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U.S. Department of Transportation

National Highway Traffic Safety Administration

Memorandum

Subject: ACTION: Docket Submittal, PRIA, NPRM on Tire Pressure Monitoring System, FMVSS No. 138

Date: SEP 9 2004

From: Noble N. Bowie
Associate Administrator
for Planning, Evaluation and Budget

Reply to Attn. of:

To: DOCKET NHTSA-2004-19054-2

THRU: Gregory A. Walter
Senior Associate Administrator
for Policy and Operations

THRU: Jacqueline Glassman
Chief Counsel

Please submit the attached "Preliminary Regulatory Impact Analysis, NPRM on Tire Pressure Monitoring System, FMVSS No. 138", September 2004, to the appropriate docket.

Attachment

Distribution:
Senior Associate Administrator for Vehicle Safety
Associate Administrator for Rulemaking
Associate Administrator for Vehicle Safety Research
Chief Counsel

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PRELIMINARY REGULATORY IMPACT ANALYSIS

NPRM on TIRE PRESSURE MONITORING SYSTEM FMVSS No. 138

Office of Regulatory Analysis and Evaluation
Planning, Evaluation, and Budget
September 2004

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Executive Summary

Under section 13 of the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act, the Secretary of Transportation was required to complete a rulemaking for a regulation mandating a warning system in each new motor vehicle to indicate to the operator when a tire is significantly under-inflated.

Accordingly, NHTSA is proposing to require a tire pressure monitoring system (TPMS) to be installed in all new passenger cars, multipurpose passenger vehicles, trucks, and buses that have a gross vehicle weight rating (GVWR) of 4,536 kg (10,000 lbs.) or less, except those vehicles with dual wheels on an axle. The proposal would require that the driver be given a warning when tire pressure is 25 percent or more below the vehicle manufacturer's recommended cold tire inflation pressure (placard pressure) for one to four tires. (We note that the agency had previously issued a final rule providing two different compliance options with different levels of stringency. However, a court decision[1] found that the TREAD Act requires a TPMS with a four-tire detection capability, so the court vacated the standard for further rulemaking consistent with its opinion.) Thus, this NPRM proposes a single performance requirement (four-tire, 25 percent under-inflation detection). The NPRM also proposes a requirement for a TPMS malfunction indicator, as well as a warning when the system detects under-inflation of 25 percent or more in one to four tires.

For this Preliminary Regulatory Impact Analysis, the agency estimated the impacts of three TPMS systems that the manufacturers could use to meet the proposal.

Compliance Option 1 assumes that manufacturers will supply a direct system with a warning lamp and either an interactive or continuous readout of individual tire pressures.

Compliance Option 2 assumes that manufacturers will supply a direct system with a warning lamp.

Compliance Option 3 assumes that manufacturers with an ABS system would use a hybrid measurement system (indirect system with two direct tire pressure measurements) and vehicles without ABS would use a direct measurement system. We assume a warning lamp will be provided for drivers.

Since this is a performance standard, the manufacturers can use any system to meet the performance requirements. It may be possible to refine an indirect system to meet a four-tire, 25% under-inflation detection proposal. Comments are requested on feasibility, design, and costs of such a system.

Compliance Option 1 assumes that manufacturers will supply either an interactive or continuous readout of individual tire pressures. The agency believes that some

[1] Public Citizen, Inc. v. Mineta, 340 F.3d 39 (2d Cir. 2003).

proportion of drivers that have an interactive or continuous readout of individual tire pressures will pay attention to this information and fill their tires with air more often than those that wait for a warning to be given. These drivers will attain higher benefits from their systems because of this capability.

Low tire pressure may have an influence on skidding and loss of control crashes, crashes resulting from flat tires and blowouts, and may influence any crash that involves braking, since low tire pressure can result in increased stopping distance. The quantified safety benefits are based on these three types of crashes.

Annual Full Fleet Benefits of TPMS

	Non-fatal Injuries Reduced (All AIS levels)	Fatalities Reduced
Compliance Option 1	8,568	121
Compliance Option 2	8,373	119
Compliance Option 3	8,373	119

The estimated consumer cost increase for an average new vehicle would be $69.89 for Compliance Option 1, $66.08 for Compliance Option 2, and $48.44 for Compliance Option 3.

The net costs are estimated to be:

Net Costs per Vehicle
At a 3 Percent Discount Rate
(2001 Dollars)

Opt.	Vehicle Costs	Present Value of Maintenance Costs*	Present Value of Opportunity Costs of Refilling Tires	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Present Value of Property Damage and Travel Delay Savings	Net Costs
1	$69.89	$0 to $55.98	$8.38	$23.08	$4.24	$7.79	$43.16 to $99.14
2	$66.08	$0 to $55.98	$8.38	$19.07	$3.42	$7.70	$44.27 to $100.25
3	$48.44	$0 to $37.23	$8.38	$19.07	$3.42	$7.70	$26.63 to $63.86

* Maintenance costs range from a battery-less TPMS to a TPMS with 4 batteries for Compliance Options 1 and 2, and 2 batteries for Compliance Option 3.

Net Costs per Vehicle
At a 7 Percent Discount Rate
(2001 Dollars)

Opt.	Vehicle Costs	Present Value of Maintenance Costs*	Present Value of Opportunity Costs of Refilling Tires	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Present Value of Property Damage and Travel Delay Savings	Net Costs
1	$69.89	$0 to $40.50	$6.72	$18.34	$6.03	$6.25	$45.99 to $86.49
2	$66.08	$0 to $40.50	$6.72	$15.14	$4.98	$6.16	$46.52 to $87.02
3	$48.44	$0 to $26.93	$6.72	$15.14	$4.98	$6.16	$28.88 to $55.81

* Maintenance costs range from a battery-less TPMS to a TPMS with 4 batteries for Compliance Options 1 and 2, and 2 batteries for Compliance Option 3.

Total Annual Costs for 17 Million Vehicles
(Millions of 2001 Dollars)
At a 3 Percent Discount Rate

Opt.	Vehicle Costs	Present Value of Maintenance Costs*	Present Value of Opportunity Costs of Refilling Tires	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Present Value of Property Damage and Travel Delay Savings	Net Costs
1	$1,188	$0 to $952	$142	$392	$72	$132	$734 to $1,685
2	$1,123	$0 to $952	$142	$324	$58	$131	$753 to $1,704
3	$823	$0 to $633	$142	$324	$58	$131	$453 to $1,086

* Maintenance costs range from a battery-less TPMS to a TPMS with 4 batteries for Compliance Options 1 and 2, and 2 batteries for Compliance Option 3.

Total Annual Costs for 17 Million Vehicles
(Millions of 2001 Dollars)
At a 7 Percent Discount Rate

Opt.	Vehicle Costs	Present Value of Maintenance Costs*	Present Value of Opportunity Costs of Refilling Tires	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Present Value of Property Damage and Travel Delay Savings	Net Costs
1	$1,188	$0 to $689	$114	$312	$103	$106	$782 to $1,470
2	$1,123	$0 to $689	$114	$257	$85	$105	$791 to $1,479
3	$823	$0 to $458	$114	$257	$85	$105	$491 to $949

* Maintenance costs range from a battery-less TPMS to a TPMS with 4 batteries for Compliance Options 1 and 2, and 2 batteries for Compliance Option 3.

The net costs per equivalent life saved are estimated to be:

Net Cost per Equivalent Life Saved

	3% discount rate	7% discount rate
Compliance Option 1	$3.6 to $7.8 million	$4.5 to $8.5 million
Compliance Option 2	$3.7 to $8.1 million	$4.7 to $8.7 million
Compliance Option 3	$2.3 to $5.2 million	$2.9 to $5.6 million

Net Benefits (Benefits minus Costs) are estimated to be:
Note: negative values indicate that costs exceed benefits

Net Benefits with a Value of $3.5M per Statistical Life*
(Millions of 2001 Dollars)

	3% Discount Rate	7% Discount Rate
Compliance Option 1	$25 to –$927 Mil.	-$174 to -$862 Mil.
Compliance Option 2	-$13 to -$965 Mil.	-$198 to -$887 Mil.
Compliance Option 3	$287 to -$346 Mil.	$102 to -$356 Mil.

Results from the analyses included herein are:

- Battery-less TPMS are significantly more cost-effective than TPMS with batteries
- Continuous readout or individual tire pressure displays are more cost-effective than just a warning lamp
- A combination lamp malfunction indicator is cost-effective
- A separate telltale lamp for a malfunction indicator is not cost-effective

In a probabilistic uncertainty analysis (Chapter X), we identified the major independent uncertainty factors having appreciable variability and estimated the uncertainty or quantified the uncertainty by their probability distributions. Assuming a battery-less TPMS at a 3 percent discount rate, the three compliance options have between a 34 and 93 percent chance to produce a cost per equivalent life saved less than $3.5 million (and a 92 to 100 percent chance to produce a cost per equivalent life saved less than $5.5 million). At the other end of the range, TPMS with batteries at a 7 percent discount rate have almost no chance to produce a cost per equivalent life saved less than $3.5 million (and almost no chance for Options 1 and 2 and a 32 percent chance for Option 3 to produce a cost per equivalent life saved less than $5.5 million).

Another way to look at uncertainty is to examine the range of mean values of the cost per equivalent life saved, which range from costs of $2.4 to $9.1 million at 3 percent and $3.2 to $9.8 million at a 7 percent discount rate, depending on the compliance option chosen by manufacturers. The 90 percent certainty level is from $1.5 million to $14.5 million per equivalent life saved at a 3 percent discount rate and $2.2 million to $15.7 million at a 7 percent discount rate. In other words, given all the uncertainties examined combined, we are 90 percent certain that the cost per equivalent life saved is between $1.5 and $15.7 million.

The mean value for net benefits-costs ranges from a net cost of $650 million to a net benefit of $599 million, depending upon the specific technology chosen for compliance and the discount rate utilized. A 90 percent certainty level around the net benefits-costs results in a range of a net cost of $1,156 million to a net benefit of $1,302 million.

I. INTRODUCTION

As required by the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act, the agency promulgated Federal Motor Vehicle Safety Standard (FMVSS) No. 138 Tire Pressure Monitoring System (TPMS), which required a TPMS to be installed in all passenger cars, multipurpose passenger vehicles, trucks and buses that have a Gross Vehicle Weight Rating of 4,536 kg (10,000) pounds or less, except those vehicles with dual wheels on an axle. Two alternatives were allowed in the final rule.[1] The first alternative required the TPMS to give the driver a warning when tire pressure is 25 percent or more below the placard pressure for one to four tires. The second alternative required the TPMS give the driver a warning when tire pressure is 30 percent or more below the placard pressure for any single tire. However, a court ruling[2] found that based upon the administrative record before the agency, only the first alternative was reasonable, and the court vacated the standard for further rulemaking consistent with its opinion. In response, this NPRM proposes to require that the TPMS give the driver a warning when tire pressure is 25 percent or more below the placard pressure for one to four tires.

There are two basic types of TPMS in production, direct measurement systems that have a tire pressure sensor mounted in each wheel, and indirect measurement systems that determine tire inflation pressure by measuring relative rotational differences in the wheels.

The indirect measurement systems are designed for use with the anti-lock brake system (ABS) and compare the relative wheel speed of one wheel to another. Wheel speed correlates to tire pressure since the rolling radius of a tire decreases slightly with decreasing tire inflation

[1] Published in the Federal Register on 6/05/02 (67 FR 38704), Docket No. 8572-219.
[2] Public Citizen, Inc. v. Mineta, 340 F.3d 39 (2d Cir. 2003).

pressure. Since the current indirect measurement systems compare relative wheel speed, they cannot determine when all four tires lose air at about the same rate.[3] Commenters to the docket indicated that current indirect measurement systems could not meet the proposal.

This Preliminary Regulatory Impact Analysis has several new analyses as compared to the Final Economic Assessment.[4] The agency requests specific comments on these analyses. They are:

1) Chapter V -- Property damage savings and travel delay savings from avoiding crashes.
2) Chapter VI – Cost estimates for malfunction systems and malfunction warning lamps.
3) Chapter VI -- Opportunity cost analyses to estimate the cost of the time it takes to refill tires and the cost charged for air to refill tires at some service stations.
4) Chapter VII -- Net benefit analysis
5) Chapter VII – Cost/Benefit analysis of the malfunction warning lamp
6) Chapter X – Probabilistic Uncertainty Analysis

[3] However, it may be possible to meet the 25 percent one to four tire proposal with an indirect system, that takes more measurements than the current indirect systems, as technology evolves.
[4] March 2002 "Final Economic Assessment, Tire Pressure Monitoring System, FMVSS No. 138", Docket No. 8572-216.

II. BACKGROUND and ALTERNATIVES

The following section discussed the details of various types of Tire Pressure Monitoring Systems (TPMS), including systems currently in production as well as anticipated systems.

There are two basic types of Tire Pressure Monitoring Systems (TPMS) currently available that can alert the driver while driving that the tire pressure is low: direct measurement systems and indirect measurement systems. A direct measurement system measures tire pressure directly. A variation of the direct measurement system (a direct measurement system with a pump) will soon be available that can inflate the tire when it gets low, relieving the driver of that responsibility. An indirect measurement system measures wheel speed or something factors other than tire pressure. Most current ABS-based systems are indirect measurement systems. They measure wheel speed and then compare the variance in wheel speed from one wheel to another to determine whether a tire is under-inflated.

Although not currently in production, we believe that it would be possible to produce hybrid TPMSs with performance characteristics of both direct and indirect TPMSs.

Direct measurement systems

Most direct measurement systems have pressure and temperature sensors in each tire, usually attached to the inflation valve. They broadcast their data to a central receiver, or in some cases to individual antennae that transmit the data to the control module, which analyzes them and sends appropriate signals to a display. This display can be as simple as a single telltale, or as complex as pressure and temperature displays for all four tires (or five if the spare is included).

Direct measurement systems' advantages include: (1) much greater sensitivity to small pressure losses, with claims ranging from +/- 0.1 psi to 1 psi; (2) the ability to directly measure pressure in any tire at any time, including before starting the vehicle, and including the spare tire. The disadvantages include: (1) the higher cost; (2) possible maintenance problems when tires are taken on and off the rim (sensors have been broken off). These systems have not been installed on many vehicles, although they have been used on cars with run-flat tires and as accessories on high-end luxury vehicles.

Direct measurement system with a pump

A direct measurement system with a pump has the same qualities as a pressure-sensor-based system, except that it also has the ability to pump the tire back up to the placard tire pressure. Each tire has a separate sensor and a pump. The system display is designed to give a warning when a particular tire needs to be continuously inflated and if the tire pressure gets too low, indicating that a particular tire has a problem and needs servicing. Unless there is a catastrophic failure or a rapid loss of pressure due to a nail or puncture, the pump can keep the tire inflated to get the vehicle to its destination. However, once the vehicle stops, the pump stops, and the tire may deflate. The advantages of these systems include: (1) driver convenience, (only need to worry about tire inflation when a warning of a continuing problem that the pump has to continue working to control); (2) better fuel economy, tread wear, and safety by keeping tires up to correct pressure. The disadvantages include: (1) the higher cost; (2) maintenance considerations - when rotating the tires, the pumps must stay on the same side of the car. These systems have not been installed on any light vehicles, although they have been used on a number of heavy trucks for several years. Because of cost issues, a direct measurement system with a pump has not been considered in further analyses.

Indirect measurement systems

The current indirect measurement systems utilize the wheel speed sensors of Anti-lock Brake Systems (ABS). They take information from the ABS wheel-speed sensors and look for small changes in wheel speed that occur when a tire loses pressure. Low pressure results in a smaller wheel radius, which increases the speed of that wheel relative to the others. The systems work by comparing the relative speed of one tire to the other tires on the same vehicle.

The advantages for these systems include: (1) low cost and (2) the need for only minor changes to the vehicle that has an ABS system, including a new dashboard telltale and upgraded software in the electrical system. Disadvantages include: (1) not all vehicles have ABS, so costs are significantly higher for vehicles without ABS; (2) the indirect system cannot tell which tire is underinflated; (3) if all tires lose pressure evenly, it cannot detect it, since it works on the relative wheel speed; (4) in some current systems, some combinations of two tires being underinflated cannot be detected (e.g., two tires on the same axle or the same side of the vehicle). (Regarding #3 and 4, current ABS-based systems cannot detect certain conditions of low tire pressure. To meet the proposal, the ABS-based systems would need to be improved.) (5) they cannot check the spare tire; (6) the vehicle must be moving; (7) they require significant time, sometimes hours, to calibrate the system and several minutes, sometimes tens of minutes, to detect a pressure loss; and (8) they cannot detect small pressure losses. (Regarding #8, the best claim is that they can detect a 20 percent relative pressure loss differential between tires, but others state they can only detect a 30 percent loss, e.g., a tire properly inflated to 30 pounds per square inch (psi) would have to deflate to 21 psi before the system would detect it.) (9) some systems cannot detect a pressure loss at vehicle speeds of 70 mph or higher.

Hybrid measurement systems

The agency believes that an indirect measurement system supplemented with direct tire pressure measurement in two wheels and a radio frequency receiver, a "hybrid" system, could meet the proposal. This system was first discussed by TRW in its docket comment[1]. To date, no such systems have been produced.

ALTERNATIVES

In contrast to the June 5, 2002, final rule the agency is not proposing alternative levels of stringency. The proposal is that the driver must be given a warning when tire pressure is 25 percent or more below the placard pressure for one to four tires, or when tire pressure is at or below the defined minimum activation pressure (MAP).

The MAP presented in Table II-1 shows the level at or below which the warning must be activated. The floor is different depending upon the tire type. All tires are required to have a single maximum inflation pressure labeled on the sidewall and that pressure must be one of the values indicated in the table. If a vehicle has p-metric tires marked 240, 300, or 350 kPa, it is a

[1] Docket No. 8572-110.

standard load tire that will be tested at 25 percent below placard, or 140 kPa, whichever is higher. If a vehicle has a p-metric tire marked 280 or 340 kPa, it is an extra load tire that will be tested at 25 percent below placard, or 160 kPa, whichever is higher. (Extra load tires are marked "XL" or "extra load" on the sidewall). LT-tires on light trucks have higher maximum inflation pressures and, therefore, have been assigned a higher floor below, which the warning has to be activated. The values in Table II-1 are the only values that can be used for maximum inflation pressure.

Table II-1
TPMS Lamp Minimum Activation Pressure

Tire type	Maximum or Rated Inflation Pressure (kPa)*	Maximum or Rated Inflation Pressure (psi)	Activation Floor (kPa)	Activation Floor (psi)
P-metric - Standard Load	240, 300, or 350	35, 44, or 51	140	20
P-metric – Extra Load	280 or 340	41 or 49	160	23
Load Range C (LT)	350	51	200	29
Load Range D (LT)	450	65	260	38
Load Range E (LT)	550	80	320	46

* The standard is based on kPa, the psi values have been rounded to the nearest whole number.

Currently, the lowest P-metric tire recommended placard pressure is 26 psi. At 26 psi recommended placard pressure, the 20-psi floor would come into play.

The rationales for the minimum activation pressure are:

A 20 psi floor for p-metric tires is proposed because the agency believes that below that level, safety in terms of vehicle handling, stability performance, and tire failure is an issue. The agency ran a variety of p-metric tires in what it calls a "low pressure endurance test" at 20 psi with a 100 percent load at 75 mph for 90 minutes on a dynamometer. None of these tires failed. In a second set of test it calls a "low pressure high speed test" at 20 psi with a 67 percent load for 90 minutes, in 30 minutes steps at 140, 150, and 160 km/h (87, 93, and 99 mph), about 30 percent of the tires failed. Since tires could pass the "low pressure high speed test" at 20 psi, this leads the agency to believe that there will be a safety margin, in terms of tire failures, if a TPMS warning is provided at or above 20 psi, that will allow consumers to fill their tires back up before the tire fails, unless the vehicle is driven at very high speeds (above 140 km/h or 87 mph).

The lowest inflation pressure used in the 2000 Tire & Rim Association Yearbook is 140 kPa (20 psi) for P-metric tires. In the 2001 Tire & Rim Association Yearbook, the 140-kPA pressures have been deleted, apparently because the Association believes they are too low for P-metric tires. The agency agrees that 140 kPA is too low and believes a floor is needed to assure that drivers are warned when tire pressure gets to or below that level. For the LT tires, we used the 2000 JATMA yearbook for the lower limits for Load Range C, D, and E tires. For most cases, the floor is about 58 percent of the maximum inflation pressure.

For this Preliminary Regulatory Impact Analysis, the agency estimates the impacts of three TPMS systems that the vehicle manufacturers could use to meet the proposal (called "compliance options").

Compliance Option 1 assumes that manufacturers will supply a direct system with either an interactive or continuous readout of individual tire pressures.

Compliance Option 2 assumes that manufacturers will supply a direct system with just a warning lamp.

Compliance Option 3 assumes that manufacturers with an ABS system would use a hybrid measurement system (indirect system with two direct tire pressure measurements) and vehicles without ABS would use a direct measurement system. We assume a warning lamp will be provided for drivers.

New Issues and Analytical Assumptions

For Compliance Option 3, we assume a hybrid system would be provided for vehicles that have ABS-systems currently (about two-thirds of the fleet). For vehicles that do not have an ABS-type system, we assume that a direct measurement system would be supplied. A direct measurement system costs less than adding ABS to the vehicle. A manufacturer could add ABS to the vehicle, but that is a marketing decision not brought on by the TPMS requirements.

Maintenance Costs

Since the court ruling, the agency has learned of advancements in direct system TPMS technology that have a large impact on the maintenance cost estimates the agency made in the March 2002, Final Economic Assessment.[2] A battery-less TPMS system[3] will soon be on the market. This system will reduce the need for battery maintenance, since there will be no battery to replace, resulting in no quantified maintenance costs. For this analysis, the agency is providing a range from no maintenance costs for a battery-less direct TPMS system, to the estimates the agency previously used in its analysis for maintenance costs for a TPMS with a

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[2] March 2002 "Final Economic Assessment, Tire Pressure Monitoring System, FMVSS No. 138", Docket No. 8572-216.

See IQ Mobil docket submission No. 8572-318.

battery. One of the unknowns in the previous analysis is whether consumers would pay to maintain their TPMS systems, and keep achieving benefits in the later years of the vehicle. With a battery-less TPMS, this is no longer a concern. Comments are requested on whether a battery-less TPMS system will be the predominate design of the future.

<u>Malfunction/Warning</u>

In the March 2002, Final Economic Assessment, the agency assumed that all replacement tires would work with all of the TPMS systems and that the systems are maintained and reliable. This does not appear to be the case. As a result, the agency has decided to change its approach regarding replacement tires, and the NPRM proposes an additional requirement that was not in the June 2002 TPMS final rule.

In the final rule, manufacturers were required to certify that their TPMS would work with any replacement tire that was of a tire size recommended for the vehicle. A number of vehicle manufacturers petitioned for reconsideration of this requirement arguing that they have no control over the replacement tire market and that a direct measurement system would not work with some tires. There appear to be three primary factors that might cause some replacement tires not to work with particular types of TPMS (i.e., carbon content of the tire, steel in the sidewall of the tire, and run-flat tires). First, the carbon content of the tire could cause sensor signal attenuation, rendering the TPMS inoperable. The carbon content is not labeled on the tire or available for consumers to determine before mounting the tires on the vehicle. Second, steel belts in the sidewall can also cause various levels of sensor signal attenuation. Steel belts in the sidewall are labeled on the tire but the labels do not provide information that would distinguish

TPMS operability with those tires. Third, run-flat tires work with some TPMS but not others. Based on these findings, labeling does not appear to be a workable solution.

As a result of the above considerations, the agency is proposing that each TPMS have a malfunction/warning system to indicate when the TPMS is not functioning properly, either because there has been a loss of power in the system, one or more of the radio frequency signals from an individual wheel are not being received by the control module of the system (signal attenuation), or for some other reason. The agency is proposing a malfunction/warning feature to alert consumers when the TPMS is not functioning properly, to help preserve the benefits.

The agency is requesting comments on whether the malfunction/warning system should be a separate warning lamp or just provide a different warning signal using the same lamp. Currently, the low tire pressure warning lamp is required to come on when the system detects low tire pressure and must stay illuminated until the problem is solved. If the system detects a malfunction, the same warning lamp could, for example, blink or flash for 30 seconds or one minute (the agency is proposing one minute) each time the vehicle is started and then stay illuminated. This pattern would be repeated upon vehicle start-up until the problem is solved. The flashing lamp would give an indication that there was a problem with the TPMS and not a low tire pressure problem. The agency would like to have different indications for the two different problems (not necessarily the example given above), yet at the same time it would like to have a consistent message for consumers. Thus, we are asking for comments on how to best provide this information to consumers in a cost-effective manner.

Similarly, if the alternative approved symbol is used, (i.e., the plan view of the vehicle showing all four tires), the symbol must stay illuminated until the problem is solved. If the system detects a malfunction, the symbol could blink or flash for one minute each time the vehicle is started and then stay illuminated until the problem is solved.

It is not easy to determine the overall effects of this proposal for a malfunction/warning, since it is not known how large of a problem there is in compatibility between replacement tires and TPMS. A letter from the Rubber Manufacturers Association (RMA)[4] indicated in 2002 that light vehicle tires having either steel body ply cords (steel casing tires) or run-flat capability accounted for less than 0.5 percent of tires distributed in the United States. This estimate accounts for two of the three problem areas discussed earlier, although probably some of these tires will work with some TPMS systems, but it does not account for carbon content of the tire. In addition, the agency does not know the extent of other system malfunctions, like a broken sensor or antenna, for which the malfunction/warning lamp would provide benefits. We assume that they will be a small percent and will be subsumed in the overall 1 percent estimate. At this time, the agency's best estimate is that if there were no malfunction warning, around 1 percent of the time the TPMS would not be working at some later stage in a vehicle's life. This would occur either because the replacement tire designs would not work with a TPMS, or because there is some other malfunction with the system brought on by maintenance problems or mechanical/electronic failures. At the high end, the agency believes that less than 10 percent of tire designs would not

[4] Letter from Steven Butcher, Vice President, Rubber Manufacturers Association, to NHTSA (October 31, 2003) (Docket No. NHTSA 2000-8572-282).

work with a TPMS or will have other malfunction problems, but until the TPMS are designed and available for testing and the systems are on the road for years, there is no way of getting a better estimate, and there is no way of knowing how the replacement tire market could change in the future.

If the agency requires a separate malfunction/warning lamp, then consumers who have replacement tires installed on their vehicle and get the malfunction warning could go back to the tire dealer and purchase a different set of tires. If the warning lamp stays lit until the system is fixed, the agency believes that most consumers will want to have their tires changed to extinguish the lamp, until they find out what it might cost them. The question is "Who pays the bill for mounting and balancing, and in some cases, the possibility that the second set of tires will cost more than the first set chosen." This could cost $50 or more. We assume this cost would fall upon the consumer, and not the tire dealer. If it is to be the consumer, we believe that many will ignore the lamp or have it turned off before they will pay another $50. We expect few consumers would go to the trouble of changing tires, just to have their malfunction lamp go off.

For this analysis, we assume that the malfunction lamp will stay on and it lets consumers know that they have to check their tires themselves and cannot rely on continues TPMS operation. The big question then is "What percent of consumers will remember to check their tire pressure, given that they have a malfunction yellow lamp continuously lit on their instrument panel?" These are people that currently don't check their tire pressure, or they wouldn't be part of the benefits of the rule. The agency has no way of knowing this answer.

The impact that a malfunction/warning lamp would have on benefits depends on what consumers do when they see such a lamp. The benefits of this proposal, safety benefits as well as tread life and fuel economy savings, are directly related to mileage. The average tread life was estimated to be 45,000 miles. The average weighted vehicle miles traveled was 126,678 miles for passenger cars and 153,319 miles for light trucks. That means that potentially 64 percent of the passenger car (1 – 45,000/126,678) and 71 percent of the light truck mileage will be driven on replacement tires. If 1 percent of the replacement tires are not compatible with TPMS designs, then an average of 0.675 percent of the benefits for both passenger cars and light trucks could potentially not be obtained if consumers were not provided with a malfunction lamp or if they ignored the malfunction lamp. Given, that the agency is proposing to require a malfunction lamp to rectify this potential loss of benefits to the extent possible, the main body of the analysis will not include a reduction in benefits for this factor. We believe the potential loss in benefits would be very small, less than 0.675 percent of the estimated benefits.

Spare Tire Issues

The above malfunction discussions do not consider issues dealing with spare tires and how spare tires work with TPMS. In the NPRM, spare tires are not required to be monitored by the TPMS. If a direct TPMS system is installed on a vehicle and a tire sensor is not included on the wheel of the spare tire, then when a driver gets a flat tire, changes it, and puts the spare tire on the vehicle, the malfunction lamp will illuminate. A TPMS malfunction lamp being continuously on is understandable when a temporary spare tire is in use. This could be considered a benefit, in that the driver would be reminded that the damaged full size tire should be repaired/replaced and the temporary spare tire should be stowed for future emergency use.

However, if the TPMS does not work with a full-size spare, a malfunction lamp being continuously lit may become quite annoying. A malfunction/warning requirement might be a cost disincentive to supply a full-size spare because dealers may get a number of questions and complaints unless the spare tire is set up to work with the TPMS system.

Manufacturers may decide to put a TPMS tire pressure sensor in the spare tire, to avoid consumer complaints in the future, at a cost of $7.50 per wheel. Since 15 percent of the vehicles come equipped with a full-size spare tire, the total cost if all full-size spare tires had a tire pressure sensor would be $19 million (17 million vehicles *.15 * $7.50). Depending upon how much manufacturers value not having consumers complain about their TPMS and spare tires, they might decide $7.50 is a worthwhile investment. The analysis does not assume that manufacturers will put a tire pressure sensor in the wheel of full-sized spare tires. The analysis does not estimate a cost for the inconvenience of a having a continuous malfunction/warning lamp on, caused by a spare tire without a tire pressure sensor.

Additional Alternatives/Compliance Options

NHTSA has not examined an indirect system in this analysis. However, it is possible that an indirect system could be developed that provides up to 4-tire capability. To date, the agency is not aware of any indirect system that is available that has the capability of activating reliably at the proposed trigger level of 25 percent below placard, nor do we know what the costs would be of such a system. NHTSA requests comments as to the capabilities and limitations of indirect systems in meeting the proposed requirements of this rule. Specifically, we are interested in knowing whether such systems would be able to detect all combinations of pressure differences on individual tires, the technical aspects of how such systems would operate, the cost of such systems, and what restrictions they would face in detecting specific levels of pressure reduction.

Although NHTSA is proposing a 25 percent below placard threshold, technically, other threshold levels could also be established. Selecting a notification threshold level is a matter of balancing the safety benefits achieved by alerting consumers to low tire pressure against over-alerting them to the point of being a nuisance, such that they ignore the warning and defeat the safety benefits of this proposal. We cannot predict a specific threshold level where benefits are maximized by a combination of minimum reduction in placard pressure and maximum response by drivers. However, degradation in vehicle braking and handling performance doesn't become a significant safety issue at small pressure losses. Moreover, NHTSA is confident that existing technology can meet the 25 percent threshold. Setting a lower threshold might result in the opportunity for more savings if driver's response levels were maintained; however, we are concerned that setting a lower threshold could result in a higher rate of non-response by drivers who regard the more frequent notifications as a nuisance. Current direct TPMS systems have a margin of error of 1-2 psi. This means, for example, that for a 30-psi tire, manufacturers would have to set the system to provide a warning when tires are 4 psi below placard if we were to require a 20 percent threshold. In some circumstances, overnight temperature declines can temporarily reduce tire pressure by 2-3 psi, but normal pressure would be restored as the tires heat up during use. This is not the type of pressure decline that TPMS is intended to address, and repeated nuisance alarms could result in reduced driver response to actual low tire pressure events. We have not examined lower threshold levels in this analysis because we believe that the net impact of these offsetting factors (quicker notification, but lower frequency of driver response) is unknown and unlikely to produce a significant difference in safety benefits. We note that a 20 percent 4-tire option was examined in the March 2002 analysis, and that the total benefit for the 20 percent threshold was about 15 percent higher than from the 25 percent threshold. However, that calculation assumed the same level of driver response for both thresholds. It is also possible that lower thresholds may limit technology and discourage innovation.

