-1
2004-2006 GES Annualized, Weighted, Tractor Truck Crashes by Number of Crashes
Front of Truck-to-Others

Type	KABCO	Braked	Not Braked
No Injury	O	13,874	16,842
Possible Injury	C	3,686	2,221
Non-Incapacitating	B	2,724	1,357
Incapacitating	A	2,092	1,184
Fatal	K	462	481
Unknown		101	32
Died Prior		0	2
No Personal Coded		0	0
Total		22,940	22,118

[25] In the PRIA, the estimated fatalities were derived from the agency's 2000-2002 FARS data base. When updating the data from the PRIA years of 2000-2002 to 2004-2006, the population of crashes appeared drastically reduced. The population of interest had been defined in the PRIA as crashes in which a truck tractor (TT) was the "striking" vehicle in a crash. Thus, data shown for 2004-2006 are crashes where the tractor truck was braking and the impact point was the front of the tractor truck. The data showed that the annual average number of crashes in which a TT was a striking vehicle was 1,732 for the earlier set of years and a number that lowered to 1,470 for the later years. In searching the reason for these changes and looking at individual years of data, it was found that data for the years 2000 and 2001 were similar, but counts for the following years, while consistent within themselves, were different than the years prior to 2002. The way FARS codes Vehicle Role/Striking was redefined in 2002. While the variable definition and value were not changed, new comments were added in the 2002 annual report that described this change. To overcome the ambiguity of the FARS code, a data run was performed without using a parameter "striking" or "struck" vehicle.

Table IV-2
2004-2006 GES Annualized, Weighted, Tractor Truck Crashes by Occupant Injuries
Front of Truck-to-Others

Type	KABCO	Truck Occupants		Non-Truck Occupants	
		Braked	Not Braked	Braked	Not Braked
No Injury	O	22,753	21,486	25,030	16,499
Possible Injury	C	645	938	5,784	2,494
Non-Incapacitating	B	660	1,053	3,417	1,453
Incapacitating	A	493	482	2,318	1,393
Fatal	K	33	51	490	563
Injury Severity Unknown		0	17	177	54
Died Prior		0	2	12	0

Table IV-3
2004-2006 GES Annualized, Weighted, Tractor Truck Crashes by Number of Vehicles Involved
Front of Truck-to-Others

Type	KABCO	Braked	Not Braked
No Injury	O	27,825	28,576
Possible Injury	C	8,491	4,718
Non-Incapacitating	B	6,566	2,472
Incapacitating	A	4,918	2,335
Fatal	K	1,000	1,070
Injury Severity Unknown		224	68
Died Prior		0	2
No Person		0	0

For the analysis, the "KABCO" injury severity scale was converted to the MAIS injury severity scale. The conversion was necessary to estimate the property damage savings that would result from the final rule and also to calculate the "equivalent fatalities" that these injury estimates represent. The conversion methodology is discussed in detail in Appendix A. The results from such a conversion of the "KABCO" injuries prevented estimated from Table IV-2 are shown in Table IV-4a and -4b.

Table IV-4a
2004-2006 FARS Annualized Average Tractor Truck Fatalities

Truck Occupants	Front of Truck		Non-Truck Occupants	Front of Truck		Total
	No	Yes		No	Yes	
Not braked	177	252	Not braked	1,007	1,210	
Braked	36	77	Braked	138	787	864

Table IV-4b
Estimated Number of Occupant Injuries in Braked Tractor Truck Crashes
Front of Truck to Others
(Truck and Non-Truck Occupants),
Adjusted with 2004-2006 FARS data[26]

MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
45,678	12,896	1,855	709	101	53	864	62,156

Although the target population can be expressed with the AIS scale, there is no information on how these injuries are distributed with respect to vehicle delta-V in crashes involving large trucks. Unlike crashes involving passenger cars and light trucks, NASS-CDS data do not include information on heavy truck vehicle impact speed (i.e., delta-V) and the probability of injury for heavy truck crashes.[27] Thus, the agency does not have direct knowledge on how prevention of crashes at certain delta-V's and reduction in impact speed would affect the injuries that would occur at these delta-V's.

In order to estimate the impact of improved stopping distance on vehicle safety, we examined passenger vehicle occupant injury distribution data previously analyzed for the tire pressure monitoring FEA. In the FEA, separate target populations were derived for passenger cars and LTVs, and for crashes that occur on wet and dry pavement. The crashes where at least one vehicle used brakes on dry pavement are shown below:

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[26] 2004 FARS: 79 truck and 881 non-truck occupants; 2005 FARS: 76 truck and 736 non-truck occupants; 2006 FARS: 75 truck and 748 non-truck occupants. The numbers were rounded to the nearest integer.

[27] In Final Economic Assessment for Tire Pressure Monitoring System, NASS-CDS data were examined to derive a relationship between vehicle impact speed (delta-V) and the probability of injuries. The percent probability risk of MAIS 0, MAIS 1+, MAIS 2+, MAIS 3+, MAIS 4+, MAIS 5+, and fatal injuries was calculated for each delta-V between 0 and 70 mph (31.3 meter/second).

Table IV-5
Passenger vehicle occupants in crashes where at least one vehicle used brakes
(Impacted by passenger cars and LTVs, DRY condition)

Delta-V	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality	Total
0-35 mph	294,609	279,763	28,310	12,416	1,120	731	1,664	618,613
36-50mph	305,966	317,828	32,478	14,108	1,320	821	2,184	674,705
51+mph	102,554	124,813	23,098	8,924	966	744	1,684	262,783

Table IV-6
Weighted for each AIS level by passenger cars + LTVs

Delta-V	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
0-35 mph	41.9%	38.7%	33.7%	35.0%	32.9%	31.8%	30.1%
36-50mph	43.5%	44.0%	38.7%	39.8%	38.8%	35.8%	39.5%
51+mph	14.6%	17.3%	27.5%	25.2%	28.4%	32.4%	30.4%
Total	100%	100%	100%	100%	100%	100%	100%

Table IV-7
Passenger vehicle occupants in crashes where at least one LTV used brakes,
(Impacted by LTVs, DRY Condition)

Delta-V	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality	Total
0-35 mph	98,640	99,100	11,291	4,800	466	293	699	215,289
36-50mph	87,072	98,763	12,016	4,985	460	341	911	204,548
51+mph	44,147	50,883	9,399	3,687	412	321	726	109,575

Table IV-8
Weighted for each AIS level, LTVs only

Delta-V	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
0-35 mph	42.9%	39.8%	34.5%	35.6%	34.8%	30.7%	29.9%
36-50mph	37.9%	39.7%	36.7%	37.0%	34.4%	35.7%	39.0%
51+mph	19.2%	20.5%	28.7%	27.4%	30.8%	33.6%	31.1%
Total	100%	100%	100%	100%	100%	100%	100%

The weighted passenger vehicle occupant injury distributions above were compared, as shown below:

Table IV-9
Percent Difference in Weighted AIS Level Between
LTVs and LTVs + Passenger Cars, above

Delta-V	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
0-35 mph	-1.0%	-1.1%	-0.8%	-0.6%	-1.9%	1.2%	0.2%
36-50mph	5.6%	4.3%	2.0%	2.8%	4.4%	0.1%	0.5%
51+mph	-4.6%	-3.2%	-1.2%	-2.2%	-2.4%	-1.2%	-0.6%

The results in Table IV-9 show that occupants in passenger vehicles would have a slightly higher probability of nonfatal and fatal injuries for a vehicle delta-V range of 36-50 mph when struck by passenger cars and LTVs combined. When struck by LTVs only, passenger vehicle occupants would have a slightly higher probability of nonfatal and fatal injuries for a vehicle delta-V range of 51+ mph. Although LTVs are stiffer, heavier and have a higher riding position, the percent differences in Table IV-9 show that the overall injury distribution profiles are similar for each AIS level for the ranges where at least one vehicle used brakes[28]. The injury distribution for a given speed limit is shown in Tables IV-10, -11 and -12.

Table IV-10
Occupant Injury Distribution by AIS level and Vehicle Delta-V (mph)
LTVs
0-35 MPH Speed Limit, Dry Pavement

Delta V	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
1	0	0	0	0	0	0	0	0
2	842	74	4	4	0	1	0	925
3	600	87	3	3	0	1	0	696
4	3759	795	32	32	0	5	0	4623
5	1211	348	14	11	0	0	2	1588
6	4835	1804	68	54	7	0	7	6781
7	10471	4920	205	142	16	0	16	15770
8	23183	13458	565	415	38	0	38	37697
9	9311	6480	327	196	0	16	16	16364
10	1253	1039	57	31	2	2	2	2387
11	11846	11576	688	369	25	25	25	24577
12	7636	8653	586	276	34	0	34	17237
13	2383	3125	229	118	6	6	12	5884
14	5556	8326	689	329	30	15	30	14975
15	2208	3752	358	156	13	7	20	6514
16	7080	13498	1485	594	69	23	69	22840
17	2319	4949	623	238	25	16	25	8194
18	2233	5288	762	286	26	17	35	8655

[28] Although the overall injury distribution profiles are similar for each AIS level, for a given impact speed, occupants in passenger vehicles would have a higher probability of serious injuries when compared to occupants in LTVs in collisions between LTVs and cars.

Table IV-10 (continued)

19	1368	3581	588	215	17	12	29	5823
20	321	921	176	62	6	5	8	1500
21	237	739	162	55	6	4	7	1211
22	175	590	151	49	5	4	7	982
23	93	337	100	32	3	2	5	573
24	438	1677	576	182	18	15	29	2936
25	162	651	259	81	8	6	14	1181
26	520	2176	1007	314	33	29	54	4129
27	106	460	248	77	8	6	15	920
28	168	752	471	147	16	14	29	1597
29	61	278	204	64	8	6	13	634
30	33	152	129	41	5	4	9	374
31	6	28	28	9	1	1	2	76
32	70	311	359	123	16	14	30	923
33	0	0	0	0	0	0	0	0
34	9	38	60	22	3	3	6	142
35	0	0	0	0	0	0	0	0
36	0	3	5	2	0	0	1	12
37	0	1	2	1	0	0	0	5
38	0	47	103	47	8	8	18	230
39	0	15	38	18	3	3	8	85
40	0	22	62	32	6	6	15	142
41	0	5	15	8	2	2	4	35
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	7	41	32	8	10	33	130
48	0	0	1	1	0	0	1	5
49	0	1	8	7	2	3	9	28
50	0	0	2	2	1	1	3	9
51	0	0	0	0	0	0	0	0
52	0	1	4	4	1	2	9	21
53	0	0	0	0	0	0	0	0
54	0	1	9	9	3	5	26	52
55	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0

Table IV-10 (continued)

62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0
Total	100,495	100,965	11,504	4,890	475	299	712	219,462

Table IV-11
36-51 MPH Speed Limit, Dry Pavement

Delta V	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
1	0	0	0	0	0	0	0	0
2	33	3	0	0	0	0	0	36
3	0	0	0	0	0	0	0	0
4	1544	327	13	13	0	2	0	1900
5	2954	848	35	27	0	0	4	3872
6	2669	996	37	30	4	0	4	3743
7	9986	4692	195	135	15	0	15	15038
8	4604	2672	112	82	7	0	7	7486
9	11040	7683	388	233	0	19	19	19402
10	4478	3710	205	111	9	9	9	8529
11	17206	16813	1000	535	36	36	36	35697
12	4922	5578	378	178	22	0	22	11112
13	6240	8182	601	308	15	15	31	15408
14	4094	6136	508	243	22	11	22	11035
15	6882	11693	1117	487	41	20	61	20300
16	2986	5693	626	250	29	10	29	9633
17	2942	6279	790	301	31	21	31	10396
18	1271	3010	434	163	15	10	20	4927
19	1540	4030	662	242	20	13	33	6553
20	408	1170	223	78	8	6	10	1905
21	441	1372	301	101	11	7	13	2249

Table IV-11 (continued)

22	653	2206	565	183	18	15	26	3670
23	177	637	189	61	5	4	10	1084
24	569	2179	748	237	23	19	38	3816
25	480	1932	768	242	25	18	42	3506
26	117	491	228	71	7	7	12	933
27	144	627	338	105	11	9	20	1255
28	39	176	110	34	4	3	7	373
29	44	202	148	47	6	5	10	461
30	100	458	389	124	16	14	27	1127
31	97	439	435	143	18	17	33	1182
32	31	136	157	54	7	6	13	404
33	7	30	41	14	2	2	4	100
34	8	34	54	20	3	3	6	127
35	3	11	21	8	1	1	2	47
36	0	24	40	16	2	2	5	91
37	0	31	60	26	4	4	9	135
38	0	56	124	56	9	9	22	277
39	0	22	56	27	5	5	11	126
40	0	25	70	36	6	7	17	160
41	0	1	4	2	0	0	1	9
42	0	0	0	0	0	0	0	0
43	0	13	51	32	6	8	20	129
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	1	0	0	0	0	2
47	0	0	0	0	0	0	0	0
48	0	1	5	4	1	2	5	18
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0
52	0	1	7	7	2	3	14	35
53	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0

Table IV-11 (continued)

65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	3	4
67	0	0	9	8	3	8	206	235
68	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0
Total	88,710	100,620	12,242	5,078	469	348	928	208,527

Table IV-12

LTVs

>=51 MPH Speed Limit, Dry Pavement

Delta V	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	2917	617	25	25	0	4	0	3588
5	0	0	0	0	0	0	0	0
6	8202	3060	115	92	12	0	12	11503
7	1644	772	32	22	2	0	2	2475
8	4490	2607	110	80	7	0	7	7302
9	1546	1076	54	33	0	3	3	2718
10	2967	2458	136	73	6	6	6	5651
11	7345	7178	427	229	15	15	15	15239
12	2205	2499	169	80	10	0	10	4977
13	1214	1592	117	60	3	3	6	2998
14	3285	4923	407	195	18	9	18	8853
15	263	447	43	19	2	1	2	776
16	2401	4577	503	201	23	8	23	7744
17	2010	4289	540	206	21	14	21	7101
18	250	592	85	32	3	2	4	969
19	857	2244	369	135	11	7	18	3649
20	572	1641	313	110	11	8	13	2672
21	936	2914	640	215	24	14	29	4777
22	98	332	85	28	3	2	4	553
23	165	596	177	57	5	4	9	1014

Table IV-12 (continued)

24	308	1180	405	128	12	10	21	2067
25	555	2232	887	279	28	20	49	4050
26	234	979	453	141	15	13	24	1859
27	70	303	163	51	5	4	10	606
28	3	12	8	2	0	0	0	26
29	204	932	682	214	25	21	45	2123
30	43	198	168	54	7	6	12	488
31	55	250	248	82	10	9	19	674
32	60	265	306	105	13	12	26	787
33	10	45	60	21	3	3	6	148
34	50	207	330	122	17	16	34	776
35	18	68	130	50	7	7	15	295
36	0	656	1100	449	67	65	147	2483
37	0	28	54	23	4	4	8	121
38	0	18	39	18	3	3	7	87
39	0	0	0	0	0	0	0	0
40	0	39	109	56	10	10	26	250
41	0	0	0	0	0	0	0	0
42	0	1	5	3	1	1	2	11
43	0	0	0	0	0	0	0	0
44	0	2	9	6	1	1	4	23
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	1	4	3	1	1	3	11
48	0	10	66	53	13	19	62	223
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0
53	0	1	5	5	1	3	12	26
54	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0

Table IV-12 (continued)

67	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	7	8
Total	44,978	51,840	9,576	3,756	420	327	739	111,703

Table IV-13
All Speed Limits, LTV

Delta V	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
1	0	0	0	0	0	0	0
2	875	77	4	4	0	1	0
3	600	87	3	3	0	1	0
4	8220	1739	71	71	0	10	0
5	4166	1196	49	38	0	0	5
6	15705	5859	220	176	22	0	22
7	22101	10385	433	300	33	0	33
8	32277	18737	787	577	52	0	52
9	21897	15240	770	462	0	38	38
10	8698	7207	398	215	17	17	17
11	36397	35567	2114	1133	76	76	76
12	14763	16730	1133	533	67	0	67
13	9838	12898	947	486	24	24	49
14	12934	19384	1604	767	70	35	70
15	9353	15892	1517	662	55	28	83
16	12467	23768	2614	1046	121	40	121
17	7270	15517	1952	745	77	51	77
18	3754	8891	1280	480	44	29	58
19	3766	9855	1619	593	48	32	80
20	1301	3732	711	249	24	18	30
21	1615	5025	1104	371	41	25	49
22	926	3128	801	260	26	21	36
23	435	1570	465	150	13	11	24
24	1314	5035	1728	547	53	44	88
25	1197	4814	1913	603	61	44	105
26	872	3647	1688	526	55	48	90

Table IV-13 (continued)

27	320	1390	748	234	25	19	44
28	210	941	589	184	20	18	36
29	309	1413	1033	325	39	32	68
30	177	808	686	219	28	24	48
31	158	717	711	234	29	27	54
32	161	713	823	281	36	32	70
33	17	75	101	36	5	4	9
34	67	279	444	164	23	21	46
35	21	79	150	59	8	8	17
36	0	683	1146	468	70	67	153
37	0	61	117	50	8	8	18
38	0	121	265	121	20	20	46
39	0	38	93	45	8	8	19
40	0	86	240	124	22	23	57
41	0	6	19	10	2	2	5
42	0	1	5	3	1	1	2
43	0	13	51	32	6	8	20
44	0	2	9	6	1	1	4
45	0	0	0	0	0	0	0
46	0	0	1	0	0	0	0
47	0	7	45	35	8	11	35
48	0	11	72	58	15	21	69
49	0	1	8	7	2	3	9
50	0	0	2	2	1	1	3
51	0	0	0	0	0	0	0
52	0	1	12	11	3	5	23
53	0	1	5	5	1	3	12
54	0	1	9	9	3	5	26
55	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0
66	0	0	0	0	0	0	3
67	0	0	9	8	3	8	206
68	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0

Table IV-13 (continued)

71	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0
77	0	0	0	0	0	0	7
Total	23,4183	25,3426	33,321	13,725	1,364	974	2,380

The percent distribution of the all injuries is shown in Table IV-14.

Table IV-14
Percent Distribution, All Speed Limits, LTV

Delta V (mph)	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
1	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
2	0.3737%	0.0304%	0.0115%	0.0280%	0.0000%	0.0988%	0.0000%
3	0.2564%	0.0343%	0.0104%	0.0253%	0.0000%	0.0715%	0.0000%
4	3.5103%	0.6863%	0.2124%	0.5157%	0.0000%	1.0386%	0.0000%
5	1.7789%	0.4718%	0.1475%	0.2785%	0.0000%	0.0000%	0.2294%
6	6.7064%	2.3120%	0.6611%	1.2839%	1.6147%	0.0000%	0.9256%
7	9.4373%	4.0977%	1.2986%	2.1825%	2.4400%	0.0000%	1.3986%
8	13.7830%	7.3934%	2.3626%	4.2063%	3.8475%	0.0000%	2.2053%
9	9.3505%	6.0134%	2.3099%	3.3647%	0.0000%	3.9531%	1.6171%
10	3.7142%	2.8438%	1.1933%	1.5692%	1.2145%	1.7018%	0.6962%
11	15.5422%	14.0343%	6.3454%	8.2527%	5.5357%	7.7567%	3.1730%
12	6.3043%	6.6014%	3.4005%	3.8850%	4.8861%	0.0000%	2.8007%
13	4.2008%	5.0895%	2.8430%	3.5396%	1.7807%	2.4951%	2.0413%
14	5.5232%	7.6489%	4.8130%	5.5883%	5.1115%	3.5812%	2.9299%
15	3.9939%	6.2708%	4.5540%	4.8244%	4.0451%	2.8341%	3.4780%
16	5.3238%	9.3788%	7.8452%	7.6185%	8.8447%	4.1311%	5.0697%
17	3.1046%	6.1230%	5.8596%	5.4282%	5.6500%	5.2779%	3.2385%
18	1.6031%	3.5081%	3.8428%	3.4985%	3.2000%	2.9893%	2.4457%
19	1.6081%	3.8888%	4.8573%	4.3200%	3.5242%	3.2922%	3.3668%
20	0.5554%	1.4725%	2.1340%	1.8155%	1.7821%	1.8729%	1.2769%
21	0.6894%	1.9828%	3.3127%	2.7008%	3.0194%	2.5385%	2.0768%
22	0.3956%	1.2342%	2.4054%	1.8960%	1.9076%	2.1384%	1.5308%
23	0.1859%	0.6197%	1.3946%	1.0897%	0.9789%	1.0973%	1.0100%
24	0.5611%	1.9869%	5.1873%	3.9836%	3.8788%	4.5293%	3.7055%
25	0.5111%	1.8996%	5.7422%	4.3922%	4.4833%	4.4872%	4.4054%
26	0.3723%	1.4390%	5.0672%	3.8317%	4.0582%	4.9757%	3.7800%
27	0.1366%	0.5487%	2.2450%	1.7020%	1.8348%	1.9996%	1.8696%
28	0.0895%	0.3711%	1.7680%	1.3386%	1.4639%	1.8462%	1.5104%

Table IV-14 (continued)

29	0.1319%	0.5575%	3.1004%	2.3683%	2.8312%	3.3059%	2.8399%
30	0.0756%	0.3187%	2.0599%	1.5945%	2.0418%	2.4524%	2.0064%
31	0.0676%	0.2828%	2.1332%	1.7028%	2.1239%	2.7777%	2.2725%
32	0.0686%	0.2812%	2.4684%	2.0489%	2.6350%	3.2579%	2.9319%
33	0.0074%	0.0295%	0.3042%	0.2600%	0.3451%	0.4582%	0.3957%
34	0.0286%	0.1101%	1.3334%	1.1958%	1.6860%	2.1477%	1.9328%
35	0.0088%	0.0314%	0.4514%	0.4268%	0.6028%	0.8094%	0.7342%
36	0.0000%	0.2694%	3.4380%	3.4102%	5.1184%	6.9064%	6.4110%
37	0.0000%	0.0240%	0.3496%	0.3665%	0.5541%	0.8032%	0.7447%
38	0.0000%	0.0478%	0.7961%	0.8820%	1.4355%	2.0725%	1.9449%
39	0.0000%	0.0148%	0.2803%	0.3303%	0.5564%	0.8230%	0.7974%
40	0.0000%	0.0338%	0.7207%	0.9050%	1.6188%	2.3817%	2.3893%
41	0.0000%	0.0024%	0.0569%	0.0757%	0.1406%	0.2153%	0.2211%
42	0.0000%	0.0005%	0.0140%	0.0199%	0.0383%	0.0618%	0.0639%
43	0.0000%	0.0051%	0.1533%	0.2299%	0.4645%	0.7837%	0.8313%
44	0.0000%	0.0008%	0.0257%	0.0410%	0.0866%	0.1493%	0.1660%
45	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
46	0.0000%	0.0000%	0.0018%	0.0033%	0.0076%	0.0140%	0.0170%
47	0.0000%	0.0030%	0.1338%	0.2515%	0.6016%	1.1627%	1.4863%
48	0.0000%	0.0044%	0.2173%	0.4252%	1.0832%	2.1502%	2.8871%
49	0.0000%	0.0004%	0.0232%	0.0474%	0.1249%	0.2596%	0.3710%
50	0.0000%	0.0001%	0.0071%	0.0151%	0.0416%	0.0894%	0.1372%
51	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
52	0.0000%	0.0005%	0.0352%	0.0798%	0.2377%	0.5512%	0.9771%
53	0.0000%	0.0002%	0.0153%	0.0351%	0.1088%	0.2613%	0.5055%
54	0.0000%	0.0003%	0.0272%	0.0641%	0.2022%	0.5080%	1.0761%
55	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
56	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
57	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
58	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
59	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
60	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
61	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
62	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
63	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
64	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
65	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
66	0.0000%	0.0000%	0.0005%	0.0011%	0.0037%	0.0150%	0.1313%
67	0.0000%	0.0002%	0.0282%	0.0599%	0.2067%	0.8688%	8.6383%
68	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
69	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
70	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
71	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%

Table IV-14 (continued)

72	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
73	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
74	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
75	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
76	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
77	0.0000%	0.0000%	0.0003%	0.0004%	0.0011%	0.0070%	0.3086%
Total	100%	100%	100%	100%	100%	100%	100%

Due to limited data, the passenger car occupant injury distribution derived in the FEA for FMVSS No. 138 was used as a proxy measure for a relationship between truck impact speed (delta-V) and the probability of injury[29]. For the large truck target population, the totals of each injury category were distributed with the percent distribution shown in Table IV-14. The redistributed large truck target population is shown in Table IV-15.

Table IV-15
Truck Target Population Distribution, All Speed Limits

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
Total	45,678	12,896	1,855	709	101	53	864
Delta V	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
1	0	0	0	0	0	0	0
2	171	4	0	0	0	0	0
3	117	4	0	0	0	0	0
4	1,603	89	4	4	0	1	0
5	813	61	3	2	0	0	2
6	3,063	298	12	9	2	0	8
7	4,311	528	24	15	2	0	12
8	6,296	953	44	30	4	0	19
9	4,271	776	43	24	0	2	14
10	1,697	367	22	11	1	1	6
11	7,099	1,810	118	58	6	4	27
12	2,880	851	63	28	5	0	24

[29] Crash prevention may be more likely under some circumstances than others. For example, it is possible that a larger portion of side impacts might be prevented than head-on or head-to-rear crashes. In side impacts where vehicles are moving perpendicular to each other, improved braking by one vehicle reduces the speed at which it enters the crash zone and potentially allows the second vehicle to move through the crash zone, thus avoiding the impact. However, in some cases, it is possible that the reduced speed may increase injury severity by shifting the impact area. For example, in a front-to-side crash, if the striking vehicle impacts with the forward section of the occupant compartment, the delay might cause the striking vehicle to hit the occupant compartment, thus increasing injury severity.

Table IV-15 (continued)

13	1,919	656	53	25	2	1	18
14	2,523	986	89	40	5	2	25
15	1,824	809	84	34	4	2	30
16	2,432	1,210	146	54	9	2	44
17	1,418	790	109	38	6	3	28
18	732	452	71	25	3	2	21
19	735	502	90	31	4	2	29
20	254	190	40	13	2	1	11
21	315	256	61	19	3	1	18
22	181	159	45	13	2	1	13
23	85	80	26	8	1	1	9
24	256	256	96	28	4	2	32
25	233	245	107	31	5	2	38
26	170	186	94	27	4	3	33
27	62	71	42	12	2	1	16
28	41	48	33	9	1	1	13
29	60	72	58	17	3	2	25
30	35	41	38	11	2	1	17
31	31	36	40	12	2	1	20
32	31	36	46	15	3	2	25
33	3	4	6	2	0	0	3
34	13	14	25	8	2	1	17
35	4	4	8	3	1	0	6
36	0	35	64	24	5	4	55
37	0	3	6	3	1	0	6
38	0	6	15	6	1	1	17
39	0	2	5	2	1	0	7
40	0	4	13	6	2	1	21
41	0	0	1	1	0	0	2
42	0	0	0	0	0	0	1
43	0	1	3	2	0	0	7
44	0	0	0	0	0	0	1
45	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0
47	0	0	2	2	1	1	13
48	0	1	4	3	1	1	25
49	0	0	0	0	0	0	3
50	0	0	0	0	0	0	1
51	0	0	0	0	0	0	0
52	0	0	1	1	0	0	8
53	0	0	0	0	0	0	4
54	0	0	1	0	0	0	9
55	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0

Table IV-15 (continued)

59	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0
66	0	0	0	0	0	0	1
67	0	0	1	0	0	0	75
68	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0
77	0	0	0	0	0	0	3
Total	45,678	12,896	1,855	709	101	53	864

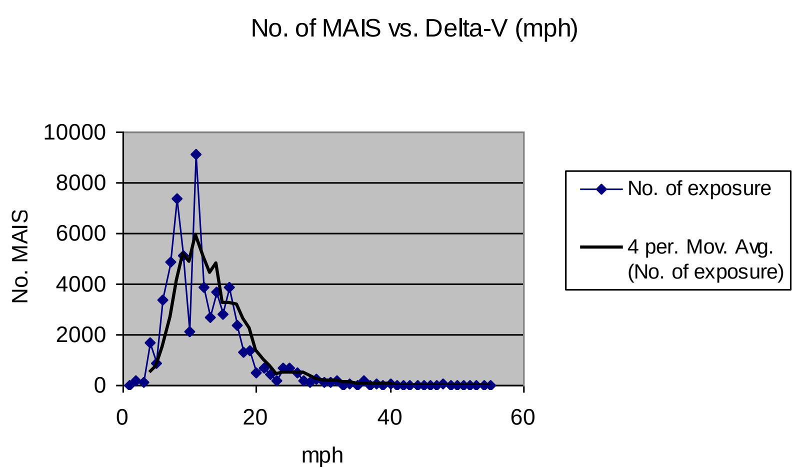

Figure IV-1. Large Truck Estimated Injury Distribution By Delta-V

(Note that the target population only addresses injury crashes, including AIS 0 injuries. Property damage only (PDO) crashes would also be impacted by the improved stopping distance. Additional discussion is provided in a section titled “Estimated Property Damage Benefits.”)

Dry and Wet Road Conditions:

The effectiveness rates were based on "Dry-Road-Surface" conditions. In reality, even with antilock brakes, wet roads possess a lower tire-road friction coefficient so stopping distances are expected to be longer. Although we speculate that the condition would increase the dry road stopping distance by about 20 percent[30], the agency does not have any test data on wet roads that could be used in the analysis.

If we assume that the stopping distance is longer by 20% and that 16.4% of all crashes occur in wet road surface condition[31] the baseline braking performance could be shown below:

Table IV-16
Weighted Percent Reduction in Dry and Wet Road Conditions

Stopping Distance (meters)				Weighted Stopping Distance		Percent Reduction	Difference (meters)
Dry Original	Dry Improved	Wet Original	Wet Improved	Original	Improved		
90.7	75.9	108.8	91.1	93.7	78.4	16%	15.3

[30] As mentioned, the agency does not have wet condition stopping distance data. However, the LTV crash data in the Tire Pressure Monitoring FEA shows that the fatal injury rate on wet roads is 4.4 times higher than the rate on dry roads when all speeds were considered (for LTVs equipped with and without ABS). If only high delta-Vs are considered (36+ mph), the ratio drops to 4.2. The analysis shows that brakes are less influential in preventing and/or reducing injury severity in high delta-V crashes (as shown in Table IV-23). In addition, since high delta-V crashes would have a short duration between the initial braking and the time of impact (as shown in Table VI-19), road conditions would have a minimal effect on the delta-V. Thus, the difference in fatality in high delta-V crashes is most likely resulting from a difference in crash exposure. Accordingly, the number of “wet road” injuries were adjusted with the 4.2 exposure ratio, as shown below:

Condition	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
Wet	66,107	79,457	7,820	3,534	301	227	529
Adjusted Wet	277,649	333,719	32,844	14,843	1,264	953	2,222
DRY	229,859	248,746	32,706	13,472	1,338	955	2,336
% Difference	17%	25%	1%	9%	-6%	0%	-5%

The results show that wet roads would result in a roughly 20 percent higher rate for MAIS 0 and MAIS 1injuries. Since the majority of MAIS 0 and MAIS 1 would be “preventable” injuries resulting from a reduction in stopping distance (as shown in Table IV-26), the adjusted percent (in the table above) could be used as a proxy for the reduction in stopping distance between wet and dry road conditions. Thus, the wet stopping distance would be about 20% higher when compared to the dry stopping distance.