Overall, we feel that the 25 percent threshold adequately captures the circumstances at which low tire pressure becomes a safety issue. We also believe that this level would be acceptable to most drivers and would not be considered a nuisance to the point that it would be ignored by large numbers of drivers. We also believe there is no reason to examine higher thresholds (e.g., a 30 percent threshold), which would provide fewer benefits for similar costs.

III. TIRE PRESSURE SURVEY AND TEST RESULTS

In February 2001, the agency conducted a tire pressure study to determine the extent to which passenger vehicle operators are aware of the recommended air pressure for their tires, if they monitor air pressure, and to what extent the actual tire pressure differs from that recommended tire pressure by the vehicle manufacturer on the placard. The most useful information for this analysis is the snap shot in time that tells us where the actual tire pressure of the fleet is in comparison to the vehicle manufacturer's recommended tire pressure. Although this was not a nationally representative survey, it is being treated as such in this analysis.

The field data collection was conducted through the infrastructure of 24 locations of the National Automotive Sampling System Crashworthiness Data System (NASS CDS). Data were collected on 11,530 vehicles that were inspected at a sample of 336 gas stations. There were 6,442 passenger cars, 1,874 sport utility vehicles (SUVs), 1,376 vans, and 1,838 light conventional trucks. Data can be separated by passenger cars with P-metric tires; trucks, SUVs and vans with P-metric tires; and trucks, SUVs, and vans with either LT-type or high flotation tires. For this analysis we only compare the passenger car tire pressures and the light truck tire pressures, without separating the light trucks by type of tire. Complete data were collected on 5,967 passenger cars and 3,950 light trucks for a total of 9,917 vehicles.[1]

The average placard pressure for passenger cars was about 30 psi, while the average placard pressure for light trucks was about 35 psi, although the light trucks have a much wider range of

[1] The Rubbers Manufacturers Association (Docket 8572-116) argued the tire pressure survey measured tires when they were hot. Thus, NHTSA's under-inflation estimates are conservative. The agency considered this point, but also notes that the survey was done in February when tires lose more pressure because of the ambient temperature and considered these to be unquantifiable offsetting conditions.

manufacturer recommended placard pressure. Because of the wide range of placard pressure for light trucks, it was determined that it would be best to propose a percentage reduction from the placard than a straight psi reduction.

The issue addressed is how often drivers would get a warning from a low tire pressure monitoring system. Table III-1 shows how often a driver would be warned anytime one or more tires fell 25% below the placard recommended pressure. An estimated 26 percent of passenger cars and 29 percent of light trucks (an average of 27.5 percent of the passenger car and light truck drivers) would get a warning at 25% below the placard recommended pressure.

Table III-2 shows the distribution of tire pressure when at least one tire is 25 percent or more below placard in terms of whether one, two, three, or all four tires were at least 25 percent below placard.

At the time the survey was done, there were 207 million vehicles on the road. An estimated 57 million vehicles, have at least one tire 25 percent or more below placard at any time.

Table III-1

Percent of Vehicles That Would Get a Warning

	Passenger Cars	Light Trucks
25% or more Below Placard	26%	29%

Table III-2
Distribution of the Number of Tires on Vehicles
That Have One or More Tires that is
25% or more Below Placard

Number of Tires 25% or more Below Placard	Passenger Cars	Percent	Light Trucks	Percent
1	880	55.9%	542	47.2%
2	399	25.3	313	27.3
3	139	8.8	145	12.6
4	157	10.0	148	12.9
Total	1,575	100%	1,148	100%

TPMS Test Results

The agency tested six direct measurement systems (Systems E through J in Table III-3) to determine both the level at which they provided driver information and the accuracy of the systems. The warning level thresholds were determined by dynamic testing at GVWR at 60 mph by slowly leaking out air out of one tire to a minimum of 14 psi. Some of the systems provide two levels of driver information, an advisory and a warning level. System F was a prototype with much lower thresholds for advisory and warning than the other systems. If System F is not considered, based on our testing, the typical advisory level is given at 20 percent under placard pressure, however the warning level averaged 36 percent below the placard. The static accuracy tests showed that those systems that displayed tire pressure readings were accurate to within 1 to 2 psi.

Table III-3
Direct measurement systems
Driver information provided at (%) below placard for one tire

System	E	F	G	H	I	J
Advisory	N.A.	-42%	N.A.	-20%	N.A.	-19%
Warning	-20%	-68%	-33%	-53%	-35%	-41%

The agency tested four indirect measurement systems (Systems A to D) to determine when they provided driver information. The warning thresholds were determined by slowly leaking out air out of one tire to a minimum of 14 psi, while driving at 60 mph under a lightly loaded vehicle weight condition (LLVW) and at gross vehicle weight rating (GVWR). Table III-4 provides these results. The agency believes that the difference in the warning levels between the front and rear axle are due to variability in the system. The indirect systems could not detect when air was leaked out of different combinations of two tires and all four tires.

Table III-4
Indirect measurement systems
Driver warning provided at (%) below placard for one tire

Load	Axle	System A	System B	System C	System D	Ave. of 3
LLVW	Front	-21%	No Warning	-40%	-28%	-30%
LLVW	Rear	-16%	No Warning	-37%	-38%	-30%
GVWR	Front	-16%	No Warning	-18%	-31%	-24%
GVWR	Rear	-9%	No Warning	-20%	N/a	-14%

Vehicle Stopping Distance Tests

One of the potential safety benefits the agency is examining is the impact of low tire pressure on vehicle stopping distance. In the PRIA, we present two sets of data from different sources – Goodyear Tire and Rubber Company and NHTSA's Vehicle Research and Test Center (VRTC). In a comment to the docket, Goodyear presented the results of additional testing. The information provided by these sources did not lead to the same conclusions.

Table III-5 shows data provided by Goodyear on an ABS-equipped vehicle. These wet stopping distance data indicate:

1. Stopping distance generally increases with lower tire pressure. The only exception was on concrete at 25 mph.
2. With fairly deep water on the road, (0.050 inches is equivalent to 1 inch of rain in an hour) lowering inflation to 17 psi and increasing speed to 45 mph increases the potential for hydroplaning and much longer stopping distances.
3. Except for 25 mph on macadam, the difference between 25 and 29 psi is relatively small.

Goodyear provided test data to the agency on Mu values to calculate dry stopping distances. This information is used in the benefits chapter later in this assessment.

Table III-5
Braking Distance (in feet) provided by Goodyear
Wet Stopping Distance (0.050" water depth)

Surface	Speed	17 psi	25 psi	29 psi	35 psi
Macadam	25 mph	32.4	30.8	29	27.4
Macadam	45 mph	107.6	101	100.8	98.6
Concrete	25 mph	47.4	48.2	48.2	48
Concrete	45 mph	182.6	167.2	167.4	163.6

Table III-6 shows test data from NHTSA - VRTC on stopping distance. Tests were performed using a MY 2000 Grand Prix with ABS. Shown is the average stopping distance based on five tests per psi level. The concrete can be described as a fairly rough surface that has not been worn down like a typical road. The asphalt was built to Ohio highway specifications, but again has not been worn down by traffic, so it is like a new asphalt road. A wet road consists of wetting down the surface by making two passes with a water truck; thus it has a much lower water depth than was used in the Goodyear tests.

Table III-6
Braking Distance (in feet) from NHTSA testing
Stopping Distance from 60 mph

Surface	15 psi	20 psi	25 psi	30 psi	35 psi
Wet Concrete	148.8	147.5	145.9	144.3	146.5
Dry Concrete	142.0	143.0	140.5	140.4	139.8
Wet Asphalt	158.5	158.6	162.6	161.2	158.0
Dry Asphalt	144.0	143.9	146.5	148.2	144.0

These stopping distances indicate:

1. There is generally an increase in stopping distance as tire inflation decreases from the 30 psi placard on this vehicle on both wet and dry concrete.
2. On wet and dry asphalt, the opposite generally occurs, stopping distance decreases as tire inflation decreases from the 30 psi placard.
3. There is very little difference between the wet and dry stopping distance on the concrete pad (about 4 feet at 30 psi), indicating the water depth was not enough to make a noticeable difference on the rough concrete pad. There is a larger difference between the wet and dry stopping distance on the asphalt pad (13 feet at 30 psi).
4. No hydroplaning occurred in the NHTSA tests, even though they were conducted at higher speed (60 mph vs. 45 mph in the Goodyear tests) and at lower tire pressure (15 psi

vs. 17 psi in the Goodyear tests). Again, this suggests that the water depth in the VRTC tests was not nearly as deep as in the Goodyear testing.

In general, these data suggest that the road surface and depth of water on the road have a large influence over stopping distance. Given a specific road condition, one can compare the difference in stopping distance when the tire inflation level is varied. The Goodyear test results imply that tire inflation can have a significant impact on stopping distance, while the NHTSA testing implies these impacts would be minor or nonexistent on dry surfaces and wet surfaces with very little water depth.

In a comment to the docket (8572-160) Goodyear presented an extensive series of test data. These tests included two vehicles having tires with full tread depth and half tread depth on vehicles with ABS and on tires with full tread depth without ABS and on a dry, 0.02 inch wet and 0.05 inch wet macadam surface at three different psi levels. The full tread depth on the Integrity tire used on the Dodge Caravan was 10/32 inch and the half tread depth was 5/32 inch. The full tread depth on the Wrangler tire used on the Ford Ranger was 13/32 inch and the half tread depth was 6.5/32 inches. The stopping distance in feet is the average of six stops for most of the scenarios. The stopping distance was collected from 45 mph to 5 mph. Goodyear found that collecting the data at 5 mph reduced the variability in the results as compared to a full stop to 0 mph. Tables III-7 (a), (b), and (c) summarize these results.

Table III-7 (a)

Goodyear data – Second Test Series
Dry Macadam Surface
(Stopping Distance in Feet)

2001 Dodge Grand Caravan Sport	20 psi	28 psi	35 psi
Full Depth Tread with ABS	75.5	76.2	75.8
½ Depth Tread with ABS	69.9	68.1	66.3
Full Depth Tread without ABS	98.3	95.9	91.6
1997 Ford Ranger			
Full Depth Tread with ABS	80.8	78.2	77.6
½ Depth Tread with ABS	79.0	74.8	71.4
Full Depth Tread without ABS	97.8	96.5	94.1

Table III-7 (b)
Goodyear data – Second Test Series
0.02 Inch Wet Macadam Surface
(Stopping Distance in Feet)

2001 Dodge Grand Caravan Sport	20 psi	28 psi	35 psi
Full Depth Tread with ABS	79.8	78.5	77.1
½ Depth Tread with ABS	84.7	73.7	81.4
Full Depth Tread without ABS	111.1	110.2	108.6
1997 Ford Ranger			
Full Depth Tread with ABS	83.8	81.5	79.8
½ Depth Tread with ABS	91.5	89.4	84.6
Full Depth Tread without ABS	131.9	126.0	118.4

Table III-7 (c)
Goodyear data – Second Test Series
0.05 Inch Wet Macadam Surface
(Stopping Distance in Feet)

2001 Dodge Grand Caravan Sport	20 psi	28 psi	35 psi
Full Depth Tread with ABS	80.0	81.1	82.7
½ Depth Tread with ABS	103.7	99.7	92.2
Full Depth Tread without ABS	118.0	112.2	111.7
1997 Ford Ranger			
Full Depth Tread with ABS	89.7	86.0	81.5
½ Depth Tread with ABS	125.7	118.5	104.5
Full Depth Tread without ABS	142.9	134.8	125.7

These data indicate that stopping distance is longer with lower psi for every case except for two cases with the full depth tread with ABS on the Dodge Caravan. Full depth tread tires had shorter stopping distance than ½ depth tread tires on wet surfaces, but not dry surfaces, and vehicles with ABS had shorter stopping distances than those vehicles without ABS.

The value of Mu is dependent on surface material (concrete, asphalt, etc.), surface condition (wet vs. dry), inflation pressure, and initial velocity. The following tables presents coefficient of friction data provided by The Goodyear Tire and Rubber Company in response to the earlier NPRM, NHTSA developed a model that predicts Mu based on initial velocity and inflation pressure. Separate models were developed for Mu at both peak (the maximum level of Mu achieved while the tire still rotates under braking conditions) and slide (the level of Mu achieved when tires cease to rotate while braking (i.e., skid)). These models are used in the benefits section when estimating stopping distance.

GOODYEAR COEFFICIENT OF FRICTION DATA – M
Macadam Surface
1215/70R15 Integrity – 1080 lbs. Load

0.020" Wet				0.050" Wet			DRY		
	20 mph			20 mph			20 mph		
	35 psi	28 psi	20 psi	35 psi	28 psi	20 psi	35 psi	28 psi	20 psi
Peak	0.864	0.846	0.818	0.830	0.795	0.796	0.980	0.992	0.966
Slide	0.566	0.546	0.528	0.553	0.512	0.497	0.716	0.671	0.648
	0.020" Wet			0.050" Wet			DRY		
	40 mph			40 mph			40 mph		
	35 psi	28 psi	20 psi	35 psi	28 psi	20 psi	35 psi	28 psi	20 psi
Peak	0.827	0.808	0.786	0.740	0.687	0.690	0.940	0.926	0.921
Slide	0.474	0.454	0.448	0.444	0.416	0.397	0.696	0.696	0.682
	0.020" Wet			0.050" Wet			DRY		
	60 mph			60 mph			60 mph		
	35 psi	28 psi	20 psi	35 psi	28 psi	20 psi	35 psi	28 psi	20 psi
Peak	0.832	0.831	0.802	0.564	0.484	0.488	0.930	0.910	0.923
Slide	0.368	0.373	0.348	0.280	0.220	0.148	0.730	0.737	0.766

NHTSA - TIRE COEFFICIENT OF FRICTION DATA - m
Macadam Surface
P235/75R15 Wrangler RT/S - 1490 lbs. Load

	0.020" Wet 20 mph			**0.050" Wet 20 mph**			**DRY 20 mph**		
	35 psi	**28 psi**	**20 psi**	**35 psi**	**28 psi**	**20 psi**	**35 psi**	**28 psi**	**20 psi**
Peak	0.924	0.913	0.864	0.878	0.844	0.790	0.942	0.961	0.904
Slide	0.600	0.562	0.522	0.548	0.502	0.491	0.690	0.606	0.644
	0.020" Wet 40 mph			**0.050" Wet 40 mph**			**DRY 40 mph**		
	35 psi	**28 psi**	**20 psi**	**35 psi**	**28 psi**	**20 psi**	**35 psi**	**28 psi**	**20 psi**
Peak	0.888	0.848	0.808	0.800	0.752	0.708	0.916	0.882	0.834
Slide	0.466	0.465	0.440	0.422	0.382	0.347	0.618	0.631	0.620
	0.020" Wet 60 mph			**0.050" Wet 60 mph**			**DRY 60 mph**		
	35 psi	**28 psi**	**20 psi**	**35 psi**	**28 psi**	**20 psi**	**35 psi**	**28 psi**	**20 psi**
Peak	0.840	0.806	0.770	0.602	0.626	0.555	0.882	0.860	0.814
Slide	0.364	0.346	0.314	0.266	0.212	0.133	0.672	0.700	0.704

IV. TARGET POPULATION

Safety Problems Associated with Low Tire Pressure

Under-inflation affects many different types of crashes. In commenting to the docket, the International Tire & Rubber Association (ITRA) (Docket No. 8572-123) stated that when developing ITRA training programs they look closely at tire performance and have the opportunity to analyze a significant number of tires that failed in service. ITRA has found that the single most common cause of tire failure is under-inflation.

The types of crashes that under-inflation influences are:

1. skidding and/or a loss of control of the vehicle in a curve, like an off-ramp maneuver coming off of a highway at high speed, or simply taking a curve at high speed
2. skidding and/or loss of control of the vehicle in a lane change maneuver,
3. hydroplaning on a wet surface, which can affect both stopping distance and skidding and/or loss of control.
4. an increase in stopping distance,
5. crashes caused by flat tires and blowouts
6. overloading the vehicle

We can identify target populations for skidding and loss of control crashes, flat tires and blowouts, and stopping distance (which involves any vehicle that brakes during a crash sequence). We cannot identify from our crash files, or other reports, the incidence of hydroplaning specifically (we do however identify wet surfaces and loss of control in our "skidding and loss of control" analysis of crashes), or the impacts of overloading a vehicle (this may be captured somewhat in tire blowouts).

Skidding and loss of control

The 1977 Indiana Tri-level study associated low tire pressure with loss of control, on both wet and dry pavements. That study did not identify low tire pressure as a "definite" (95 percent certain that the crash would not have occurred without this cause) cause of any crash, but did identify it as a "probable" cause (80 percent confidence level - highly likely that the crash would not have occurred) of the crash in 1.4 percent of the 420 in-depth crash investigations.[1]

"Probable cause" was broken up into two levels: a causal factor and a severity-increasing factor. A causal factor was defined as "had the factor not been present in the accident sequence, the accident would not have occurred." A severity-increasing factor was not sufficient to result in the occurrence of the accident, but resulted in an increase in speed of the initial impact. Under-inflated tires were a causal factor in 1.2 percent of the probable causes and a severity-increasing factor in 0.2 percent of the probable causes.

Note that more than one "probable cause" could be assigned to a crash. In fact, there were a total of 138.8 percent causes listed as probable cause (92.4 percent human factors, 33.8 percent environmental factors, and 12.6 percent vehicular factors). Thus, under-inflation's part of the total is 1.0 percent (1.4/138.8). If we focus on just the probable cause cases, under-inflation represents 0.86 percent of crashes (1.2/1.4*1.0).

[1] **Tri-level Study of the Causes of Traffic Accidents: Executive Summary,** Treat, J.R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E., Stansifer, R.L., & Castellan, N.J. (1979). (Contract No. DOT HS 034-3-535). DOT HS 805 099. Washington, DC: U.S. Department of Transportation, NHTSA. See pages A-51 and D-23 to D-30.

There are several important factors to know about the Indiana Tri-Level study and their implications for this analysis. This information was verified with the authors of the study and NHTSA contract technical managers on the study.

1) None of the cases in which under-inflation was cited as a probable cause dealt with stopping distance. They were all cases of loss of control in a curve or in a crash avoidance maneuver.
2) High speed was not a factor in these cases. In order to be considered for an under-inflation case, the vehicle had to be going within a reasonable speed to make the turn, for example.
3) In order for under-inflation to be cited in the study, there had to be a significant amount of under-inflation, 10 to 15 psi low or more compared to placard levels. Thus, the estimates would apply to all three Compliance Options fairly equally.
4) There were particular vehicles that were known to lose traction when their tires were under-inflated in particular patterns, sometimes the rear tires, or sometimes a disparity in inflation. The authors particularly noted the Chevrolet Corvair and the early-60's Volkswagen Beetle. Problem vehicles like this were not a big part of the sample but raised the rate somewhat and do not appear to be a problem today. We assume this factor could reduce the probable cause estimate by 10 percent to 0.77 (0.86*.9).

At the time of the study, radial tires were on 12% of passenger vehicles, and now they are on more than 90% of passenger vehicles, including all tires on new automobiles. The question is whether the 1977 results are applicable in today's tire environment. The agency at this time is unable to quantify how the cornering force capability of different tire constructions (bias ply, bias belted and radial) at different tire inflation pressures affects the frequency of loss of control crashes. Radial tires provide better tread contact with the pavement since their sidewalls are more flexible in the lateral direction than bias ply tires. Accordingly, radial tires can generate about twice the lateral force as bias ply tires. However, drivers get feedback from their tires and drive vehicles with different types of tires in different ways around corners. Bias and bias belted tires provide more feedback to the driver by feel and noise that the vehicle might not negotiate a curve, and the driver can sometimes slow down and correct the situation before going off the road. While radial tires generate more lateral forces, they do not provide progressive feedback to the driver and tend to lose traction without as much warning. In essence, drivers have learned how to go around entrance and exit ramps, and other curves, on highways at a higher rate of speed with radial tires. However, if the road is wet and their tire pressure is low, then they might have problems taking that curve at the same speed. Thus, we can't determine how to correct the Indiana Tri-Level study to account for the difference in types of tires. It may well be, and for this assessment we assume, that the same percentage of under-inflation influenced crashes occur with radial tires as with bias and bias-belted tires.

To get an estimate of the target population of the low tire pressure cases in which skidding and loss of control could be a factor, we took data from "Traffic Safety Facts, 1999" which shows there were about 47,848 passenger vehicles (passenger cars and light trucks) involved in fatal crashes, about 3.6 million passenger vehicles involved in injury crashes and about 6.9 million passenger vehicles involved in property damage only crashes. These crashes resulted in 32,061 passenger vehicle occupants being killed and almost 3 million passenger vehicle occupants being injured.

Taking 0.77 percent of these cases, loss of control and skidding due to low tire pressure would account for an estimated 247 occupants killed, 23,100 occupants injured, and 53,130 property damage only crashes.

As a second check on these estimates, the 1999 NASS-GES was examined to identify particular crash scenarios in which loss of control occurred. The following scenarios that could be identified were examined totaling over 413,000 vehicles (3.9 percent of the vehicles in all crashes). Certainly there are other scenarios that couldn't be identified, but this check was made to assure ourselves that 0.77 percent was not impossibly high, which it did.

Negotiating a curve: Where the vehicle left the roadway, left the travel lane, lost control or skidded (213,759 vehicles)
Changing lanes where the vehicle left the roadway, lost control or skidded (4,890 vehicles), and
Raining/wet road cases where the vehicle lost control and skidded (194,709 vehicles).

Flat tires and blowouts

There is no direct evidence in NHTSA's current crash files (FARS and NASS) that points to low tire pressure as the cause of a particular crash. This is because we have no measurements of tire pressure in our data bases (plans are underway to start collecting this data in 2002). The closest data element is "flat tire or blowout". Even in these cases, crash investigators cannot tell whether low tire pressure contributed to the tire failure. Tire failures, especially blowouts, are associated with rollover crashes. Low tire pressure can also lead to loss of control or a skid initially. Skids can lead to tripping and then to a rollover.

The agency examined its crash files to gather whatever information is available on tire-related problems causing crashes. The National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) has trained investigators who collect data on a sample of tow-away crashes around the country. These data can be weighted up to national estimates. The NASS-CDS contains on its General Vehicle Form a space for the following information (where applicable): a critical pre-crash event, vehicle loss of control due to a blowout or flat tire. This category only includes part of the tire-related problems causing crashes. It does not include cases where there was improper tire pressure in one or more tires that did not allow the vehicle to handle as well as it should have in an emergency situation. This coding would only be used when the tire went flat or there was a blowout and caused a loss of control of the vehicle, resulting in a crash. However, as stated above, low tire pressure may contribute directly to the crashes discussed in the paragraphs below. In addition, there may be other crashes, not included in the paragraphs below, where low tire pressure played a part.

NASS-CDS data for 1995 through 1998 were examined and average annual estimates are provided below in Table IV-1. Table IV-1 shows that there are an estimated 23,464 tow-away crashes caused per year by blowouts or flat tires. Thus, about one half of a percent of all crashes are caused by these tire problems. When these cases are broken down by passenger car versus light truck, and compared to the total number of crashes for passenger cars and light trucks individually, it is found that blowouts cause more than three times the rate of crashes in light trucks (0.99 percent) than in passenger cars (0.31 percent). When the data are further divided into rollover versus non-rollover, blowouts cause a much higher proportion of rollover crashes

(4.81) than non-rollover crashes (0.28); and again more than three times the rate in light trucks (6.88 percent) than in passenger cars (1.87 percent).

Table IV-1
Estimated Annual Average Number and Rates of
Blowouts or Flat Tires Causing Tow-away Crashes

	Tire Related Cases	Percent Tire Related
Passenger Cars Total	*10,170*	*0.31%*
Rollover	1,837 (18%)	1.87%
Non-rollover	8,332 (82%)	0.26%
Light Trucks Total	*13,294*	*0.99%*
Rollover	9,577 (72%)	6.88%
Non-rollover	3,717 (28%)	0.31%
Light Vehicles Total	*23,464*	*0.51%*
Rollover	11,414 (49%)	4.81%
Non-rollover	12,049 (51%)	0.28%

Table IV-2 shows the estimated number of fatalities and injuries in those cases in which a flat tire/blowout was considered the cause of the crash[2]. There are an estimated 414 fatalities and 10,275 non-fatal injuries in these crashes.

Table IV-2
Injuries/Fatalities in Crashes Caused by
Flat Tire/Blowout

	Non-fatal AIS 1	Non-fatal AIS 2	Non-fatal AIS 3	Non-fatal AIS 4	Non-fatal AIS 5	Fatalities
Number of Injuries	8,231	1,476	362	155	51	414

[2] Since CDS typically underestimates the number of fatalities, a factor was developed based on the number of occupant fatalities in FARS divided by the number of occupant fatalities in CDS for those years of 1.163, which was multiplied by the actual estimate of flat tire/blowout fatalities.

The Fatality Analysis Reporting System (FARS) was also examined for evidence of tire problems involved in fatal crashes. In the FARS system, tire problems are noted after the crash, if they are noted at all, and are only considered as far as the existence of a condition. In other words, in the FARS file, we don't know whether the tire problem caused the crash, influenced the severity of the crash, or just occurred during the crash. For example, (1) some crashes may be caused by a tire blowout, (2) in another crash, the vehicle might have slid sideways and struck a curb, causing a flat tire which may or may not have influenced whether the vehicle rolled over. Thus, while an indication of a tire problem in the FARS file gives some clue as to the potential magnitude of the tire problem in fatal crashes, it can neither be considered the lowest possible number of cases nor the highest possible number of cases. In 1995 to 1998 FARS, 1.10 percent of all light vehicles were coded with tire problems. Light trucks had slightly higher rates of tire problems (1.20 percent) than passenger cars (1.04 percent). The annual average number of vehicles with tire problems in FARS was 535 (313 in passenger cars and 222 in light trucks). On average, annually there were 647 fatalities in these crashes (369 in passenger cars and 278 in light trucks). Thus, these two sets of estimates seem reasonably consistent: 647 fatalities in FARS in crashes in which there was a tire problem and 414 fatalities from CDS, in which the flat tire/blowout was the cause of the crash.

Geographic and Seasonal Effects

The FARS data were further examined to determine whether heat is a factor in tire problems (see Table IV-3). Two surrogates for heat were examined: (1) in what part of the country the crash occurred, and (2) in what season the crash occurred. The highest rates occurred in light trucks in southern states in the summer time, followed by light trucks in northern states in the summer time, and by passenger cars in southern states in the summertime. It thus appears that tire problems are heat related.

Table IV-3
Geographic and Seasonal Analysis of Tire Problems
(Percent of Vehicles in) FARS with Tire Problems

	Passenger Cars	Light Trucks	All Light Vehicles
Northern States			
Winter	1.01%	0.80%	0.94%
Spring	1.12%	1.01%	1.08%
Summer	0.98%	**1.46%**	1.15%
Fall	1.04%	0.93%	1.00%
Southern States			
Winter	0.87%	0.99%	0.92%
Spring	1.09%	1.27%	1.16%
Summer	**1.31%**	**1.99%**	1.59%
Fall	0.89%	1.07%	1.00%

Winter = December, January, February.
Spring = March, April, May
Summer = June, July, August
Fall = September, October, November.
Southern States = AZ, NM, OK, TX, AR, LA, KY, TN, NC, SC, GA., AL., MS, and FL.
Northern States = all others.

There are also crashes indirectly caused or indirectly involved with tire related problems. If a vehicle stops on the side of the road due to a flat tire, there is the potential for curious drivers to slow down to see what is going on. This can create congestion, potentially resulting in a rear-end impact later in the line of vehicles when some driver isn't paying enough attention to the traffic in front of them. The agency has not attempted to estimate how often a TPMS would give the driver enough warning of an impending flat tire that they could have the tire repaired before they get stuck having to repair a flat tire in traffic. However, it should be a very large number.

An indirectly involved crash relating to tire repairs on the road can occur when someone is in the act of changing a tire on the shoulder of the road. Sometimes drivers repairing tires are struck (as pedestrians) by other vehicles. This phenomena is not captured in NHTSA's data files, but there are three states (Pennsylvania, Washington, and Ohio), which have variables in their state files, which allow you to search for and combine codes such as "Flat tire or blowout" with "Playing or working on a vehicle" with "Pedestrians". An examination of these files for calendar year 1999 for Ohio and Pennsylvania and for 1996 for Washington found the following information shown in Table IV-4.

Table IV-4
State data on tire problems and pedestrians

	Ohio	Washington	Pennsylvania
Pedestrians Injured	3,685	2,068	5,226
Pedestrians Injured While Playing or Working on Vehicle	50 (1.4%)	27 (1.3%)	56 (1.1%)
Pedestrians Injured While Working on Vehicle with Tire Problem	0	2	0
Total Crashes	385,704	140,215	144,169
Crashes with Tire Problems	862 (0.22%)	1,444 (1.03%)	794 (0.55%)

The combined percent of total crashes with tire problems of these three states (3,100/670,088 = 0.46 percent) compares very favorably with the NASS-CDS data presented in Table IV-1 of 0.51 percent. The number of pedestrians coded as being injured while working on a vehicle with tire problems is 2/10,979 = 0.018 percent. Applying this to the estimated number of pedestrians injured annually across the U.S. (85,000 from NASS-GES), results in an estimated 15 pedestrians injured per year. It is possible that these numbers could be much higher, if they were coded correctly. The agency is not going to estimate how many of the pedestrian injuries could be reduced with a TPMS.

V. Benefits Analysis

Human Factors Issues

The Tire Pressure Monitoring Systems (TPMS) will provide notification to drivers that their tire pressure has dropped below the level recommended by the manufacturer. However, driver response to this information may vary depending upon the nature of the information provided by the TPMS. NHTSA believes that almost all drivers will respond in some manner to the warning, but the level of information presented to the driver by different display systems may result in different behavior by drivers.

The direct measurement systems could display individual tire pressures and tell the driver which tire(s) are low. Although individual tire pressures are not proposed to be required, this analysis assumes in Compliance Option 1 that all of the vehicles will be supplied with direct measurement systems that will display individual tire pressures because it will be helpful to drivers in terms of fuel economy, tread wear and safety. This was done because of uncertainty regarding the exact nature of displays that manufacturers will install. The indirect and hybrid measurement systems can only provide a warning lamp that tire pressure is low. Compliance Options 2 and 3 assume all vehicles will be equipped with only a warning lamp.

We anticipate that drivers will react differently to the different amounts of information. Some drivers will keep track of the individual tire pressures and will add pressure to their tires whenever necessary, say at 10 percent below placard, even before the warning is given. These drivers will accrue more safety benefits and more benefits in terms of fuel economy and tread life than drivers that wait longer for a warning. On the other hand, some drivers who currently check their own tires frequently enough to avoid significant under-inflation may start to rely on the TPMS to indicate under-inflation, rather than checking their tires frequently and filling them up whenever they were below the placard level. We believe this would happen more often under Compliance Options 2 and 3, where only a warning lamp comes on when tire pressure goes below a specified threshold, rather than under Compliance Option 1, where individual tire pressures could be monitored continuously. These drivers would actually accrue fewer safety, tread wear and fuel economy benefits than they did without the TPMS.

The agency has little information that would help it estimate how a TPMS would affect overall driver tire maintenance behavior. A survey question in the Bureau of Transportation Statistics Omnibus Survey of July 2001 asked 1,004 respondents "To what extent do you agree that an indicator lamp in your vehicle that warns the driver about under-inflation in any of the vehicle's tires would allow you to be less concerned with routinely maintaining the recommended tire pressure?" The responses were 40 percent to "a very great extent", 25 percent to "a great extent", 18 percent to "some extent", 7 percent to "a little extent", and 10 percent to "no extent". Putting this information together with survey data from the tire pressure survey, where one-third of those surveyed indicated that they check their tire pressure at least once a month, indicates that some people would check their tire pressure less frequently.

The agency has some information that would help it estimate what percent of drivers would put to use the information on individual tire pressures. From the agency's tire pressure survey, we found that about one-third of the interviewed drivers indicated that they check their tire pressure once a month or more frequently. For Compliance Option 1, we assume that one-third of the drivers would pay attention to the individual tire pressure information provided on a monitor and would refill their tires when they were 10 percent below the placard. This means that if the average passenger car tire placard is 30 psi, we assume for Compliance Option 1 that one-third of the drivers would refill their tires when they get to 27 psi. The other two-thirds of the drivers would refill their tires when the warning is given at 25 percent below placard, or 22.5 psi for the average passenger car.

The second question is whether drivers, given a warning, will stop and inflate their tires back to the placard pressure. We do not expect driver compliance with the TPMS telltale, which is amber or yellow, to be 100 percent. In the Final Economic Assessment, we assumed that 95 percent of drivers will fill the low tire(s) to make sure they don't get a flat tire and be stranded somewhere. Given just a telltale, the driver will probably need to check all the tires. Given a reading of tire pressure on all four tires with a direct measurement system, the driver will know which tire(s) are low and need to be filled.

This assumption was based on NHTSA's own estimates and a study relating to the Cycloid Pump. "Examining the Need for Cycloid's Pump: An Analysis of Attitudes and a Study of Tire Pressure and Temperature Relationships", December 7, 2001 by the University of Pittsburgh Department of Mechanical Engineering, Department of Industrial Engineering. This study included a survey of people's attitudes. The survey was not a random survey of consumers representing a national picture. The 225 respondents to the survey were:

1) classmates, faculty, and anyone they thought would respond to an E-mail survey
2) a group of consumers at a supermarket who were willing to participate.

One of the questions was:

Q21. Would you respond to a dashboard warning lamp informing you that your tire pressure was low?

a) Yes

b) No.

219 out of 225 (97.3%) responded Yes.

Note that there were several questions before this one on how often do you check your tire pressure, when was the last time you checked your tire pressure, what is the recommended tire pressure in your vehicle, etc. These types of questions set up the respondents to thinking that tire pressure is an important topic worthy of checking out.

While this is not a random sample, the question format may have biased the responses, and driver's actual deeds are often different from their telephone response, the response is overwhelming and leads some small credence to a very high estimate (our initial estimate was 95 percent of drivers will respond to a warning lamp).

In 2003, NHTSA collected information on direct and indirect systems, in terms of tire pressure and asked the owners several questions. This report is still in progress. Preliminary results from questions in this survey to determine consumer reaction to existing TPMS systems indicated that in almost 95% of cases where vehicles had direct systems, and the driver was given a low tire pressure warning, the drivers responded by taking appropriate action. These preliminary survey results thus validate NHTSA's initial assumption. However, considering that these are all new vehicles and relatively expensive vehicles that have a direct TPMS, and that typically the reactions of purchasers of more expensive vehicles to behavioral warnings will be higher than the reactions of the average or second-time owners, we have assumed a more conservative 90 percent response rate to a warning.

In the Final Economic Assessment we assumed that there will be a natural process whereby, people fill up their tires and then the tires lose air over time. Thus, the benefits of the system are going from the level of pressure in the tire survey to an average level of pressure between times the tires are refilled using the following assumptions:

1. Given a warning lamp goes on, 90 percent of people will check their tires and refill them back to the placard level.
2. Tires lose air at an average of 1 psi per month.
3. The warning has to be given at 25 percent below placard. For passenger cars, assuming the average placard is 30 psi, the warning would be given at 22.5 psi. In Compliance Options 2 and 3, the tires would be refilled at the time of the warning, and then would slowly lose air down to 29 psi at the end of month 1, 28 psi at the end of month 2, etc, until they reached 22.5 psi again when a new warning would be given. Thus, the average steady state psi in this example is 26.3 psi [(30+29+28+27+26+25+24+23+22.5/2)/8.5].
4. For Compliance Option 1, we assume the display that will show individual tire pressures and that one-third of the drivers would pay attention to the display and fill up their tires every time they got to 10 percent below placard or 27 psi. For these individuals that pay attention to the display, the average steady state psi in this example is 28.5 psi. We also assume that the other two-thirds of the drivers will not pay attention to the display and

will fill up their tires when they get a warning at 22.5 psi. Thus, their average steady state psi is 26.3 psi. A weighted average of these is 27.0 psi (28.5*.333 + 26.3*.667).

5. These same assumptions are used for the light truck fleet, except we assume that the average placard for light trucks is 35 psi. The following table shows the results of the steady state assumptions for the different compliance options. These mean that benefits are taken from the psi level at which vehicles would be getting a warning under each of the compliance options to the steady state assumptions of where the average fleet psi would be over time. The benefits would then be multiplied by the 90 percent response rate to get the final estimated benefits.

	Steady State psi Level for Passenger Cars	Steady State psi Level for Light Trucks
Compliance Option 1	27.0 psi	31.5 psi
Compliance Option 2	26.3 psi	30.6 psi
Compliance Option 3	26.3 psi	30.6 psi

Skidding and Loss of Control

For loss of control crashes, speed is the most critical factor. Excessive speed alone can cause a loss of control in a curve or in a lane change maneuver. Tread depth, inflation pressure of the tires, and road surface condition are the most notable of a long list of factors including vehicle steering characteristics and tire cornering capabilities that affect the vehicle/tire interface with the road. In the Indiana Tri-Level Study, under-inflation was not considered a contributing factor to a crash when there was high speed involved. It was only considered when the tires were significantly under-inflated (an undefined term generally taken by the investigators to mean at least 10 to 15 psi below recommended pressure). Still, it is hard to know whether correcting this one problem area could result in the collision being avoided or reduced in severity. That is one reason why under-inflation was never cited as the definite cause of a crash. We tried to consider this by comparing under-inflation as a percentage of all of the probable causes in crashes. Certainly, reducing under-inflation is an important area and a move in the right direction. However, it is difficult to determine what the effectiveness of increasing tire pressure would be on these crashes. The following discussions describe how inflation pressure affects these crash types to the extent known.

Skidding and/or loss of control in a curve

Low tire pressure generates lower cornering stiffness because of reduced tire stiffness. When the tire pressure is low, the vehicle wants to go straight and requires a greater steering angle to generate the same cornering force in a curve. The maximum speed at which an off-ramp can be driven while staying in the lane is reduced by a few mph as tire inflation pressure is decreased. An example provided by Goodyear shows that when all four tires are at 30 psi the maximum speed on the ramp was 38 mph, at 27 psi the maximum speed was 37 mph, and at 20 psi the maximum speed was 35 mph while staying in the lane. Having only one front tire under-inflated by the same amount resulted in about the same impact on maximum speed. But, the influence of having only one rear tire under-inflated by the same amount was only about one-half of the impact on maximum speed (a 1.5 mph difference from 30 psi to 20 psi).

The agency also has run a series of tests to examine the issue of decreases in tire pressure on vehicle handling. A 2001 Toyota 4-Runner was run through 50 mph constant speed/decreasing radius circles to see the effects of inflation pressure on lateral road holding. We examined lefthand turns from 0 to 90 degrees handwheel angle for tire inflation pressures varied from 15 to 35 psi. The data indicate to us that in on-ramps/off ramps, tire inflation pressure is a critical factor in vehicle handling. The data show how much friction the vehicle can utilize, in terms of lateral acceleration (g's), before it slides off the road. The more lateral g's the vehicle can utilize, the better it stays on the road. So, if you are going around an off-ramp and need to turn the wheel 50 degrees at 50 mph, you can utilize 0.27 g's at 15 psi, or you can utilize 0.35 g's at 30 psi.

Skidding and/or loss of control in a lane change maneuver

In a quick lane change maneuver, under-inflated tires result in a loss of tire sidewall stiffness, causing poor handling. Depending upon whether the low tire(s) are on the front or rear axle impacts the vehicle's sensitivity to steering inputs, directional stability, and could result in a spin out and/or loss of control of the vehicle.

Skidding and/or loss of control benefits estimate

In Chapter IV, we estimated a target population for skidding and loss of control crashes for under-inflated tires of 247 fatalities, 23,100 injuries and 53,130 property-damage-only crashes. The agency assumes that 90 percent of drivers will fill their tires back to placard pressure.

It is difficult to determine the effectiveness estimate, (i.e., what percent of the crashes would be avoided by just improving low tire pressure). For this analysis, we assume 20 percent effectiveness to go from a very low pressure, where a warning would be given, to the steady state condition, although it could potentially be much higher. Thus, the benefits by Compliance

Option are shown in Table V-1. An example calculation resulting in the estimated 44 fatalities is (247*.90*.20*.99 to account for one percent current compliance).

Table V-1
Impacts for Skidding/Loss of Control Crashes

	PDO	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Non-Fatal Inj. Total	Fatal
Opt. 1	-9,468	-3,529	-393	-168	-16	-10	-4,116	-44
Opt. 2	-9,468	-3,529	-393	-168	-16	-10	-4,116	-44
Opt. 3	-9,468	-3,529	-393	-168	-16	-10	-4,116	-44

Note that the benefits are the same for all the Compliance Options, since they all require warnings at 25 percent below placard pressure. It is assumed that the benefits would come from increasing tire pressure from a low state to a pressure close to placard pressure. This reflects the finding that the levels of under-inflation in the Indiana Tri-Level study were higher than 25 percent to have under-inflation reported as a probable cause.

Stopping Distance

Tires are designed to maximize their performance capabilities at a specific inflation pressure. When tires are under-inflated, the shape of the tire's footprint and the pressure it exerts on the road surface are both altered. This degrades the tire's ability to transmit braking force to the road surface. There are a number of potential benefits from maintaining the proper tire inflation level including reduced stopping distances, better handling of the vehicle in a curve or in a lane change maneuver, and less chance of hydroplaning on a wet surface, which can affect both stopping distance and skidding and/or loss of control.

The relationship of tire inflation to stopping distance is influenced by the road conditions (wet versus dry), as well as by the road surface composition. Decreasing stopping distance is beneficial in several ways. First, some crashes can be completely avoided by stopping quicker. Second, some crashes will still occur, but they occur at a lower impact speed because the vehicle is able to decelerate quicker during braking.

In Chapter III, a variety of stopping distance test results are discussed. For the Preliminary Economic Assessment, NHTSA examined test results submitted by Goodyear Tire and Rubber Company as well as tests conducted at its own Vehicle Research Test Center (VRTC). In tests conducted by Goodyear Tire and Rubber Company, significant increases were found in the stopping distance of tires that were under-inflated. By contrast, tests conducted by NHTSA at their VRTC testing ground found only minor differences in stopping distance, and in some cases these distances actually decreased with lower inflation pressure. The NHTSA tests also found only minor differences between wet and dry surface stopping distance. It is likely that some of these differences were due to test track surface characteristics. The NHTSA track surface is considered to be aggressive in that it allows for maximum friction with tire surfaces. It is more representative of a new road surface than the worn surfaces experienced by the vast majority of road traffic. The Goodyear tests may also have been biased in other ways. Their basic wet surface tests were conducted on surfaces with .05" of standing water. This is more than would typically be encountered under normal wet road driving conditions and may thus exaggerate the stopping distances experienced under most circumstances. A general problem that applied to both data sets was that they measured stopping distance impacts for new tires only, while most vehicle miles are traveled on tires that are worn down to a level that is somewhere between full and minimal tread depths. Since tread depth and tread profile can greatly influence both water retention and tire friction, this could have a significant impact on estimates of tire pressure on stopping distance. Generally speaking, the Goodyear test results implied a significant impact on stopping distance from proper tire pressure, while the NHTSA tests implied these impacts would be minor or nonexistent at lesser water depths. The PEA estimated stopping distance impacts using the Goodyear data to establish an upper range of potential benefits. A lower range of no benefit was implied based on the NHTSA test results.

In the earlier PEA and in a subsequent memo to the docket (Docket No. 8572-81), NHTSA expressed concern regarding the adequacy of the currently available test data. In response, Goodyear conducted a new and comprehensive series of tests to evaluate the effects of tire inflation pressure on stopping distance. The Goodyear tests were conducted using two different vehicles (Dodge Caravan and Ford Ranger), two different tires (P235/75R15 Wrangler and 215/70R15 Integrity), three inflation pressures (35, 28, and 20 psi), two tread depths (full tread and half tread), and three water depths (dry, .02 inches, and .05 inches). In addition, the tests were run with vehicles with ABS and without ABS. The stopping distance was collected from 45 mph to 5 mph. Goodyear found that collecting the data at 5 mph reduced the variability in the results as compared to a full stop to 0 mph. A separate set of traction truck tests were also run to establish peak and slide coefficients of friction for these tires under similar circumstances but at speeds of 20, 40, and 60 mph.

NHTSA examined the new data submitted by Goodyear and determined that it provided a much more comprehensive data set than was used previously for the earlier PEA. The variety of water depths and tread depths were particularly important to resolving critical concerns with the initial data sets used in the earlier PEA. During the comment period, NHTSA contracted with the National Oceanic and Atmospheric Administration (NOAA) (See Docket No. 8572-167) to develop a data base that could be used to analyze the relative frequency of rainfall intensity in the U.S. Based on these data, the conditions which are likely to produce a surface water depth level of .05 inch, which was the basis for the original Goodyear tests, only occur about 10 percent of the time that it rains. Thus, the addition of a second lesser water depth test of .02 inch was critical to measuring the impact on crashes that occur under most wet road conditions. The new Goodyear data also confirmed that tread depth has a significant influence on stopping distance. Overall, the new test data provided a comprehensive picture of the impacts of tire inflation on stopping distance, and were relatively free of the contradictions found in the earlier data sets. For these reasons, NHTSA based the final analysis on the new data set provided by Goodyear, rather than average the results of the two previous conflicting sets of data.

Impact Speed/Injury Probability Model

In order to estimate the impact of improved stopping distance on vehicle safety, NASS-CDS data were examined to derive a relationship between vehicle impact speed (delta-V) and the probability of injury. Following is a description of the derivation of this model.

Data: From 1995-1999 CDS, all passenger vehicle occupants involved in crashes where at least one passenger vehicle used brakes.

Methodology: (1) 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 77 mph. The percent probability risk of each MAIS j+ injury level at each delta-V i mph is defined as the number of MAIS j+ injury divided by the total number of occupants involved at i mph delta-V. If j = 0 represents MAIS 0 injuries and j = 6 represents fatalities, the probability of injury risk can be represented by the following formula:

$$p^{+}_{i,j} = \frac{100.0x_{i,j}}{T_i} \quad i = 0 \text{ to } 77, j = 0 \text{ to } 6$$

Where :

$p^{+}_{i,j}$ = percent probability risk of MAIS j+ injuries at i mph delta-V,

$x_{i,j}$ = the number of j+ injuries (i.e., MAIS 0, MAIS 1+, MAIS 2+, …, fatal) at i mph delta-V

T_i = total number of occupants at i mph delta-V

Note that $p^{+}_{i,0}$ = percent probability risk of MAIS 0 injuries at i mph delta-V and $p^{+}_{i,6}$ = percent probability risk of fatalities at i mph delta-V. $I_{i,0}$ = the number of MAIS 0 injuries and $I_{i,6}$ the number of fatalities at i mph delta-V.

(2) The risk-prediction curve for each j injury level was derived using a mathematical modeling process. The process used delta-V as the independent variable (i.e., predictor) and $p^{+}_{i,j}$ as the dependent variable and modeled all the data points (delta-V, percentage risk) for each j injury level. For example, for MAIS 1+ injuries, the process used the data points: (0, $p^{+}_{0,1}$), (1, $p^{+}_{1,1}$), (2, $p^{+}_{2,1}$), …, (75, $p^{+}_{75,1}$), (76, $p^{+}_{76,1}$), (77, $p^{+}_{77,1}$) to derive the MAIS 1+ risk curve. Table V-2 shows all the risk-prediction formula. These formulas were developed under two assumptions: a) no one was injured at 0 mph, i.e., $p^{+}_{0,0}$ = 100 percent, and $p^{+}_{0,j}$ = 0 percent for j=1…6, and b)

everyone was assumed to have at least MAIS 1 injuries for 36 mph and higher delta-V, i.e., $p^{+}_{i,0} = 0$, for i >=36 mph. This assumption was based on the injury distribution derived from 1995-1999 CDS.

Table V-2
Injury Probability Risk Curve Formula

Injury Level	Risk-Prediction Formula
MAIS 0	$p^{+}_{i,0} = 100 * e^{-0.0807*i}, i \leq 35$ $= 0, i \geq 36$
MAIS 1+	$p^{+}_{i,1} = 93.2210 * SIN(0.0449 * i), i \leq 35$ $= 100, i \geq 36$
MAIS 2+	$p^{+}_{i,2} = 100 * \frac{e^{0.1683*i-5.0345}}{1+e^{0.1683*i-5.0345}}$
MAIS 3+	$p^{+}_{i,3} = 100 * \frac{e^{0.1292*i-5.5337}}{1+e^{0.1292*i-5.5337}}$
MAIS 4+	$p^{+}_{i,4} = 100 * \frac{e^{0.1471*i-7.3675}}{1+e^{0.1471*i-7.3675}}$
MAIS 5+	$p^{+}_{i,5} = 100 * \frac{e^{0.1516*i-7.8345}}{1+e^{0.1516*i-7.8345}}$
Fatal (j=6)	$p^{+}_{i,6} = 100 * \frac{e^{0.1524*i-8.2629}}{1+e^{0.1524*i-8.2629}}$

(3) The percent probability risk $p_{i,j}$ was calculated for individual MAIS level. For MAIS 0 (j=0) and fatal injuries (j=6), $p_{i,0} = p^{+}_{i,0}$ and $p_{i,6} = p^{+}_{i,6}$. The percentage risk for each MAIS 1 to MAIS 5 injury level is the difference between the two predicted risks. Thus, $p_{i,1}$ (risk of MAIS 1 at i mph delta-V) = $p^{+}_{i,1} - p^{+}_{i,2}$, $p_{i,2} = p^{+}_{i,2} - p^{+}_{i,3}$, $p_{i,3} = p^{+}_{i,3} - p^{+}_{i,4}$, $p_{i,4} = p^{+}_{i,4} - p^{+}_{i,5}$, and $p_{i,5} = p^{+}_{i,5} - p^{+}_{i,6}$.

(4) Adjusted total row percent risk to 100 percent. Because of statistical measurement variation and predicting errors, the row risk percentages at some delta-Vs do not add to 100 percent. To adjust to a total of 100 percent for these delta-Vs, an adjustment factor (f_i) is applied to every risk probability. The adjustment factor is 100/(actual total percentage), i.e.,

$$f_i = \frac{100}{\sum_j p_{i,j}} \text{ where } j = 0 \ldots 6.$$

The adjusted risk probabilities for i mph delta-V would be $f_i * p_{i,j}$. For example, at 10 mph delta-V, $f_{10} = 100/85 = 1.1765$. The risk probability for MAIS 0 becomes 52.5 (= 44.6*1.1765) and MAIS 1 becomes 43.5 (= 37.0*1.1765). These adjusted risk probabilities are higher than those predicted by the original curves listed in Table V-2. However, the general shape of each curve does not alter significantly. Table V-3 shows the adjusted percent probabilities of risk. Note that cell probabilities were rounded to the nearest tenth. Therefore the sum of the individual cells may not total exactly 100 percent.

Once this relationship was established, crash data from 1999 CDS and FARS were distributed across this matrix to establish a "base case" injury distribution. This was done separately for 3 different groups of crashes stratified according to the speed limits on the roadways where crashes occurred. The roadway stratification was selected because stopping distances are largely dependent on initial pre-braking travel speed, and speed limits were assumed to provide a reasonable stratification for this variable. However, actual travel speeds differ from speed limits. For this analysis, it was assumed that actual travel speeds were 5 mph higher than the mean speed limit in each category. The 3 speed limit categories were 0-35mph, 36-50mph, and 51 mph and over. The mean speed limits for each category were 30, 44, and 57. There were only minor differences between speed limits for wet and dry surfaces, or for passenger cars and LTVs. Therefore, the same average speed limit is used regardless of road surface or vehicle type. Allowing for a 5 mph difference for travel speed, the three assumed average speeds that represent the speed limit categories are 35, 49, and 62 mph.

Table V-3
Adjusted Percent Probabilities of Injury Risk

Delta-V (mph)	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
1	95.6	3.5	0.4	0.3	0.1	0.0	0.0	99.9
2	91.0	8.0	0.4	0.4	0.0	0.1	0.0	99.9
3	86.3	12.5	0.5	0.5	0.0	0.1	0.0	99.9
4	81.3	17.2	0.7	0.7	0.0	0.1	0.0	100.0
5	76.3	21.9	0.9	0.7	0.0	0.0	0.1	99.9
6	71.3	26.6	1.0	0.8	0.1	0.0	0.1	99.9
7	66.4	31.2	1.3	0.9	0.1	0.0	0.1	100.0
8	61.5	35.7	1.5	1.1	0.1	0.0	0.1	100.0
9	56.9	39.6	2.0	1.2	0.0	0.1	0.1	99.9
10	52.5	43.5	2.4	1.3	0.1	0.1	0.1	100.0
11	48.2	47.1	2.8	1.5	0.1	0.1	0.1	99.9
12	44.3	50.2	3.4	1.6	0.2	0.0	0.2	99.9
13	40.5	53.1	3.9	2.0	0.1	0.1	0.2	99.9
14	37.1	55.6	4.6	2.2	0.2	0.1	0.2	100.0
15	33.9	57.6	5.5	2.4	0.2	0.1	0.3	100.0
16	31.0	59.1	6.5	2.6	0.3	0.1	0.3	99.9
17	28.3	60.4	7.6	2.9	0.3	0.2	0.3	100.0
18	25.8	61.1	8.8	3.3	0.3	0.2	0.4	99.9
19	23.5	61.5	10.1	3.7	0.3	0.2	0.5	99.8
20	21.4	61.4	11.7	4.1	0.4	0.3	0.5	99.8
21	19.6	61.0	13.4	4.5	0.5	0.3	0.6	99.9
22	17.8	60.1	15.4	5.0	0.5	0.4	0.7	99.9
23	16.3	58.8	17.4	5.6	0.5	0.4	0.9	99.9
24	14.9	57.1	19.6	6.2	0.6	0.5	1.0	99.9
25	13.7	55.1	21.9	6.9	0.7	0.5	1.2	100.0
26	12.6	52.7	24.4	7.6	0.8	0.7	1.3	100.1
27	11.5	50.0	26.9	8.4	0.9	0.7	1.6	100.0
28	10.5	47.1	29.5	9.2	1.0	0.9	1.8	100.0
29	9.6	43.9	32.1	10.1	1.2	1.0	2.1	100.0
30	8.9	40.6	34.5	11.0	1.4	1.2	2.4	100.0
31	8.2	37.1	36.8	12.1	1.5	1.4	2.8	99.9
32	7.6	33.7	38.9	13.3	1.7	1.5	3.3	100.0
33	7.0	30.2	40.9	14.4	1.9	1.8	3.8	100.0
34	6.4	26.7	42.5	15.7	2.2	2.0	4.4	99.9
35	6.0	23.2	43.9	17.1	2.4	2.3	5.1	100.0
36	0.0	26.4	44.3	18.1	2.7	2.6	5.9	100.0
37	0.0	23.3	44.7	19.3	2.9	3.0	6.8	100.0
38	0.0	20.4	44.7	20.4	3.3	3.4	7.8	100.0
39	0.0	17.8	44.3	21.5	3.6	3.8	9.0	100.0
40	0.0	15.5	43.5	22.5	4.0	4.2	10.3	100.0
41	0.0	13.4	42.5	23.3	4.3	4.7	11.8	100.0
42	0.0	11.6	41.1	24.0	4.6	5.3	13.4	100.0
43	0.0	10.0	39.5	24.4	4.9	5.9	15.3	100.0
44	0.0	8.5	37.7	24.8	5.2	6.4	17.4	100.0
45	0.0	7.3	35.7	24.9	5.5	6.9	19.7	100.0

Table V-3
Adjusted Percent Probabilities of Injury Risk, Cont.

46	0.0	6.3	33.6	24.7	5.7	7.5	22.2	100.0
47	0.0	5.3	31.5	24.4	5.8	8.0	25.0	100.0
48	0.0	4.5	29.4	23.7	6.0	8.5	27.9	100.0
49	0.0	3.9	27.2	22.9	6.0	8.9	31.1	100.0
50	0.0	3.3	25.1	21.9	6.0	9.2	34.5	100.0
51	0.0	2.8	23.0	20.8	6.0	9.4	38.0	100.0
52	0.0	2.4	21.0	19.6	5.8	9.6	41.6	100.0
53	0.0	2.0	19.2	18.2	5.6	9.6	45.4	100.0
54	0.0	1.7	17.4	16.9	5.3	9.5	49.2	100.0
55	0.0	1.4	15.8	15.5	5.0	9.3	53.0	100.0
56	0.0	1.2	14.2	14.1	4.7	9.1	56.7	100.0
57	0.0	1.0	12.8	12.8	4.3	8.7	60.4	100.0
58	0.0	0.9	11.4	11.5	3.9	8.3	64.0	100.0
59	0.0	0.7	10.3	10.2	3.6	7.7	67.5	100.0
60	0.0	0.6	9.2	9.1	3.2	7.2	70.7	100.0
61	0.0	0.5	8.2	8.0	2.9	6.6	73.8	100.0
62	0.0	0.4	7.4	7.0	2.5	6.1	76.6	100.0
63	0.0	0.4	6.5	6.1	2.2	5.6	79.2	100.0
64	0.0	0.3	5.8	5.3	2.0	5.0	81.6	100.0
65	0.0	0.3	5.1	4.6	1.7	4.5	83.8	100.0
66	0.0	0.2	4.6	4.0	1.4	4.0	85.8	100.0
67	0.0	0.2	4.0	3.5	1.2	3.6	87.5	100.0
68	0.0	0.2	3.5	3.0	1.1	3.1	89.1	100.0
69	0.0	0.1	3.2	2.5	0.9	2.8	90.5	100.0
70	0.0	0.1	2.8	2.2	0.8	2.4	91.7	100.0
71	0.0	0.1	2.5	1.8	0.7	2.1	92.8	100.0
72	0.0	0.1	2.2	1.5	0.6	1.8	93.8	100.0
73	0.0	0.1	1.9	1.3	0.5	1.6	94.6	100.0
74	0.0	0.1	1.7	1.1	0.4	1.4	95.3	100.0
75	0.0	0.1	1.4	1.0	0.3	1.2	96.0	100.0
76	0.0	0.0	1.4	0.8	0.2	1.1	96.5	100.0
77	0.0	0.0	1.2	0.7	0.2	0.9	97.0	100.0

Separate target populations were also derived for passenger cars and LTVs, and for crashes that occur on wet and dry pavement. These distinctions were necessary because stopping distance is strongly influenced by pavement conditions and vehicle characteristics. In addition, LTVs have significantly different levels of under-inflation than passenger cars and this impacts calculations of delta-V reductions. Note that the presence or absence of anti-lock brakes also has a significant influence on stopping distance. However, because reliable data on the presence of these systems is not included in crash databases, these differences will be accounted for at a different stage of the analysis. A total of 12 separate target population cells were thus produced. The fatalities and injuries for each cell are summarized in Table V- 4 for passenger cars and Table V-5 for LTVs. Table V-6 summarizes the target populations across all passenger vehicles.

Table V-4
Passenger Vehicle Occupants in Crashes Where
at Least One Passenger Car Used Brakes
1995-1999 CDS, Annual Average

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
WET								
0-35mph	85606	75611	6775	3101	275	163	362	171892
36-50mph	54150	68246	6886	3007	249	161	361	133060
51+mph	22209	23586	2391	1064	94	70	146	49560
DRY								
0-35mph	195969	180663	17018	7616	654	438	965	403322
36-50mph	218895	219066	20463	9123	860	480	1273	470158
51+mph	58407	73930	13700	5237	554	423	959	153208
Total	635236	641101	67233	29147	2685	1735	4064	1381201

Table V-5
Passenger Vehicle Occupants in Crashes Where
at Least One LTV Used Brakes
1995-1999 CDS, Annual Average

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
WET								
0-35mph	23345	27243	2621	1156	101	66	135	54668
36-50mph	34549	42404	3664	1729	121	95	212	82774
51+mph	8183	9810	1535	649	79	66	182	20503
DRY								
0-35mph	98640	99100	11291	4800	466	293	699	215290
36-50mph	87072	98763	12016	4985	460	341	911	204547
51+mph	44147	50883	9399	3687	412	321	726	109575
Total	295936	328204	40526	17006	1639	1182	2865	687358

Table V-6
Passenger Vehicle Occupants in Crashes Where
at Least One Vehicle Used Brakes
1995-1999 CDS, Annual Average

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
WET								
0-35mph	108951	102854	9396	4257	376	229	497	226561
36-50mph	88699	110650	10551	4736	370	256	573	215835
51+mph	30392	33396	3926	1712	173	136	328	70064
DRY								
0-35mph	294609	279763	28310	12416	1120	731	1664	618612
36-50mph	305966	317828	32478	14108	1320	821	2184	674705
51+mph	102554	124813	23098	8924	966	744	1684	262783
Total	931172	969305	107759	46153	4325	2917	6930	2068560

Preventable Crashes

The impact of small reductions in stopping distance will, in most cases, result in a reduction in the impact velocity, and hence the severity, of the crash. However, 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 benefits that would accrue from preventable crashes would only impact that portion of the fleet that:

a) Has low tire pressure, and
b) Would be notified by the TPMS
c) Is driven by drivers who will respond to the warning

Data from NHTSA's tire pressure survey (see Table III-1) indicate that 26 percent of passenger cars and 29 percent of LTVs have at least one tire that is 25 percent or more below recommended placard pressure. For these vehicles, notification of this under-inflation would not be given until the system is triggered. For example, under the proposed requirements, a direct TPMS will trigger at 25% below placard pressure, or roughly 22.5 psi for passenger cars and 26.25 psi for trucks. The portion of the vehicle fleet that is below these levels will potentially experience some reduction in crash incidence due to improved stopping distance. However, in order to experience this reduction in stopping distance, the driver must respond to the warning. For the March 2002 Final Economic Assessment, NHTSA assumed that 95 percent would respond to a warning and refill their tires back to the placard level.

Preliminary results from a recent survey conducted to determine consumer reaction to existing TPMS systems indicated that in 95% of cases where vehicles had direct systems, the drivers responded by taking appropriate action. These preliminary survey results thus validate NHTSA's initial assumption. However, the vehicles that have existing TPMS tend to be more expensive luxury vehicles that are typically purchased by upper income populations. Since these groups are typically more safety conscious than lower income groups, it is likely that the survey results imply a lower level of response for the overall driving public. Based on this, the overall response rate across all income groups will be estimated to be 90%.

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 the existing crash-involved vehicle fleet, and for that fleet if they had correct tire inflation pressure. The method used to calculate these stopping distances is described later in this section of the analysis. The results indicate that the existing passenger car fleet would, on average, experience a stopping distance of 86.5 feet, while the crash-involved LTV fleet experienced an average stopping distance of 91.9 feet. These differences between passenger car and LTV stopping distances reflect the distribution of injuries by speed and road conditions for each vehicle type. By contrast, the average stopping distance for passenger cars with correctly inflated tires would be 85.2 feet, while for LTVs it would be 90.7 feet.

In theory, current crashes occur under a variety of stopping distances but if these distances were shortened due to improved inflation pressure then a portion of these crashes would be prevented. Crashes could be prevented over a variety of travel speeds and braking distances. For example, a vehicle might be able to avoid an intersection crash by slowing quickly enough to miss a speeding vehicle running a red light. In an angular head-on crash, better braking could reduce the chance of two vehicles striking their corners, given that crash avoidance maneuvers are also taking place. An example for rear impacts could involve sudden braking to avoid a vehicle swerving to cross lanes on an interstate highway. We anticipate that a large portion of the fatality and serious injury benefits for crash avoidance would occur in intersection crashes, since both vehicles are moving at high speeds, and a small change in braking efficiency could result in the avoidance of a high-impact crash.