[31] For additional discussion, see page 24, Table 18, "Large Truck Crash Profile: The 1998 National Picture," FMCSA, US Department of Transportation, Jan. 2000.

When the weighted stopping distance is used, the original stopping distance would decrease by 15.3 meters (50 ft) if the improved braking system provides the same 16% percent reduction in stopping distance.[32]

Preventable Crashes:

The impact of reductions in stopping distance will, in most cases, result in a reduction in the impact velocity, and hence the severity, of crashes. In some cases, reduced stopping distance will actually prevent the crash from occurring. This would result, for example, if the braking vehicle were able to stop just short of impacting another vehicle instead of sliding several more feet into the area it occupied.

The portion of crashes that would actually be preventable is unknown. However, an estimate can be derived from relative stopping distance calculations for vehicles that were involved in crashes. The average stopping distance was calculated for a selected vehicle fleet, as shown in the Chapter III. The results indicate that the existing truck tractor fleet would, on average, experience a stopping distance of 298 feet. The required 30% reduction in stopping distance (with respect to the 355 feet minimum distance specified in FMVSS No. 121) would reduce the stopping distance by 16% to 249 feet.

In theory, current crashes occur under a variety of stopping distances, but if these distances were shortened through the use of improved brakes, then a portion of these crashes would be prevented. Crashes could be prevented over a variety of travel speeds, braking distances, and crash modes. For example, a vehicle might be able to avoid an intersection crash by slowing

[32] As discussed in the assumption section, we did not consider wet road conditions in the analysis.

quickly enough to miss a speeding vehicle that is running a red light. For such cases, reduction in stopping distance would prevent such crashes from occurring, rather than resulting in reduction in striking speed (in other words, reduction in vehicle delta-V). Although we suspect that these "miss-able" side crashes could occur at any speed, the agency does not have data to show how many crashes could be missed by reduction in stopping distance in crashes involving trucks. We just don't know. Therefore, for the analysis, we assumed that lateral velocity of the struck vehicle is zero with respect to the striking vehicle in front-to-side crashes.

NHTSA does not have data that indicate average stopping distance in crashes. Under these circumstances, it is not unreasonable to assume that crashes are equally spread over the full range of stopping distances. With equal distribution of crashes across all stopping distances, the portion of crashes that occur within the existing stopping distance that exceeds the stopping distance with the improved braking system represents the portion of crashes that are preventable. The method used to calculate the preventable crashes is described later in this section of the analysis[33].

Non-Preventable Crashes:

In the vast majority of crashes, a reduction in stopping distance will not prevent the crash, but will reduce the speed at impact and thus the severity of the crash. To estimate the impact of reduced crash speeds, the change in stopping distance was used to calculate impact speeds for a given distance from the initial braking point. These changes in impact speed will then be used to

[33] For the proposed 30% reduction in stopping distance, injuries resulting from the preventable crashes are shown below. See additional discussion in the benefit section.

AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
22,341	3,080	152	95	9	4	61

redefine the delta-V profile of the crashes, and the safety benefits will be calculated as the difference between the existing and the redefined vehicle delta-V profile.

Effectiveness Rates:

Level of Stopping Distance Performance Improvement:

For the general upgrade in stopping distance performance, the level of improvements measured as the percent reduction in stopping distance, was estimated by comparing weighted average stopping distance of current vehicles tested to a 30% reduction of the stopping distance required by the current standard. Typically, due to production variation in their vehicles, manufacturers attempt to design in a safety margin in order to assure that 100% of their vehicles are in compliance. However, we note that in the FMVSS No. 121 test requirements for 60 mph service brake stops, each vehicle is only required to stop in the required distance in one out of six stops. Thus, this requirement seems far less demanding in terms of margin of compliance than a requirement that each 60 mph stop meet the required distance. For this analysis, we assume no margin of compliance and estimate benefits from the baseline stopping distance to the required stopping distance.

Stopping Distance:

Stopping distance can be computed as a function of initial velocity and the friction force acting on the braking system. As discussed above, for the analysis, we assumed that the ABS would prevent any sliding (i.e., wheel lock-up) between the tire and the road surface during braking. The formula used for computing stopping distance is as follows[34]:

$$V(d) = \sqrt{(Vi)^2 - 2(a_{cont.})d} \quad -(EQ-1)$$

$$d = \frac{1}{2a}\left[Vi^2 - V(d)^2\right] \quad -(EQ-2)$$

Where:

V(d): velocity of vehicle at distance d after braking

Vi: Initial braking speed

a: deceleration

d: distance traveled during braking of vehicle

As in the tire pressure monitoring FEA, the equation implies that the deceleration is constant during braking. In other words, the deceleration would remain constant with no-slide condition, regardless of initial braking speed.

Delta-V:

Changes in stopping distances were used to calculate the decrease in crash forces that would occur due to the decrease in striking velocity of the vehicle. The formula used to calculate striking velocity is:

$$V(d) = \sqrt{Vi^2 - 2ad} \quad -(EQ-3)$$

The delta-V experienced by each vehicle would be dependent on vehicle mass. For example, if the mass of each vehicle were equal, it would result in a delta-V of ½ of the striking speed for

[34] This assumes constant deceleration during the stop. However, in setting the new FMVSS No. 121 stopping distance requirements for initial speeds below 60 mph, the agency is considering also the initial buildup in deceleration versus the steady-state deceleration during the majority f stop.

each vehicle. Typically, tractor trucks are much heavier than passenger cars or light trucks. The gross weight can reach 80,000 lbs or more when they are fully loaded. Although the large difference in mass would result in greater damage to the passenger car in collisions between these vehicles, the agency does not know the mass of these vehicles in collisions. For the analysis, we assumed that large trucks on the road are about 50,000 lbs (combining both loaded and empty gross weight). Whereas, 3,500 lbs and 4,600 lbs were assumed for passenger cars and light trucks[35], respectively, as shown in Table IV-17.

Table IV-17
Estimated Vehicle Mass

Vehicles	Condition	Assumed Gross Weight (lbs)	Assumed Operation Frequency	Estimated Gross Vehicle Weight (lbs)
Large Truck	Fully Loaded	65,000	50%	50,000
	Empty	35,000	50%	
Passenger Cars			100%	3,500
Light Trucks			100%	4,600

As for frequency of crashes, we estimated the frequency based on Vehicle Miles Traveled (VMT). According to the NHTSA Traffic Safety Facts 2002 report, there are 7,927,280 large trucks on the road with 214,530 million VMT[36], as shown below:

Table IV-18
Mass Ratio Weighted with VMT, Used for Delta-V

Vehicle Type	No. of Vehicle	VMT (Millions)	Mass (lb)	Weighted Average Weight	Mass Ratio
Passenger Cars	129,906,797	1,608,464	3,500	7,407	1
Light Trucks	82,085,865	1,016,360	4,600		
Large Trucks	7,927,280	214,530	50,000		
Large Trucks	7,927,280		50,000	50,000	6.75

[35] The agency does not have information on the weight of light trucks on the road. For LTVs with a GVWR of 8,500 lbs or less, the average test weight (curb weight plus 300 pounds) for General Motors, Ford, and Daimler Chrysler light trucks subject to Corporate Average Fuel Economy Standard for MY 2005 - 2007 was 4,627 pounds. For additional information, see Final Economic Assessment, Corporate Average Fuel Economy Standard for MY 2005 - 2007, page IV-1, dated April 2003.

[36] The VMTs are for 2002 calendar year. Additional information, see Tables 7, 8 and 9 in the report.

As shown in Table IV-18, for this analysis, the mass of truck (the striking vehicle) was assumed to be 6.75 times of the mass of the struck vehicle[37] or:

$$\left|V_f\right| = (0.871)(StrikingSpeed)$$

Where V_f = Initial velocity after impact [38]

In Chapter III, we estimated that trucks on-road would stop in a distance of 90.7 m (298 ft) with an initial braking speed of 26.8 m/s (60 mph) on a dry road surface.[39] At the 90.7 m stopping distance, the equation (1) above can be expressed as follows. (This is a simple modification of the formula previously discussed for stopping distance.)

$$a_{const.} = \frac{1}{2d}\left[(Vi)^2 - (V(d))^2\right]$$
$$= \frac{1}{2(90.7)}\left[(26.8)^2 - (0)^2\right]$$

$$a_{cont.} = 3.97\left(m/s^2\right)$$

From equation (1) and the derived 3.97 m/s^2 constant deceleration rate above, for a given initial braking speed, we can estimate the corresponding vehicle speed at a particular distance from the initial braking point.[40] (The corresponding vehicle speeds are derived from tests conducted on a

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37 $$V_{i,1}M_1 + V_{i,2}M_2 = V_f(M_1 + M_2), \quad V_f = \left(\frac{M_1}{M_1 + M_2}\right)V_{i,1}$$
$$M_1 = 6.75, \quad M_2 = 1$$
$$V_f = \left|\frac{6.75}{(6.75+1)}\right|V_i$$
$$= (0.871)V_i \quad Where\,V_i = Striking\ Speed$$

38 Assuming the coefficient of restitution, e = 0; both vehicles remain in contact at the same velocity after collision.

39 According to FMVSS No. 121, when stopped six times, each tractor trucks must stop at least once in 355 ft measured from the point at which movement of the service brake control begins.

40 For example, for an initial braking speed of 26.8 m/s , the vehicle would be moving at a speed of 25.3 m/s when it passes a point located 10 meters from the initial braking point.

dry test track surface at a single braking speed.) The estimated striking speeds for a given initial braking speed are shown in Table IV-19.

Table IV-19
Baseline, Front of Truck Striking "Other Vehicle"
(Dry Road Surface Condition)
Striking Speed (m/s) vs. Initial Braking Speed at a Given Distance

Distance (m)	Initial Braking Speed (m/s)								
	13	16	18	20	22	25	27	29	31
	Striking Speed (m/s)								
0	13	16	18	20	22	25	27	29	31
2	13	15	17	20	22	24	27	29	31
4	12	15	17	19	22	24	26	28	31
6	11	14	17	19	21	24	26	28	31
8	11	13	16	19	21	23	26	28	30
10	10	13	16	18	21	23	25	28	30
12	9	12	15	18	20	23	25	27	30
14	8	12	14	17	20	22	25	27	29
16	7	11	14	17	19	22	24	27	29
18	6	10	13	16	19	22	24	26	29
20	5	9	13	16	19	21	24	26	29
22	2	8	12	15	18	21	23	26	28
24	0	7	11	15	18	20	23	26	28
26		6	11	14	17	20	23	25	28
28		5	10	14	17	20	22	25	28
30		3	9	13	16	19	22	25	27
32		0	8	12	16	19	22	24	27
34			7	12	15	18	21	24	27
36			6	11	15	18	21	24	26
38			4	10	14	17	20	23	26
40			2	9	14	17	20	23	26
42			0	9	13	16	20	23	25
44				8	12	16	19	22	25
46				6	12	15	19	22	25
48				5	11	15	18	22	24
50				3	10	14	18	21	24
52				0	9	14	18	21	24
54					9	13	17	20	23
56					8	13	17	20	23
58					6	12	16	20	23
60					5	11	16	19	22
62					3	11	15	19	22
64					0	10	15	18	22
66						9	14	18	21
68						8	13	17	21
70						7	13	17	21

Table IV-19 (continued)

72						6	12	17	20
74						4	12	16	20
76						2	11	16	19
78							10	15	19
80							9	14	19
82							8	14	18
84							7	13	18
86							6	13	17
88							5	12	17
90							2	11	16
92							0	11	16
94								10	15
96								9	15
98								8	14
100								7	14
102								6	13
104								4	12
106								2	12
108								0	11
110									10
112									10
114									9
116									8
118									7
120									5
122									3
124									0

With the 30% reduction in stopping distance, the deceleration would increase from 3.97 m/s^2 to 4.74 m/s^2. Based on the equation (1) and the estimated 4.74 m/s^2 deceleration rate, the corresponding striking speeds were derived for a given initial braking speed at a given distance, as shown below:

Table IV-20
Striking Speed with Improved Braking
(DRY Road Surface condition)

At Distance (m)	Initial Braking Speed (m/s)								
	13	16	18	20	22	25	27	29	31
	Striking Speed (m/s)								
0	13	16	18	20	22	25	27	29	31
2	13	15	17	20	22	24	26	29	31
4	12	14	17	19	22	24	26	28	31

Table IV-20 (continued)

6	11	14	16	19	21	23	26	28	30
8	10	13	16	18	21	23	25	28	30
10	9	12	15	18	20	23	25	27	30
12	8	11	14	17	20	22	25	27	29
14	7	11	14	17	19	22	24	27	29
16	5	10	13	16	19	21	24	26	29
18	3	9	12	15	18	21	23	26	28
20	0	7	11	15	18	20	23	26	28
22		6	11	14	17	20	23	25	28
24		4	10	13	17	19	22	25	27
26		0	9	13	16	19	22	24	27
28			7	12	15	18	21	24	27
30			6	11	15	18	21	24	26
32			4	10	14	17	20	23	26
34			0	9	13	17	20	23	26
36				8	13	16	19	22	25
38				7	12	16	19	22	25
40				5	11	15	18	22	25
42				3	10	14	18	21	24
44				0	9	14	17	21	24
46					8	13	17	20	23
48					7	12	16	20	23
50					5	11	16	19	22
52					3	11	15	19	22
54					0	10	14	18	22
56						9	14	18	21
58						7	13	17	21
60						6	12	17	20
62						4	11	16	20
64						0	11	15	19
66							10	15	19
68							9	14	18
70							7	13	18
72							6	13	17
74							4	12	17
76							0	11	16
78								10	16
80								9	15
82								8	14
84								7	14
86								5	13
88								3	12
90								0	11
92									10
94									9
96									8

Table IV-20 (continued)

98									7
100									6
102									4
104									0

As shown in Tables IV-19 and IV-20 above, the analysis assumed that brakes were applied at various initial brake speeds: 30 mph, 35 mph, 40 mph, 45 mph, 50 mph, 55 mph, 60 mph, 65 mph, and 70 mph.[41] For example, the estimated striking speeds with an initial braking speed of 27 m/s (60 mph) are illustrated in Figure IV-2.

As shown in Figure IV-2, for example, for the 27 m/s (60 mph) initial braking speed, the improved braking system would decrease the <u>distance</u> from 90.7 m to 76.1 m. The figure shows that the striking <u>speed</u> would also be reduced for a given distance measured from the point at which the brake is applied. For example, for an initial braking speed of 27 m/s, the original striking speed results in Table IV-19 show that the striking speed at 78 m would be 10 m/s. With the improved brake system, the striking speed at the same distance would be zero. Thus, for an

[41] Due to limited data, we didn't not consider reduced braking that occurs between 121's first movement of brake pedal and time when constant deceleration actually occurs (i.e., brake system reaction time). The distance gets shorter as initial braking speed is decreased from the baseline of 60 mph.

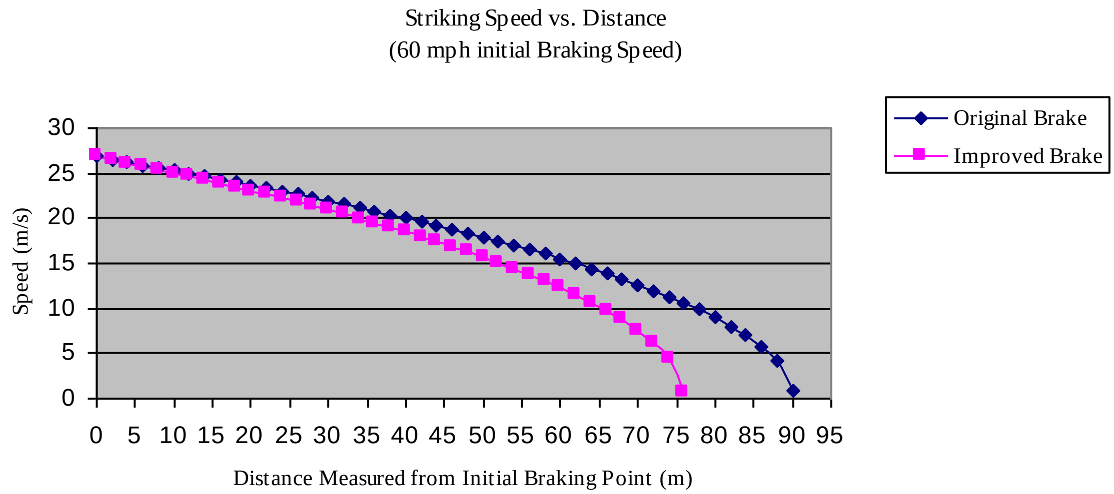

Figure IV-2. Illustration of Striking Speed with and without Improved Brakes: Striking Speed at a given distance with an Initial Braking Speed of 27 m/s (60 mph)[42]

initial braking speed of 27 m/s, all crashes occurring at striking speeds of less than 10 m/s with the original brakes would be prevented with the improved braking system.

For each initial braking speed, the striking speed distribution resulting from the improved braking system was compared to the original striking speed distribution at a given distance. Based on the comparison, a percent reduction in striking speed was derived, as shown in Table IV-21.

[42] Tables IV-19 and –20 show the estimated striking speed at a given distance and the stopping distance with and without the improved brake system for 30mph, 35mph, 40mph, 45mph, 50mph, 55mph, 60mph, 65mph and 70 mph initial braking speeds.

Table IV-21
Reduction in Striking Speed at Given Distance

At Distance (m)	Initial Braking Speed (m/s) 13	16	18	20	22	25	27	29	31
0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	0.95%	0.68%	0.51%	0.40%	0.32%	0.26%	0.22%	0.19%	0.16%
4	2.11%	1.46%	1.08%	0.83%	0.66%	0.54%	0.45%	0.38%	0.33%
6	3.58%	2.38%	1.72%	1.30%	1.03%	0.84%	0.69%	0.58%	0.50%
8	5.48%	3.47%	2.44%	1.82%	1.42%	1.15%	0.95%	0.80%	0.68%
10	8.04%	4.78%	3.26%	2.40%	1.85%	1.48%	1.22%	1.02%	0.86%
12	11.68%	6.40%	4.21%	3.03%	2.31%	1.84%	1.50%	1.25%	1.05%
14	17.30%	8.44%	5.31%	3.74%	2.81%	2.22%	1.80%	1.49%	1.25%
16	27.21%	11.10%	6.61%	4.54%	3.36%	2.62%	2.11%	1.74%	1.46%
18	50.71%	14.71%	8.17%	5.44%	3.96%	3.06%	2.44%	2.01%	1.68%
20	100.00%	19.91%	10.07%	6.46%	4.61%	3.53%	2.80%	2.28%	1.90%
22	100.00%	28.12%	12.43%	7.64%	5.34%	4.03%	3.17%	2.57%	2.14%
24		43.49%	15.47%	9.01%	6.15%	4.58%	3.57%	2.88%	2.38%
26		100.00%	19.52%	10.63%	7.05%	5.17%	4.00%	3.20%	2.63%
28		100.00%	25.20%	12.56%	8.07%	5.82%	4.45%	3.54%	2.90%
30		100.00%	33.89%	14.92%	9.22%	6.53%	4.94%	3.90%	3.18%
32			49.36%	17.85%	10.54%	7.31%	5.46%	4.29%	3.47%
34			100.00%	21.63%	12.06%	8.17%	6.03%	4.69%	3.77%
36			100.00%	26.67%	13.83%	9.13%	6.64%	5.12%	4.09%
38			100.00%	33.82%	15.94%	10.19%	7.30%	5.57%	4.43%
40			100.00%	44.99%	18.48%	11.39%	8.01%	6.06%	4.78%
42				67.09%	21.60%	12.75%	8.79%	6.57%	5.16%
44				100.00%	25.54%	14.31%	9.65%	7.13%	5.55%
46				100.00%	30.71%	16.10%	10.59%	7.72%	5.96%
48				100.00%	37.84%	18.20%	11.64%	8.36%	6.40%
50				100.00%	48.58%	20.68%	12.80%	9.05%	6.87%
52					68.54%	23.67%	14.09%	9.80%	7.36%
54					100.00%	27.36%	15.56%	10.61%	7.88%
56					100.00%	32.04%	17.22%	11.50%	8.44%
58					100.00%	38.22%	19.12%	12.46%	9.04%
60					100.00%	46.92%	21.33%	13.52%	9.68%
62					100.00%	60.77%	23.93%	14.70%	10.36%
64						100.00%	27.02%	16.00%	11.10%
66						100.00%	30.80%	17.45%	11.90%
68						100.00%	35.52%	19.09%	12.76%
70						100.00%	41.65%	20.95%	13.69%
72						100.00%	50.10%	23.08%	14.71%
74						100.00%	63.16%	25.54%	15.82%
76							100.00%	28.42%	17.05%
78							100.00%	31.87%	18.40%
80							100.00%	36.06%	19.91%
82							100.00%	41.32%	21.59%

Table IV-21 (continued)

84							100.00%	48.20%	23.49%
86							100.00%	57.89%	25.64%
88							100.00%	74.19%	28.12%
90							100.00%	100.00%	30.99%
92								100.00%	34.38%
94								100.00%	38.46%
96								100.00%	43.49%
98								100.00%	49.93%
100								100.00%	58.73%
102								100.00%	72.61%
104								100.00%	100.00%
106									100.00%
108									100.00%
110									100.00%
112									100.00%
114									100.00%
116									100.00%
118									100.00%
120									100.00%
122									100.00%

The percent reduction scores for each initial braking speed were averaged for a given striking speed range, as shown in Table IV-22.

Table IV-22
Average Percent Reduction in Striking Speed
For Given Striking Speed Range
With Respect to Initial Braking Speed[43]

Speed	Initial Braking Speed (m/s)								
Range (m/s)	13	16	18	20	22	25	27	29	31
1 to 2	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
3 to 5	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
6 to 8	31.74%	47.88%	83.12%	89.03%	100.00%	100.00%	100.00%	100.00%	100.00%
9 to 11	7.19%	11.42%	23.52%	35.16%	51.65%	76.92%	90.79%	100.00%	100.00%
12 to 14	1.02%	3.70%	8.52%	15.52%	22.45%	28.40%	37.02%	51.53%	76.25%

[43] For example, a truck equipped with the original brakes would travel in a speed range of 12 - 14 m/s at a distance range of 58 - 50 m measured from the initial braking. With the improved brakes, the travel speed would be reduced to 9 – 11 m/s in the same distance range of 58 - 50 m. When a crash occurs at these striking speeds (12 - 24 m/s) with an initial braking speed of 25 m/s, the improved brakes would reduce striking speeds by 28.40%, on average. Likewise, with an initial braking speed of 20 m/s, the same 12 - 14 m/s striking speeds would occur at a distance range of 34 – 26 m. With improved brakes, the travel speed would be reduced by 15.52% for an initial braking speed of 20 m/s. If all truck crashes occurred with 20 m/s and 25 m/s initial braking speeds (with the same frequency), hypothetically, 12 - 14 m/s striking speeds in the crashes would be reduced on average by 22% (average of 28.4% and 15.52%). The results in the table show that the percent reduction in striking speed would be relatively small at high original striking speeds regardless of initial braking speed. However, the percent reduction increases drastically when the striking speed decreases. In some cases, the percent reduction reaches to 100%, which indicates that these crashes would be prevented with improved brakes.

Table IV-22 (continued)

15 to 17		0.34%	2.20%	6.14%	10.13%	13.82%	18.54%	24.82%	33.51%
18 to 20			0.00%	1.40%	4.08%	6.67%	9.83%	13.75%	18.71%
21 to 23					0.88%	2.49%	4.78%	7.53%	10.54%
24 to 25						0.41%	1.55%	3.45%	5.62%
26 to 29							0.11%	0.83%	2.43%
30 to 32									0.51%

The results in Table IV-22 were averaged[44] for the striking speed ranges, as shown in Table IV-23.

Table IV-23
Average Percent Reduction in Striking Speed and Vehicle Delta-V

Striking Speed Range (m/s)	Vehicle Delta-V (mph)	% Reduction
1 to 2	1 to 4	100.00%
3 to 5	5 to 10	100.00%
6 to 8	11 to 16	83.53%
9 to 11	17 to 21	55.18%
12 to 14	22 to 27	27.16%
15 to 17	28 to 33	13.69%
18 to 20	34 to 38	7.78%
21 to 23	39 to 45	5.25%
24 to 26	46 to 49	2.76%
27 to 29	50 to 57	1.12%
30 to 32	58 to 62	0.51%

Whereas the percent reduction (r) is defined as:

$$r = 1 - \left(\frac{RF_{imp.}}{RF_{org.}} \right) \quad -(EQ-4)$$

$RF_{org.}$: Vehicle speed that would occur at a given distance for a given initial braking speed with unmodified brake system.

$RF_{imp.}$: Vehicle speed that would occur at a given distance for a given initial braking speed with improved brake system.

[44] For the analysis, we assumed that initial braking speeds are evenly distributed.

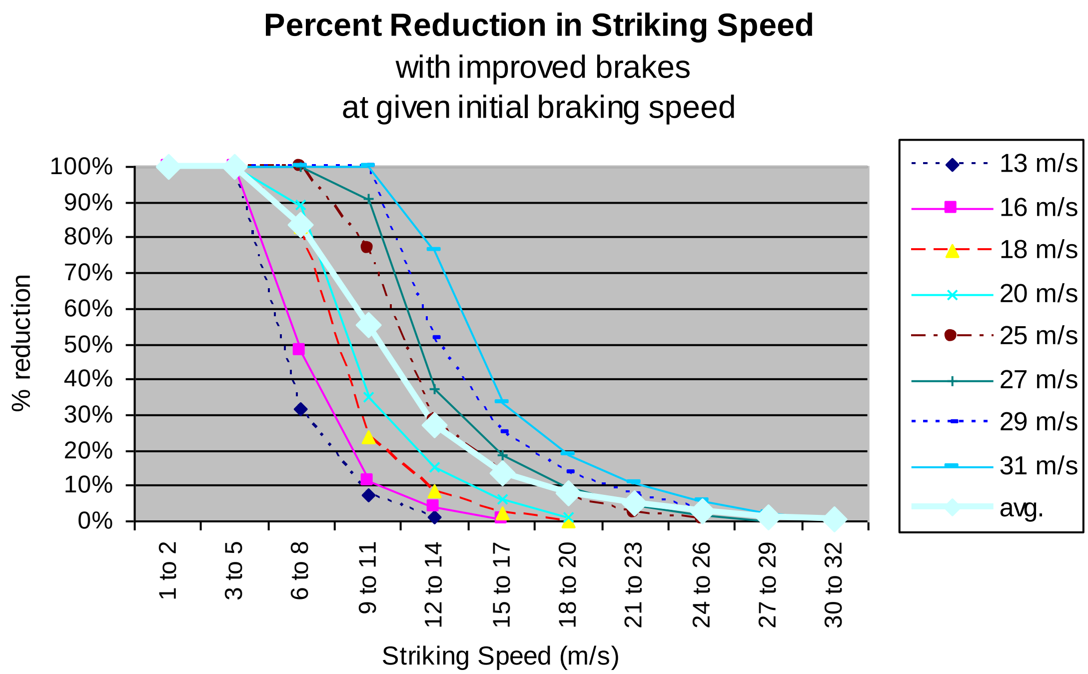

Figure IV-2. Average Percent Reduction in Striking Speed with respect to Initial Braking Speed

The results in Table IV-23 show that the percent reduction in striking speed would be higher for crashes at lower speeds. For the majority of low delta-Vs, the results in Table IV-23 show that the percent reduction rate is 100%. Thus, crashes occurred at these delta-Vs would be prevented with the expected reduction in stopping distance (i.e., preventable crashes). For example, according to the results in Table IV-23, any crashes with a striking speed of 5 m/s or less would be prevented if all applicable trucks were equipped with the improved braking system (i.e., meeting the 30% reduction requirement). We note that the change in delta-V is virtually non-existent in crashes at higher speeds[45], but becomes significant as the distance traveled during braking increases. (This phenomenon is illustrated in Figure IV-2. The upper plot shows the expected striking speed with the original brake system at a given distance measured from the point at which brake control begins, whereas the lower plot shows the striking speed with the

[45] The speeds are based on the initial braking speed. For the analysis, crashes with delta-V's equal to or less than 55 mph were considered.

improved brake system. When the distance increases, the difference in striking speed increases drastically.)

As discussed, NHTSA does not have data that indicate average stopping distance in crashes with respect to the braking speed. Therefore, it was assumed that crashes are equally spread over the full range of stopping distances. Under this assumption, the change in stopping distance can be used as proxy for the portion of crashes that are preventable.

The estimated effectiveness rates are then applied to the estimated number of "unable-to-stop-in-time" crashes, and the resulting PDO vehicle involvements, injuries and fatalities for crashes involved truck trailers.

Current Compliance:

As discussed in the Cost chapter, approximately 10% of all 2 and 3 axle trucks are equipped with larger S-cam drum brakes installed on the steer axle and 3% at the drive axles, as shown in Table IV-24 below. Although we do not know whether the trucks with larger steer axle brakes are also the trucks with larger drive and/or trailer axle brakes, the data indicate that not more than 3% of the trucks could currently meet the 30% reduction in stopping distance requirement without modification. Thus, this portion of the fleet would not require costs or achieve benefits for the final rulemaking.

Table IV-24
Brake Size and Type vs. Percent of Total Population[46]

Brake Size: Dia. x Width (in)	Percent of Total Population			Comments
	Steer Axle	Drive Axle (s)	Trailer (Dolly) Axle(s)	
12.25 x 4	0	0	2%	Special trailer chassis brake
15 x 4	90%	0	0	Standard steer axle brake tractors
15 x 5	3%	0	0	Option for smaller tires, longer lining life package (MX500)
15 x 6	0	0.5%	0.5%	Wedge brake
15 x 7	0	0.5%	0.5%	Wedge brake
15 x 8.63	0	3%	3%	Option for smaller tires
16.5 x 5	5%	0	0	Truck, special tractor longer lining life
16.5 x 6	5%	0	0	Truck
16.5 x 7	0	95%	95%	Standard rear truck / tractor and trailer brake
16.5 x 8	0	1%	1%	Option for longer lining life package (MX500)
16.5 x 8.63	0	2%	2%	Option for longer lining life on some fleets

We note that the effect on in-use braking performance of the stopping distance improvement is based on the fully loaded condition. However, since the agency does not have information on brake effectiveness with respect to the mass, we assumed that the effectiveness rates and benefits are applicable to all load conditions.