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. Under this assumption, the change in stopping distance under proper inflation conditions can be used as a proxy for the portion of crashes that are preventable. 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 correct pressure represents the portion of crashes that are preventable. For passenger cars, this portion is (86.5-85.2)/86.5 or 1.38 percent of all current crashes. For LTVs, this portion is (92.0-90.7)/92.0 or 1.36 percent.

Benefits from preventable crashes were thus calculated as follows:

$Ip_{(s)}=Pp*I_{(s)}*Pu*Pr$

Where,

$Ip_{(s)}$ = Preventable injuries of severity (s)

Pp = portion of crashes that are preventable

$I_{(s)}$ = Existing injuries of severity (s)

Pu = portion of vehicles with under-inflated tires that will receive notification from TPMS

Pr = portion of drivers who will respond to the TPMS notification

The results of this analysis are shown for passenger cars under Compliance Options 2 and 3 in Table V-7. The results for LTVs are shown in Table V-8, and for all passenger vehicles Table V-9. Results for Compliance Option 1 will be summarized at the end of this section, but will not be demonstrated. Note that these results have been adjusted to reflect a small amount of overlap that occurred in the separate examination of passenger car and LTV crashes, as well as potential overlap with "loss of control" crashes, which are accounted for separately in a previous section. A combined adjustment factor of .959 was applied to account for this overlap. This factor was derived by comparing the sum of the two separate crash counts to a total count based on all passenger vehicles. These estimates were also adjusted to reflect the impact of threshold braking, as well as current compliance. These concepts are discussed in detail in the following section on non-preventable crashes.

The benefits from preventable crashes, shown in Tables V-7, 8 and 9 were assumed to occur over all crash types and severities. This assumption recognizes that there are a variety of crash circumstances for which marginal reductions in stopping distance may prevent the crash from occurring. 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 collisions. 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. In a head-on collision, both vehicles are moving toward the crash and a reduction in stopping distance for one vehicle may be less likely to avoid a high-speed crash than in the case discussed above for side impacts. Further, if a separate analysis were conducted for different crash types and severities, the portion of crashes prevented would be greater for crashes at higher speeds. However, NHTSA does not have sufficient information to conduct a separate analysis of each crash circumstance and has used an overall estimate across all crash types instead.

Note that this analysis only addresses injury crashes. Property-damage-only crashes would also be impacted by proper tire inflation. These crashes are addressed separately in a later section of this analysis.

Table V-7
Potential Benefits from Preventable Crashes,
Passenger Cars Adjusted for Properly Inflated Vehicles,
90% Response Rate, Overlap, Threshold Braking and Current Compliance
Compliance Option 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	170	-150	-13	-6	-1	0	-1
36-50mph	108	-136	-14	-6	0	0	-1
51+mph	44	-47	-5	-2	0	0	0
DRY							
0-35mph	210	-194	-18	-8	-1	0	-2
36-50mph	235	-235	-22	-10	-1	-1	-2
51+mph	63	-79	-15	-6	-1	0	-2
Total	829	-840	-87	-38	-3	-2	-7

NOTE: Negative signs indicate reductions in injury levels.

Table V-8
Potential Benefits from Preventable Crashes, LTVs
Adjusted for Properly Inflated Vehicles,
90% Response Rate, Overlap, and Threshold Braking

Compliance Option 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	53	-62	-6	-3	0	0	0
36-50mph	79	-97	-8	-4	0	0	-1
51+mph	19	-22	-4	-1	0	0	0
DRY							
0-35mph	122	-122	-14	-6	-1	0	-1
36-50mph	107	-122	-15	-6	-1	0	-2
51+mph	54	-63	-12	-5	-1	0	-1
Total	434	-488	-58	-25	-2	-2	-6

NOTE: Negative signs indicate reductions in injury levels.

Table V-9
Potential Benefits from Preventable Crashes, All Passenger Vehicles
Adjusted for Properly Inflated Vehicles,
90% Response Rate, Overlap, and Braking Threshold

Compliance Options 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	223	-212	-19	-9	-1	0	-1
36-50mph	186	-232	-22	-10	-1	-1	-1
51+mph	63	-69	-8	-4	0	0	-1
DRY							
0-35mph	332	-316	-32	-14	-1	-1	-3
36-50mph	342	-357	-37	-16	-1	-1	-4
51+mph	117	-142	-26	-10	-1	-1	-3
Total	1263	-1328	-145	-62	-6	-4	-13

Non-Preventable Crashes

In the vast majority of crashes, small changes in stopping distance will not prevent the crash, but will reduce the speed at impact and thus the severity of the crash. As noted above, 1.38 percent of braking passenger cars and 1.36 percent of braking trucks could have avoided crashes with proper tire inflation. The remaining 98.6 percent of passenger car and LTV crashes would still occur, but at a reduced impact speed. To estimate the impact of reduced crash speeds, changes in stopping distance will be estimated and used as inputs to recalculate impact speeds for the population of non-preventable crashes. These changes in impact speeds will then be used to redefine the injury profile of this crash population shown in Table V-3, and safety benefits will be calculated as the difference between the existing and the revised injury profiles.

Stopping Distance

Stopping distance can be computed as a function of initial velocity and tire friction. The formula for computing stopping distance is as follows:

$SD = Vi^2/(2*g*Mu*E)$

Where:

SD =Stopping Distance (in feet)

Vi = initial velocity (mean speed limit for specific data group + 5 mph)

g = gravity constant (32.2 ft/second squared)

Mu = tire friction constant (ratio of friction force/vertical load)

E = ABS braking efficiency (estimated @ 0.8)

About a third of all passenger vehicles sold in the U.S. do not have anti-lock brakes, although the portion is higher in the on-road fleet. For these regular braking systems, the term for anti-lock brake efficiency (E) would not be used.

Calculating Mu

The value of Mu is dependent on surface material (concrete, asphalt, etc.), surface condition (wet vs. dry), inflation pressure, and initial velocity. Based on data provided by The Goodyear Tire and Rubber Company in response to the NPRM, NHTSA developed a model that predicts Mu based on Vi and inflation pressure. Separate models were developed for Mu at both peak (the maximum level of Mu achieved while the tire still rotates under braking conditions) and slide (the level of Mu achieved when tires cease to rotate while braking (i.e., skid)). The peak models are used for vehicles with antilock brake systems. The slide models are appropriate for vehicles with non-antilock brake systems. The models are as follows:

For Wet surface conditions

$Mp = 0.83140+(.0037109*ip)-(0.0038408*Vi)+(0.000023292*Vi^2)$

$Ms = 0.55093+(0.0029423*ip)-(0.0036979*Vi)-(0.000020146*Vi^2)$

For Dry surface conditions

$Mp = 0.978764+(.002557*ip)-(0.005542*Vi)+(0.0000470863*Vi^2)$

$Ms = 0.717073+(0.000618*ip)-(0.005242*Vi)+(0.000082917*Vi^2)$

Where:

Mp = Mu peak value

Ms = Mu slide value

ip = inflation pressure (psi)

V_i = initial vehicle speed (mph)

Note that the wet surface condition model is based on 2 separate models. One was derived from the Goodyear tests conducted with .05 inches of water, and one with .02 inches of water. As noted previously, data from NOAA (See Docket No. 8572-167) indicate that only about 10 % of rainfall events occur at rates that would be necessary to produce .05 inches of water on road surfaces. The 2 wet condition models were therefore weighted to produce a single model based on weights of 90% for the .02 inch model and 10% for the .05 inch model

Mu Surface Adjustments

The above formulae were derived from tests conducted on a Traction Truck surface (this is a specific surface calibrated to specifications of OEM customers). In order to relate them to real world surfaces, predicted values from the formulas were compared to actual test results obtained using the same tires mounted on vehicles. The vehicles used were a Dodge Caravan with a 215/70R15 Integrity tire, and a Ford Ranger with a P235/75R15 Wrangler tire. Generally, the Integrity tests were intended to represent passenger cars while the Wrangler tests were intended to represent LTV performance. The tests were all run with an initial velocity of 45 mph, with braking measured down to 5 mph. Goodyear did not record data to a complete stop. In order to compare the predicted stopping distance results from the Mu regressions to real world results, braking distance was measured using the following equation:

$SD = (Vi^2 - Vii^2)/(2*g*Mu*E)$

Where:

SD = braking distance

Vi = initial speed before braking

Vii = speed to which vehicle braking is measured

This is a simple modification of the formula previously discussed for stopping distance. The Vii term is necessary to adjust for the 5 mph braking limit in the vehicle tests. Mu peak and slide values were estimated for each of the 3 psi levels used in the Goodyear vehicle tests at 45 mph. The resulting predicted SDs were then compared to the actual stopping distance found in the corresponding vehicle tests. The actual SDs were weighted to reflect an average of the full and half tread tests. Weighting factors for the actual SDs were derived from tread depth data obtained in NHTSA's tire inflation survey. Full tread for the Integrity tire (assumed to represent passenger tires) was 10/32 inch and half tread was 5/32 inch. For the Wrangler tire (assumed to represent LTVs), full tread was 13/32 inch and half tread was 6.5/32 inch). Data from the NHTSA survey indicate that about 2/3 of all vehicle tires had tread depths more similar to the ½ tread level and about 1/3 had tread depths more similar to the full depth levels.

A comparison of the predicted and actual weighted SDs indicated close similarity across the three different psi levels. Therefore, factors were averaged across the 3 levels. However, they differed significantly by tire type, surface condition, and for peak vs. slide. Overall, the results of this comparison indicate that factors of from roughly 1.3 to 1.8 are required to adjust the stopping distances predicted using the Mu-based algorithms. The Wrangler factors were applied to LTV estimates and the Integrity factors were applied to passenger car estimates. Wet and dry factors were also applied to their corresponding cases. Peak factors were applied to vehicles with antilock brakes, while slide factors were applied to vehicles without antilock brakes. The factors used are summarized in Table V-11.

Table V-11
Vehicle Surface Adjustment Factors

	Wrangler	Integrity
Wet Peak	1.8379	1.7246
Wet Slide	1.4856	1.2709
Dry Peak	1.7586	1.6260
Dry Slide	1.5954	1.5203

Anti-lock and Normal Braking Systems

Roughly 2/3 of all passenger vehicles sold in the U.S. have anti-lock brakes, but the portion is smaller in the on-road fleet. For vehicles with anti-lock brake systems, Mp is used to calculate stopping distance because it represents the peak controlled braking force that anti-lock brakes attempt to maintain. For vehicles with regular brake systems, Ms is used because it represents the level of friction encountered under normal braking by most drivers without assistance from anti-lock brakes. Also, for these regular braking systems, the term for anti-lock brake efficiency (E) would not be used.

Delta-V

Changes in stopping distances were then used to calculate the decrease in crash forces (measured by delta-V) that would occur due to the decrease in striking velocity of the vehicle. The formula used to calculate striking velocity is:

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

Where:

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

Vi = initial velocity before braking

a = deceleration

d = distance traveled during braking of vehicle

In this case, $V_{(d)}$ is a measure of the speed at which the vehicle with under-inflated tires would be traveling when it reaches the distance at which it would have stopped had its tires been correctly inflated (d). Deceleration (a) is calculated for the vehicle with under-inflated tires. The derived formula for deceleration is:

$$a = (V(d)^2 - Vi^2)/(2*d)$$

Since V = 0 at d, the formula becomes:

$a = (Vi^2)/(2*d)$ (the negative sign that would precede the formula indicates deceleration and will be ignored from this point on)

The distance over which a is calculated is the stopping distance for the vehicle with under-inflated tires. This will be designated as SDu. The formula thus becomes:

$a = (Vi^2)/(2*SDu)$

Where:

SDu = stopping distance with under-inflated tires

The striking velocity is then expressed in mph by multiplying by 1/ 5280 ft.*3600 sec. hour. The delta-V experienced by each vehicle would be dependent on vehicle mass. For this analysis, the mass of each vehicle was assumed to be equal, giving a delta-V of 1/2 V(d) for each vehicle or:

DELTA-V = (V(d)*3600/5280)/2

Where:

DELTA-V = the change in velocity resulting from increased tire pressure.

The base case target population represents the injury profile that results from the fleet of passenger vehicles that were on the road at that time. In order to determine the inflation pressure that exists in that fleet, NHTSA conducted a survey of both recommended and actual inflation pressures on vehicles. (Details of that survey are discussed elsewhere in this analysis). The results of the survey indicate that 74% of all passenger vehicles are driven with under-inflated tires. However, because TPMS would not notify drivers of low pressure until it dropped 25% below placard, no stopping distance benefits would accrue to vehicles with smaller tire pressure deficits. Weighting factors were derived from the tire pressure survey to represent the affected population under this requirement. The distribution of each level of under-inflation is shown in Table V-12. The left column indicates the average under-inflation of the 4-tires, given that one tire was under-inflated by 25 percent or more.

Table V-12
Percent of Vehicles Under-inflated 25% or more below Placard Level

Under-Inflated Pressure (psi)	Percent Under-Inflated PCs	Percent Under-Inflated LTVs
-1	0.2%	0.2%
-2	7.4%	4.9%
-3	11.2%	6.0%
-4	11.8%	8.2%
-5	13.7%	8.4%
-6	12.3%	13.1%
-7	12.2%	11.2%
-8	9.7%	11.2%
-9	7.4%	8.5%
-10	4.8%	7.6%
-11	3.1%	5.1%
-12	2.4%	3.5%
-13	1.3%	2.2%
-14	0.6%	1.6%
-15	0.8%	0.9%
-16	0.4%	1.7%
-17	0.2%	1.0%
-18	0.1%	0.7%
-19	0.0%	0.4%
-20	0.1%	0.4%
-21	0.1%	0.4%
-22	0.1%	0.3%
-23	0.0%	0.4%
-24	0.1%	0.4%
-25	0.0%	0.3%
-26	0.1%	0.2%
-27	0.0%	0.3%
-28	0.0%	0.1%
-29	0.1%	1.3%
Total	100.0%	100.0%

As noted previously, the value of Mu in the formula for stopping distance is dependent on inflation levels. For each speed limit category, a set of delta-Vs corresponding to each under-inflation level was calculated. In each case, an average placard pressure of 30 psi was assumed for passenger cars. For LTVs, an average pressure of 35 psi was assumed. The rates of under-inflation in Table V-12 were used to weight the change in delta-V that results from each corresponding psi under-inflation level to an overall weighted average change across all levels. The resulting changes in delta-V are summarized in Table V-13 for each passenger car and LTV target population category for vehicles with ABS systems, non-ABS systems and combined systems, based on weighting factors representing the relative portion of the vehicle fleet that has Anti-lock brakes. Note that these estimates do not reflect any impact for vehicles with inflation levels that are less than the assumed set point for the TPMS system. This analysis assumes a set point of 25 percent below the placard pressure, or 7.5 psi based on the assumption of a 30 psi recommended pressure. Benefits would only accrue to those tires that are more than 7.5 psi beneath their recommended pressure. For LTVs, benefits would accrue for those tires that are more than 8.75 psi beneath their recommended pressure.

Table V-13
Weighted Average Reductions In Delta-V
from Improved Tire Inflation Pressure

Alternative 3

		Anti-lock	Non-Anti-lock	Combined
Passenger Cars				
Wet Pavement				
	0-35mph	2.858	3.342	3.018
	36-50mph	4.065	5.092	4.404
	51+mph	5.196	7.151	5.841
Dry Pavement				
	0-35mph	2.263	1.319	1.952
	36-50mph	3.208	1.814	2.748
	51+mph	4.068	2.213	3.456
LTVs:				
		Anti-lock	Non-Anti-lock	Combined
Wet Pavement				
	0-35mph	3.185	3.710	3.358
	36-50mph	4.530	5.637	4.895
	51+mph	5.789	7.886	6.481
Dry Pavement				
	0-35mph	2.533	1.483	2.187
	36-50mph	3.589	2.040	3.078
	51+mph	4.406	2.488	3.773

Calculation of Safety Benefits

Safety benefits were calculated by reducing the delta-V for each injury by the appropriate level for each specific target population category shown in Table V-13. The injury totals for each delta-V category were redistributed according to the injury probabilities of the reduced delta-V level. This resulted in a new injury profile. Totals for each injury severity category were then compared to the original injury totals to produce the net benefits from reducing delta-Vs. An example of the original target population distribution and the revised distribution is shown in Tables V-14 and V-15. Note that the revised distribution shown in Table V-15 represents a whole number delta-V change (in this case, 6 delta-V). Since actual average reductions were fractional, interpolation was used to calculate the results of the fractional reductions. These interpolated results are reflected in Table V-16. Table V-20 summarizes the results for all scenarios for passenger cars under Compliance Alternative 2.

By comparing current tire pressure levels to placard, benefit estimates reflect raising pressure levels to the placard level and retaining them there. However, over time tire pressure will drop back down to the threshold notification level again and drivers will again fill their tires to the placard level. Over time, the benefit that drivers obtain will be an average of the benefits from the various levels above the notification threshold. For this analysis, it was assumed that pressure loss is roughly constant at one psi per month and a revised average psi level was calculated for passenger cars and LTVs under each Alternative. These averages were previously shown in Table V-1x. Under the assumption that there is a reasonable correspondence between changes in delta-V and safety benefits, changes in Delta-V were recalculated based on the averages in Table V-1x. This was done by substituting the new average psi levels for the placard pressure in previous calculations. An additional adjustment was made to reflect the impact on that portion of the fleet for which at least one tire was below the notification threshold, but for which the average psi across all 4 tires fell above the revised average psi level but below the placard level. This was done because these cases would be excluded by calculations based on 4 tire average psi levels below placard. The output from this process was a set of factors that were used to modify the results. These factors typically reduced benefit calculations based on full placard inflation levels to about 60% of their full placard level. The results of applying these factors are shown in Table V-21.

Adjustments to Non-Preventable Crash Safety Benefits

A number of adjustments must be made to the benefit estimates in Table V-19. These include:

1) Adjustment for crash braking distance distribution
2) Adjustment for portion of vehicle fleet with no under-inflation or under-inflation less than notification level
3) Adjustment for driver response
4) Adjustment for target population overlap travel speeds.
5) Adjustment for braking threshold
6) Adjustment for current compliance.

Table V-14
Passenger Cars, Original Injury Distribution
>=51 MPH Speed Limit, Wet 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	280	59	2	2	0	0	0	345
5	69	20	1	1	0	0	0	91
6	359	134	5	4	1	0	1	503
7	921	433	18	12	1	0	1	1387
8	4158	2414	101	74	7	0	7	6761
9	3762	2618	132	79	0	7	7	6611
10	1113	922	51	28	2	2	2	2121
11	3889	3800	226	121	8	8	8	8068
12	1372	1555	105	50	6	0	6	3097
13	3015	3953	290	149	7	7	15	7444
14	551	826	68	33	3	1	3	1486
15	731	1242	119	52	4	2	6	2156
16	528	1006	111	44	5	2	5	1702
17	1169	2494	314	120	12	8	12	4129
18	0	0	0	0	0	0	0	0
19	141	369	61	22	2	1	3	600
20	81	231	44	15	2	1	2	376
21	265	824	181	61	7	4	8	1351
22	161	544	139	45	5	4	6	905
23	7	25	7	2	0	0	0	42
24	1	2	1	0	0	0	0	4
25	17	68	27	8	1	1	1	123
26	39	162	75	23	2	2	4	307
27	30	131	71	22	2	2	4	262
28	2	7	4	1	0	0	0	15
29	51	232	170	53	6	5	11	529
30	0	0	0	0	0	0	0	0
ETC.								
Total	22717	24126	2446	1088	96	72	149	50726

Table V-15
Passenger Cars, Modified Injury Distribution
>=51 MPH Speed Limit, Wet Pavement

Delta-V	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
-5	0	0	0	0	0	0	0	0
-4	0	0	0	0	0	0	0	0
-3	0	0	0	0	0	0	0	0
-2	345	0	0	0	0	0	0	345
-1	91	0	0	0	0	0	0	91
0	503	0	0	0	0	0	0	503
1	1326	49	6	4	1	0	0	1387
2	6153	541	27	27	0	7	0	6761
3	5705	826	33	33	0	7	0	6611
4	1724	365	15	15	0	2	0	2121
5	6156	1767	73	56	0	0	8	8068
6	2208	824	31	25	3	0	3	3097
7	4943	2323	97	67	7	0	7	7444
8	914	531	22	16	1	0	1	1486
9	1227	854	43	26	0	2	2	2156
10	894	740	41	22	2	2	2	1702
11	1990	1945	116	62	4	4	4	4129
12	0	0	0	0	0	0	0	0
13	243	319	23	12	1	1	1	600
14	140	209	17	8	1	0	1	376
15	458	778	74	32	3	1	4	1351
16	281	535	59	24	3	1	3	905
17	12	26	3	1	0	0	0	42
18	1	3	0	0	0	0	0	4
19	29	75	12	5	0	0	1	123
20	66	188	36	13	1	1	2	307
21	51	160	35	12	1	1	2	262
22	3	9	2	1	0	0	0	15
23	86	311	92	30	3	2	5	529
24	0	0	0	0	0	0	0	0
25	3	13	5	2	0	0	0	23
26	8	32	15	5	0	0	1	61
27	0	0	0	0	0	0	0	0
Etc.								
Total	35561	13478	976	538	39	38	61	50726
Difference	12844	-10648	-1470	-550	-58	-34	-88	0

Table V-16
Estimated Non-Preventable Passenger Car Stopping Distance Impacts
Compliance Options 2 and 3 , Unadjusted

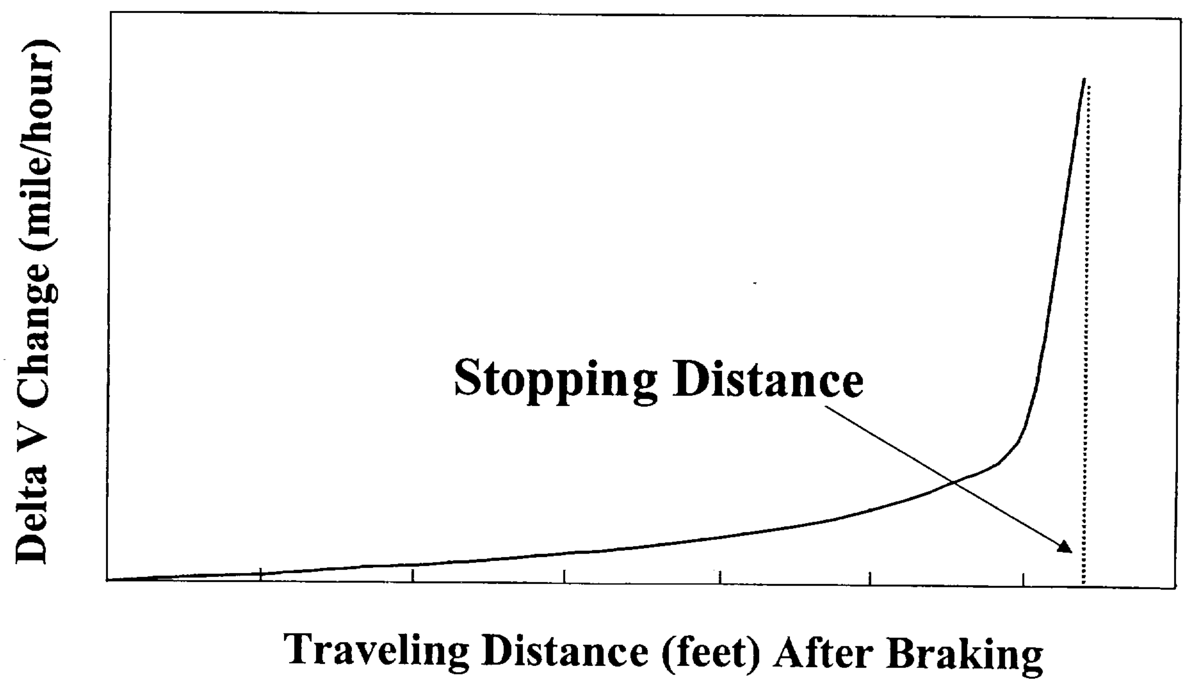
	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	13915	-11488	-1670	-580	-72	-19	-112
36-50mph	14789	-11549	-2226	-764	-81	-40	-137
51+mph	7812	-6463	-904	-336	-34	-22	-65
DRY							
0-35mph	20496	-16330	-2858	-969	-111	-63	-164
36-50mph	33476	-26821	-4616	-1502	-222	-49	-321
51+mph	11889	-7517	-2907	-1001	-123	-92	-295
Total	102377	-80168	-15180	-5153	-644	-284	-1093

Braking Distance Distribution

Table V-16 represents safety impacts that would occur from the reduced stopping distance of a tire at the point where it would stop if pressure were corrected. It represents the maximum change in delta-V that would occur in cases where the actual braking distance in the crash just equals the correct stopping distance. In reality, crashes occur over a variety of braking distances, and the change in delta-V is a direct function of this distance. This relationship is illustrated in Figure V-2 below. The change in delta-V is virtually non-existent in crashes where braking distance is minimal, but becomes significant as the distance traveled during braking increases.

Figure V-2

Generalized Relationship Between Change in Delta-V and Traveling Distance



To account for the variety of possible outcomes, a factor was calculated based on the relationship between calculated delta-V changes and travel distance. The techniques used to calculate this factor are fully described in Appendix A. The results indicate that the impacts over the variety of travel speeds would be about 7 percent of those based on maximum impact for both passenger cars and for LTV's.

Properly Inflated Vehicles

As previously mentioned, 26 percent of all vehicles have no tires under-inflated. In addition, many vehicles have a level of under-inflation that would not trigger a warning from the TPMS. The target population used in the above calculations assumes a full fleet of under-inflated vehicles and must be adjusted for the portion of the fleet that is not under-inflated, and that will be notified of the problem. The portions differ by Alternative and vehicle type. Based on NHTSA's tire pressure survey 26 percent of passenger cars and 29 percent of light trucks would benefit from a TPMS.

Driver Response

Table V-16 also represents the benefits that would accrue if all drivers responded immediately to the TPMS and inflated their tires to the proper level. Since this is unlikely to occur, an adjustment was made to represent the driver response rate, which, based on preliminary results from a survey of TPMS equipped vehicles, the agency estimates to be 95 percent.

Overlapping Target Populations

As previously noted separate target populations were derived for passenger cars and light trucks because the under-inflation profile is different for these vehicle types. These populations were stratified based on the vehicle braking. However, a comparison of the two separate injury counts to a single count done for any passenger vehicle indicated that a small amount of double counting resulted from a simple addition of the two separate braking vehicle populations. Based on this comparison, an adjustment factor of .9685 was applied to the benefit estimates to eliminate the overlap. In addition, there is potential overlap between the target population examined here and the one used to calculate "out of control" crash impacts earlier in this analysis. To adjust for this overlap, an analysis of overlapping cases was conducted and an adjustment of 1% (i.e., a factor of .99 was applied) was made to reflect these cases.

Driver Response- Braking Threshold

When drivers are faced with potential crash circumstances, they apply their brakes at a rate that reflects both their perceptions of the need to stop and the vehicles actual response to this need. Theoretically, braking systems should be capable of the needed response, if drivers apply it, up to a threshold at which the tires loose their friction capabilities. On dry pavement, this would occur when tires exceed their peak coefficient of friction and start to skid rather than grip the pavement. In this analysis, it will be assumed that during emergency braking, all potential inadequacies in braking performance, including those caused by underinflated tires, will be perceived by drivers and that they will respond by applying more pressure to the brakes to compensate. Under these circumstances, any small impacts to stopping distance due to changes in the tire pressure that would occur prior to skidding on dry pavement would be compensated for by the driver. However, when skidding occurs, the driver can no longer compensate for such changes. To reflect this, CDS data from 1995-1999 was examined to determine what portion of fatalities and injuries occurred in crashes in which skidding occurred on dry surfaces. This analysis indicated that 72% of fatalities and 54% of injuries that occurred on dry pavement happened in crashes with skidding. On dry pavement, only these crashes with skidding would benefit from the TPMS. These factors were thus applied to all dry pavement stopping distance benefits. Given the high level of skidding involved on dry pavement, this analysis assumes that all crashes that occur on wet pavement involve some level of skidding and thus would benefit from TPMS. This may slightly overstate the impacts of TPMS in wet pavement crashes.

Current Compliance

About one percent of the new car fleet already has a direct monitoring system. This portion of the fleet would not require costs or experience benefits from this rulemaking. A total of 5 percent of the fleet has either an indirect system (4%) or a direct system (1%). However, the indirect systems would not meet the requirements of this proposal.

The above 6 adjustments were accomplished by multiplying the results in Table V-16 by factors of .07, .26, .95, .9589, .72 or .54 (dry pavement only), and .99 to account for current compliance. Similar adjustments were made for each vehicle type and Compliance Option. Table V-17 summarizes the total adjusted non-preventable crash benefits for passenger cars under Compliance Option 2. Table V-18 summarizes the benefits from non-preventable crashes under Compliance Option 2 for LTVs. Table V-19 summarizes the non-preventable benefits for all vehicle types under Compliance Option 2. Table V-20 summarizes total safety benefits for all crashes (Preventable and Non-Preventable) for passenger cars under Option 2. Table V-21 summarizes the Total safety benefits for all crashes for LTVs under Option 2. Table V-22 summarizes the total potential stopping distance impacts for all crashes and all vehicle types under Option 2. Note that safety benefits would be identical for Compliance Options 2 and 3. Table V-23 shows the potential stopping distance impacts across all crashes and vehicles for Compliance Option 1, which assumes a continuous readout of tire pressure is provided.