Quantifiable Safety Benefits:

Safety benefits were calculated by reducing the delta-V for each injury by the appropriate level. The injury totals for each injury level were redistributed according to the injury probability of the reduced delta-V level. This resulted in a new injury profile. Totals for each injury level

[46] Data provided by Heavy Duty Brake Manufacturers Council, a letter dated April 20, 2004. We note that the percent does not add up to exactly 100%. We suspect that these percentages are estimated and not weighted. In some cases, perhaps percentages are for tractors and others are for trucks. Although the percent does not add up to 100%, it shows that only a small fraction of heavy trucks are equipped with larger air drum brakes. For the analysis, we assumed that 3% of trucks would meet the proposed 30% reduction in stopping distance.

(severity category) were then compared to the original injury totals to produce the net benefits from reducing delta-Vs. The original injury distribution is shown in Table IV-25.

Table IV-25
Original Injury Distribution[47]
(Excluding Crashes with Delta-V Greater than 55 mph)

Delta-V (mph)[48]	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
1 to 4	1,891	97	4	4	0	1	0
5 to 10	20,450	2,983	148	91	9	3	61
11 to 16	18,677	6,322	553	239	30	11	168
17 to 21	3,453	2,189	371	126	17	9	107
22 to 27	988	997	409	120	17	10	141
28 to 33	201	237	220	66	12	8	103
34 to 39	17	64	123	47	10	7	109
40 to 45	0	5	18	9	2	2	32
46 to 49	0	1	7	5	2	2	41
50 to 55	0	0	2	1	1	1	23
Total	45,678	12,896	1,854	708	101	53	785

As shown Table IV-23, the improved brake system[49] would prevent all injuries that occurred at a vehicle delta-V of 10 mph or less[50]. These preventable injuries for each severity category are shown in Table IV-26.

Table IV-26
Preventable Injuries for Each Injury Severity Category
(For the required 30% reduction in stopping distance)

	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality	Average
No. of Injuries	22,341	3,080	152	95	9	4	61	-----
% Reduction[51]	49%	24%	8%	13%	9%	7%	8%	17%

The average percent reduction in Table IV-26 shows that the 16% reduction in stopping distance would result in 17% of the crashes being prevented. In addition, the results show that the percent

[47] The injury numbers were rounded to the nearest integer.
[48] Since the percent reduction in delta-V is very small for delta-Vs greater than 55 mph, as shown in Table IV-23, these delta-Vs were not considered. This results in a reduction in the fatality population from 864 to 785.
[49] For the proposed 30% reduction in stopping distance.
[50] The results in Table IV-23 show that crashes occur at a striking speed of 5 m/s (11.18 mph) or below would be prevented by the improved braking system. The corresponding delta-V would be about 10 mph.
[51] % Reduction = (Number of Prevented)/(Total injuries at each AIS level). For example, 22,341/45,678 = 49%.

reduction decreases as injury severity increases. The decrease in percent reduction reflects the fact that the portion of serious injuries would be smaller for crashes at low delta-Vs.

The injury totals for each delta-V category were redistributed according to the injury probabilities of the reduced delta-V level. The totals for each injury severity category were then compared to the original totals to produce the net benefits from reducing delta-Vs in the crashes that still occur. The resulting new injury distribution is shown in Table IV-27.

Table IV-27
Injury Distribution with Improved Braking System
(For the required 30% reduction in stopping distance)

Delta V	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
1	0	0	0	0	0	0	0
2	107	2	0	0	0	0	0
3	73	3	0	0	0	0	0
4	1001	53	3	2	0	0	0
5	507	36	2	1	0	0	1
6	1913	177	8	6	1	0	6
7	2692	314	15	10	2	0	9
8	3932	567	28	19	3	0	13
9	2667	461	27	15	0	1	10
10	1060	218	14	7	1	1	4
11	4434	1077	75	37	4	3	19
12	1798	507	40	18	3	0	17
13	1198	391	33	16	1	1	12
14	1576	587	57	25	3	1	18
15	1139	481	54	22	3	1	21
16	1519	720	92	34	6	2	31
17	886	470	69	25	4	2	20
18	457	269	45	16	2	1	15
19	459	298	57	20	2	1	20
20	158	113	25	8	1	1	8
21	197	152	39	12	2	1	13
22	113	95	28	9	1	1	9
23	53	48	16	5	1	0	6
24	160	152	61	18	3	2	23
25	146	146	68	20	3	2	27
26	106	110	60	17	3	2	23
27	39	42	26	8	1	1	11
28	26	28	21	6	1	1	9

Table IV-27 (continued)

29	38	43	37	11	2	1	17
30	22	24	24	7	1	1	12
31	19	22	25	8	1	1	14
32	20	22	29	9	2	1	18
33	2	2	4	1	0	0	2
34	8	8	16	5	1	1	12
35	3	2	5	2	0	0	4
36	0	21	41	15	3	3	39
37	0	2	4	2	0	0	5
38	0	4	9	4	1	1	12
39	0	1	3	1	0	0	5
40	0	3	8	4	1	1	15
41	0	0	1	0	0	0	1
42	0	0	0	0	0	0	0
43	0	0	2	1	0	0	5
44	0	0	0	0	0	0	1
45	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0
47	0	0	2	1	0	0	9
48	0	0	3	2	1	1	18
49	0	0	0	0	0	0	2
50	0	0	0	0	0	0	1
51	0	0	0	0	0	0	0
52	0	0	0	0	0	0	6
53	0	0	0	0	0	0	3
54	0	0	0	0	0	0	7
55	0	0	0	0	0	0	0
Total	28,527	7,674	1,178	452	66	37	553

The resulting net benefits and the (percent) effective rates are shown in Table IV-28.

Table IV-28
Overall Brake Benefits and Percent Effectiveness
(For the required 30% reduction in stopping distance)

	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Original	45,678	12,896	1,854	708	101	53	785
Improved	28,527	7,674	1,178	452	66	37	553
Net Benefits	17,346	5,287	684	259	35	16	234
Effectiveness	38%	41%	37%	37%	35%	30%	30%

The results in Table IV-28 show that the 30% reduction in stopping distance would result in an average effectiveness[52] rate of 33% for all serious and fatal injuries[53]. As discussed, about three percent of the trucks would meet the required stopping distance requirement without any modification. The incremental benefits were estimated based on the three percent compliance rate and the estimated effectiveness rates, as shown below:

$$\text{Potential Injury} = \frac{\text{Observed Injury}}{1-(\text{Compliance Rate in Potential Crashes})\,\text{x}\,(\text{Effective Rate})} \quad -(EQ-5)$$

Injuries Prevented = (Potential Injury) x (Effectiveness Rate) – (EQ-6)
Remaining Injuries = Potential Injury – Injury Prevented – (EQ 7)
Incremental Benefits = Observed Injury – Remaining Injury – (EQ-8)

Table IV-29
Overall Benefits by AIS level
For 30% Reduction in Stopping Distance
(DRY Road Surface Condition, Adjusted with the 3% compliance Rate)

	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Unadjusted	17,346	5,287	684	259	35	16	234
Adjusted	16,825	5,128	664	251	34	15	227

The results in Table IV-29 show that the stopping requirement would prevent 5,128 AIS 1, 664 AIS 2, 251 AIS 3, 34 AIS 4, 15 AIS 5 injuries and save 227 lives, annually.[54] Among the 227

[52] In the FEA for "Stability and Control During Braking Requirements and Reinstatement of Stopping Distance Requirements for Medium and Heavy Vehicle" dated February 1995, the agency found that for severity reduction potential, a 15% stopping distance reduction was estimated to result in about 15% of the crashes being reduced in severity. A 5% reduction in stopping distance was estimated to result in 10% of the crashes being prevented. In the FEA, for the purpose of calculating the number of fatalities, injuries, and accidents prevented by a decrease in heavy vehicle stopping distance, the agency assumed a 1 to 1 ratio, so that a 1% reduction in stopping distance would corresponding to a 1% reduction on fatalities, injures, PDO vehicle involvements and accidents.

If the 1 to 1 ratio is used, it would result in 156 lives saved and 137 serious injuries prevented, as shown below:

	AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Original	45,678	12,896	1,854	708	101	53	785
Benefits	7,380	2,063	297	113	16	8	156

[53] The results show that a 16% reduction in stopping distance would result in about 33% of the crashes being reduced in severity. The percent reduction rates would result in a 1 to 2 ratio.
[54] The estimate is based on, as assumed, dry road surface conditions for all crashes with 3% compliance rate.

fatal benefits, about 61 lives saved would result from the preventable crashes[55] and the remaining 166 would result from reduction in injury severity.

Equivalent Lives Saved:

The corresponding equivalent lives[56] saved for the required 30% reduction in stopping distance are shown in Table IV-30.

Table IV-30
Equivalent Lives Saved by Improved Brake System
For 30% Reduction in Stopping Distance

	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Factors	N/A	0.0028	0.0436	0.0804	0.1998	0.6656	1.0000	
Equivalent Lives	0	14	29	20	7	10	227	307

Estimated Property Damage Benefits:

The reductions in property damage were calculated by multiplying the estimated amount of property damage and travel delay costs per injury at various levels of severity, including property-damage-only (PDO) crashes, by the estimated number of injuries prevented, fatalities prevented and the number of vehicle involvements in PDO prevented, respectively.

The estimates of the property damage and travel delay costs per injury levels of severity and per fatality, and property damage costs per vehicle involved in PDO crashes are made based on the estimated property damage used in the Preliminary Regulatory Impact Analysis, FMVSS Nos. 105 & 121 NPRM, "Stability and Control While Braking Requirements for Medium and Heavy Vehicles," as shown below:

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[55] See Table IV-26.
[56] For additional information on equivalent life, see Chapter VI in this document.

Table IV-31
Estimated "Property Damage" per
PDO Vehicle Involvement, Injury or Fatality
In Heavy Vehicle Crashes[57]

Property Damage per:	Property Damage
PDO Vehicle Involvement[58]	$6,935
AIS 1 Injury	$7,119
AIS 2 Injury	$7,380
AIS 3 Injury	$7,273
AIS 4 Injury	$7,427
AIS 5 Injury	$7,418
Fatality	$19,291

The costs were adjusted with Implicit Price Deflator to 2007 dollars. For the property damage, the 1992 deflator was used, as shown below:

Table IV-32a
Implicit Price Deflator[59]

	1992	2007
Implicit Price Deflator	86.385	119.682

Table IV-32b
Adjustment Factor

	Adjustment Factor
Property Damage	1.3854

[57] A 1991 Federal Highway Administration (FHA) report, The Cost of Highway Crashes, included data which compared the property damage, travel delay and emergency service costs of crashes involving heavy vehicles and those involving other vehicle classes. However, the data in the FHA report are not broken down per fatality, per injury at different levels of injury severity or per vehicle involved in PDO crashes. For the Preliminary Regulatory Impact Analysis for FMVSS Nos. 105 & 121 dated September 1993, the agency was able to obtain such a breakdown from the author as shown in Table 7 in the report.

[58] For the estimates of the "property damage" related to vehicles involved in PDO crashes, costs other than those directly resulting from damage to the vehicles and property and travel delay that resulted from the crash were included. These other costs included "workplace" costs, insurance administration costs, emergency service costs, and household productivity. The actual damage was about 90% of the total cost per vehicle involved in a PDO crash (i.e., 90% of $7,705 = $6,935). In the case of estimated "property damage" related to injuries and fatalities, only those costs related to property damage and travel delay resulting from the crash were included since these other costs were assumed to be part of the costs related to the injury or fatality.

[59] U.S. Gross Domestic Product, and Implicit Price Deflator, 1949-2005. 2000 = 100.

Table IV-33
Estimated "Property Damage" per
PDO Vehicle Involvement, Injury or Fatality
In Heavy Vehicle Crashes
Adjusted to 2007 Level with Implicit Price Deflator

Property Damage per:	Property Damage Adjusted to 2007 level
PDO Vehicle Involvement	$9,607
AIS 1 Injury	$9,863
AIS 2 Injury	$10,224
AIS 3 Injury	$10,076
AIS 4 Injury	$10,289
AIS 5 Injury	$10,277
Fatality	$26,726

For the analysis, we used an average of $10,056 for non-fatal crashes and $26,726 for fatal crashes. For the cost analysis, PDO cost includes both property damage and travel delay.

According to 2004 -2006 GES data, there are 45,058 crashes involving tractor trucks, annually, where the front of a truck impacts with the struck vehicle, as shown below:

Table IV-34
Number of Crashes in Truck Frontal Crashes

Crashes	No. of Crashes
Braking	22,940
No-Braking	22,118
Total	45,058

Among the 22,940 braking & frontal crashes, 49,024 vehicles were involved in the crashes, as shown below:

Table IV-35
Number of Vehicles Involved

Severity	No. of Injuries
No injury	27,825
Possible	8,491
Non-incapacitating	6,566
Incapacitating	4,918
Fatal	1,000
Unknown	224
Died Prior	0
No Person	0
Total	49,024

In the preventable crash analysis, we found that 22,341 MAIS 0 injuries (in Table IV-26) were in the preventable crash category[60]. Although the majority of MAIS 0 would be from PDO crashes, non-PDO crashes would also result in MAIS 0 injuries in vehicle-to-vehicle crashes[61]. Since we do not have the PDO distribution with respect to vehicle delta-V, for the analysis, we assumed that the 22,341 preventable MAIS 0 injuries are from PDO crashes.

According to Tables IV-4, IV-34 and IV–35, there were 62,156 occupants in the 22,940 braking & frontal crashes involving 49,024 vehicles. Thus, based on the number of occupants[62] and the vehicles involved, we assumed that each vehicle was occupied by 1.27 occupants in the crashes (1.27-ratio, hereafter). When adjusted with the 1.27-ratio, the 22,341 MAIS 0 preventable injuries resulted in 17,621 PDO vehicles. In other words, the improved brakes would prevent 17,621 vehicles from crashes where only property damages occurred[63].

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[60] The estimated net reduction in MAIS 0 is shown in Table IV-29.
[61] For example, the driver may sustain AIS 1 injuries but the front occupant may suffer no injury during a low delta-V side crash.
[62] Among 62,156 occupants, 62,076 resulted from a delta-V of 55 mph or less.
[63] There were 49,024 vehicles involved in braked-crashes involving 62,156 injured occupants. Thus, there were an average of 1.27 occupants in each vehicle involved in crashes (62,156/49,024 = 1.27 (1.2679)). We assumed that all MAIS 0 (no injuries) result from PDO crashes. (22,341/1.2679 = 17,621)

The same estimated property damage per PDO vehicle involvement was applied to PDO vehicle involvements prevented for both trucks and "other vehicles." For property damage in injury and fatality producing crashes, the same estimated property damage per injury or fatality was applied to injuries or fatalities prevented for truck occupants and "other vehicle" occupants. Based on the estimated "property damage" above, the following Property Damage benefit estimates were made[64], as shown below:

Table IV-36
Estimated Property Damage for PDO Vehicle Involvements
Injuries and Fatalities Prevented
For 30% Reduction in Stopping Distance

Benefit Category	Estimated Benefits	Property Damage Prevented per Unit Benefit	Property Damage Prevented
PDO Vehicle Involvement	17,621	$10,056	$177,198,843
AIS 1 Injury	5,128	$10,056	$51,571,684
AIS 2 Injury	664	$10,056	$6,672,836
AIS 3 Injury	251	$10,056	$2,528,899
AIS 4 Injury	34	$10,056	$339,068
AIS 5 Injury	15	$10,056	$154,553
Fatality	227	$26,726	$6,064,719
Total Property Damage Prevented:			$244,530,602

The results in Table IV-36 show that the required 30% reduction in stopping distance, as specified in the standard, would save about $245 million in property damages, annually.

Summary of Benefits Estimated[65]*:*

Summarizing from Tables IV-29 and -36, the potential benefits to be derived from the required 30% reduction in stopping distance requirement are:

1. 300 vehicle occupant serious injuries (AIS 3, 4 & 5) per year.
2. 227 vehicle occupant fatal injuries per year.