The results indicate a potential safety impact under Compliance Options 2 and 3 of 40 fatalities eliminated and roughly 3,500 nonfatal injuries prevented or reduced in severity from improved stopping distance. The safety impact of Compliance Option 1 would be 43 fatalities and about 3,700 nonfatal injuries prevented

Table V-17

Estimated Non-Preventable Passenger Car Stopping Distance Impacts
Adjusted for Properly Inflated Vehicles,
Delta-V Distribution, 90% Response Rate, Overlap, Threshold Braking and Current Compliance
Compliance Options 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	216	-179	-26	-9	-1	0	-2
36-50mph	230	-180	-35	-12	-1	-1	-2
51+mph	121	-100	-14	-5	-1	0	-1
DRY							
0-35mph	172	-137	-24	-8	-1	-1	-2
36-50mph	281	-225	-39	-13	-2	0	-4
51+mph	100	-63	-24	-8	-1	-1	-3
Total	1121	-884	-162	-55	-7	-3	-14

Table V-18
Estimated Non-Preventable LTV Stopping Distance Impacts,
Adjusted for Properly Inflated Vehicles,
Delta-V Distribution, 90% Response Rate, Overlap, Threshold Braking and Current Compliance
Compliance Options 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	85	-66	-13	-4	0	0	-1
36-50mph	193	-157	-24	-9	0	-1	-1
51+mph	57	-42	-9	-3	0	0	-1
DRY							
0-35mph	115	-87	-19	-6	-1	0	-2
36-50mph	150	-112	-26	-9	-1	-1	-3
51+mph	93	-62	-20	-7	-1	-1	-3
Total	693	-527	-111	-39	-4	-3	-11

Table V-19
Total Estimated Non-Preventable Stopping Distance Impacts, All Passenger Vehicles
Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 90% Response Rate,
Overlap, Threshold Braking, and Current Compliance
Compliance Options 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	301	-245	-39	-13	-2	-1	-2
36-50mph	423	-337	-59	-21	-2	-1	-4
51+mph	179	-143	-23	-9	-1	-1	-2
DRY							
0-35mph	287	-224	-43	-15	-2	-1	-4
36-50mph	432	-337	-65	-21	-3	-1	-6
51+mph	193	-125	-45	-16	-2	-2	-6
Total	1814	-1411	-273	-94	-11	-6	-25

Table V-20
Total Estimated Stopping Distance Impacts, Passenger Cars
Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 90% Response Rate, Overlap, Threshold Braking, and Current Compliance
Compliance Options 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	386	-329	-39	-15	-2	-1	-3
36-50mph	337	-315	-48	-18	-2	-1	-3
51+mph	166	-147	-19	-7	-1	0	-1
DRY							
0-35mph	382	-331	-42	-16	-2	-1	-3
36-50mph	516	-460	-61	-22	-3	-1	-6
51+mph	162	-142	-39	-14	-2	-1	-5
Total	1950	-1725	-249	-93	-10	-5	-21

Table V-21
Total Estimated Stopping Distance Impacts, LTVs
Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 90% Response Rate, Overlap, Threshold Braking, and Current Compliance
Compliance Options 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	138	-129	-19	-7	-1	0	-1
36-50mph	272	-254	-32	-13	-1	-1	-2
51+mph	76	-65	-13	-5	-1	-1	-2
DRY							
0-35mph	236	-209	-33	-12	-1	-1	-3
36-50mph	258	-233	-41	-15	-1	-1	-4
51+mph	147	-124	-32	-12	-1	-1	-4
Total	1127	-1015	-170	-64	-6	-5	-17

Table V-22
Total Estimated Stopping Distance Impacts, All Passenger Vehicles
Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 90% Response Rate, Overlap, Threshold Braking, and Current Compliance
Compliance Options 2 and 3

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	524	-457	-58	-22	-2	-1	-4
36-50mph	610	-569	-81	-31	-2	-2	-5
51+mph	241	-212	-32	-12	-1	-1	-3
DRY							
0-35mph	618	-540	-75	-29	-3	-2	-7
36-50mph	774	-694	-102	-37	-4	-2	-10
51+mph	310	-267	-71	-26	-3	-2	-9
Total	3077	-2739	-418	-157	-17	-10	-38

Table V-23
Total Estimated Stopping Distance Impacts, All Passenger Vehicles
Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 90% Response Rate, Overlap, Threshold Braking, and Current Compliance
Compliance Option 1

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	557	-485	-61	-23	-2	-1	-4
36-50mph	644	-602	-85	-32	-3	-2	-5
51+mph	256	-225	-34	-13	-1	-1	-3
DRY							
0-35mph	655	-572	-79	-30	-3	-2	-7
36-50mph	820	-735	-108	-40	-4	-2	-11
51+mph	327	-282	-75	-27	-3	-3	-10
Total	3258	-2900	-442	-166	-17	-11	-40

Flat tires and Blowouts

There are many factors that influence crashes of these types. For blowouts, there is speed, tire pressure, and the load on the vehicle. Blowouts to the front tire can cause roadway departure, or can cause a lane change resulting in a head-on crash. Blowouts in a rear tire can cause spinning out and loss of control. As discussed in the target population section, a target population can be estimated for tire problems, but the agency doesn't know how many of these crashes are influenced by under-inflation. However, reducing under-inflation will be a real benefit in reducing flat tires and blowouts. The agency's best estimates of these effects are discussed below.

The target population is 414 fatalities and 10,275 non-fatal injuries that occur annually in light vehicles in which the cause of the crash is a flat tire/blowout. It is difficult to determine the impacts of under-inflation. Puncture is the most common reason for a blowout. However, there are also many cases where a tire is punctured, loses air, and then fails later after being driven a distance under-inflated. In these cases, a TPMS would provide information of the low tire pressure before the tire failed. We are assuming that under-inflation is involved in 20 percent of the cases that caused the crash. At the same time, we realize that the influence that under-inflation has on the chances of a blowout are influenced by the properties of the tire. Thus, we believe that better tires could take care of 50 percent of this problem and are assigning this value to the tire upgrade rulemaking. In conclusion, it is estimated that 41 fatalities (414 x .2 x .5) and 1,028 injuries are caused annually by flat tires/blowouts, where under-inflation is the cause of the flat tire/blowout. At the same time we estimate that there are 41 fatalities and 1,028 injuries in the target population for better tires brought about by the tire upgrade rulemaking.

The agency assumes that 90 percent of drivers will fill their tires back to placard pressure when given a warning. For this situation, the agency does not believe that the steady state analysis has any impacts on the benefits. Any tire above the warning level is not very susceptible to a flat tire, and it probably doesn't matter whether the tire is at a placard level of 30 psi or at a steady state level of say 27 psi in terms of its likelihood of failing due to a flat tire. We also apply a .99 factor to take into account the one percent of the fleet that already has a direct measurement system.

Thus, the benefits for flat tires/blowouts for Compliance Options 1 through 3 are the same:
37 lives saved (41 x .90 x .99) and 916 injuries reduced (1,028 x .90 x .99)
Non-fatal injuries are divided into the AIS levels based on the injury levels in 1995-98 NASS-CDS distribution of injuries in vehicles with flat tires causing the crash. These are: AIS 1 = 80.1 percent, AIS 2 = 14.4 percent, AIS 3 = 3.5 percent, AIS 4 = 1.5 percent, AIS 5 = 0.5 percent.

Total Quantifiable Safety Benefits

Table V-24 provides the total quantifiable safety benefits by Compliance Option adding together the benefits for skidding/loss of control, stopping distance, and flat tires/blowouts.

Table V-24
Quantifiable Safety Benefit Impacts

	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Non-Fatal Total	Fatal
Opt 1							
Skid	-3,529	-393	-168	-16	-10	-4,116	-44
Stop	-2,900	-442	-166	-17	-11	-3,536	-40
Flat	-733	-132	-32	-14	-5	-916	-37
Total	-7,162	-967	-366	-47	-26	-8,568	-121
Opt 2							
Skid	-3,529	-393	-168	-16	-10	-4,116	-44
Stop	-2,739	-418	-157	-17	-10	-3,341	-38
Flat	-733	-132	-32	-14	-5	-916	-37
Total	-7,001	-943	-357	-47	-25	-8,373	-119
Opt 3							
Skid	-3,529	-393	-168	-16	-10	-4,116	-44
Stop	-2,739	-418	-157	-17	-10	-3,341	-38
Flat	-733	-132	-32	-14	-5	-916	-37
Total	-7,001	-943	-357	-47	-25	-8,373	-119

Fuel Economy Benefits

Correct tire pressure will improve a vehicles' fuel economy. Current radial tires are a vast improvement over the old-fashioned bias-ply tires, yet they still use more fuel when they are run under-inflated, although not as much as bias-ply tires. According to a 1978 report[1], fuel efficiency is reduced by one percent (1%) for every 3.3 pounds per square inch (psi) of under-inflation. More recent data provided by Goodyear indicates that fuel efficiency is reduced by one percent for every 2.96 psi of under-inflation, fairly close to the 1978 estimate.

[1] **Evaluation of Techniques for Reducing In-use Automotive Fuel Consumption**; The Aerospace Corporation, June 1978. Original reference from Goodyear, pp 3-45.

For this analysis, we assumed that there was no effect of tire over-inflation, and that savings only started once the warning went on. In other words, if the placard pressure were 30 psi, and a warning were given at 22.5 psi (25 percent below placard), no benefits are assumed for those vehicles that have tires with lowest pressure above 22.5 psi. However, there is a benefit for those vehicles with continuous displays, in that their steady state psi position is higher in Compliance Option 1, than in Compliance Options 2 and 3. Data from the tire pressure survey was used to estimate the average under-inflation of all 4 tires for those vehicles for which a warning would be given. Table V-25 provides the average under-inflation and the percentage of the fleet that would get a warning by the TPMS. All the Compliance Options are the same because they give a warning at 25 percent below placard.

Table V-25
Analysis of Fleet Tire Pressure Survey

	Passenger Cars Average psi below placard of those vehicles warned	Percent of Fleet Affected	Light Trucks Average psi below placard of those vehicles warned	Percent of Fleet Affected
Compliance Option 1	6.8 psi	26%	8.7 psi	29%
Compliance Option 2	6.8 psi	26%	8.7 psi	29%
Compliance Option 3	6.8 psi	26%	8.7 psi	29%

Tables V-26 and V-27 show the weighted vehicle miles traveled by age of vehicle for passenger cars and light trucks. They also show the 7 percent discount rate and the assumed price of gasoline. The projected price of gasoline was taken from a DOE projection from January 2001[2]. It excludes fuel taxes, at $0.38 per gallon, since these are a transfer payment and not a cost to society. The projections were for gasoline prices to steadily decline from 2001 through about 2005 when they will level off. A second group of adjustments were made to the price of gasoline to account for environmental costs and international oil market costs.

One product of the combustion of hydrocarbon fuels, such as gasoline and diesel, is CO_2. The environmental and economic consequences of these releases are not included in the price of gasoline. While there are estimates of these consequences in the literature, the administration has not taken a position on their costs. Using estimates from the literature would result in very little savings on a per vehicle basis and they have not been included in this analysis.
A second environmental cost of gasoline use relates to the hydrocarbon and toxic chemical releases from the gasoline supply chain, including oil exploration, refining, and distribution. Marginal costs of these activities combined have been estimated at $0.02 per gallon.[3]

The Organization of Petroleum Exporting Countries (OPEC) operates as a cartel that restricts the supply of oil to escalate the price above the free-market level. The greater the consumption of oil, the higher will be the price. Since the higher price of oil applies to all oil imports from OPEC, not just the increased oil use, the financial cost to the United States exceeds the market

[2] DOE Energy Information Administration, Annual Energy Outlook 2001, Table A3, Energy Prices by Sector.
[3] "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards", National Research Council, July 2001, Pages 5-5 to 5-6.

payment for the increased amount. Leiby et al.,[4] estimated this impact to be $3.00 per barrel. This equates to $0.07 per gallon ($3/42 gallons per barrel). The impact is dependent upon the amount of oil saved. The $0.07 per gallon is about right for the savings of this program.

Thus, the price of gasoline has been reduced by $0.38 per gallon to account for taxes, and has been increased by $0.09 per gallon to account for environmental and economic considerations.

Table V-26
Passenger Cars Vehicle Miles Traveled, Discount Factor, and Assumed Price of Gasoline in (2001 Dollars)

Passenger Cars

Vehicle Age (years)	Vehicle Miles Traveled	Survival Probability	Weighted Vehicle Miles Traveled	Gasoline Price, Excluding Taxes	7 Percent Mid-Year Discount Factor
1	13,533	0.995	13,465.3	$1.05	0.9667
2	12,989	0.988	12,833.1	1.04	0.9035
3	12,466	0.978	12,191.7	1.05	0.8444
4	11,964	0.962	11,509.4	1.06	0.7891
5	11,482	0.938	10,770.1	1.07	0.7375
6	11,020	0.908	10,006.2	1.07	0.6893
7	10,577	0.87	9,202.0	1.08	0.6442
8	10,151	0.825	8,374.6	1.07	0.602
9	9,742	0.775	7,550.1	1.07	0.5626
10	9,350	0.721	6,741.4	1.06	0.5258
11	8,974	0.644	5,779.3	1.06	0.4914
12	8,613	0.541	4,659.6	1.06	0.4593
13	8,266	0.445	3,678.4	1.05	0.4292
14	7,933	0.358	2,840.0	1.05	0.4012
15	7,614	0.285	2,170.0	1.05	0.3749
16	7,308	0.223	1,629.7	1.05	0.3504
17	7,014	0.174	1,220.4	1.05	0.3275
18	6,731	0.134	902.0	1.05	0.326
19	6,460	0.103	665.4	1.04	0.286
20	6,200	0.079	489.8	1.04	0.2673
			126,678		

[4] "Oil Imports: An Assessment of Benefits and Costs", P.N. Leiby, D.W. Jones, T.R. Curlee, and L. Russell, 1997, ORNL-6851, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Table V-27
Light Trucks Vehicle Miles Traveled, Discount Factor, and
Assumed Price of Gasoline in (2001 Dollars)

Light Trucks

Vehicle Age (years)	Vehicle Miles Traveled	Survival Probability	Weighted Vehicle Miles Traveled	Gasoline Price, Excluding Taxes	7 Percent Mid-Year Discount Factor
1	12,885	0.998	12,859	$1.05	0.9667
2	12,469	0.995	12,407	1.04	0.9035
3	12,067	0.989	11,934	1.05	0.8444
4	11,678	0.980	11,444	1.06	0.7891
5	11,302	0.967	10,929	1.07	0.7375
6	10,938	0.949	10,380	1.07	0.6893
7	10,585	0.924	9,781	1.08	0.6442
8	10,244	0.894	9,158	1.07	0.602
9	9,914	0.857	8,496	1.07	0.5626
10	9,594	0.816	7,829	1.06	0.5258
11	9,285	0.795	7,382	1.06	0.4914
12	8,985	0.734	6,595	1.06	0.4593
13	8,696	0.669	5,818	1.05	0.4292
14	8,415	0.604	5,083	1.05	0.4012
15	8,144	0.539	4,390	1.05	0.3749
16	7,882	0.476	3,752	1.05	0.3504
17	7,628	0.418	3,189	1.05	0.3275
18	7,382	0.364	2,687	1.05	0.326
19	7,144	0.315	2,250	1.04	0.286
20	6,913	0.271	1,873	1.04	0.2673
21	6,691	0.232	1,552	1.04	0.2498
22	6,475	0.198	1,282	1.04	0.2335
23	6,266	0.169	1,059	1.04	0.2182
24	6,064	0.143	867	1.04	0.2039
25	5,869	0.121	710	1.03	0.1906
			153,706		

The baseline miles-per-gallon figure for cars was 27.5 mpg at placard inflation, and for light trucks was 22.2 mpg (the MY 2007 light truck standard) at placard inflation. A sample calculation for passenger cars for Compliance Option 1 is:

The average of all four tires on a passenger car that would be warned based on our survey would be 6.8 psi lower than placard. The average steady state condition after TPMS are in place would be 3.0 psi lower than placard. Thus, the incremental steady state improvement of the TPMS is 3.8 psi (6.8 – 3.0). Since 1 percent fuel efficiency is equivalent to 2.96 psi lower, the average passenger car with a warning would get 1.0128 percent (3.8/2.96) higher fuel economy when re-inflated. With a baseline of 27.5 mpg, the average fuel economy of those vehicles warned that increased their tire pressure up to placard would be 27.5 * 1.012838 = 27.853 mpg. Based on our estimated vehicle miles traveled by age, scrappage by age, a 7 percent present value discount rate and estimated fuel costs per year, the baseline passenger car (at 27.5 mpg discounted by 15 percent to account for real on-road mileage) would spend $3,968.88 present value for fuel over its lifetime. Those drivers warned who filled up to placard pressure and achieved 27.853 mpg (discounted by 15 percent to account for real on-road mileage) would spend $3,918.58 for fuel over their car's lifetime. The difference is $50.30. Since 26 percent of the fleet get a warning, and it is assumed that 90 percent of the drivers would fill their tires to placard, the average benefit is $11.77 ($50.30*0.26*0.90). The estimated benefit for each subgroup under the different compliance options is shown in Table V-28, under a 7 percent and 3 percent discount rate.

Table V-28
Fuel Economy Benefits Compared to the Baseline Fleet
Present Discounted Value over Lifetime
(2001 Dollars)

	Passenger Cars		Light Trucks	
	3% Discount	7% Discount	3% Discount	7% Discount
Compliance Option 1	$14.35	$11.77	$31.28	$24.53
Compliance Option 2	$11.74	$9.62	$25.95	$20.34
Compliance Option 3	$11.74	$9.62	$25.95	$20.34

Weighting light trucks (9/17)[5] and passenger cars (8/17) and taking into account the one percent of the fleet that already has a direct measurement system results in the following overall benefit in fuel economy shown in Table V-29.

Table V-29
Fuel Economy Benefits Compared to the Baseline Fleet
Present Discounted Value over Lifetime
(2001 Dollars)

	Average Passenger Vehicle 3% Discount Rate	Average Passenger Vehicle 7% Discount Rate
Compliance Option 1	$23.08	$18.34
Compliance Option 2	$19.07	$15.14
Compliance Option 3	$19.07	$15.14

[5] We assume sales of 8 million passenger cars and 9 million light trucks for a total of 17 million vehicles annually.

Emissions Effect

Since there are fuel economy improvements, there are comparable savings in gasoline usage. Fewer gallons of gasoline used mean fewer emissions. Table V-30 shows the lifetime gallons of gasoline saved per vehicle for the different Compliance Options. These per vehicle estimates are multiplied by 17 million vehicles. Assuming constant vehicle sales from year to year, once all vehicles in the fleet meet the standard, the annual gasoline savings are equal to the lifetime savings of fuel of one model year. The rule of thumb for equating gasoline savings to emissions savings used by the Department of Energy is that for every billion gallons of gasoline saved, emissions are reduced by 2.4 million metric tons carbon equivalent (MMTCE).

Table V-30
Lifetime Gallons of Gasoline Saved Per Vehicle

	Passenger Cars	Light Trucks	Average Savings Per Light Vehicle
Compliance Option 1	16	37	27
Compliance Option 2	13	31	22
Compliance Option 3	13	31	22

Table V-31
Annual Emission Reduction for the Fleet

	Average Gasoline Savings Per Light Vehicle	Annual Gasoline Savings (Millions of Gallons)	Annual Emissions Reduction (MMTCE)
Compliance Option 1	27	459	1.10
Compliance Option 2	22	374	0.90
Compliance Option 3	22	374	0.90

Tread Life

Driving at lower inflation pressure impacts the rate of tread wear on tires. This will cause tires to wear out earlier than necessary and decrease tread life. When a tire is under-inflated, it puts more pressure on the shoulders of the tire and does not wear correctly. This analysis will attempt to quantify the impact of increased tread wear on consumer costs.

Based on data provided by Goodyear (see Docket No. NHTSA-2000-8572-26), the average tread life of tires is 45,000 miles and the average cost is $61 per tire (in 2001 dollars).

For Compliance Option 1

Assuming a direct measurement system, the TPMS warns the driver anytime a tire is 25 percent or more below the placard and the driver inflates all of the tires back to the placard levels, then we can estimate the impact on tread life using the following calculations.

Goodyear provided data estimating that the average tread wear dropped to 68 percent of the original tread wear if tire pressure dropped from 35 psi to 17 psi. Goodyear also assumed that this relationship was linear. Thus, for every 1 psi drop in inflation pressure, tread wear would decrease by 1.78 percent [(100-68%)/(35-17psi)]. These effects would take place over the lifetime of the tire. In other words, if the tire remained under-inflated by 1 psi over its lifetime, the tread wear would decrease by 1.78 percent or about 800 miles (45,000*0.178).

Data from our tire pressure survey indicated that 1,575 out of 5,967 passenger car tires (26 percent) had at least one tire under-inflated by 25 percent or more below the placard level. The average under-inflation of the 4 tires for these vehicles was 6.8 psi. Based on our steady state assumptions discussed earlier, the average psi of the fleet under Compliance Option 1 would improve by 3.8 psi (placard pressure is 30 psi, steady state pressure under Compliance Option 1 is 27.0 psi, thus a 3.0 psi difference; 6.8 – 3.0 = 3.8 psi improvement). Thus, on average, passenger cars lose an estimated 3,040 miles (3.8 * 800 miles) of tread life for each tire due to the way they are currently under-inflated that could be remedied under Compliance Option 1 if everyone filled all their tires back up to the placard pressure when they were notified by a TPMS. If we assume that 90 percent of the people actually inflate their tires properly, then on average 2,736 miles of tread life would be saved per tire.

If the average current lifetime of tires is 45,000 miles at current inflation levels, the average lifetime could be 47,736 miles with a TPMS. The agency estimates that the average lifetime per passenger car is 126,678 miles. Thus, currently the average car would have 3 sets of tires on their car over its lifetime (new, at 45,000 miles, and at 90,000 miles) and with TPMS the average car would have 3 sets of tires purchased (new, at 47,736 miles, and at 95,472 miles). The benefit to consumers is the delay in purchasing those tires and getting interest on that money at an assumed 3 percent or 7 percent rate of return. Using a mid-year 3 percent and 7 percent interest rate and discount rate, the discounted present value of these delayed tire purchases is estimated to be $5.71 at a 3 percent discount rate and $10.23 at a 7 percent discount rate for those passenger cars that would be notified by a TPMS that they are under-inflated. Since 26 percent would be notified, the present discounted benefits are $1.48 ($5.71 * 0.26) at a 3 percent discount rate, $2.66 ($10.23 * 0.26) at a 7 percent discount rate, and 711 miles (2,736 * 0.26) of tread life.

For light trucks, data from our tire pressure survey indicated that 1,148 of 3,950 light truck tires (29 percent) had at least one tire under-inflated by 25 percent or more compared to the placard. The average under-inflation of the 4 tires for these vehicles was 8.7 psi. Based on our steady state assumptions discussed earlier, the average psi of the fleet under Compliance Option 1 would improve by 5.2 psi (placard pressure is 35 psi, steady state pressure under Compliance Option 1 is 31.5 psi, thus a 3.5 psi difference; 8.7 – 3.5 = 5.2 psi improvement). Thus, on average, light trucks lose an estimated 4,160 miles (5.2*800) of tread life for each tire due to the way they are currently under-inflated that could be remedied if everyone filled all their tires back up to the placard pressure when they were notified by a TPMS. If we assume that 90 percent of the people actually inflate their tires properly, then on average 3,744 miles of tread life would be saved per tire.

If the average current lifetime of tires is 45,000 miles at current inflation levels, the average lifetime could be 48,744 miles with a TPMS. The agency estimates that the average lifetime per light truck is 153,706 miles. Thus, the average light truck would have 4 sets of tires on their truck over its lifetime (new, at 45,000 miles, at 90,000 miles, and at 135,000 miles) and with a TPMS the average light truck would have four sets purchased (new, at 48,744 miles, at 97,488, and at 146,232 miles). Using the same methodology as for passenger car tires, the benefit in delaying purchasing tires is estimated to be a present discounted benefit of $23.33 at the 3 percent discount rate and $31.54 at the 7 percent discount rate. Since in 29 percent of the vehicles at least one tire is under-inflated by 25 percent or more, the average benefit for light trucks is estimated to be $6.77 ($23.33 * 0.29) at the 3 percent interest and discount rate, $9.15 ($31.54 * 0.29) at the 7 percent interest and discount rate, and 1,086 miles (3,744 * 0.29) of tread life.

The weighted tread life savings for passenger cars and light trucks after considering current compliance for Compliance Option 1 is $4.24 [($1.48 * 8/17) + ($6.77 * 9/17)]*.99 at the 3 percent interest rate and discount rate and $6.03 [($2.66 * 8/17) + ($9.15 * 9/17)]*.99 at the 7 percent interest rate and discount rate and 900 [(711 * 8/17) + (1,086 * 9/17)]*.99) miles of tread life.

For Compliance Options 2 and 3

Data from our tire pressure survey indicated that 1,575 out of 5,967 passenger car tires (26 percent) had at least one tire under-inflated by 25 percent or more below the placard level. The average under-inflation of the 4 tires for these vehicles was 6.8 psi. Based on our steady state assumptions discussed earlier, the average psi of the fleet under Compliance Options 2 and 3 with direct systems would improve by 3.1 psi (placard pressure is 30 psi, steady state pressure under Compliance Options 2 and 3 is 26.3 psi, thus a 3.7 psi difference; 6.8 – 3.7 = 3.1 psi improvement). Thus, on average, passenger cars lose an estimated 2,480 miles (3.1 * 800 miles) of tread life for each tire due to the way they are currently under-inflated that could be remedied if everyone filled all their tires back up to the placard pressure when they were notified by a TPMS. If we assume that 90 percent of the people actually inflate their tires properly, then on average 2,232 miles of tread life would be saved per tire.

If the average current lifetime of tires is 45,000 miles at current inflation levels, the average lifetime could be 47,232 miles with a TPMS. The agency estimates that the average lifetime per passenger car is 126,678 miles. Thus, currently the average car would have 3 sets of tires on their car over its lifetime (new, at 45,000 miles, and at 90,000 miles) and with TPMS the average car would have 3 sets of tires purchased (new, at 47,232 miles, and at 94,464 miles). The benefit to consumers is the delay in purchasing those tires and getting interest on that money at an assumed 3 and 7 percent rate of return. Using a mid-year 3 and 7 percent interest rate and discount rate, the discounted present value of these delayed tire purchases is estimated to be $4.68 at the 3 percent discount rate and $8.42 at the 7 percent discount rate for those passenger cars that would be notified by a TPMS that they are under-inflated. Since 26 percent would be notified, the present discounted benefits are $1.22 ($4.68 * .26) at the 3 percent discount rate, $2.19 ($8.42 * .26) at the 7 percent discount rate and 580 miles (2,232 * 0.26) of tread life.

For light trucks, data from our tire pressure survey indicated that 1,148 of 3,950 light truck tires (29 percent) had at least one tire under-inflated by 25 percent or more compared to the placard. The average under-inflation of the 4 tires for these vehicles was 8.7 psi. Based on our steady state assumptions discussed earlier, the average psi of the fleet under Compliance Options 2 and 3 would improve by 4.3 psi (placard pressure is 35 psi, steady state pressure under Compliance Options 2 and 3 is 30.6 psi, thus a 4.4 psi difference; 8.7 – 4.4 = 4.3 psi improvement). Thus, on average, light trucks lose an estimated 3,440 miles (4.3*800) of tread life for each tire due to the way they are currently under-inflated that could be remedied if everyone filled all their tires back up to the placard pressure when they were notified by a TPMS. If we assume that 90 percent of the people actually inflate their tires properly, then on average 3,096 miles of tread life would be saved per tire.

If the average current lifetime of tires is 45,000 miles at current inflation levels, the average lifetime could be 48,096 miles with a TPMS. The agency estimates that the average lifetime per light truck is 153,706 miles. Thus, the average light truck would have 4 sets of tires on their truck over its lifetime (new, at 45,000 miles, at 90,000 miles, and at 135,000 miles) and with a TPMS the average light truck would have four sets purchased (new, at 48,096 miles, at 96,192, and at 144,288 miles). Using a mid-year 3 and 7 percent interest rate and discount rate, the discounted present value of these delayed tire purchases is estimated to be $18.76 at the 3 percent discount rate and $26.02 at the 7 percent discount rate for those light trucks that would be notified by a TPMS that they are under-inflated. Since in 29 percent of the vehicles at least one tire is under-inflated by 25 percent or more, the average benefit for light trucks is estimated to be $5.44 ($18.76*0.29) at the 3 percent interest and discount rate and $7.55 ($26.02 * 0.29) at the 7 percent interest and discount rate and 896 miles (3,096 * 0.29) of tread life.

The weighted tread life savings for passenger cars and light trucks after considering current compliance for Compliance Options 2 and 3 are $3.42 [($1.22 * 8/17) + ($5.44 * 9/17)]*.99 at the 3 percent interest rate and discount rate and $4.98 [($2.19 * 8/17) + ($7.55 * 9/17)]*.99 at the 7 percent interest rate and discount rate and 740 miles [(580 * 8/17) + (896 * 9/17)]*.99) of tread life per tire.

Table V-32 shows the tread life savings per vehicle after considering current compliance.

Table V-32
Estimated Tread Life Savings per Vehicle
(Weighted Passenger Cars and Light Trucks)

	3 % Discount Rate	7% Discount Rate
Compliance Option 1	$4.24	$6.03
Compliance Option 2	$3.42	$4.98
Compliance Option 3	$3.42	$4.98

There are other potential non-quantified benefits of increasing tread wear. Some people would not have to purchase the last set of tires for a vehicle if they were going to scrap the vehicle soon, or if it were totaled in a crash shortly before they were going to purchase new tires. So, there will be cases where the total purchase price of tires $244 ($61 per tire * 4) will be saved. However, we can't estimate the frequency of that occurrence.

Property Damage and Travel Delay Savings

Reduced stopping distance, blowouts, and loss of control in skidding will prevent crashes and reduce the severity of impacts and the injuries that result. Property damage and travel delay will also be mitigated by these improvements. To the extent that crashes are avoided, both property damage and travel delay will be completely eliminated. Crashes that still occur but at less serious impact speeds will still cause property damage and delay other motorists, but to a lesser extent than they otherwise would have.

Preventable Crashes:

NHTSA has developed data on the cost of both travel delay and property damage stratified by injury severity on a per-person injured basis[6]. Travel delay is defined as the value of lost time experienced by motorists not involved in a crash, but who are delayed in traffic congestion resulting from these crashes. Property damage is the value of vehicles, cargo, and other items damaged in traffic crashes. The number of injuries prevented, as well as the number of PDO crashes prevented in out of control skids, has already been estimated in Chapter V. An estimate of total PDO involved vehicles was derived as follows.

Table V-33 summarizes the injuries that would be prevented by TPMS. To estimate the impact on PDOs, it will be assumed that PDOs are reduced in the ratio of overall occurrence of PDOs to injuries. The PDO cost data mentioned above is expressed in terms of per damaged vehicle. Therefore, PDOs will be measured in these same units. The number of vehicles involved in crashes that produced the injury savings in Table V-34 is estimated based on the average number of police reported injuries per vehicle (1.35)[7]. The results are shown on the Injury Vehicles line in that Table. For the stopping distance and blowout categories, these estimates were then multiplied by the overall ratio of PDO involved vehicles to injury involved vehicles[8] to estimate the total number of police reported PDOs that would be prevented. The out of control skidding category was handled differently because a specific estimate of PDO crashes prevented was derived in Chapter V. For this category, the number of crashes prevented (9,994) was multiplied by the overall ratio of PDO vehicles per crash[9].

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[6] Blincoe et al, Ibid.
[7] Ibid.
[8] Ibid.
[9] Ibid.

PDOs are notoriously underreported. Many localities don't even record crashes unless they involve some variable damage threshold and often drivers involved in single vehicle PDOs will leave before police arrive. Overall, NHTSA estimates that only 52% of the vehicles involved in PDO crashes get reported[10]. An adjustment was made to the 3 PDO vehicle totals to reflect this. The final results are shown in the Total PDO Vehicles line of Table V-33.

The MAIS0 line in Table V-33 represents uninjured occupants that are present in vehicles that avoid crashes due to TPMS. They are estimated based on the ratio of uninjured occupants to injured occupants in police reported crashes[11]. They are included here because the unit property damage and travel delay costs used in this analysis were distributed over all occupants and to fully account for all savings in these avoided crashes they must also be accounted for.

[10] Blincoe et al, Ibid.
[11] Ibid.

Table V-33
Property Damage and Travel Delay Savings from
Crashes Prevented by TPMS

Crash Involvements Prevented By TPMS					Property Damage & Travel Delay	
	Injured Persons in Crashes Due To: Preventable				Unit Costs (2001$)	Total Savings
	Stop. Dist	Skid	Flat	Total		
MAIS0	748	1997	457	3202	$1,843	$5,901,406
MAIS1	1328	3529	733	5590	$4,752	$26,566,430
MAIS2	145	393	132	670	$4,937	$3,307,512
MAIS3	62	168	32	262	$7,959	$2,085,314
MAIS4	6	16	14	36	$11,140	$401,048
MAIS5	4	10	5	19	$19,123	$363,339
Fatal	13	44	37	94	$19,974	$1,877,521
Total	1558	4160	953	6671		$40,502,570
Inj. Vehicles	1150	3071	704	4925		
Ratio PDO/Inj Veh	4		4			
Total P.R. PDO Veh	4589	17511	2807			
Total PDO Vehicles	8825	33675	5398	47897	$2,352	$112,657,838
Total Including PDOs						$153,160,408

Table V-33 also lists the total per-case Travel Delay and Property Damage costs stratified by injury severity[12]. The costs are expressed as per- injured person for all injury levels, and per damaged vehicle for PDOs. These unit costs were multiplied by the corresponding injury and PDO incidence savings to estimate total savings in travel time and property damage from crashes prevented by TPMS.