[64] The adjusted net benefits were based on the estimated 3% compliance rate.
[65] We estimated that the 20% reduction in stopping distance would result in 91 lives saved, 127 serious injuries prevented and $32 million property damage prevented at 7% discount.

3. $244,530,602 of property damages prevented.

V Costs

The stopping distance reduction requirement would only affect tractor trucks. We estimate that 130,000 tractor trucks are manufactured annually. Among these 130,000 vehicles, 13,000 of them have two axles and the remaining 117,000 have three axles.[66] The countermeasures used and the cost to equip tractors to meet the required stopping distance requirement depends on the new 60 mph stopping distance that is required.

<u>Vehicle Modification Costs</u>:

30% Reduction in Stopping Distance: Based on the VRTC test report and the three test reports[67] from Federal Mogul and Motion Control Industries, a 30 percent reduction in stopping distance could be met by using larger S-cam drum brakes or disc brakes at all wheel positions on tractors. The agency believes that the cost to install larger drum brakes would be much lower than the cost to install air disc brakes, although we do not have specific cost information on the various modifications to truck tractor braking systems[68]. In the PRIA, the agency assumed that the cost for larger S-cam drum brakes is \$75 for the steer axle[69] and \$50 for each drive axle[70] to meet the 30% reduction requirement. For typical three-axle tractors, which make up about 82 percent of annual production, we estimated \$175 ($\$75_{steer} + 2 \times \$50_{drive} = \$175$) for large drum brakes. In their comments to the PRIA, Freightliner stated that large drum brakes at all wheel positions would be \$222. However, the manufacturer did not break costs associated with steer and drive

[66] The agency received public comments in response to the NPRM that indicate 4x2 tractor make up 10 percent of annual tractor production (130,000x10% = 13,000, 130,000 – 13,000 = 117,000). See Chapter II for additional discussion.
[67] Test Report Nos. RAI-FM-20, RAI-MC-04, AND RAI-FM-21.
[68] The agency requires more data on the cost to install larger S-cam drum brakes and also air disc brakes.
[69] The size increases from 15” x 4” to 16.5” x 5” or 16.5” x 6”
[70] The size increases from 16.5” x 7” to 16.5” x 8 5/8” or 16.5” x 8”. As stated, the unit cost estimates included in the analysis are preliminary. More definitive cost and weight estimates are currently in preparation.

axles. Due to limited data, we assumed that the cost for larger S-cam drum brakes is $85 for the steer axle and $65 for each drive axle ($215 for typical three-axle tractors) in 2005 economics. Although the estimated $215 is lower than Freightliner's $222 cost (about 3% lower), we would expect that when larger quantities of brakes are produced the cost would be lower than the current $222. Based on information submitted by the Heavy Duty Brakes Manufacturers Council (HDBMC)[71], the agency estimates that three percent of all tractor trucks would meet the required 30% reduction in stopping distance without any modification. The percentage of vehicles that already have larger S-cam drum brakes is shown in Table V-1.

Table V-1
Percent Distribution of Larger S-Cam Drum Brake

Type	Percent of Total Population			Brake Size		
	Steer Axle	Drive Axle	Trailer	Steer	Drive	Trailer
Larger S-Cam Drum	5%	2%	2%	16.5" x 5"	16.5" x 8 5/8	16.5" x 8 5/8
	5%	1%	1%	16.5" x 6"	16.5" x 8"	16.5" x 8"
Disc	0%	0%	0%	*	*	*

* No Data Available

The results in Table V-1 show that 10% of brakes on the steer and 3% of brakes on the drive axles are equipped with larger S-cam brakes. The costs associated with these brakes would be $1,706,125 in 2007 economics, as shown in Table V-2.

Table V-2
Current Estimated Cost Spent on Larger S-Cam Brakes in 2007 economics

Axle	No.	% of Total	Unit Cost	Cost/Axle
Steer	130,000	10%	$91(1)	$1,188,207
Drive	247,000	3%	$70(2)	$517,918
			Total Cost	$1,706,125

(1) $91.40 (2) $69.80

The agency is basing the cost estimates on tractor production of 130,000 units per year. While this number can vary greatly from year-to-year, the agency received no comments in response to the December 15, 2005 NPRM or Preliminary Regulatory Impact Analysis (PRIA) regarding this

[71] A letter submitted by HDBMC dated April 20, 2004.

issue. Therefore, the 130,000 tractor value is considered to be representative of a typical production year.

When the agency requires a 30 percent reduction in stopping distance for all tractor trucks and if large S-cam drum brakes are installed at each wheel position, the incremental cost would be about $27M dollars, as shown in Table V-3, or about $211 per truck tractor ($27,439,882/130,000).

Table V-3
Estimated Incremental Costs with Larger S-Cam Drum Brake System
(30% reduction in stopping distance) in 2007 economics

Axle	No.	% of Total	Unit Cost	Cost/Axle
Steer	130,000	90%	$91	$10,693,859
Drive	247,000	97%	$70	$16,746,023
			Incremental Cost	$27,439,882

Alternatively, the required stopping distance could be met with air disc brakes, although the agency believes that the majority of the affected vehicles would be equipped with larger S-cam drum brakes. Air disc brakes cost considerably more than drum brakes, and have not been widely used on tractors in the U.S. Problems to be addressed as fleet penetration increases include tire valve stem clearance issues with existing wheels, availability of replacement parts, brake technician training, and in-service inspection procedures. The agency does not have cost information on disc brakes, but assumes that the cost would be $500 per axle (either steer or drive axles) in 2005 economics. If all affected vehicles are equipped with disc brakes to meet the requirement, the agency estimates that the associated incremental cost would be about $192M (or

$1,475 per truck tractor) to fit disc brakes at each wheel position of the 130,000 tractor trucks manufactured each year in 2007 economics. [72] The cost estimate is shown in Table V-4.

Table V-4
Estimated Incremental Costs With Disc Brake System
(30% reduction in stopping distance) in 2007 economics

Axle	No.	% of Total	Unit Cost	Cost/Axle
Steer	130,000	90%	$538	$62,905,050
Drive	247,000	97%	$538	$128,815,564
			Incremental Cost	$191,720,614

As discussed in Chapter III, a truck equipped with front disc brakes and rear larger S-cam drum brakes could meet the stopping distance requirements. If all applicable vehicles are equipped with front disc and rear larger S-cam drum brakes, the associated cost would be about $80M (or $613 per vehicle) in 2007 economics. The cost estimate for the front disc and rear large S-cam drum brakes is shown in Table V-5.

Table V-5
Estimated Incremental Costs With Front Disc and Larger Rear S-Cam Drum Brake System
(30% reduction in stopping distance) in 2007 economics

Axle	No.	% of Total	Unit Cost	Cost/Axle
Steer	130,000	90%	$538	$62,905,050
Drive	247,000	97%	$70	$16,746,023
			Incremental Cost	$79,651,073

In summary, potential compliance costs for the 30% reduction in stopping distance vary considerably and are dependent upon the types of foundation brakes chosen by the manufacturers and the number of axles. The cost for installing new brake systems ranges from large drum brakes at $231 per vehicle for typical three-axle tractors to disc brakes at $1,613 per vehicle for severe-service three-axle tractors in 2007 economics.

[72] Some of the typical three-axle tractors may need disc brakes on the steer axle only, and many of these tractors may be able to comply by upgrading to enhanced drum brakes (the lowest-cost option). Thus it is unlikely that the total cost to implement the requirements would be close to the high-end cost estimate in the FRIA (which was to install disc brakes on all tractors).

In the analysis, the agency used an array of foundation brake upgrades to estimate increased costs for the brake system improvements because the agency could not accurately predict the precise methods that truck manufacturers would use to upgrade tractor brake systems to meet the new requirements. However, if the current market share of different types of tractors remains unchanged, we could estimate costs associated with the probable outcome of brake systems under the tractor stopping distance finale rule. The test data indicate that typical three-axle tractors, which make up 82% of annual production, could meet the 30 percent reduction requirement by using large drum brakes at all wheel positions. For two-axle tractors, which make up about 10% of production, and severe-service three-axle tractors, which make up 8% of production, we could assume that they will need disc brakes at all wheel positions. The weighted cost without considering any current compliance rate, therefore, would be about $426 per vehicle [(82% x $231) + (10% x $1,075) + (8% x $1,613) = $426].[73] If we don't consider the compliance rate and the $426 weighted brake cost is used, the total associated cost would be $55.4 million based on 130,000 tractors manufactured each year. As shown in Table V-2, the current estimated cost spent on larger S-cam brakes is about $1.7 million. Thus, the most likely estimated incremental cost is $53.7 million or about $413 per vehicle [($55.4 million - $1.7 million)/130,000 = $413].

20% Reduction in Stopping Distance: Although the final rule requires a 30% reduction in stopping distance, we reevaluated the potential benefits result from and costs associated with a

[73] Note that we would not expect any tractor to need disc brakes on more than three axles. Typical 4-axle severe service tractor would have a lift axle that we state in the final rule that could continue to use drum brakes. For the highest-GVWR tractors (>70,000 lbs. on three axles and >85,000 pounds on four or more axles), we don't really know too much. The three-axle would probably go to all disc brakes ($1,614). A twin-steer, twin drive axle tractor would probably stay drum brakes all around, but we don't know. It would be possible that it would have disc brakes all around ($2,152), or maybe on the steer axles ($1,076). They have pretty big drum brakes on them already.

20% reduction in stopping distance with new cost information on larger S-cam drum brakes. Similar to the methodology used for the 30% reduction, we estimated incremental costs of $19M, $134M, and $58M for all larger S-cam drum brakes, all disc brakes, and front disc and rear larger S-cam drum brakes, respectively, as shown in Table VI-5b. Regarding the most likely combination brake system for the 20% reduction, the test data indicate that typical three-axle tractors, which make up 82% of annual production, could meet the 20 percent reduction requirement by using large drum brakes at all wheel positions. For two-axle tractors, which make up about 10% of production, they will need disc brakes at steer wheel and larger drum brakes at drive wheel positions. For severe-service three-axle tractors, which make up 8% of production, we could assume that they will need disc brakes at all wheel positions. The weighted cost without considering any current compliance rate, therefore, would be about $379 per vehicle (82% x $231) + (10% x $608) + (8% x $1,613) = $379). If we don't consider the compliance rate and the $379 weighted brake cost is used, the total associated cost would be $49.3 million based on 130,000 tractors manufactured each year. The current estimated cost spent on larger S-cam brakes is about $1.7 million. Thus, the most likely estimated incremental cost is $47.6 million or about $366 per vehicle [($49.3 million - $1.7 million)/130,000 = $366].

Costs Affecting Operational Life:

When compared to the brake modification/installation cost, typically costs affecting the operational life of the vehicle are small. There are two factors that would significantly affect the cost: weight of the equipment that would affect the fuel economy and maintenance requirements for the upgraded equipment over the life of the vehicle. The agency has very limited information on both of these issues.

(1) Increased Lifetime Fuel Costs Due to Additional Vehicle Weight:

The weight of required equipment would depend on the means to achieve improved braking performance. Larger S-cam drum brakes weigh more than conventional S-cam drum brakes (either steer axle or drive axle brakes), so they would impose some weight penalty. Disc brakes also have been described as having some weight penalty over conventional S-cam drum brakes[74]. However, the agency does not have information on the equipment weight to determine a weight penalty. The NPRM Request for Comments section also asked for information on tractor components other than the foundation brakes (e.g., frames and suspensions) that may need to be modified to meet shorter stopping distance requirements of 20 to 30 percent. As part of the request, the agency was seeking to identify weight penalties that might be required to meet the new stopping distance requirements. The commenters provided little specific information on the vehicle modifications that may be required to reliably equip tractors with more powerful foundation brakes.

- Bendix provided data on drum brake versus disc brake weights. It stated that the heaviest drum brakes weigh more than the lightest disc brakes, while the heaviest disc brakes weigh more than the lightest drum brakes. It stated that for a three-axle tractor equipped with all disc brakes, total vehicle weight could increase by 212 pounds, or could decrease by 134 pounds compared to an all drum-braked tractor, depending on which disc or drum brakes are used for comparison.

[74] We note that changing European trucks and tractors to disc brakes resulted in a weight saving because the conventional European S-cam drum brake was much heavier than a typical U.S. drum brake, mainly due to differences in the thickness of the brake drums. A thick brake drum as used in Europe would have higher thermal capacity and less in-stop brake fade than thinner drum brakes, thus providing better high-speed stopping performance.

Based on the comment provided, the weight penalties for improved brake systems are hard to determine.

(2) Maintenance Costs:

Regarding the maintenance of conventional S-cam, larger S-cam, and disc brakes, the agency expects that conventional S-cam and larger S-cam brake maintenance costs would be similar, although the larger S-cam brakes have been described as having longer lining life. Longer lining life has been described as one reason for the development of large drive axle brakes[75] that are available on some tractors. However, the agency does not have pertinent information to determine the costs.

Disc brakes have only been used in somewhat limited applications on U.S. heavy vehicles, most commonly motor coaches and specialty vehicles such as fire and rescue vehicles, and the agency does not have information on their maintenance requirements compared to drum brakes in similar applications. Disc brakes have a higher initial cost than S-cam brakes, and although brake lining changes may be a relatively simple operation, wheel bearing service and rotor replacements may be more complex than for S-cam drum brakes. However, if the intervals for brake lining replacement are found to be greatly extended for disc brakes, this would have a measurable benefit for trucking fleets.

[75] 16.5" x 8 5/8"or 16.5" x 8" versus standard 16.5" x 7"

VI Cost Effectiveness & Benefit-Cost Analyses

The intent of the final rulemaking is to prevent crashes that occur at low delta-Vs and reduce injury severity in "unable-to-stop-in-time" (or "unpreventable") crashes. To achieve these goals, the agency is considering a new stopping distance requirement for tractor trucks. This section estimates the number of lives to be saved and injuries to be prevented per dollar spent for the 30% reduction in stopping distance and an alternative of a 20% reduction in stopping distance. It should be noted that the costs of the equipment needed to meet the requirements are incurred when the vehicles are purchased, but the benefits of improved braking performance will accrue over the lifetime of the fleet. Therefore, discount factors are applied to estimate the present value of benefits for a meaningful comparison to costs.

Cost Effectiveness:

With respect to reduction in the number of fatalities and injuries, the agency estimates the number of "equivalent fatalities" that would be prevented, or "equivalent lives saved," a concept that incorporates a reduction in both the number of fatalities and injuries. The estimated equivalent lives saved and property damages prevented are discounted. The costs are reduced by the amount of discounted property damage prevented to derive "net costs." These "net costs" are then compared to the estimated equivalent lives saved.

There is general agreement within the economic community that the appropriate basis for determining discount rates is the marginal opportunity costs of lost or displaced funds. When these funds involve capital investment, the marginal, real rate of return on capital must be considered. However, when these funds represent lost consumption, the appropriate measure is 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[76] 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[77] put the rate at between one and five percent, based on returns to stocks and three-month Treasury bills. Moore and Viscusi[78] 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 three percent and seven 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 are appropriate proxy measures for the distribution of such crashes over the vehicle's lifetime. Multiplying the percent

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[76]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.)
[77]J. Kolb and J.D. Sheraga, "A Suggested Approach for Discounting the Benefits and Costs of Environmental Regulations,: unpublished working papers.
[78]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.

of a vehicle's total lifetime mileage that occurs in each year by the discount factor and summing these percentages over the 36 years of the vehicle's operating life, results in multipliers for the heavy truck as shown in Table VI-1. These values are multiplied by the equivalent lives saved to determine their present value.

In the context of this particular regulatory evaluation of the efforts to improve the braking performance of heavy trucks, safety benefits occur when there is a potential crash severe enough to result in occupant death or injury that would predictably be prevented by the required technology. The benefits could occur at any time over the truck's lifetime. This analysis assumes that crashes over the truck fleet's lifetime will occur in proportion to the number of miles a given year's new truck fleet will be driven from year to year as it ages. Table VI-1 contains the vehicle miles of traveled (VMT) by vehicle age and the survival probability schedules used in calculating age and survival factors. The values in the column indicating the percentage of fleet travel that would occur each year, i.e., weighted yearly travel, are used to distribute savings by year of vehicle operation. The vehicle miles traveled (VMT) by vehicle age distribution is used to determine the percentage of lifetime mileage that occurs each year that in turn is used to calculate the discount factors by year for the three and seven percent discount rates. The two right-hand columns in Table VI-1 show the weighted values for these discount factors. These values are derived by multiplying the yearly discount factors by the share of lifetime travel that occurs in the respective years and summing these factors over the 36 years. The values in the two columns are then summed to produce the following multipliers for the respective discount rates: 0.8392 for a three percent discount rate and 0.6903 for a seven percent discount rate, as shown in Table VI-1.

Table VI-1
Mid-Year Discount Factors, Heavy Trucks[79]

Age, VMT	VMT (a)	Survival (b)	(a) x (b)	% of VMT	3%	7%	Weighted 3%	Weighted 7%
1	100,000	0.9995	99950	12.55%	0.9853	0.9667	0.1236	0.1213
2	90,000	0.9985	89865	11.28%	0.9566	0.9035	0.1079	0.1019
3	81,000	0.9953	80619	10.12%	0.9288	0.8444	0.0940	0.0855
4	72,900	0.9874	71981	9.04%	0.9017	0.7891	0.0815	0.0713
5	65,610	0.9747	63950	8.03%	0.8755	0.7375	0.0703	0.0592
6	59,049	0.9574	56534	7.10%	0.8500	0.6893	0.0603	0.0489
7	53,144	0.9354	49711	6.24%	0.8252	0.6442	0.0515	0.0402
8	47,830	0.9092	43487	5.46%	0.8012	0.6020	0.0437	0.0329
9	43,047	0.8790	37838	4.75%	0.7778	0.5626	0.0370	0.0267
10	38,742	0.8453	32749	4.11%	0.7552	0.5258	0.0310	0.0216
11	34,868	0.8083	28184	3.54%	0.7332	0.4914	0.0259	0.0174
12	31,381	0.7687	24123	3.03%	0.7118	0.4593	0.0216	0.0139
13	28,243	0.7270	20533	2.58%	0.6911	0.4292	0.0178	0.0111
14	25,419	0.6836	17376	2.18%	0.6710	0.4012	0.0146	0.0088
15	22,877	0.6392	14623	1.84%	0.6514	0.3749	0.0120	0.0069
16	20,589	0.5942	12234	1.54%	0.6324	0.3504	0.0097	0.0054
17	18,530	0.5491	10175	1.28%	0.6140	0.3275	0.0078	0.0042
18	16,677	0.5045	8414	1.06%	0.5961	0.3060	0.0063	0.0032
19	15,009	0.4608	6916	0.87%	0.5788	0.2860	0.0050	0.0025
20	13,509	0.4183	5651	0.71%	0.5619	0.2673	0.0040	0.0019
21	12,158	0.3774	4588	0.58%	0.5456	0.2498	0.0031	0.0014
22	10,942	0.3385	3704	0.47%	0.5297	0.2335	0.0025	0.0011
23	9,848	0.3017	2971	0.37%	0.5142	0.2182	0.0019	0.0008
24	8,863	0.2673	2369	0.30%	0.4993	0.2039	0.0015	0.0006
25	7,977	0.2353	1877	0.24%	0.4847	0.1906	0.0011	0.0004
26	7,179	0.2058	1477	0.19%	0.4706	0.1781	0.0009	0.0003
27	6,461	0.1789	1156	0.15%	0.4569	0.1665	0.0007	0.0002
28	5,815	0.1545	898	0.11%	0.4436	0.1556	0.0005	0.0002
29	5,233	0.1326	694	0.09%	0.4307	0.1454	0.0004	0.0001
30	4,710	0.1130	532	0.07%	0.4181	0.1359	0.0003	0.0001
31	4,239	0.0957	406	0.05%	0.4059	0.1270	0.0002	0.0001
32	3,815	0.0805	307	0.04%	0.3941	0.1187	0.0002	0.0000
33	3,434	0.0673	231	0.03%	0.3826	0.1109	0.0001	0.0000
34	3,090	0.0558	172	0.02%	0.3715	0.1037	0.0001	0.0000
35	2,781	0.0460	128	0.02%	0.3607	0.0969	0.0001	0.0000
36	2,503	0.0377	94	0.01%	0.3502	0.0905	0.0000	0.0000
			796,518				0.8392	0.6903

[79] These estimates are derived from the Census Bureau's 2002 Vehicle Use and Inventory Survey (VIUS). The analysis utilized the unweighted miles in VIUS, which are not adjusted for partial-year operation of tractors. Therefore, the values reported here should accurately represent the actual mileage driven as a function of age, rather than a weighted value which treats all vehicles as if they were in operation for the full year. Details can be found in *An In-Service Analysis of ABS Maintenance and Repair Expenses for Tractors and Trailers* by Kirk Allen, draft, January 2008."

These multipliers are applied to the estimated number of equivalent fatalities prevented to give the present values of estimated safety benefits for the respective discount rates.

Fatality and Injury Prevented Benefits:

As a primary measure of the impact of the required stopping distance, this analysis will measure the cost per equivalent life saved and also benefits in preventing property damage involved in the crashes. In order to calculate a cost per equivalent fatality, nonfatal injuries must be expressed in terms of fatalities. This is done by comparing the value of preventing nonfatal injuries to the value of preventing a fatality. Comprehensive values, which include both economic impacts and lost quality (or value) of life considerations will be used to determine the relative values of fatalities and nonfatal injuries. In the past, these values were taken from a study published by NHTSA when the estimated economic value of preventing a human fatality was $3.0 million.[80] Recently, the Department of Transportation has determined that the best current estimate of the economic value of preventing a human fatality is $5.8 million. However, relative value coefficients for preventing injuries of different severity have not been developed. NHTSA is conducting research to revise the previously developed estimates. The revised estimates will be published when they become available. In the interim, we have adjusted the current estimates to reflect the revised $5.8 million statistical life for both crash avoidance and crashworthiness Federal motor vehicle safety standards (see Appendix B). Tables VI-2a and VI-2b show the comprehensive values used for each injury severity level, as well as the relative incident-based weights for nonfatal injuries, AIS 1-5.

[80] See Table A-1, The Economic Impact of Motor Vehicle Crashes 2000, DOT HS 809 446, NHTSA/DOT, L. Blincoe, A. Seay, E. Zaloshnja, T. Miller, E.Romano, S. Luchter, R. Spicer, May, 2002.

Table VI-2a
Process of Converting Nonfatal Injuries to Equivalent Fatalities
(Resulted from 30% reduction in stopping distance)

Injury Severity	No. of Fatalities and Injuries	Conversion Factor	Equivalent Fatalities (Undiscounted)
Fatalities	227	1.0000	227
AIS 5	15	0.6656	10
AIS 4	34	0.1998	7
AIS 3	251	0.0804	20
AIS 2	664	0.0436	29
AIS 1	5,128	0.0028	14
Total			307

Table VI-2b
Process of Converting Nonfatal Injuries to Equivalent Fatalities
(Resulted from 20% reduction in stopping distance)

Injury Severity	No. of Fatalities and Injuries	Conversion Factor	Equivalent Fatalities (Undiscounted)
Fatalities	91	1.0000	91
AIS 5	6	0.6656	4
AIS 4	13	0.1998	3
AIS 3	108	0.0804	9
AIS 2	268	0.0436	12
AIS 1	2,506	0.0028	7
Total			125

The results in Tables VI-2a and -2b show that the 30% reduction in stopping requirement would save 307 equivalent fatalities, whereas the 20% reduction would result in 125 equivalent fatalities saved.[81]

In Table VI-3, the safety benefits from Tables VI-2 have been discounted at three and seven percent rates to express their present values over the lifetime of one model year's production. The discount factors and the discounted fatal equivalents are summarized in Table VI-3.

[81] For additional discussion on the 20% reduction in stopping distance, see "Preliminary Regulatory Impact Analysis, Notice of Proposed Rulemaking FMVSS No. 121 Air Brake Systems Stopping Distance," Docket NHTSA-05-23306-01. The numbers were rounded to the nearest integer.

Table VI-3
Present Discounted Value of Lives Saved[82]
(For 30% and 20% reduction in stopping distance)

Fatal Equivalent	Discount Rate	Discounted Fatal Equivalent
307	0.8392 at 3%	258
	0.6903 at 7%	212
125	0.8392 at 3%	105
	0.6903 at 7%	87

The discounted fatal equivalents in Tables VI-3 show that the required 30% reduction in stopping distance would save 212 equivalent lives discounted at seven percent and 258 equivalent lives discounted at three percent, respectively.

Property Damage Prevented Benefits

Table VI-4 presents the discounted values of the estimated property damage prevented that the requirement would have at the respective discount rates. As in the case for discounting the equivalent fatality benefits, the numbers were derived by multiplying the estimated amount of property damage prevented by the discount factors that were derived in Table VI-1.

Table VI-4
Estimated Property Damage Prevented (in $M) at 3% and 7% Discount Rates

Requirement	No Discount	3% discount	7% discount
30% reduction	$244.5	$205.2	$168.8
20% reduction	$46.6	$39.1	$32.2

Net Cost Per Equivalent Life Saved

The costs per equivalent life saved for heavy trucks are computed using the annual net cost figures and the discounted equivalent lives saved. (The net costs are shown in Table VI-5a.) For the required 30% reduction in stopping distance, only the disc brake system at the 7 percent

[82] The discounted fatality numbers were rounded to the nearest integer.

discount rate resulted in net costs. The net cost per equivalent life saved for the system was $108,017 at a seven percent discount rate. The derived net cost per equivalent life showed that the larger S-cam brake system is the most cost effective among the systems considered. For 20% reduction in stopping distance, all but the larger S-cam drum brake system resulted in net costs. The net costs per equivalent life saved for these systems were $1.17M, $0.29M and $0.18M at a seven percent discount rate for the all disc, front disc and rear S-cam drum and most likely combination brake systems, respectively. The derived net cost per equivalent life showed that the larger S-cam brake system is the most cost effective among the systems considered.

When the (benefit) figures from Table VI-4 are combined with (i.e., subtracted from) the estimated annual cost of implementing the requirement, it results in discounted "net" costs of implementing the requirement. The resulting estimated discounted "net" costs are shown in Table VI-5a. The negative net costs in Table VI-5a indicate that the estimated property damage only (PDO) benefits are greater than the estimated implementation costs for the countermeasures.

Table VI-5a
Estimated Net Cost (Cost less Property Damage Prevented)
At Various Discount Rates
For 30% Reduction in Stopping Distance
(in millions)

Implementation Costs	All Larger S-Cam Drum Brakes		
	Property Benefits		Net Cost
$27.4	No Discount	$244.5	-$217.1
	3% discount	$205.2	-$177.8
	7% discount	$168.8	-$141.4
Implementation Costs	All Disc Brakes		
	Property Benefits		Net Cost
$191.7	No Discount	$244.5	-$52.8
	3% discount	$205.2	-$13.5
	7% discount	$168.8	$22.9

Table VI-5a (continued)

Implementation Costs	Front Disc and Rear Larger S-Cam Drum Brakes		
	Property Benefits		Net Cost
$79.7	No Discount	$244.5	-$164.9
	3% discount	$205.2	-$125.6
	7% discount	$168.8	-$89.1
Implementation Costs	Most Likely Combination		
	Property Benefits		Net Cost
$53.7	No Discount	$244.5	-$190.8
	3% discount	$205.2	-$151.5
	7% discount	$168.8	-$115.1

Table VI-5b
Estimated Net Cost (Cost less Property Damage Prevented)
At Various Discount Rates
For 20% Reduction in Stopping Distance
(in millions)

Implementation Costs	All Larger S-Cam Drum Brakes		
	Property Benefits		Net Cost
$19.2	No Discount	$46.6	-$27.4
	3% discount	$39.1	-$20.0
	7% discount	$32.2	-$12.9
Implementation Costs	All Disc Brakes		
	Property Benefits		Net Cost
$133.8	No Discount	$46.6	$87.2
	3% discount	$39.1	$94.7
	7% discount	$32.2	$101.6
Implementation Costs	Front Disc and Rear Larger S-Cam Drum Brakes		
	Property Benefits		Net Cost
$57.5	No Discount	$46.6	$10.9
	3% discount	$39.1	$18.4
	7% discount	$32.2	$25.3
Implementation Costs	Most Likely Combination		
	Property Benefits		Net Cost
$47.6	No Discount	$46.6	$0.99
	3% discount	$39.1	$8.5
	7% discount	$32.2	$15.4

The total annual net costs from Table V-5 for vehicles with larger S-cam drum brakes, disc brakes at all wheel positions and front disc and rear larger S-cam brakes were divided by the discounted fatal equivalent lives saved from Tables VI-3 to produce estimates of the net cost per equivalent life saved, as shown in Tables VI-6a and VI-6b. The results in Tables VI-6a and VI-6b show that the cost would be much lower than the $5.8 million per statistical life used in valuing reduction in premature fatalities.

Table VI-6a
Costs per Equivalent Life Saved†
For 30% Reduction in Stopping Distance

Brake Systems	Net Cost (millions)	Equivalent Lives Saved	Costs Per Equivalent Life Saved
All Larger S-Cam Drum Brake	-$177.8 (at 3%)	258 (at 3%)	N/A
	-$141.4 (at 7%)	212 (at 7%)	N/A
All Disc Brakes	-$13.5 (at 3%)	258 (at 3%)	N/A
	$22.9 (at 7%)	212 (at 7%)	$108,017
Front Disc and Rear Larger S-Cam Drum Brakes	-$125.6 (at 3%)	258 (at 3%)	N/A
	-$89.1 (at 7%)	212 (at 7%)	N/A
Most Likely Combination	-$151.5 (at 3%)	258 (at 3%)	N/A
	-$115.1 (at 7%)	212 (at 7%)	N/A

Table VI-6b
Costs per Equivalent Life Saved†
For 20% Reduction in Stopping Distance

Brake Systems	Net Cost (millions)	Equivalent Lives Saved	Costs Per Equivalent Life Saved
All Larger S-Cam Drum Brake	-$20.0 (at 3%)	105 (at 3%)	N/A
	-$12.9 (at 7%)	87 (at 7%)	N/A
All Disc Brakes	$94.7 (at 3%)	105 (at 3%)	$900,023
	$101.6 (at 7%)	87 (at 7%)	$1,174,409
Front Disc and Rear Larger S-Cam Drum Brakes	$18.4 (at 3%)	105 (at 3%)	$174,954
	$25.3 (at 7%)	87 (at 7%)	$292,940
Most Likely Combination	$8.5 (at 3%)	105 (at 3%)	$80,694
	$15.4 (at 7%)	87 (at 7%)	$178,347

† The benefit numbers were rounded to the nearest integer.

Benefit-Cost Analysis:

Effective January 1, 2004, OMB Circular A-4 requires that analyses performed in support of final rules must include both cost effectiveness and benefits-cost analysis. Benefits-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 values of costs to derive an estimate of net benefit. In valuing reductions in premature fatalities, we used a value of $5.8 million per statistical life based on the most current DOT guidance on valuing fatalities[83]. This value represents an updated version of a meta-analysis of studies that were conducted prior to 1993.