Non-Preventable Crashes:

The impact on non-preventable crashes is more subtle and measuring it requires some assumptions regarding the nature of injury mitigation. The injuries prevented in non-preventable

[12] Ibid.

crashes are summarized in Table V-34. These represent the net impact on total injuries in each severity category after the severity of each crash was reduced. For all but minor injuries, this would typically involve a tumble-down effect, where injuries are reduced to a lower severity level rather than being eliminated entirely. Since the savings are a net result of this process, this means that the total number of injuries reduced in each category is really the sum of the savings in that category plus those injuries that tumbled-down into that category from a more severe level. To simulate this, it will be assumed that each injury mitigated will fall only one level. The second column in Table V-34 shows the resulting gross savings for each severity level. In the third column, the difference in unit costs of travel delay and property damage between the specific injury level and the next highest level are shown. These numbers represent the change in these costs that occurs from each reduction in injury levels. Total costs for each level are the product of these unit costs and the total injuries saved at that level.

Table V-34
Non-Preventable Crash Stopping Distance
Property Damage and Travel Delay Savings

	Net Injuries Prevented	Total Injuries Prevented	Unit Costs (2001$)	Total Savings
MAIS1	1411	1684	$2,910	$4,899,598
MAIS2	273	367	$184	$67,562
MAIS3	94	105	$3,023	$317,376
MAIS4	11	17	$3,181	$54,077
MAIS5	6	31	$7,983	$247,469
Fatal	25	25	$851	$21,263
Total				$5,607,346

Total travel delay and property damage cost savings from non-preventable crash severity mitigation is thus estimated to total $5.6 million. Total savings from all crash types, including preventable injury and PDO crashes would total $158,767,754. Since these savings would occur over the life of the vehicle, a discount factor will be applied to express their present value. At a 3% discount rate, the present value of total travel delay and property damage savings would be $130,713,492 (.8233 combined factor). At a 7% rate, this value would be $104,786,718 (.6600 combined factor). These are the estimates for Compliance Options 2 and 3.

For Compliance Option 1, the same methodology results in total savings from all crash types, including preventable injury and PDO crashes would total $160,871,765. At a 3% discount rate, the present value of total travel delay and property damage savings would be $133,445,724 (.8233 combined factor). At a 7% rate, this value would be $106,175,365 (.6600 combined factor).

Non-quantifiable Benefits

Under-inflation affects many different types of crashes. These include crashes which result from:

7. an increase in stopping distance,
8. flat tires and blowouts
9. skidding and/or a loss of control of the vehicle in a curve, like an off-ramp maneuver coming off of a highway at high speed, or simply taking a curve at high speed
10. skidding and/or loss of control of the vehicle in a lane change maneuver,
11. hydroplaning on a wet surface, which can affect both stopping distance and skidding and/or loss of control.
12. overloading the vehicle

The agency has quantified the effects of under-inflation in a crash involving skidding and loss of control, flat tires and blowouts, and the reduction in stopping distance. However, it cannot quantify the effects of under-inflation on hydroplaning and overloading the vehicles. The primary reason that the agency can't quantify these benefits is the lack of crash data indicating tire pressure and how large of a problem these conditions represent by themselves, or how often they are contributing factors to a crash. The agency has just starting collecting tire pressure in its crash data investigations.

Skidding and/or loss of control from hydroplaning

The conditions that influence hydroplaning include speed, tire design, tread depth, water depth on the road, load on the tires, and inflation pressure. At low speeds (less than about 50 mph), if your tires are under-inflated, you actually have more tire touching the road. However, hydroplaning does not occur very often at speeds below 50 mph, unless there is deep water (usually standing water) on the road. As you get to about 55 mph and the water pressure going under the tire increases, an under-inflated tire has less pressure in it pushing down on the road and you have less tire-to-road contact than a properly inflated tire as the center portion of the tread gets lifted out of contact with the road. As speed increases to 70 mph and above and water depth increases due to a severe local storm with poor drainage, the under-inflated tire could lose 40 percent of the tire-to-road contact area compared to a properly inflated tire. The higher the speed (above 50 mph) and the more under-inflated the tire is, then the lower the tire-to-road contact and the higher is the chance of hydroplaning.

Tread depth has a substantial impact on the probability of hydroplaning. If you make a simplifying assumption that the water depth exceeds the capability of the tread design to remove water (which most likely would occur with very worn tires), then an approximation of the speed at which hydroplaning can occur can be estimated by the following formula:

Hydroplaning speed $= 10.35 \times \sqrt{\text{inflation pressure}}$[13]

Under this assumption of water depth exceeding the capability of the tread design to remove water:

At 30 psi, hydroplaning could occur at 56.7 mph

At 25 psi, hydroplaning could occur at 51.8 mph

At 20 psi, hydroplaning could occur at 46.3 mph.

This is presented to show the relative effect of inflation pressure on the possibility of hydroplaning.

Overloading the vehicle

When a vehicle is overloaded, (too much weight is added for the suspension, axle, and tire systems to carry) and the tires are under-inflated, there is an increased risk of tire failures. This can result in a loss of control of the vehicle.

Potential Benefits for Antilock Brake Systems

If a manufacturer decided that the difference in the cost between an indirect and direct TPMS was enough to make antilock brakes a marketable feature for that vehicle, then it might decide to

[13] "Mechanics of Pneumatic Tires" edited by Samuel K. Clark of the University of Michigan, published by NHTSA, printed by the Government Printing Office in 1981.

increase its use of ABS and use an indirect TPMS to meet the phase-in part of the final rule. The agency has been analyzing the safety impacts of ABS for several years. The initial findings[14]were mixed. Fatal crash involvements in multi-vehicle crashes on wet roads and fatal crashes with pedestrians and bicyclists were significantly reduced. However, these reductions were offset by a statistically significant increase in the frequency of single vehicle, run-off-road crashes (rollovers or impacts with fixed objects). The run-off-road crashes were surprising in view of the good performance of ABS in stopping tests conducted by the agency and others. The agency has spent several years trying to determine why run-off-road crashes have increased with ABS, without a satisfactory answer.

Two more recent studies of ABS have found no statistically significant fatality improvement with ABS. The Farmer study from IIHS[15] found the results shown in Table V-35. (A ratio of 1.0 means there is no effect on fatalities. Less than one is a reduction in fatalities, more than 1.0 is an increase in fatalities. In order for the results to be statistically significant, the confidence bounds would have to be both below 1.0 or both above 1.0). The only statistically significant findings were that fatalities went up in non-GM cars in calendar years 1986-1995 and overall from 1986-1998.

[14] "Preliminary Evaluation of the Effectiveness of Antilock Brake Systems for Passenger Cars", NHTSA, December, 1994, DOT HS 808 206.

[15] "New Evidence Concerning Fatal Crashes by Passenger Vehicles Before and After Adding Antilock Braking System", Charles M. Farmer, Insurance Institute for Highway Safety, February, 2000.

Table V-35
Results from the Farmer Study of the Impacts of ABS

	All crashes	95 percent confidence bounds	
	Ratio	Lower	Upper
GM cars in 1993-95	1.03	.94	1.12
GM cars in 1996-98	.96	.87	1.05
GM cars in 1993-98	.99	.93	1.05
Non-GM cars in 1986-95	1.16 (Significant)	1.06	1.27
Non-GM cars in 1996-98	.91	.77	1.06
Non-GM cars in 1986-98	1.09 (Significant)	1.01	1.18

Farmer's theory is that people learned how to use ABS better in calendar years 1996-98 and they were no longer overinvolved in run off the road fatal crashes. Farmer never states that ABS reduced fatalities. His statement on the GM cars for 1996-98 is "When all fatal crash involvements were considered, disregarding in which vehicle the fatalities occurred, the risk ratio was slightly lower than, but not significantly different from 1.0."

The second recent analysis by Ellen Hertz (NHTSA)[16], in which she included optional ABS to get more cases, also resulted in no overall statistically significant findings for fatalities. ABS effects were examined separately for passenger cars and light trucks for five types of crashes (frontal impacts, side impacts, rollover, run-off-road, and pedestrian). The only statistically significant finding was that fatalities in light truck rollover crashes went up in ABS vehicles compared to non-ABS vehicles (see Table V-36). In this study, a negative is an improvement in safety (fewer fatalities) and a positive is an increase in fatalities.

[16] "Analysis of the Crash Experience of Vehicles Equipped with All Wheel Antilock Braking Systems (ABS) – A Second Update Including Vehicles with Optional ABS", NHTSA, September 2000,

Table V-36
Results from the Hertz Study of the Impacts of ABS

	Point	95 percent confidence bounds	
	Estimate	Lower	Upper
Frontal – PC	-4.9%	-19.9%	11.5%
Frontal – LTV	17.9	-7.1	49.6
Side Impact – PC	32.4	-1.0	77.2
Side Impact – LTV	-0.3	-42.3	72.2
Rollover – PC	12.3	-17.2	52.2
Rollover – LTV	106.5 (Significant)	49.2	185.9
Run-Off-Road – PC	-13.4	-28.1	4.2
Run-Off-Road – LTV	21.8	-12.6	69.5
Pedestrian – PC	-0.4	-16.3	18.4
Pedestrian – LTV	-22.7	-50.1	19.6

The Hertz study did find that antilock brakes had an overall effect of reducing crashes, but not fatalities.

If NHTSA believed that antilock brakes were cost/beneficial, we would consider requiring them to be installed. We have not considered requiring antilock brakes because we have not been able to show that they are beneficial in reducing fatalities. Reducing their costs, by offsetting the costs with a TPMS, does not affect our conclusions to date that we have not been able to prove that ABS reduces fatalities.

VI. COSTS and LEAD TIMES

Systems Costs

These cost estimates are NHTSA-derived estimates based on a tear-down study of costs by a contractor of three direct measurement systems and one indirect measurement system and confidential discussions with a variety of suppliers and manufacturers about how their systems work and the various components in their systems. All costs provided here are consumer costs. Variable cost estimates received from suppliers were multiplied times 1.51 to mark them up to consumer cost levels. These cost estimates assume high production volumes, U.S. raw material prices, Detroit area labor rates (union shop), U.S. manufacturing processes, methods, and overhead application rates. For this analysis, we estimate there will be sales volumes of 17 million light vehicles per year, 8 million passenger cars and 9 million light trucks.

Indirect measurement systems:

There are different ways of using indirect measurement systems for a Tire Pressure Monitoring Systems (TPMS). The first assumes that the vehicle has an existing ABS system and that manufacturers will add the capability to monitor the wheel speed sensors, make changes to the algorithms, add the ability to display the information and a reset button. The incremental cost of adding these features to an existing ABS vehicle was estimated to be $13.29 per vehicle. In model year 2000, about 76 percent of all passenger cars and light trucks had an ABS system. However, you need a 4 wheel ABS system and you need a 4-channel ABS for the TPMS system to work. In model year 2000, 74 percent of all new light trucks and 63 percent of all new passenger cars had a 4 wheel ABS systems. However, a large percentage of these trucks (about

60 percent)[1] have a 3-channel ABS system (defined as a 3 channel system because the rear axle has one wheel speed sensor rather than a separate wheel speed sensor on each wheel, which would be required for a TPMS system). In the FEA, the agency discussed the costs for adding an indirect system to some pickup trucks. In order to pass the proposal that the system be able to detect when any one of the tires are low, the agency believed these trucks would have their wheel speed detection system redesigned to include individual sensors on both rear wheels at an estimated cost of $25 per vehicle. About 52 percent of the 4-wheel ABS systems are light trucks; if 60 percent of these need a fourth wheel speed detector, then 31.35 percent of all passenger cars and light trucks with 4-wheel ABS will need a fourth wheel detector. Thus, the average cost of providing an indirect system for ABS vehicles is estimated to be $21.13 ($13.29 + $25*.3135).

NHTSA tested four ABS-indirect measurement systems and none of the four met the proposed requirements to provide a driver warning at 25 percent below placard and to detect "one, two, or three, or four tires" being low. They could not detect when four tires were low and had problems detecting two tires low on the same axle or when two tires on the same side of the vehicle were low. Indirect system costs are included as a partial basis for the hybrid system costs.

[1] Based on a model by model analysis of data in the Mitchell Service Manual.

In the FEA, the agency also discussed the possibility of manufacturers adding wheel sensors at a cost of $130 per vehicle or full ABS at a cost of $240 per vehicle to provide an indirect system. Some manufacturers may decide to add a full ABS and a hybrid system as a countermeasure to this proposed rule. However, this is a marketing decision and the additional costs of adding an ABS system are not the result of this proposal.

Direct measurement systems:

A direct measurement system has a pressure sensor inside each tire that broadcasts tire pressure, and in some systems internal air temperature, to a central receiver on the vehicle (or in most cases to four separate antennae on the vehicle which relay the data to a central processor). It sends the information to a central processor that in turn displays a low-pressure warning when appropriate. Thus, there are two main costs of these systems (sensors and a receiver/central processor).

The agency has a teardown study performed by its contractor Ludtke & Associates.[2] Three direct measurement systems, the Beru tire pressure warning system, the SmarTire system, and the Johnson Controls system, have been torn down and their costs estimated.

[2] Beru Tire Pressure Warning System, for No. DTNH22-00-C-02008 Task Order No. Three (3).

The Beru system goes beyond the bare minimum needed to pass the proposal. The Beru system is capable of providing a "soft warning" with an amber telltale lamp when the inflation pressure drops 2.8 or more psi below the recommended pressure, and a "hard warning" with a red telltale lamp when the under-inflation is 5.7 psi or greater below the recommended inflation pressure.

The costs of the Beru direct measurement system are broken into the following categories (1 control unit at $44, 4 wheels electronic modules to measure tire pressure and transmit the data at $32, 4 reception antenna at $11, 4 valves at $7, the instrument panel display at $2, assembly and miscellaneous costs at $10) for a total of $106.

The costs of the SmarTire direct measurement system are broken into the following categories (1 control unit which includes one antenna at $30, 4 wheels electronic modules to measure tire pressure and transmit the data at $30, 4 valves at $5, the instrument panel display at $4, assembly and miscellaneous costs at $11) for a total of $80.

The costs of the Johnson Controls direct measurement system are broken into the following categories (1 control unit which includes one antenna at $19, electronic sensor modules in the 4 wheels to measure tire pressure and transmit the data at $30, 4 valves at $7, the instrument panel display at $4, assembly and miscellaneous costs at $9) for a total of $69.

Thus, one can see that the direct measurement system component cost estimates are very consistent between systems with the exception being the control module. As with most electronic systems, the agency believes that the costs of the control module will decrease in the future as engineers learn how to design the systems more efficiently. Thus, we will use the least expensive control module cost in our calculations. However, it is possible that this cost could be reduced even further over time.

Based on the three direct measurement systems costed out in the teardown studies, the average price for the tire pressure sensors is about $7.50 per wheel or $30 per vehicle.

For the direct measurement system, in Compliance Option 1 the agency assumes that manufacturers will provide a display system ("selectable display") that will allow the driver to check and see the tire pressure for all four tires individually. This system is not required by the proposal, however, we believe that consumers will value this information and that the manufacturers will provide it in some cases. Two systems with a selectable display feature were costed out. The selectable display feature in the design of the Johnson Controls system costs $4.28 and the design in the SmarTire system cost $3.73. Thus, the average cost is $4 per vehicle. These designs were individual displays. If the design of the system is set up in an existing display that the driver can access, the costs would be much less, probably on the order of $1 per vehicle. A selectable display is currently available in high-end vehicles as an option and is purchased by a small percent of those purchasers. The agency estimates that about 5 percent of total sales have a selectable display currently. Thus, the average cost is estimated to be $3.85 ($4*.95 + $1*.05). This cost is in addition to the cost of the telltale lamp that would typically be provided on the instrument panel to provide a warning when the system detects that tires are low. The cost of the telltale lamp was estimated in the Beru system to be $1.58.

To summarize, a direct measurement system with a selectable display (Compliance Option 1) is estimated to cost $70.35 ($7.50 per wheel or $30 per vehicle for the tire pressure sensors, $19 per vehicle for the control module, $3.85 for a selectable display, 4 valves at $6, and $11.50 for the combination of an instrument panel telltale, assembly, and miscellaneous wiring, etc.). A direct measurement system with only a telltale lamp (Compliance Option 2) is estimated to cost $66.50 ($70.35 - $3.85).

A direct measurement system with a pump:

Cycloid Company makes a pump based system that uses 4 wheel electronic modules, like a direct measurement system, as well as a pump to inflate the tires to proper pressure while the vehicle is being driven. Each tire has a sensor and a pump. The pump is attached under the hubcap. The display is designed to give a warning to the driver when a particular tire has a problem and needs servicing. For slow leaks, the pump can keep inflating the tire enough to get the vehicle to its destination. However, once the vehicle stops, the pump stops, and the tire will deflate. The cost of this system is estimated to be the same as a sensor-based system, except that there is the addition of a pump at an estimated cost of $10 per wheel, or $40 per vehicle. The benefit of this system is that it eliminates the need for the driver to stop for air for normal tire pressure loss conditions.

Hybrid systems

A hybrid system is an indirect system for ABS-equipped vehicles with 2 direct wheel sensors. The agency believes such a system could detect when one to four wheels are 25 percent or more below placard. TRW estimated that adding two direct tire measurement systems to a vehicle that had ABS would cost about 60 percent of the cost of a direct measurement system. The hybrid system would not be able to tell drivers the inflation pressure in all four tires, so we do not believe that a selectable display would be provided. Thus, the estimated cost for a hybrid system is $39.90 ($70.35 - $3.85)*.60).

Malfunction/Warning Lamp

We anticipate the cost of adding a separate malfunction/warning lamp to the system to be close to the costs of adding a telltale lamp to the system ($1.58). In addition, the cost of adding circuitry for the malfunction capability would add an estimated $0.25 to the system. Thus, the cost of a separate malfunction/warning lamp with the added circuitry for the malfunction capability is estimated to be $1.83. This would be added to each Compliance Option analyzed above if a separate malfunction/warning lamp were required. The agency proposes that both functions be performed, but is not proposing to require a separate malfunction warning lamp. We anticipate the cost of having two functions performed by the same lamp to be negligible. Thus, we assume only the $0.25 costs for the malfunction capability for performing two functions using one telltale lamp.

Table VI-1 shows the estimated incremental costs for the different types of systems

Table VI-1
Cost Summary of TPMS Costs
(With Malfunction Capability)
(2001 Dollars)

Direct Measurement System with Selectable Display	$70.60
Direct Measurement System with Only a Telltale Display	$66.75
Hybrid Measurement System	$40.15

TPMS Systems in New Vehicles

Voluntary use of TPMS in new vehicles was determined by using the calendar year 2000 sales, a model year 2001 list of the make/models with each type of system, and an estimate that 2 percent of sales were purchased as an option for those optional systems, to estimate the percent of the year 2000 sales that had each type of system. The resulting estimates are that 4 percent of the model year 2001 light vehicle fleet has an ABS-type indirect measurement TPMS, and 1 percent of the fleet has a direct measurement system.

System Cost Summary by Compliance Option

Compliance Option 1: Assuming a direct measurement system with a selectable display, the incremental cost would be an estimated $69.89 per vehicle ($70.60 per vehicle * 99 percent to account for the 1 percent of sales in the current fleet).

Compliance Option 2: Assuming a direct measurement system with only a telltale lamp, the incremental cost would be an estimated $66.08 per vehicle ($66.75 per vehicle * 99 percent to account for the 1 percent of sales in the current fleet).

Compliance Option 3: In the near term it is assumed that for Compliance Option 3 that a hybrid system would be provided for the 67 percent of the fleet that is already equipped with ABS, and that a direct measurement system with a telltale display will be installed in the remaining 33 percent of the fleet. The average overall cost for this Compliance Option is estimated to be $48.44[40.15*.67 + $66.75*.33]*.99 to account for one percent current compliance.

Maintenance Costs

The current direct measurement systems have a battery to transmit data, which has a finite life of 7 to 10 years, which will have to be eventually replaced to keep the system functioning. At this time, the tire pressure sensor has a battery in an enclosed package, which does not open to replace the battery. Thus, the entire sensor must be replaced to replace the battery. This may be necessary to ensure the lifetime use of the sensor given its location in the wheel considering vibrations. To estimate the present discounted value of this maintenance cost the following assumptions were made. The agency assumes that the second time the tires are changed, in the 90,000 to 100,000 mile range, that the sensor and battery will be replaced. This occurs in year 9 for all Compliance Options for passenger cars and light trucks. Survival probability and discount factors from year 9 are used (see Chapter V). The cost of the sensor ($7.50 each for 4 tires) is multiplied by 3 to account for typical aftermarket markups.

At the 3 percent discount rate, the estimated maintenance costs are $54.25 for passenger cars ($7.50 * 4 * .775 * .7778 * 3) and $59.99 for light trucks ($7.50 * 4 * .857 * .7778 * 3), making the average maintenance costs for a direct measurement system for all four wheels of $56.55 (57.12*.99 to account for current compliance). When a hybrid system is used with a direct measurement system in two wheels, the average maintenance costs would be $28.28 ($56.55*0.5).

At the 7 percent discount rate, the estimated maintenance costs are $39.24 for passenger cars ($7.50 * 4 * .775 * .5626 * 3) and $43.39 for light trucks ($7.50 * 4 * .857 * .5626 * 3), making the average maintenance costs for a direct measurement system for all four wheels of $40.91

(41.32*.99 to account for current compliance). When a hybrid system is used with a direct measurement system in two wheels, the average maintenance costs would be $20.45 ($40.91*0.5).

If the agency requires a malfunction/warning system, then consumers who have replacement tires that are incompatible with the TPMS put on their vehicle and get the malfunction warning, could go back to the tire dealer and purchase a different set of tires. If the warning lamp stays lit until the system is fixed, the agency believes that most consumers will want to have their tires changed to extinguish the lamp, until they find out what it might cost them. The question is "Who pays the bill for the second mounting, and balancing, and in some cases, the additional cost of more expensive tires than were originally purchased?" This could cost $50 or more. We assume this cost would fall upon the consumer, and not the tire dealer. If it is to be the consumer, many will ignore the lamp or have it turned off before they will pay another $50. We expect very few consumers would go to the trouble and expense of changing tires, just to have their malfunction lamp go off.

For this analysis, we assume that the malfunction lamp will stay on and it lets consumers know that they have to check their tires themselves and can't rely on the TPMS working. The big question then is "What percent of consumers will remember to check their tire pressure, given that they have a malfunction yellow lamp continuously lit on their instrument panel?" These are people that currently don't check their tire pressure, or they wouldn't be part of the benefits of the rule. The agency has no way of knowing this answer.

The malfunction/warning lamp would provide information on more than just the tires not being compatible with the TPMS. There are a variety of reasons why the system might not be working. These include: a battery in an individual wheel sensor went dead after its 7 to 10-year life or stopped working earlier, a wheel sensor was broken while mounting a tire on a rim, there was an electronic failure of any type, or there was a failure in the system for some other reason. The agency has not estimated the potential occurrence of any of these failure modes, with the exception of the battery.

It should be noted that all suppliers of direct measurement systems are working on systems that do not use batteries. At least two designs are being worked on. IQ-mobil Electronics GmbH stated in its docket comment (Docket No. 2000-8572, No. 174) that it has designed a battery-less transponder chip at the valve that is 1" by 1" in size. They have further developed this system and claim it will be ready for production by the proposed effective date. A second system could use kinetic energy in the rotating wheel to provide power for the system. The Cycloid Company already uses a similar technology to power its pump. For this analysis, we present a range in maintenance costs; however, there is a very good chance that the maintenance costs discussed above may only last for a few model years as technology to reduce maintenance costs becomes more widespread.

Since a battery-less TPMS system will soon be on the market, which will eliminate the need for maintenance when the battery dies, this system will result in no maintenance costs to replace batteries. For this analysis, the agency is providing a range from no maintenance costs for a battery-less direct TPMS system, to the estimates for maintenance costs for a TPMS with a battery.

Maintenance costs can also be affected by compatibility between replacement tires and TPMS designs. If the TPMS won't work because of a compatibility problem with replacement tires, then there is no reason to do maintenance on the TPMS. Thus, for this analysis the maintenance costs, which were assumed to occur in year 9 or 10 of the vehicle to replace batteries in the direct system TPMS, are reduced by 1 percent to represent the 1 percent of the systems that are assumed to be incompatible.

At the 3 percent discount rate, the average maintenance costs for a direct measurement system for all four wheels would be $55.98 (56.55*.99). When a hybrid system is used with a direct measurement system in two wheels, the average maintenance costs would be $28.00 ($28.28*0.99).

At the 7 percent discount rate, the average maintenance costs for a direct measurement system for all four wheels would be $40.50 (40.91*.99). When a hybrid system is used with a direct measurement system in two wheels, the average maintenance costs would be $20.25 ($20.45*0.99).

At the 3 percent discount rate, for Compliance Options 1 and 2, the present discounted value of the quantified maintenance costs is $0 to $55.98. For Compliance Option 3, the present discounted value of the quantified maintenance costs is $0 to $37.23 ($28.00*.67 + $55.98*.33).

At the 7 percent discount rate, for Compliance Options 1 and 2, the present discounted value of the quantified maintenance costs is $0 to $40.50. For Compliance Option 3, the present discounted value of the quantified maintenance costs is $0 to $26.93 ($20.25*.67 + $40.50*.33).

Owner's manual costs

The agency is proposing to require that the owner's manual must describe the operational performance of the TPMS telltale and the malfunction indicator. The cost implication of adding information to the owner's manual is small, probably on the order of $0.01 per vehicle.

Opportunity Costs and Other Impacts from Driver Response to TPMS

A portion of drivers who respond to TPMS will fill up their tires at an earlier time than they would have without the TPMS notification. This means that over the life of the vehicle, they will fill up their tires with more frequency. Since this requires time that would otherwise be spent with other activities, there is a small opportunity cost associated with this activity. Conversely, drivers will save time because improved treadwear will result in fewer tire purchases, resulting in fewer trips to the tire store. Moreover, when crashes are prevented, drivers avoid the delays associated with getting their vehicles towed, responding to police, and dealing with other involved drivers, as well as the time consuming process of getting repair estimates and the inconvenience of going without their vehicle while it is being repaired. These impacts are to some degree offsetting.

Added Fill Ups

In 2001 NHTSA conducted a special study of driver attitudes and habits towards maintaining correct pressure in their tires[3]. In this survey drivers were asked to specify the frequency with which they refilled their tires. The responses were grouped into specific categories and are summarized below:

Table VI-2
Frequency of Tire Pressure Check

Weekly	9%
Monthly	24%
When They Seem Low	25%
When Serviced	28%
Before a Long Trip	2%
Other	7%
Never	5%

As mentioned previously, tires generally lose air at the rate of about 1 psi per month under normal circumstances. Given the average passenger car and LTV placard levels (30 and 35 psi respectively), and the notification requirement of 25% below placard, notification would typically occur every 7.5 months for passenger cars and every 8.75 months for LTVs. Passenger cars have an expected lifetime of 20 years and LTVs have an expected lifetime of 25 years. Over this time frame, if drivers only filled their tires when notification was made by the TPMS, they would fill their tires a total of 32 (PCs) and 34 (LTVs) times over the vehicle's life. The impact of a TPMS will vary depending on the frequency with which drivers normally check and fill their tires.

[3] Tire Pressure Special Study: Interview Data, NHTSA Research Note, August 2001, DOT HS 809 315

Weekly and Monthly:

Two of the categories of drivers listed in Table VII-1 would clearly not benefit from TPMS because they check their tires more frequently than the 7-8 months needed for a typical tire to reach its trigger point. Barring a puncture or other damage related leak, drivers who check their tires weekly or monthly will maintain adequate tire pressure without the TPMS. In fact, it is possible that these groups may eventually respond by relying on the TPMS rather than their current routine. They thus may experience fewer tire checks over the vehicles life.

When Low:

The drivers who check their pressure when it "seems low" are engaging in subjective judgment that is difficult to measure. The relevant question is whether these drivers perceive tires that are 25% below their placard level to be low, or whether they perceive this prior to, or after the 25% reduction is experienced. NHTSA has no data regarding this question. To estimate the impact of TPMS on this group, a vehicle mounted tire was photographed in a controlled position under successive levels of pressure reduction (10% below placard, 20% below placard, etc.). These photos were then shown to a convenience sample of employees within NHTSA. Based on their responses, we estimate that some drivers began to notice low pressure when tires are around 40% below placard level, and that all drivers would notice low pressure when it declines to 60% below placard. Within this construct, we assume that the proportion of drivers who will notice tire pressure is low is directly proportional to the relative percentage of placard pressure that tires have lost. Thus, 100% of drivers would notice at 60% underinflation, 83% at a 50% underinflation, and 67% at 40% underinflation. Note that this represents a controlled circumstance in which people were actively looking for underinflation. The portion that would actually notice the problem and take action at each subsequent unit drop in pressure under casual circumstances is a separate issue. Our examination of the photos indicated that underinflation becomes significantly more obvious and more serious at levels of 50% and higher. It is thus believed that the progressive air losses that occur between the 40% and 60% underinflation levels will result in an increasing sense of urgency to correct the problem. Based on this, it was assumed that the probability of a driver taking action is proportional to the relative portion of drivers who could perceive the low pressure. A probability of perception was thus calculated relative to the base 40% underinflation threshold level. Thus, for example, a driver is 50% more likely to take action when a tire is 60 percent underinflated than when it is 40% underinflated (100%/67%). These relative probabilities were used as weights to distribute the different impacts that would occur for drivers at the various levels where they would otherwise have checked their tires in the absence of TPMS. This process is illustrated in Table VI-3. In that table, the aggregate impact at each level of underinflation is summed at the bottom. This indicates that the net impact on all drivers in this category is 16 additional fill-ups for passenger car drivers and 17 additional fill-ups for LTV drivers over the vehicle's life.

Table VI-3
Estimation of Impact of TPMS on Drivers Who Check Tires When They Seem Low

Underinflation Level	Low Presser Perception Threshold at this (psi)		Months to Refill		Lifetime Tire Refills		Difference in Lifetime Refills Vs. TPMS		% Pop Who Perceive Low Tire Pr.	Relative Probability of Perception	Aggregrative Relative Extra Low Weight Tire Check		
	PC	LTV	PC	LTV	PC	LTV	PC	LTV				PC	LTV
25%	22.5	26.25	7.5	8.75	32.0	34.3	0.0	0.0	NA	NA	NA	NA	NA
40%	18	21	12	14	20.0	21.4	12.0	12.9	66.7%	1	3.81%	0.4571	0.4898
41%	17.7	20.65	12.3	14.35	19.5	20.9	12.5	13.4	68.3%	1.025	3.90%	0.4876	0.5224
42%	17.4	20.3	12.6	14.7	19.0	20.4	13.0	13.9	70.0%	1.05	4.00%	0.5181	0.5551
43%	17.1	19.95	12.9	15.05	18.6	19.9	13.4	14.4	71.7%	1.075	4.10%	0.5486	0.5878
44%	16.8	19.6	13.2	15.4	18.2	19.5	13.8	14.8	73.3%	1.1	4.19%	0.5790	0.6204
45%	16.5	19.25	13.5	15.75	17.8	19.0	14.2	15.2	75.0%	1.125	4.29%	0.6095	0.6531
46%	16.2	18.9	13.8	16.1	17.4	18.6	14.6	15.7	76.7%	1.15	4.38%	0.6400	0.6857
47%	15.9	18.55	14.1	16.45	17.0	18.2	15.0	16.0	78.3%	1.175	4.48%	0.6705	0.7184
48%	15.6	18.2	14.4	16.8	16.7	17.9	15.3	16.4	80.0%	1.2	4.57%	0.7010	0.7510
49%	15.3	17.85	14.7	17.15	16.3	17.5	15.7	16.8	81.7%	1.225	4.67%	0.7314	0.7837
50%	15	17.5	15	17.5	16.0	17.1	16.0	17.1	83.3%	1.25	4.76%	0.7619	0.8163
51%	14.7	17.15	15.3	17.85	15.7	16.8	16.3	17.5	85.0%	1.275	4.86%	0.7924	0.8490
52%	14.4	16.8	15.6	18.2	15.4	16.5	16.6	17.8	86.7%	1.3	4.95%	0.8229	0.8816
53%	14.1	16.45	15.9	18.55	15.1	16.2	16.9	18.1	88.3%	1.325	5.05%	0.8533	0.9143
54%	13.8	16.1	16.2	18.9	14.8	15.9	17.2	18.4	90.0%	1.35	5.14%	0.8838	0.9469
55%	13.5	15.75	16.5	19.25	14.5	15.6	17.5	18.7	91.7%	1.375	5.24%	0.9143	0.9796
56%	13.2	15.4	16.8	19.6	14.3	15.3	17.7	19.0	93.3%	1.4	5.33%	0.9448	1.0122
57%	12.9	15.05	17.1	19.95	14.0	15.0	18.0	19.2	95.0%	1.425	5.43%	0.9752	1.0449
58%	12.6	14.7	17.4	20.3	13.8	14.8	18.2	19.5	96.7%	1.45	5.52%	1.0057	1.0776
59%	12.3	14.35	17.7	20.65	13.6	14.5	18.4	19.8	98.3%	1.475	5.62%	1.0362	1.1102
60%	12	14	18	21	13.3	14.3	18.7	20.0	100.0%	1.5	5.71%	1.0667	1.1429
									Totals	26.25	1	16.00	17.14

When Serviced:

Many of the drivers who fill their tires "When Serviced", are also likely to maintain adequate tire pressure without the TPMS. Given the roughly 8 month time span for routine pressure drop to reach the trigger point, drivers who bring their car in for service 2 or more times per year are unlikely to ever get a TPMS warning unless their tire is damaged. Drivers who get their vehicle serviced one time each year are likely to get one warning before their next service appointment. NHTSA currently does not have information on the frequency of vehicle service, but we believe that most vehicles are serviced 1-2 times per year. The frequency of service is likely to increase as vehicles age. To estimate the impact of TPMS on tire checks for this group, it will be assumed that half of them get serviced 2 or more times per year, and half of them only once. Thus, 14% of drivers are estimated to check their tires one additional time per year due to TPMS. This would add 20 checks over the lifetime of a passenger car and 25 over the lifetime of an LTV.

Before a Trip, Other, and Never:

The three remaining categories, "Before a long trip", "Other", and "Never", will be treated as "When Serviced". A driver who literally "never" checked his tires would be running on wheel rims within 2-3 years due to normal pressure loss over time. Clearly, therefore, these drivers are checking their tires, or getting somebody else to check them, at some point within this time frame. It is likely that in most cases this is being done when the vehicle is serviced. Likewise, the small portion of drivers who only check tire pressure before a long trip and those in the Other category will be assumed to experience the same basic impact as those who have it checked when the vehicle is serviced.

These 4 groups "When Serviced", Before a Long Trip", "Other", and "Never" comprise 42 percent of all drivers, and half of them or 21 percent, are estimated to experience from 20 (PC) to 25 (LTV) additional lifetime tire checks.

It will be assumed that these tire checks are performed during the next stop for gasoline, thus no additional stops will be required. Drivers will take time to move their vehicles from the fuel pump to the air pump and then locate and fill the underinflated tire or tires. It will be assumed that this process takes 5 minutes. The average value of business travel time specified by DOT for a single driver is $18.80/hour in 1995 dollars[4]. This value was expressed in its 2001 equivalent based on the change in average hourly earnings as measured by the Bureau of Labor Statistics[5]. Values for personal travel specified by DOT were also adjusted to 2001 levels. These values are a varying percentage of the full wage rate, depending on travel type (local vs. intercity). When weighted together by travel frequency, the average value for travel time for all types of surface travel was $11.10 per hour in 2001$.

Although the activity of checking and refilling tires is usually performed by the driver, passengers who are present would also be delayed by this process. Data from the National Personal Transportation Survey indicate that an average of 1.6 occupants ride in vehicles during

[4] "Departmental Guidance for Valuation of Travel Time in Economic Analysis", memorandum from Frank E. Kruesi, Assistant Secretary for Transportation Policy, U.S. Department of Transportation, to Secretarial Officers and Modal Administrators, April 9, 1997.

[5] Series CEU0500000049, Average Hourly Earnings, 1982 Dollars, Annual Average. The average hourly earnings was $7.53 in 1995 and $8.11 in 2001.

daily trips. However, frequently drivers schedule trips to gas stations to avoid inconveniencing other passengers. For example, drivers may make a trip to a nearby station specifically to obtain gasoline or they may do it on the way to accomplish other chores. It is therefore likely that average ridership for trips to gas stations is less than the average for all trip types. For this analysis, it will be assumed that an average of 1.3 occupants are delayed by added fill ups. The value of a tire check is thus estimated to be $1.20 ($11.10*5/60*1.3)

This analysis assumes annual vehicle sales of 17 million units (9 million LTVs and 8 million passenger cars). It is further assumed that the survey results noted in Table VI-2 represent the tire pressure habits of all new vehicle fleet buyers. Under these circumstances, an estimated 25 percent of drivers who currently check tires when they seem low would experience an increase of from 16 to 17 additional fill-ups over the vehicle's life. However, as previously noted, about 10% of drivers will ignore the TPMS, and will thus not experience this impact. Moreover, about 1% of vehicles already have a TPMS that complies with this proposal. After adjusting for these cases, the total impact is 62,879,143 added lifetime fillups valued at $75.6 million. An additional 21 percent of the new fleet or 3,570,000 vehicles (those that check tires when serviced, before a long trip, never, or "other") would be driven by owners who would experience an average of 22.65 additional tire checks over the vehicle's life. This totals 72,637,350 added checks over the vehicles' life, valued at $86.6 million. The total for these groups is $162.2 million.

Table VI-4
Summary of Opportunity Costs Due to Added Tire Checks/Fillups

	Current Tire Check Frequency % Drivers	Portion w/Extra Tire Checks w/TPMS	Additional Lifetime Tire Checks w/TPMS	Opportunity Cost
Weekly	0.09	0	0	$0
Monthly	0.24	0	0	$0
When Low	0.25	0.25	62,879,143	$75,612,169
When Serviced	0.28	0.14	48,024,900	$57,749,942
Before a Long Trip	0.02	0.01	3,430,350	$4,124,996
Other	0.07	0.035	12,006,225	$14,437,486
Never	0.05	0.025	8,575,875	$10,312,490
Total			134,916,493	$162,237,083
Total Discounted @ 3%				$133,566,927
Total Discounted @ 7%				$107,079,338

Since these added checks occur over the vehicles life they must be discounted to express their current value. At a 3% discount rate (.8233 factor weighted by vehicle type), they are valued at $133.6 million. At a 7% discount rate (.6600 factor) they are valued at $107.1 million. These results are summarized in Table VI-4.

Note that these calculations are based on normal inflation loss. The sudden or gradual air loss that results from a tire puncture would result in repair or replacement of the tire, and thus is not considered here.

Fees Charged for Air Pump Use

Although air pumps have traditionally been provided as a free service by gas and service stations to lure customers, many stations now charge nominal fee – usually either .25 or .50, to use their pump. In a recent survey of air pumps at gas stations, NHTSA found that 43 percent of stations charged a fee for pump use[6]. Frequently, this fee is waived for customers who refuel their vehicles, which is the scenario contemplated here.

NHTSA has no data regarding the average level of fees charged across the country, but fees of 25 cents and 50 cents have both been observed. To estimate the cost of fees for the added tire fill ups, it will be assumed that half of those stations charging fees charge 50 cents and half charge 25 cents. The average charge is thus 37.5 cents. It will also be estimated that half of these stations waive the fees for their gasoline customers.

The total number of extra tire refills was estimated to be 134,916,493 (after adjustment for current systems and driver response) and 43 percent of these are estimated to occur at stations that charge for air. The total fee cost is thus estimated to be $10,877,642 (134,916,493 x .43 x .5 x $0.375). Discounted over the vehicle's life, the present value of these fees is $8,955,371 at 3%, and $7,179,436 at 7%.

Time Saved from Prevented Crashes

When crashes occur, drivers must get estimates for insurance purposes before getting the vehicle fixed, and then must arrange to deliver the vehicle to the selected body shop or garage. While

[6] Stevano, Joseph M.S. Ph.D., "Air Pumps and Gas Stations: Major Findings Regarding Availability, Reliability and Fees", Research Note, NHTSA, U.S. Department f Transportation, DOT HS 809 366, November 2001.

the vehicle is being repaired they must either rent a replacement vehicle, borrow a second car, take public transportation, or modify their activities. This occurs after the initial crash, which can tie up those involved for hours while their vehicles are towed, while police process the crash, or while occupants are transported to and treated in hospitals. There are thus lost opportunity costs associated with every crash. To the extent that TPMS prevent crashes, they will mitigate these costs.

Table VI-5 illustrates the number of currently damaged vehicles that would be involved in crashes that are prevented by TPMS. The estimates were derived in several steps. The number of injury crash vehicles was estimated by totaling all injuries prevented by TPMS in each category and dividing by 1.35, the ratio of injuries to injury involved vehicles from the 2000 NHTSA report on the cost of motor vehicle crashes[7]. From this same report, there were approximately 4 PDO involved vehicles for every injury involved vehicle. This factor was used to estimate the total PDO involved damaged vehicles that would be saved by TPMS. PDO crashes are largely under reported – only 52% of PDO crashes are reported to the police. This factor was applied to Police reported PDOs to estimate the total number of PDO involved vehicles. Overall, about 4,900 vehicles involved in injury-related crashes, and 47,900 involved in PDO crashes would be mitigated by TPMS.

[7] Blincoe L., Seay A., Zaloshnja E., Miller T., Romano E., Luchter S., Spicer R., "The Economic Impact of Motor Vehicle Crashes, 2000", U.S. Department of Transportation, NHTSA, DOT HS 809 446, May 2002.

Table VI-5
Crash Involvements Prevented by TPMS
Injured Persons

	Preventable			
	Stop. Dist	Skid	Flat	
MAIS1	1,328	3,529	457	3,202
MAIS2	145	393	132	670
MAIS3	62	168	32	262
MAIS4	6	16	14	36
MAIS5	4	10	5	19
Fatal	13	44	37	94
Total	1,558	4,160	953	6,671
Inj. Vehicles	1,150	3,071	704	4,925
Ratio PDO/Inj Veh	4		4	
Total P.R. PDO Vehicles	4,589	17,511	2,807	
Total PDO Vehicles	8,825	33,675	5,398	47,897
Total Vehicles Crash Involvement Prevented				52,822

In order to estimate the impact these prevented crashes will have on drivers, a number of assumptions must be made. These assumptions include:

Process delay at crash site: This represents the time that elapses from the occurrence of a non-injury involved crash to the time the involved drivers resume their trip. For minor bumper damage where drivers just exchange information, it might be relatively short, but in crashes where damage is more extensive and police get involved, it could result in significant delays. We estimate an average occurrence to be 30 minutes.

Injury related delay: This represents the additional delay that occurs for persons injured in crashes as they are initially transported to hospitals and treated for their injuries. It does not include long term work or time loss during recovery, as that is considered under lost productivity, a line item in the comprehensive costs used in determining equivalent fatalities. It is possible that there is some overlap between these 2 measures, but this is uncertain. We estimate an average of 5 hours delay for each injured person.

Time spent getting repair estimates: Typically insurance companies require that drivers get 3 estimates before making claims for vehicle repair. In addition, drivers must spend time dealing with the administrative tasks involved in completing claims forms, contacting agents, etc. This activity occurs for both PDO and injury crashes. We estimate an average of 4 hours time lost to this process for each involved vehicle.

The total crash related delay time mitigated by TPMS is thus estimated to be 37,185 hours for injury vehicles (4,925 vehicles x 5.5 hours *1.35 injuries/vehicle) and 38,318 hours for PDO vehicles (47,897 vehicles x 0.5 hours). The total hours of repair related activities for all vehicles is 264,112 (52,822 vehicles x 4 hours). The value of this prevented lost opportunity cost is $3,769,096 (339,614 x $11.10). Discounted at a 3% rate, this value is $3,103,030. At a 7% rate it is $2,487,670.

Although we have analyzed these positive impacts on time savings from TPMS, they are to a large extent already included in estimates of lost productivity that are used in determining the relative values of nonfatal injuries when estimating fatal equivalents in the cost effectiveness analysis. As such, it would not be appropriate to include them again at this stage of the analysis. Therefore, this segment of the analysis is provided for illustrative purposes only, and will not be carried forward into the cost effectiveness or cost benefit analysis.

The present value of total opportunity costs is $142,522,298 ($133,566,927 + $8,955,371) at the 3% discount rate and $114,258,774 ($107,079,338 + $7,179,436) at the 7% discount rate.

Total Costs by Compliance Option

Table VI-6 provides the total cost by Compliance Option adding the vehicle consumer cost, the present discounted value of maintenance costs, and opportunity costs.

Table VI-6
Cost Summary
(Per vehicle)
At a 3 Percent Discount Rate

	Consumer Cost Increase	Present Value of Maintenance Costs	Opportunity Costs	Total Cost
Compliance Option 1	$69.89	$0 to $55.98	$8.38	$78.27 to $134.34
Compliance Option 2	$66.08	$0 to $55.98	$8.38	$74.46 to $130.44
Compliance Option 3	$48.44	$0 to $37.23	$8.38	$56.82 to $94.05

At a 7 Percent Discount Rate

	Consumer Cost Increase	Present Value of Maintenance Costs	Opportunity Costs	Total Cost
Compliance Option 1	$69.89	$0 to $40.50	$6.72	$76.61 to $117.11
Compliance Option 2	$66.08	$0 to $40.50	$6.72	$72.80 to $113.30
Compliance Option 3	$48.44	$0 to $26.93	$6.72	$55.16 to $82.09

Table VI-7
Cost Summary for 17 Million Vehicles
(Millions of 2001 Dollars)
At a 3 Percent Discount Rate

	Consumer Cost Increase	Present Value of Maintenance Costs	Opportunity Costs	Total Cost
Compliance Option 1	$1,188	$0 to $952	$143	$1,331 to $2,283
Compliance Option 2	$1,123	$0 to $952	$143	$1,266 to $2,218
Compliance Option 3	$823	$0 to $633	$143	$966 to $1,599

At a 7 Percent Discount Rate

	Consumer Cost Increase	Present Value of Maintenance Costs	Opportunity Costs	Total Cost
Compliance Option 1	$1,188	$0 to $689	$114	$1,302 to $1,991
Compliance Option 2	$1,123	$0 to $689	$114	$1,237 to $1,926
Compliance Option 3	$823	$0 to $458	$114	$937 to $1,395

Other Maintenance Costs (non-quantified)

The agency anticipates that there will be maintenance costs other than batteries for direct measurement systems associated with both a direct and a hybrid measurement system. With hybrid and indirect systems, the agency is aware of problems with wheel speed sensors with mis-adjustment, maintenance, and component failures. With direct systems, there is the possibility that the wheel sensors could be broken off when tires are being changed. Without estimates of these maintenance problems and costs, the agency is unable to quantify their impact.

Testing Costs

The test to show compliance starts with the tires at the placard pressure. The vehicle would be run for a specified time to check out the system. For this cost analysis, it is assumed that every possible combination of deflated tires would be tested. First, one tire would be deflated and the vehicle driven for 10 minutes to determine the response. Each of the other three tires would be deflated separately and the response of the system checked. Then, different combinations of two tires would be deflated at a time and the vehicle driven for ten minutes, different combinations of three tires would be deflated at the same time and finally all four tires would be deflated at the same time. Before and during these tests, the system may need to be calibrated. The data must be collected, analyzed and a test report written.

Assuming one set of tires on one vehicle at one vehicle load, the man-hours for the test are 6 hours for a manager, 30 hours for a test engineer and 30 hours for a test technician/driver.

Labor costs are estimated to be $75 per hour for a manager, $53 per hour for a test engineer and $31 per hour for technicians. Total testing costs are thus estimated to be $2,970 ($75 * 6 + $30 * 53 + $31 * 30). If for light trucks, it is necessary to test the vehicle unloaded and fully loaded, which is rarely done for passenger cars, since the two weights of unloaded and fully loaded are not that far apart, the test costs for light trucks would essentially double.

Lead Time

Based on information supplied by vehicle manufacturers and TPMS suppliers to a NHTSA special order request, there is ample supply capacity for direct monitoring systems to meet the following lead time phase-in proposal. However, the information required did not specify whether battery-less systems were being planned. The agency proposes that:

50 percent of light vehicles produced between September 1, 2005 and August 31, 2006,

90 percent of light vehicles produced between September 1, 2006 and August 31, 2007,

all light vehicles produced after September 1, 2007 meet the proposed requirements.

The agency will allow carry forward credits as it has done in other rulemakings, but only for vehicles that are manufactured during the phase-in, and will allow small volume vehicle manufacturers to meet the standard starting September 1, 2007.

VII. COST EFFECTIVENESS AND BENEFIT-COST ANALYSES

A. Costs Effectiveness Analysis

This section combines costs and benefits to provide a comparison of the estimated injuries and lives saved per net cost. Vehicle costs occur when the vehicle is purchased, but the maintenance costs, opportunity costs of refilling tires, safety benefits, and property damage benefits and travel delay benefits accrue over the lifetime of the vehicle. Maintenance costs, opportunity costs, and all of the benefits must therefore be discounted to express their present value and put them on a common basis with vehicle costs.

In some instances, costs may exceed economic benefits, and in these cases, it is necessary to derive a net cost per equivalent fatality prevented. An equivalent fatality is defined as the sum of: (1) fatalities and (2) nonfatal injuries prevented converted into fatality equivalents. This conversion is accomplished using the relative values of fatalities and injuries measured using a "willingness to pay" approach. This approach measures individuals' willingness to pay to avoid the risk of death or injury based on societal behavioral measures, such as pay differentials for more risky jobs.

Table VII-1 presents the relative estimated rational investment level to prevent one injury, by maximum injury severity. Thus, one MAIS 1 injury is equivalent to 0.0031 fatalities. The data represent average costs for crash victims of all ages. The Abbreviated Injury Scale (AIS) is an anatomically based system that classifies individual injuries by body region on a six point ordinal scale of risk to life. The AIS does not assess the combined effects of multiple injuries. The maximum AIS (MAIS) is the highest single AIS code for an occupant with multiple injuries.

Table VII-1

Comprehensive Fatality and Injury Relative Values	
Injury Severity	2000 Relative Value* per injury
MAIS 1	.0031
MAIS 2	.0458
MAIS 3	.0916
MAIS 4	.2153
MAIS 5	.7124
Fatals	1.000

* Includes the economic cost components and valuation for reduced quality of life.
Source: "The Economic Impact of Motor Vehicle Crashes, 2000", NHTSA, May 2002, DOT HS 809 446.

Table VII-2 shows the estimated equivalent fatalities for the different Compliance Options. The injuries from Chapter V are weighted by the corresponding values in Table VII-1, added to the fatalities, and then summed.

Table VII-2
Equivalent Fatalities (Undiscounted)

	Fatality Benefits	Injury Benefits	Equivalent Fatalities
Compliance Option 1	121	8,568	250
Compliance Option 2	119	8,373	245
Compliance Option 3	119	8,373	245

Net Costs

The average vehicle costs are estimated to be $69.89 per vehicle for Compliance Option 1, $66.08 for Compliance Option 2, and $48.44 for Compliance Option 3. Multiplying these by 17 million vehicles results in $1,188 million for Compliance Option 1, $1,123 for Compliance Option 2, and $823 million for Compliance Option 3. Maintenance costs and opportunity costs for refilling tires are added to these costs and then offset somewhat by a reduction in costs for fuel economy, tread wear, property damage and travel delay (See Table VII-3).

The net costs and total annual costs are shown in Tables VII-3 and VII-4.

Table VII-3 (a)
Net Costs per Vehicle
At a 3 Percent Discount Rate
(2001 Dollars)

Opt.	Vehicle Costs	Present Value of Maintenance Costs*	Present Value of Opportunity Costs of Refilling Tires	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Present Value of Property Damage and Travel Delay Savings	Net Costs
1	$69.89	$0 to $55.98	$8.38	$23.08	$4.24	$7.79	$43.16 to $99.14
2	$66.08	$0 to $55.98	$8.38	$19.07	$3.42	$7.70	$44.27 to $100.25
3	$48.44	$0 to $37.23	$8.38	$19.07	$3.42	$7.70	$26.63 to $63.86

* Maintenance costs range from a battery-less TPMS to a TPMS with 4 batteries for Compliance Options 1 and 2, and 2 batteries for Compliance Option 3.

Table VII-3 (b)
Net Costs per Vehicle
At a 7 Percent Discount Rate
(2001 Dollars)

Opt.	Vehicle Costs	Present Value of Maintenance Costs*	Present Value of Opportunity Costs of Refilling Tires	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Present Value of Property Damage and Travel Delay Savings	Net Costs
1	$69.89	$0 to $40.50	$6.72	$18.34	$6.03	$6.25	$45.99 to $86.49
2	$66.08	$0 to $40.50	$6.72	$15.14	$4.98	$6.16	$46.52 to $87.02
3	$48.44	$0 to $26.93	$6.72	$15.14	$4.98	$6.16	$28.88 to $55.81

* Maintenance costs range from a battery-less TPMS to a TPMS with 4 batteries for Compliance Options 1 and 2, and 2 batteries for Compliance Option 3.

Table VII-4 (a)
Total Annual Costs for 17 Million Vehicles
(Millions of 2001 Dollars)
At a 3 Percent Discount Rate

Opt.	Vehicle Costs	Present Value of Maintenance Costs*	Present Value of Opportunity Costs of Refilling Tires	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Present Value of Property Damage and Travel Delay Savings	Net Costs
1	$1,188	$0 to $952	$142	$392	$72	$132	$734 to $1,685
2	$1,123	$0 to $952	$142	$324	$58	$131	$753 to $1,704
3	$823	$0 to $633	$142	$324	$58	$131	$453 to $1,086

* Maintenance costs range from a battery-less TPMS to a TPMS with 4 batteries for Compliance Options 1 and 2, and 2 batteries for Compliance Option 3.

Table VII-4 (b)
Total Annual Costs for 17 Million Vehicles
(Millions of 2001 Dollars)
At a 7 Percent Discount Rate

Opt.	Vehicle Costs	Present Value of Maintenance Costs*	Present Value of Opportunity Costs of Refilling Tires	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Present Value of Property Damage and Travel Delay Savings	Net Costs
1	$1,188	$0 to $689	$114	$312	$103	$106	$782 to $1,470
2	$1,123	$0 to $689	$114	$257	$85	$105	$791 to $1,479
3	$823	$0 to $458	$114	$257	$85	$105	$491 to $949

*Maintenance costs range from a battery-less TPMS to a TPMS with 4 batteries for Compliance Options 1 and 2, and 2 batteries for Compliance Option 3.

One of the conclusions from this analysis is that Compliance Option 1 with the continuous display capability has equivalent or lower net costs than Compliance Option 2 (just providing a warning signal). This occurs because the fuel savings and tread wear savings are equivalent to or more than the cost of the continuous display.

Net Cost (at a 3% discount rate)/Equivalent Fatality Before Discounting Safety Benefits

Opt. 1 $734 to $1,685 mil./250 equivalent fatalities = $2.9 to $6.4 million per equivalent life

Opt. 2 $753 to $1,704 mil./245 equivalent fatalities = $3.1 to $6.7 million per equivalent life

Opt. 3 $453 to $1,086 mil./245 equivalent fatalities = $1.9 to $4.3 million per equivalent life

Net Cost (at a 7% discount rate)/Equivalent Fatality Before Discounting Safety Benefits

Opt. 1 $782 to $1,470 mil./250 equivalent fatalities = $3.0 to $5.6 million per equivalent life

Opt. 2 $791 to $1,479 mil./245 equivalent fatalities = $3.1 to $5.8 million per equivalent life

Opt. 3 $491 to $949 mil./245 equivalent fatalities = $1.9 to $3.7 million per equivalent life

Appendix V of the "Regulatory Program of the United States Government", April 1, 1990 - March 31, 1991, sets out guidance for regulatory impact analyses. One of the guidelines deals with discounting the monetary values of benefits and costs occurring in different years to their present value so that they are comparable. The agency performed a cost-effectiveness analysis resulting in an estimate of the cost per equivalent life saved, as shown on the previous pages. The guidelines state, "An attempt should be made to quantify all potential real incremental benefits to society in monetary terms of the maximum extent possible." For the purposes of the cost-effectiveness analysis, the Office of Management and Budget (OMB) has requested that the agency compound costs or discount the benefits to account for the different points in time that they occur.

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[1] estimated that the social rate of time preference is between zero and 6 percent, reflecting the rates of return on Treasury bills and stock market portfolios. Kolb and Sheraga[2] put the rate at between one and five percent, based on returns to stocks and three-month Treasury bills.

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[1]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.).

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

Moore and Viscusi[3] calculated a two percent real time rate of time preference for health, which they characterize as being consistent with financial market rates for the period covered by their study. Moore and Viscusi's estimate was derived by estimating the implicit discount rate for deferred health benefits exhibited by workers in their choice of job risk.

OMB Circular A-4 recommends agencies use both 3 percent and 7 percent as the "social rate of time preference".

Safety benefits can occur at any time during the vehicle's lifetime. For this analysis, the agency assumes that the distribution of weighted yearly vehicle miles traveled are appropriate proxy measures for the distribution of such crashes over the vehicle's lifetime. Multiplying the percent of a vehicle's total lifetime mileage that occurs in each year by the discount factor and summing these percentages over the 20 or 25 years of the vehicle's operating life, results in the following multipliers for the average passenger car and light truck as shown in Table VII-4. These values are multiplied by the equivalent lives saved to determine their present value (e.g., in Table VII-5 at 3%, 250 x .8233 = 206). The net costs per equivalent life saved for passenger cars and light trucks are then recomputed and shown in Table VII-6 using the annual net cost figures from Table VII-4a for 17 million vehicles and the discounted equivalent lives saved from Table VII-5. (e.g., for the battery-less TPMS estimate, Compliance Option 1 @ 3 percent discount rate; $734 million/206 equivalent lives saved = $3.6 million per life saved).

[3]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.

Table VII-4
Discounting Multipliers

	3 Percent	7 Percent
Passenger Cars	0.8434	0.6921
Light Trucks	0.8054	0.6315
PC/LT Average	0.8233	0.6600

Table VII-5
Discounting of Equivalent Lives Saved

	Base Equivalent	3 Percent	7 Percent
Compliance Option 1	250	206	165
Compliance Option 2	245	201	161
Compliance Option 3	245	201	161

Table VII-6
Net Costs per Discounted Equivalent Life Saved*
($ millions)

	3 Percent	7 Percent
Compliance Option 1	$3.6 to $7.8	$4.5 to $8.5
Compliance Option 2	$3.7 to $8.1	$4.7 to $8.7
Compliance Option 3	$2.3 to $5.2	$2.9 to $5.6

* The range represents battery-less TPMS to a TPMS with batteries

The results in Table VII-6 show that the cost per equivalent life saved for the battery-less TPMS range from $2.3 million to $3.7 million at a 3% discount rate and from $2.9 million to $4.7 million at a 7% discount rate. For a TPMS with batteries, the cost per equivalent life saved range from $4.6 million to $7.3 million at a 3% discount rate and from $4.9 million to $7.8 million at a 7% discount rate. Thus, a battery-less TPMS is more cost effective than a TPMS with a battery.

B. Benefit-Cost Analysis

Effective January 1, 2004, OMB Circular A-4 requires that analyses performed in support of proposed rules must include both cost effectiveness and benefit-cost analysis. Benefit-cost analysis differs from cost effectiveness analysis in that it requires that benefits be assigned a monetary value, and that this value be compared to the monetary value of costs to derive a net benefit. In valuing reductions in premature fatalities, we used a value of $3.5 million per statistical life. The most recent study relating to the cost of crashes published by NHTSA[4], as well as the most current DOT guidance on valuing fatalities[5], indicate a value consistent with $3.5 million. This value represents an updated version of a meta-analysis of studies that were conducted prior to 1993. More recent studies indicate that higher values may be justified.[6]

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[4] L. Blincoe, A. Seay, E. Zaloshnja, T. Miller, E. Romano, S. Luchter, R. Spicer, (May 2002) "The Economic Impact of Motor Vehicle Crashes, 2000". Washington D.C.: National Highway Traffic Safety Administration, DOT HS 809 446.

[5] "Revised Departmental Guidance, Treatment of Value of Life and Injuries in Preparing Regulatory Evaluations", Memorandum from Kirk K. Van Tine, General Counsel and Linda Lawson, Acting Deputy Assistant Secretary for Transportation Policy to Assistant Secretaries and Modal Administrators, January 29, 2002.

[6] For example, Miller, T.R. (2000): "Variations Between Countries in Values of Statistical Life", Journal of Transport Economics and Policy, 34, 169-188.

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 consumers after-tax lost productivity. In addition to these factors, preventing a motor vehicle fatality will reduce costs for medical care, emergency services, insurance administrative costs, workplace costs, and legal costs. If the countermeasure is one that also prevents a crash from occurring, property damage and travel delay would be prevented as well. The sum of both value of life and economic cost impacts is referred to as the comprehensive cost savings from reducing fatalities.

The countermeasures that result from the TPMS proposal relate to crash-avoidance, and thus involve property damage or travel delay. The 2002 NHTSA report cited above estimates that the comprehensive cost savings from preventing a fatality for crash-avoidance countermeasures was \$3,366,388 in 2000 economics. This estimate is adjusted for inflation to the 2001 cost level used in this report. Based on the CPI ALL Items index (177.1/172.2), this would become \$3,462,180. The basis for the benefit-cost analyses will thus be \$3.5 million.

Total benefits from injuries and fatalities reduced are derived by multiplying the value of life by the equivalent lives saved. The net benefits are derived by subtracting total net costs from the total benefits, as shown in Table VII-7. Positive Net Benefits indicate that Benefits valued at \$3.5 million per equivalent life are higher than Net Costs. Negative Net Benefits indicate that Benefits valued at \$3.5 million per equivalent life are lower than Net Costs.

Table VII-7
Net Benefits with a Value of $3.5M per Statistical Life*
(Millions of 2001 Dollars)

	3% Discount Rate	7% Discount Rate
Compliance Option 1	$25 to –$927 Mil.	$-174 to -$862 Mil.
Compliance Option 2	-$13 to -$965 Mil.	$-198 to -$887 Mil.
Compliance Option 3	$287 to -$346 Mil.	$102 to -$356 Mil.

* The range represents battery-less TPMS to a TPMS with batteries

C. The Malfunction/Warning Lamp

We examined the malfunction warning lamp from a cost per equivalent life saved basis for Compliance Option 1 at the 3 percent discount rate (the other Compliance Options and the 7% discount rate would have very similar results). We estimated the cost for a separate telltale lamp and the added circuitry for the malfunction capability at $1.83 per vehicle or $31.1 million annually. The estimated cost for a combination telltale lamp and the added circuitry for the malfunction capability is estimated to be $0.25 per vehicle or $4.3 million annually.

On the benefits side, we estimate the same benefits for providing a separate telltale lamp as for providing a combination telltale lamp as the malfunction indication. The impact that a malfunction/warning lamp would have on benefits depends on what consumers do when they see such a lamp. The benefits of this proposal, safety benefits as well as tread life and fuel economy savings, are directly related to mileage. The average tread life was estimated to be 45,000 miles. The average weighted vehicle miles traveled was 126,678 miles for passenger cars and 153,319 miles for light trucks. That means that potentially 64 percent of the passenger car (1 –

45,000/126,678) and 71 percent of the light truck mileage will be driven on replacement tires. If 1 percent of the replacement tires are not compatible with TPMS designs, then a weighted average of 0.677 percent of the benefits for both passenger cars and light trucks could potentially not be obtained if consumers were not provided with a malfunction lamp or if they ignored the malfunction lamp. Assuming that a 1 percent malfunction, either because the TPMS won't work with some replacement tires or because of another malfunction, resulted in a 0.677 percent loss in benefits, the impact on benefits would be 1 fatality (121 lives saved * 0.00677) and 58 injuries reduced, or 1.7 equivalent lives. The 0.675 percent loss in benefits will also affect the fuel savings and tread life savings. Table VII-8 shows the results of the analysis that a combination lamp would be cost effective, while a separate malfunction lamp would not be cost effective in absolute terms (the cost per equivalent life saved is about the $3.5 to $5.5 million range).