When accounting for the benefits of safety measures, cost savings not included in value of life measurements must also be accounted for. 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 consumer's 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. For the analysis, as shown in Appendix B, we used $6.1 million comprehensive cost per statistical life.

Total benefits were derived by multiplying the value of life by the equivalent lives saved, as shown in Tables VI-7 and VI-8.

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[83] "Revised Departmental Guidance, Treatment of Value of Preventing Fatalities and Injuries in Preparing Economic Analyses", Memorandum from D. J. Gribbin, General Counsel and Tyler D. Duval, Assistant Secretary for Transportation Policy, February 5, 2008.

Table VI-7
Benefits for 30% Reduction in Stopping Distance

Benefits	No Discount	Discounted Benefits		$6.1M per life		
	0%	3%	7%			
Factor	1	0.8392	0.6903	No-Discount	3%	7%
Equivalent Life Saved (life)	307	258	212	$1,875M	$1,574M	$1,294M
Property Damage Prevented ($)				$245M	$205M	$169M
			Total	$2,120M	$1,779M	$1,463M

Table VI-8
Benefits for 20% Reduction in Stopping Distance

Benefits	No Discount	Discounted Benefits		$6.1M per life		
	0%	3%	7%			
Factor	1	0.8392	0.6903	No-Discount	3%	7%
Equivalent Life Saved (life)	125	105	87	$764M	$642M	$528M
Property Damage Prevented ($)				$47M	$39M	$32M
			Total	$811M	$681M	$560M

The net benefits are derived by subtracting total net costs from the total benefits, as shown in Tables VI-9 and VI-10.

Table VI-9
Net Benefits with a Value of $6.1M per Equivalent Life
For 30% Reduction in Stopping Distance

Brake System	3% discount ($M)	7% discount ($M)
All Larger S-Cam	$1,751	$1,436
All Disc	$1,587	$1,271
Front Disc and Rear Larger S-Cam	$1,699	$1,384
Most Likely Combination	$1,725	$1,410

Table VI-10
Net Benefits with a Value of $6.1M per Equivalent Life
For 20% Reduction in Stopping Distance

Brake System	3% discount ($M)	7% discount ($M)
All Larger S-Cam	$661	$541
All Disc	$547	$426
Front Disc and Rear Larger S-Cam	$623	$502
Most Likely Combination	$633	$512

The result of our analysis of a reduction in stopping distance of 30 percent compared to a reduction in stopping distance of 20 percent is that the 30 percent alternative results in more safety benefits, more property reduction benefits, has a lower cost per equivalent life saved and results in more net benefits.

The estimated costs, benefits, net benefit, net costs and cost per equivalent life saved (ELS) for the 30% and 20% reduction in stopping distance are summarized in Tables VI-11 and VI-12.

Table VI-11
Annual Costs and Benefits in millions of 2007 dollars discounted at 7% for 30% Reduction in Stopping Distance

Costs (in millions)			Benefits (in millions)			Net Benefit			Net Cost			Cost per ELS		
Low	High	Most likely	Property damage	ELS	Monetized	Low	High	Most likely	Low	High	Most likely	Low	High	Most likely
$27	$192	$54	$169	212	$1,293	$1,271	$2,872	$1,410	-$141.4	$22.9	-$115.1*	N/A	$0.1	N/A

* The PDO benefits were greater than the costs, which resulted in a negative number.

Table VI-12
Annual Costs and Benefits in millions of 2007 dollars discounted at 7% for 20% Reduction in Stopping Distance

Costs (in millions)			Benefits (in millions)			Net Benefit			Net Cost			Cost per ELS		
Low	High	Most likely	Property damage	ELS	Monetized	Low	High	Most likely	Low	High	Most likely	Low	High	Most likely
$19	$134	$48	$32	87	$531	$426	$1,082	$512	-$12.9	$101.6	$15.4	N/A	$1.1	$0.2

VII Timeframe for Final Rulemaking

The data available at this time support pursuing improvements specifically in tractor stopping distance performance, as these vehicles have the greatest exposure in fatal crashes among all of the heavy vehicles. Substantial improvements in the braking performance of these vehicles appear feasible and continue to be explored. The agency also understands that improvements in tractor braking performance may involve more than simply increasing the foundation brake power of tractors, as changes are likely to be required to suspensions and frames, etc., to handle the higher braking power without decreasing vehicle reliability or safety.

The agency has described the available test data for typical three-axle tractors with improved brake systems, showing that compliance to the new stopping distance requirements can be readily achieved without the need to modify the burnish or other procedures in FMVSS No. 121. Therefore, the agency is requiring an effective date that is two years from the date of publication of the final rule for typical three-axle tractors. Typical tractors are defined as having three axles and a GVWR less than or equal to 59,600 pounds.

The lead time for all two-axle tractors, and severe service tractors with a GVWR greater than 59,600 pounds, is four years from the date of publication of the final rule. As previously described, available test data indicates that two-axle tractors can meet a 250-foot loaded-to-GVWR stopping distance requirement with improved brake systems, but additional lead time is needed to more fully evaluate new brake systems to ensure compatibility with existing trailers and converter dollies, when used in multi-trailer combinations, and to minimize the risk of vehicle stability and control issues.

For severe-service tractors, the agency described the available test data and analyses indicating that improvements to the new 250 and 310-foot loaded-to-GVWR stopping distance requirements is achievable, but only limited development work has been performed on these vehicles. As several commenters indicated, additional lead time is needed for complete testing and validation of new brake systems for these vehicles to ensure that full compliance can be achieved.

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VIII Small Business Impact

The Regulatory Flexibility Act of 1980 (5 U.S.C §601 et seq.) requires agencies to evaluate the potential effects of their final rules on small business, small organizations, and small Government jurisdictions in the United States.

5 U.S.C §603 requires agencies to prepare and make available for public comments initial and final regulatory flexibility analysis (RFA) describing the impact of the final rule on small entities. Section 603(b) of the Act specifies the content of a RFA. 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, the final rule;
3. A description of, and where feasible, an estimate of the number of small entities to which the final rule will apply;
4. A description of the projected reporting, recording keeping, and other compliance requirements of the 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 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 finale rule on small entities.

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

NHTSA is considering this action to improve truck tractor stopping distance to reduce fatalities, injuries, and property damage involving tractor trucks.

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

NHTSA is proposing these changes under the Authority of 49 U.S.C. 322, 30111, 30115, 30117, and 30666; delegation of Authority at 49 CFR 1.50. The agency is authorized to issue Federal motor vehicle safety standards that meet the need for motor vehicle safety.

3. Description and estimate of the number of small entities to which the final rule will apply

The final rule would affect the manufacturers of tractor trucks.

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 CRF 121.201, is the number of employees in the firm. To qualify as a small business in the Heavy Duty Truck Manufacturing (NAICS 336120) or in the Motor Vehicle Body Manufacturing (NAICS 336211) categories, the firm must have fewer than 1,000 employees.

NHTSA believes there are five vehicle manufacturers of tractor trucks in the United States (Heavy-Duty Trucks, Class 8), none of which are small businesses. These manufacturers include Freightliner/Sterling/Western Star, International (Navistar), Mack, PACCAR and Volvo Truck. These manufacturers produced more than 99.4% of the annual production in 2003[84]. The agency

[84] According to 2004 WARD's Automotive Yearbook, these five manufacturers produced 141,198 Class 8 (Heavy-Duty) trucks. The total annual production was 141,964.

is not aware of any small companies building tractor chassis. We believe that the remaining trucks (less than 1%) were finished by final stage manufacturers. We don't know who they are, but with production volumes of 1% annually, they are probably small businesses. For brakes, these final stage manufacturers rely on "pass-through" certification provided by chassis manufacturers. Since the brakes would be certified by chassis manufacturers under "pass-through" certification, the agency believes that this rule would not have a significant economic impact on small volume truck tractor manufacturers. Regarding impacts on brake manufacturers, we are not aware of any OEM air brake manufacturers that are small business. There are about six (6) brake manufacturers: Meritor, Knorr Bremse, Bendix, Dana (Eaton), Bendix-Spicer Foundation Brake LLC, and HALDEX. The largest supplier is Meritor, followed by Dana (Eaton). Meritor makes drum brakes (standard and also wider/larger) and disc brakes, and Dana makes drum brakes (standard and larger). Since the requirements could be met with disc brakes at all wheel positions, the final rule would not impose any negative impacts on disc brake manufacturers. Regarding drum brakes, since larger S-cam brakes are generally higher in price and the majority of drum brake manufacturers are either producing both sizes or capable of producing wide/large drum brakes, the final rule would provide positive impacts on drum brake manufacturers, regardless of business size.

4. A description of the projected reporting, recording keeping, and other compliance requirements of the 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

There are no reporting or record keeping requirements associated with the final rule. Manufacturers will need to certify compliance with the final rule, just like with all safety standards.

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

There are no rules that duplicate, overlap, or conflict with the finale 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.

The agency examined two alternatives, a reduction in truck tractor stopping distance of 30 percent and a reduction of truck tractor stopping distance of 20 percent. Neither of these alternatives specifically minimizes the economic impact on small businesses.

In summary, the agency does not believe that the final rule will have a significant economic impact on a substantial number of small businesses. We anticipate that truck tractor manufacturers will pass this cost on to consumers.

Appendix A.

Conversion: “KABCO” to AIS Scale

According to 2004 - 2006 GES / FARS data, the following fatal and nonfatal injuries occurred when heavy trucks braked prior to the crash and the front of the heavy truck struck the other vehicle or object:

Table A-1
Target Population In KABCO Scale
Truck Occupants, Un-weighted

	Number of Occupants
No injury "NO"	2,598
Possible Injury "C"	155
Non-Incapacitating "B"	97
Incapacitating "A"	51
Fatal "K"	15
Injury Severity Unknown "ISU"	0
Unknown "UNK"	0
Total	2,917

Table A-2
Truck Occupants
Weighted Yearly Averages

	Number of Occupants
No injury "NO"	22,753
Possible Injury "C"	645
Non-Incapacitating "B"	660
Incapacitating "A"	493
Fatal "K"	33
Injury Severity Unknown "ISU"	0
Unknown "UNK"	0
Total	24,585

Table A-3
Non-Truck Occupants, Un-Weighted

	Number of Occupants
No injury "NO"	2,698
Possible Injury "C"	1,207
Non-Incapacitating "B"	676
Incapacitating "A"	371
Fatal "K"	67
Injury Severity Unknown "ISU"	34
Unknown "UNK"	1
Total	5,055

Table A-4
Non-Truck Occupants
Weighted Yearly Averages

	Number of Occupants
No injury "NO"	25,030
Possible Injury "C"	5,784
Non-Incapacitating "B"	3,417
Incapacitating "A"	2,318
Fatal "K"	490
Injury Severity Unknown "ISU"	177
Unknown "UNK"	12
Total	37,227

Table A-5
Truck and Non-truck Occupants
Weighted Yearly Averages

	Truck and Non Truck Occupants
No injury "NO"	47,783
Possible Injury "C"	6,429
Non-Incapacitating "B"	4,077
Incapacitating "A"	2,811
Fatal "K"	523
Injury Severity Unknown "ISU"	177
Unknown "UNK"	12

Table A-6
KABCO to AIS Levels
Conversion Factors

MAIS	A	B	C	K	NO	ISU	UNK
0	0.01508	0.04937	0.19917	0.01276	0.92342	0.07494	0.81552
1	0.48917	0.79208	0.71722	0.0165	0.07421	0.70313	0.15986
2	0.27769	0.12484	0.0676	0.00676	0.00208	0.15648	0.01618
3	0.16623	0.03008	0.01509	0.00135	0.00028	0.04327	0.0078
4	0.02891	0.00267	0.00064	0.00224	0.00001	0.01706	0.0002
5	0.01752	0.00069	0.00018	0	0	0.00133	0.00044
Fatal	0.0054	0.00027	0.0001	0.96039	0	0.00379	0
Total	1	1	1	1	1	1	1

Table A-7
KABCO Target Population

A	B	C	K	NO	ISU	UNK
2,811	4,077	6,429	523	47,783	177	1

Table A-8
Distributed by MAIS Level

MAIS	A	B	C	K	NO	ISU	UNK	Total
0	42	201	1280	7	44124	13	9.78624	45,678
1	1375	3229	4611	9	3546	124	1.91832	12,896
2	781	509	435	4	99	28	0.19416	1,855
3	467	123	97	1	13	8	0.0936	709
4	81	11	4	1	0	3	0.0024	101
5	49	3	1	0	0	0	0.00528	53
Fatal	15	1	1	502	0	1	0	520
Total	2,811	4,077	6,429	523	47,783	177	12	

Table A-9
Target Population In MAIS Scale
(Based on 2004-2006 NASS GES)

MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality
45,678	12,896	1,855	709	101	53	520

Table A-10
FARS For Truck And Other Vehicle Occupants (2004-2006 FARS)

Truck Occupants	Front of Truck			Other Vehicle Occupants	Front of Truck	
	No	Yes			No	Yes
Truck Braked	36	77		Truck Braked	138	787

Table A-11
Target Population In AIS Scale Adjusted with FARS

AIS 0	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
45,678	12,896	1,855	709	101	53	864

Appendix B

Comprehensive Costs and Relative Value Factors Reflecting $5.8 million Value of a Statistical Life (VSL), in 2007 Economics

CPI	Factor	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
1.346066	Medical	$3,204	$21,032	$62,585	$176,747	$447,509	$29,741
1.204077	EMS	$117	$255	$443	$999	$1,026	$1,003
1.277512	Market Prod	$2,234	$31,960	$91,283	$135,977	$560,451	$760,577
1.277512	Household Produce	$731	$9,354	$26,924	$35,782	$190,743	$244,696
1.204077	Ins. Adm.	$892	$8,319	$22,749	$38,934	$82,114	$44,695
1.277512	Workplace	$322	$2,495	$5,450	$6,002	$10,464	$11,117
1.204077	Legal	$181	$5,998	$19,034	$40,559	$96,153	$122,982
1.277512	Travel Delay	$993	$1,081	$1,201	$1,276	$11,697	$11,687
1.204077	Property Damage	$4,628	$4,761	$8,187	$11,840	$11,374	$12,369
1.277512	QALYs	$9,118	$186,525	$262,189	$784,777	$2,674,628	$4,889,799
New Comprehensive Costs		$22,420	$271,780	$500,045	$1,232,893	$4,086,149	$6,128,666
Injury Subtotal		$16,799	$265,938	$490,657	$1,219,777	$4,063,088	$6,104,610
QALY Relatives		0.0019	0.0381	0.0536	0.1605	0.5470	1.0000
Comprehensive relatives (Crash Avoidance)		0.0037	0.0443	0.0816	0.2012	0.6667	1.0000
Comprehensive relatives (Crashworthiness)		0.0028	0.0436	0.0804	0.1998	0.6656	1.0000

QALYs: Quality-Adjusted Life-Years

Note that the $5.8 million value of a statistical life contains elements found in 3 of the factors in the above table (QALY's, household productivity, and the after-tax portion of market productivity). The value of statistical life is thus represented within these 3 factors and is not shown separately.

In Chapter IV, we estimated "property damage" benefits separately. Thus, the comprehensive relatives for crash avoidance above should not include the property damage related costs. For the estimates of the "property damage" related to vehicles involved in crashes, property damage and travel delay costs that resulted from the crash were included. When the property damage and travel delay costs were excluded from the new comprehensive costs in the table above, the comprehensive relatives for crash avoidance became the same as the comprehensive relatives for crashworthiness crashes, as shown below:

Relative Value Factors Used in Analysis

	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
Comprehensive Relatives	0.0028	0.0436	0.0804	0.1998	0.6656	1.000