Table VII-8
Incremental Cost per Equivalent Life Saved Analysis for Malfunction Lamp
Cost in Millions of 2001 Dollars

Opt. 1 (3% discount rate	Vehicle Costs	Opp. Costs	Fuel Savings	Tread Wear Savings	Prop. Damage and Travel Savings	Net Costs	Equiv. Lives Saved	Cost/ Eq. Life Saved
Separate Malfunction Lamp	$31.1	$1.0	$2.7	$0.5	$0.9	$28.0	1.7	$16.5
Combination Lamp	$4.3	$1.0	$2.7	$0.5	$0.9	$1.2	1.7	$0.7

D. Sensitivity Analysis

Above, we used a value of $3.5 million in valuing reductions in premature fatalities. In valuing reductions in fatalities, we also examined a value of $5.5 million per statistical life as a sensitivity analysis. This represents a central value consistent with a range of values from $1 to $10 million suggested by recent meta-analyses of the wage-risk value of statistical life (VSL) literature[7]. Table VII-9 presents the net benefits using a value of $5.5 million per statistical life saved.

Table VII-9
Net Benefits with a Value of $5.5M per Statistical Life*
(Millions of 2001 Dollars)

	3% Discount Rate	7% Discount Rate
Compliance Option 1	$347 to –$492 Mil.	$175 to -$514 Mil.
Compliance Option 2	$355 to -$551 Mil.	$134 to -$548 Mil.
Compliance Option 3	$655 to $68 Mil.	$434 to -$17 Mil.

* The range represents battery-less TPMS to a TPMS with batteries

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

VIII. SMALL BUSINESS IMPACTS

A. Regulatory Flexibility Act

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

Currently, there are about 4 small motor vehicle manufacturers in the United States[1]. As with other systems in the vehicle, these manufacturers will have to rely on suppliers to provide the hardware, and then they would have to integrate the system into their vehicles. The agency does not believe this will create a significant economic burden for these manufacturers. The agency is providing an alternative for the small vehicle manufacturers to meet the proposal in the last year of the phase-in period, giving them as much lead time as possible.

There are a few recreational vehicles made which are under 10,000 pounds GVWR, which would have to comply with the standard. Most of these vehicles use van chassis supplied by the larger manufacturers (GM, Ford, or Daimler Chrysler) and could use the systems supplied with the chassis. To demonstrate compliance with FMVSS 138, a final stage manufacturer would primarily rely upon the chassis manufacturer's incomplete vehicle document.

[1] Avanti, Callaway, Panoz, and Saleen.

Aftermarket Wheel and Rim Manufacturers

There were several commenters to the docket stating that there would be a significant impact on a large number of aftermarket wheel and rim manufacturers. The Specialty Equipment Market Association (Docket No. 8572-114) stated that there are 550 small businesses making aftermarket tires and custom wheels and this is a $2.1 billion industry. SEMA is concerned that many of the provisions will have the effect of restricting the ability of aftermarket suppliers to provide a full range of wheel and tire combinations to consumers. They were concerned that the language requiring aftermarket wheels to be compatible with only those combinations recommended by a vehicle manufacturer could disallow aftermarket equipment that does not match manufacturer's recommendations.

The Tire Association of North America (Docket No. 8572-129) stated that a regulation that narrows consumer choice would have a significant negative impact on small business across the United States. They argued that we should delete "recommended for use on the vehicle by the vehicle manufacturer."

Several other different types of manufacturers made related comments. Schrader Electronics (Docket No. 8572-120) stated that replacement rims do not necessarily follow the Tire and Rim Standards. Proper fitment could not be guaranteed. Thus, replacement rims should not be required to meet the standard. The Alliance (Docket No. 8572-137) stated that the agency should exempt temporary spare tires and that manufacturers can't certify replacement tires. Ford (Docket No. 8572-141) stated that the agency should limit the scope of the final rule to those tires and rims specified for use on the vehicle by the vehicle manufacturer. Nissan (Docket No. 8572-124) stated that it was premature to include replacement tire/rims in the standard.

The agency has decided to exempt temporary spare tires and aftermarket rims, that don't match the original equipment rims, from the requirements on a practicability basis. This should eliminate the concerns of small businesses that make and sell custom wheels and aftermarket rims.

Low Tire Pressure Monitoring System Suppliers

There are several suppliers of direct measurement system radio frequency transmission technology (Beru, IQ Mobil, Johnson Controls, Schrader-Bridgeport, Pacific Industrial Company, TRW, SmarTire, Rayovac, and Fleet Specialties Company). Suppliers of indirect ABS integrated technology include Continental Teves, TRW, Bosch, Eaton, and Toyota. There is one company that supplies a system that monitors the tires and puts air into the tire, Cycloid Company.

The Regulatory Flexibility Act requires the agency to make a determination on whether the proposal could have a significant economic impact on a substantial number of small businesses. A small business is defined by the Small Business Administration, for purposes of receiving Small Business Administration assistance. The criteria for determining size, as stated in 13 CFR 121.201, is the number of employees in the firm. The suppliers would fall under either Subsection 336340 Motor Vehicle Brake System Manufacturers or Subsection 336322 Other Motor Vehicle Electrical and Electronic Equipment Manufacturers. A company under these subsections must have less than 750 employees to be considered a small business. Only three of these companies could have less than 750 employees (SmarTire, Fleet Specialties Company, and Cycloid Company). The agency does not have employee data on SmarTire and Fleet Specialties Company. Cycloid Company has less than 10 employees and outsources the manufacturing of their products. However, to be considered in the substantial number of small businesses, the business headquarters should be in the United States. SmarTire is located in the United Kingdom and Canada.

In conclusion, the agency believes that this proposal will not affect a substantial number of small businesses.

B. Unfunded Mandates Reform Act

The Unfunded Mandates Reform Act of 1995 (Public Law 104-4) requires agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditures by State, local or tribal governments, in the aggregate, or by the private sector, of more than $100 million annually (adjusted annually for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for the year 2000 results in $109 million (106.99/98.11 = 1.09). The assessment may be included in conjunction with other assessments, as it is here.

This proposal is not likely to result in expenditures by State, local or tribal governments of more than $109 million annually. However, it is estimated to result in the expenditure by automobile manufacturers and/or their suppliers of more than $109 million annually. The agency has estimated that compliance with this final rule would cost from $775 million to over $1.1 billion. The final cost will depend on choices made by the automobile manufacturers.

These effects have been discussed in the Preliminary Economic Assessment; see for example the chapters on Cost, Benefits and the previous discussion in this chapter on the Regulatory Flexibility Act.

IX. CUMULATIVE IMPACTS

Section 1(b) II of Executive Order 12866 Regulatory Planning and Review requires the agencies to take into account to the extent practicable "the costs of cumulative regulations". To adhere to this requirement, the agency has decided to examine both the costs and benefits by vehicle type of all substantial final rules with a cost or benefit impact effective from MY 1990 or later. In addition, proposed rules are also identified and preliminary cost and benefit estimates provided.

Costs include primary cost, secondary weight costs and the lifetime discounted fuel costs for both primary and secondary weight. Costs will be presented in two ways, the cost per affected vehicle and the average cost over all vehicles. The cost per affected vehicle includes the range of costs that any vehicle might incur. For example, if two different vehicles need different countermeasures to meet the standard, a range will show the cost for both vehicles. The average cost over all vehicles takes into account voluntary compliance before the rule was promulgated or planned voluntary compliance before the rule was effective and the percent of the fleet for which the rule is applicable. Costs are provided in 2000 dollars, using the implicit GNP deflator to inflate previous estimates to 2000 dollars.

Benefits are provided on an annual basis for the fleet once all vehicles in the fleet meet the rule. Benefit and cost per average vehicle estimates take into account voluntary compliance.

Table IX-1

COSTS OF RECENT PASSENGER CAR RULEMAKINGS
(Includes Secondary Weight and Fuel Impacts)
(2000 Dollars)

Description	Effective Model Year	Cost Per Affected Vehicle $	Cost Per Average Vehicle $
FMVSS 114, Key Locking System to Prevent Child-Caused Rollaway	1993	$9.44 – 19.58	$0.53 - 1.08
FMVSS 214, Dynamic Side Impact Test	1994 - 10% phase-in 1995 - 25% 1996 - 40% 1997 – 100%	$69.06 – 672.59	$62.52
FMVSS 208, Locking Latch Plate for Child Restraints	1996	$0.89 – 17.93	$2.40
FMVSS 208, Belt Fit	1998	$3.41 – 17.09	$1.26 - 1.82
FMVSS 208, Air Bags Required	1997 - 95% 1998 – 100	$503.50 – 608.39	$503.50 – 608.39
FMVSS 201, Upper Interior Head Protection	1999 - 10% 2000 - 25% 2001 - 40% 2002 - 70% 2003 – 100%	$37.76	$37.76
FMVSS 225, Child Restraint Anchorage Systems	2001 - 20% 2002 - 50% 2003 - 100%	$3.01 - $7.08	$6.07
FMVSS 208, Advanced Air Bags	Two phases 2003 to 2010	$24.15 to 134.40	Depends on method chosen to comply
FMVSS 301, Fuel Tank Integrity Upgrade	2007 - 40% 2008 - 70% 2009 - 100%	$5.08	$2.35

Table IX-2

BENEFITS OF RECENT PASSENGER CAR RULEMAKINGS
(Annual benefits when all vehicles meet the standard)

Description	Fatalities Prevented	Injuries Reduced	Property Damage Savings $
FMVSS 114, Key Locking System to Prevent Child Caused Rollaway	None	50-99 Injuries	Not Estimated
FMVSS 214, Dynamic Side Impact Test	512	2,626 AIS 2-5	None
FMVSS 208, Locking Latch Plate for Child Restraints	Not estimated	Not estimated	None
FMVSS 208, Air Bags Required Compared to 12.5% Usage in 1983 Compared to 46.1% Usage in 1991	 4,570 - 9,110 2,842 - 4,505	AIS 2-5 85,930 - 155,090 63,000 - 105,000	None
FMVSS 201, Upper Interior Head Protection	575 - 711	251 - 465 AIS 2-5	None
FMVSS 225, Child Restraint Anchorage Systems – Benefits include changes to Child Restraints in FMVSS 213	36 to 50*	1,231 to 2,929*	None
FMVSS 208, Advanced Air Bags	117 to 215**	584 to 1,043 AIS 2-5**	Up to $85 per vehicle*
FMVSS 301, Fuel Tank Integrity Upgrade	4 to 11	none	none

* Total benefits for passenger cars and light trucks
** Total benefits for passenger cars and light trucks, does not count potential loss in benefits if air bags are significantly depowered.

Table IX-3

COSTS OF PROPOSED PASSENGER CAR RULES
(Includes Secondary Weight and Fuel Impacts)
(2000 Dollars)

Description	Effective Model Year	Cost Per Affected Vehicle $	Cost Per Average Vehicle $
FMVSS 202, Head Restraint Upgrade	TBD – first model year starting 3 years after final rule	$8.10 to $17.15	$10.70
FMVSS 208, Rear Center Seat Lap/Shoulder Belts	2006 - 50% 2007 - 80% 2008 - 100%	$15.41	$3.91
FMVSS 214, Side Impact Oblique Pole Test	TBD – first model year starting 4 years after final rule, then a 3 year phase in of 20%, 50%, all vehicles	$116 to $253	$87 to $199

Table IX-4

BENEFITS OF PROPOSED PASSENGER CAR RULES
(Annual benefits when all vehicles meet the standard)

Description	**Fatalities Prevented**	**Injuries Reduced**	**Property Damage Savings $**
FMVSS 202, Head Restraint Upgrade	None	12,395	None
FMVSS 208, Rear Center Seat Lap/Shoulder Belts	16	279	None
FMVSS 214, Side Impact Oblique Pole Test	343 to 516	440 to 519 AIS 3-5	None

* Total benefits for passenger cars and light trucks
** Total benefits for passenger cars and light trucks, does not count potential loss in benefits if air bags are significantly depowered.

Table IX-5
COSTS OF RECENT LIGHT TRUCK RULEMAKINGS
(Includes Secondary Weight and Fuel Impacts)
(2000 Dollars)

Description	Effective Model Year	Cost Per Affected Vehicle $	Cost Per Average Vehicle $
FMVSS 202, Head Restraints	1992	$46.87 – 113.70	$5.54
FMVSS 204, Steering Wheel Rearward Displacement for 4,000 to 5,500 lbs. unloaded	1992	$6.05 – 29.95	$1.07 – 2.03
FMVSS 208, Rear Seat Lap/Shoulder Belts	1992	$69.25	$0.41
FMVSS 114, Key Locking System to Prevent Child-Caused Rollaway	1993	$9.44 – 19.58	$0.01 - 0.03
FMVSS 208, Locking Latch Plate for Child Restraints	1996	$0.89 - 17.92	$2.40
FMVSS 108, Center High-Mounted Stop Lamp	1994	$15.06 – 22.76	$15.53
FMVSS 214, Quasi-Static Test (side door beams)	1994 - 90% 1995 – 100	$67.38 – 84.50	$62.45 – 78.45
FMVSS 216, Roof Crush for 6,000 lbs. GVWR or less	1995	$24.81 – 222.65	$0.89 – 8.82
FMVSS 208, Belt Fit	1998	$3.77 – 17.83	$6.44 - 8.68
FMVSS 208, Air Bags Required	1998 - 90% 1999 – 100	$503.50 – 608.39 dual air bags	$503.50 – 608.39 dual air bags
FMVSS 201, Upper Interior Head Protection	1999 - 10% 2000 - 25% 2002 - 70% 2003 - 100%	$37.40 – 81.90	$57.72
FMVSS 225, Child Restraint Anchorage Systems	2001 - 20% 2002 - 50% 2003 - 100%	$3.01 - $7.08	$6.07
FMVSS 208, Advanced Air Bags	two phases 2003 to 2010	$24.15 to 134.40	Depends on method chosen to comply
FMVSS 301, Fuel Tank Integrity Upgrade	2007 - 40% 2008 - 70% 2009 - 100%	$5.08	$2.35

Table IX-6
BENEFITS OF RECENT LIGHT TRUCK RULEMAKINGS
(Annual benefits when all vehicles meet the standard)

Description	Fatalities Prevented	Injuries Reduced	Property Damage Savings $
FMVSS 202, Head Restraints	None	470 - 835 AIS 1 20 - 35 AIS 2	None
FMVSS 204, Steering Wheel Rearward Displacement for 4,000 to 5,500 lbs. Unloaded	12 – 23	146 - 275 AIS 2-5	None
FMVSS 208, Rear Seat Lap/Shoulder Belts	None	2 AIS 2-5	None
FMVSS 114, Key Locking System to Prevent Child Caused Rollaway	None	1 Injury	Not Estimated
FMVSS 208, Locking Latch Plate for Child Restraint	Not estimated	Not estimated	None
FMVSS 108, Center High Mounted Stop Lamp	None	19,200 to 27,400 Any AIS Level	$119 to 164 Million
FMVSS 214, Quasi-Static Test (side door beams)	58 – 82	1,569 to 1,889 hospitalizations	None
FMVSS 216, Roof Crush for 6,000 lbs. GVWR or less	2 – 5	25-54 AIS 2-5	None
FMVSS 208, Belt Fit	9	102 AIS 2-5	None
FMVSS 208, Air Bags Required Compared to 27.3% Usage in 1991	1,082 – 2,000	21,000 - 29,000 AIS 2-5	None
FMVSS 201, Upper Interior Head Protection	298 – 334	303 - 424	None
FMVSS 225, Child Restraint Anchorage Systems – Benefits include changes to Child Restraints in FMVSS 213	36 to 50*	1,231 to 2,929*	None
FMVSS 208, Advanced Air Bags	117 to 215**	584 to 1,043 AIS 2-5**	Up to $85 per vehicle*
FMVSS 301, Fuel Tank Integrity Upgrade	4 to 11	none	None

* Total benefits for passenger cars and light trucks

** Total benefits for passenger cars and light trucks, does not count potential loss in benefits if air bags are significantly depowered.

Table IX-7
COSTS OF PROPOSED LIGHT TRUCK RULES
(Includes Secondary Weight and Fuel Impacts)
(2000 Dollars)

Description	Effective Model Year	Cost Per Affected Vehicle $	Cost Per Average Vehicle $
FMVSS 202, Head Restraint Upgrade	TBD -	$8.10 to $17.15	$10.70
FMVSS 208, Rear Center Seat Lap/Shoulder Belts	2006 - 50% 2007 - 80% 2008 - 100%	$15.41 to $201.40	$23.33
FMVSS 214, Side Impact Oblique Pole Test	TBD – first model year starting 4 years after final rule, then a 3 year phase in of 20%, 50%, all vehicles	$116 to $253	$87 to $199

Table IX-8

BENEFITS OF PROPOSED LIGHT TRUCK RULES
(Annual benefits when all vehicles meet the standard)

Description	Fatalities Prevented	Injuries Reduced	Property Damage Savings $
FMVSS 202, Head Restraint Upgrade	none	1,852	None
FMVSS 208, Rear Center Seat Lap/Shoulder Belts	17	253	None
FMVSS 214, Side Impact Oblique Pole Test	343 to 516	440 to 519 AIS 3-5	None

X. PROBABILISTIC UNCERTAINTY ANALYSIS

This chapter identifies and quantifies the major uncertainties in the preliminary regulatory impact analysis. Cost-effectiveness and net benefits are two principal measurements in the economic assessment. Throughout the course of both the cost-effectiveness and net benefit analyses, many assumptions were made; diverse data sources were used; and different statistical processes were applied. The variability of these assumptions, data sources, and statistical processes potentially would impact the estimated regulatory outcomes. These assumptions, data sources, and derived statistics all can be considered as uncertainty factors for the regulatory analysis. Some of these uncertainty factors contributed less to the overall variations of the outcomes, and thus are less significant. Some uncertainty factors depend on others, and thus can be combined with others. With the vast number of uncertainties imbedded in this regulatory analysis, the uncertainty analysis identifies only the major independent uncertainty factors having appreciable variability and quantifies them by their probability distributions. These newly defined values are then randomly selected and fed back to the cost-effectiveness and net benefit analysis process using the Monte Carlo statistical simulation technique[1]. The simulation technique induces the probabilistic outcomes accompanied with degrees of probability or plausibility. This facilitates a more informed decision-making process.

The analysis starts by establishing mathematical models that imitate the actual processes in deriving cost-effectiveness and net benefits as described in the previous chapters. Each variable (e.g., cost of technology) in the mathematical model represents an uncertainty factor that would

[1] Any statistics books describing the Monte Carlo simulation theory are good references for understanding the technique.

potentially alter the modeling outcomes if its value were changed. The variations of these variables are described by an appropriate probability distribution function based on available data. If data are not sufficient or not available, professional judgments are used to estimate the variability of these uncertainty factors.

After defining and quantifying the major uncertainty factors, the next step is to simulate the model to obtain probabilistic results rather than single-value estimates. The simulation process is run repeatedly. Each complete run is a trial. For each trial, the simulation first randomly selects a value for each of the uncertainty factors based on their probability distributions. The selected values are then fit into the models to forecast results. The simulation repeats the trials until certain pre-defined criteria are met and a probability distribution of results is generated.

A commercially available software package, Crystal Ball from Decisioneering, Inc., was used for this purpose - building models, running simulations, storing results, and generating statistical results. Crystal Ball is a spreadsheet-based risk analysis software which uses the Monte Carlo simulation technique to forecast results. In addition to the simulation results, the software also estimates the degree of certainty (or confidence, credibility). The degree of certainty provides the decision-maker an additional piece of important information to evaluate the forecast results.

Simulation Models and Uncertainty Factors

The spreadsheet based mathematical models were built to imitate the cost-effectiveness and net benefits process as developed in previous chapters. The cost-effectiveness measures the cost per fatality equivalent avoided. In other words, at a given discount rate, the cost-effectiveness is the ratio of the total costs of the rule and the total fatal equivalents avoided (or equivalent lives saved) at that discount level. The net benefits measures the cost difference between the total dollar value that would be saved from reducing fatalities and injuries and the total costs of the rule.

Both the cost-effectiveness and net benefit models comprise two principal components: total benefits and costs. In the cost-effectiveness model, benefits are represented by fatal equivalents. In the net benefit model, benefits are represented in dollars, which is the product of cost per life saved and fatal equivalents. Since benefits (fatalities and injuries reduced) were already expressed as fatal equivalents in the cost-effectiveness model, the net benefit model is just one step removed from the cost-effectiveness model. This analysis first describes the mathematical models for deriving fatal equivalents and quantifies their uncertainty factors. Then, in a parallel section, the analysis discusses the total cost models and quantifies their uncertainty factors. Finally, the analysis presents and summarizes the simulated results.

Benefit Models

As described earlier, fatal equivalents (FE) are the basic benefit measurement for both cost-effectiveness and net benefit models. The estimated FE are comprised of four mutually exclusive portions: skidding/loss of control (FE_1), flat tires and blowouts (FE_2), stopping-distance, preventable (FE_3), and stopping-distance, non-preventable (FE_4). In a mathematical format, $FE = \sum_{m=1}^{4} FE_m$. These FEs were derived using different methodologies and assumptions. As expected, these FEs have somewhat different mathematical formats and uncertainty factors. But, some of the uncertainty factors (e.g., safety target population) are shared by these FEs. Each of these common factors is consistantly represented by a mathematical symbol throughout this chapter. Also, whenever applicable the following indexes are used universally for these four FE models:

- i represents MAIS injury severity. The severity level increases with the value of i, i.e., 1 represent MAIS 1 minor injuries and 6 represents fatalities.
- j represents vehicle type with 1 = passenger cars (PC) and 2 = light trucks and vans (LTV).
- k represents roadway condition with 1 = wet and 2 = dry.
- ℓ represents traveling speeds with 1 = 0 - 35 mph, 2 = 36 - 50 mph, and 3 = 51+ mph.

Skidding/Loss of Control

The generalized fatal equivalent model (FE_1) for loss of control is:

$$FE_1 = (\sum_{i=1}^{6} P_i * e_i * r_i) * d * a_1 * a_2$$

Where P_i = Target population with i = 1: MAIS 1; 2: MAIS 2; ...: and 6: fatality

e_i = the effectiveness of TPMS in preventing skidding/loss of control

r_i = injury-to-fatality equivalence ratios

d = cumulative lifetime discount factor (at 3 percent or 7 percent)

a_1 = adjustment factor for existing TPMS system

a_2 = adjustment factor for response rate to TPMS warning light

In this model, P_i*e_i represents the benefit from reducing severity i level injuries. The number $P_i * e_i * r_i$ represents the fatal equivalents that were contributed from severity i injuries. For example, P_1*e_1 represents the total MAIS 1 injuries that will be reduced. Multiplying this number by its injury/fatality ratio r_1 derives the contribution of MAIS 1 injuries to the total FEs. The notation $\sum_{i=1}^{6} P_i * e_i * r_i$ represents the total initial estimated FEs. This initial estimated total FEs then were modified by multiplying the adjustment factors, d, a_1, and a_2 to derive the final FEs. The modification reflects the discounting level, the portion of the fleet tested that already is equipped with a TPMS, and the assumed response rate to TPMS. Each of these adjustment factors will be examined in detail in the following discussions.

Based on the FE_1 model, there are six major uncertainty factors that would impact the estimated benefit outcome: target population (P_i), effectiveness of TPMS (e_i), injury-to-fatality equivalence ratios (r_i), cumulative lifetime discount factor (d), adjustment factor for the existing TPMS systems (a_1), and adjustment factor for driver response rate to TPMS warning (a_2).

The first uncertainty factor P_i, target population, is obviously important to benefit estimates because it defines the population of risk without the rule. The major uncertainties in this factor arise from, but are not limited to, the percentage of all crashes that were caused by skidding (0.77 percent was assumed in the previous chapter), demographic projections, driver/occupant behavioral changes (e.g., shifts in safety belt use), increased roadway travel, new Government safety regulations, and survey errors in NHTSA's data sampling system NASS-CDS. Based on professional judgment and the available data (Tri-Level Study), the analysis assumes that the percent of crashes caused by skidding/loss of control is uniformly distributed from 0.52 to 1.02 percent with a mean of 0.77 percent.

The impact of demographic and driver/occupant behavior changes, roadway travel, and new automobile safety regulations are reflected in the crash database. Thus, the analysis examined the historic FARS and CDS to determine whether variations resulting from these uncertainty sources would warrant further adjustment to the future target population.

Based on 1998 to 2002 FARS, there is no definite trend for this period of time. The changes among years were small with a variation within ±2.0 percent. Thus, the analysis will not further adjust the FARS-derived fatalities and treats fatalities as a constant.

For injuries, the analysis considers the CDS associated survey errors and treats injuries as normally distributed. About 68 percent of the estimated target injuries are within one standard error (SE) of the mean survey injury population. Thus, the mean injury population and corresponding standard errors (as the proxy for standard deviation) were used for establishing the normal distribution for the size of the non-fatal injury target population. The standard errors were derived using the formula[2]:

$SE = e^{3.65254+0.04723\ln(x)^2}$, x = estimated target injuries.

Combining the variations from the percent of skidding/loss-of-control and survey errors, the final fatal target population is close to a uniform distribution from 169 to 327. The final target MAIS injuries are close to normal distributions with slightly positive skewing. Figure X-1 depicts these distributions. Note that two parameters, the maximum and the minimum values, are required to establish a uniform distribution. Mean and standard deviation (SD) are required for a normal distribution.

The second uncertainty factor in the FE_1 model is e_i – the effectiveness of TPMS against loss of control. The effectiveness measures to the extent to which involved vehicles would brake normally without skidding if the tire pressures had been corrected. Data were not available at this time to assess its variability. However, in order to estimate its impact on the benefit outcomes, the analysis assumes e_i is uniformly distributed between 10 to 30 percent and maintains its mean at 20 percent for every injury severity i.

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[2] 1995-1997 National Automotive Sampling System, Crashworthiness Data System, DOT HS 809 203, February 2001

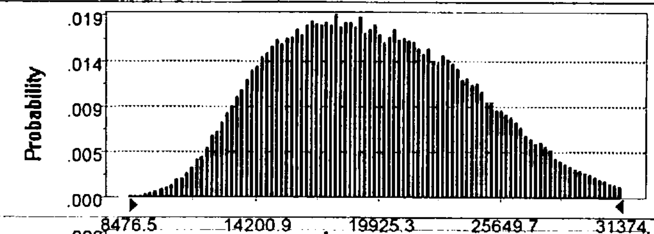
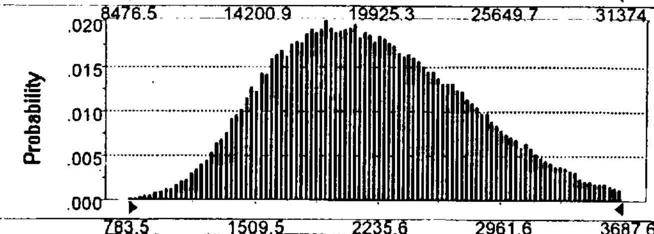
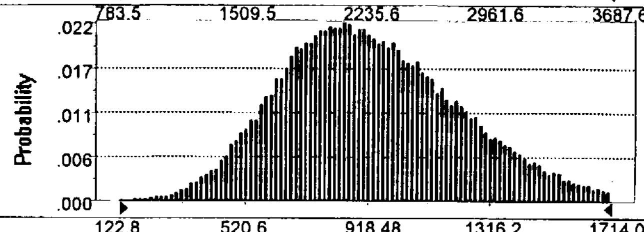
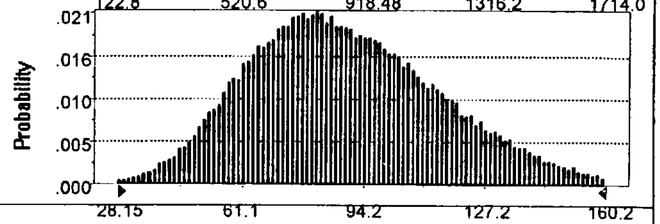
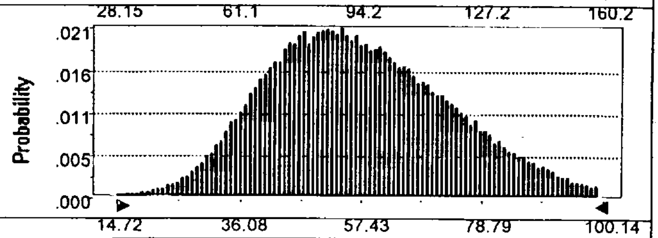
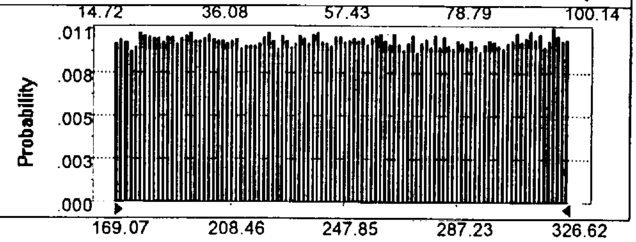
Injury Severity		Probability Distribution
MAIS 1	Mean: 19,679 SD: 4,497	
MAIS 2	Mean: 2,193 **SD: 557**	
MAIS 3	Mean: 933 SD: 284	
MAIS 4	Mean: 90 SD: 25	
MAIS 5	Mean: 58 SD: 16	
Fatality (Uniform Distribution)	Minimum: 169 Maximum: 327	

Figure X-1
Probability Distributions For
Skidding/Loss of Control Target Population

The third uncertainty factor r_i, injury-to-fatality equivalence ratios, affects the total fatal equivalent estimates. These ratios reflect the relative economic impact of injury compared to fatality based on their estimated comprehensive unit costs. They were derived based on the most current 2002 crash cost assessment[3]. The crash cost assessment itself is a complex analysis with an associated degree of uncertainty. At this time, these uncertainties are unknowns. Thus, the variations of these ratios are unknown and this analysis treats these ratios as constants. Table X-1 lists these ratios. Benefits in this rule are a mixture of both crash avoidance and crashworthiness benefits. Crashworthiness measures mitigate injury but do not prevent crashes. Crash avoidance measures reduce property damage and travel delay as well as injury related factors. Therefore, different ratios would be applicable to each type of benefit. To provide a conservative basis, this analysis used the more conservative crashworthiness ratios.

Table X-1
Injury-to-Fatality Equivalence Ratios (r_i)*

MAIS 1 (r_1)	MAIS 2 (r_2)	MAIS 3 (r_3)	MAIS 4 (r_4)	MAIS 5 (r_5)	Fatality (r_6)
0.0031	0.0458	0.0916	0.2153	0.7124	1.000

* same for each discount level

The fourth uncertainty factor d, cumulative lifetime discount factor, is treated as a constant. At the 3 percent discount rate, d = 0.8233. At the 7 percent discount rate, d = 0.6600.

The fifth uncertainty factor a_1, adjustment factor for existing TPMS, is treated as a constant. Currently, about 1 percent of passenger vehicles are equipped with a TPMS meeting the

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

proposal. Under this analysis, the initial FE was estimated assuming that no passenger vehicle was equipped with a passing TPMS. In this sense, the initial FE overestimated the actual benefits by 1 percent and had to be adjusted down to reflect this overestimation. Thus, $a_1 = 0.99$ (= 1 - 0.01).

The last uncertainty factor a_2 represents the response rate to TPMS warnings. In 2002, the agency conducted a TPMS survey. The survey included a total of 106 vehicles with a direct TPMS. Of these, 105 are applicable for analysis. Based on these 105 cases, 95 percent of drivers took the following actions: putting air into their tires, changing tires, or taking their vehicles into service stations. This factor is subject to survey errors and selection bias. The survey was terminated before its completion due to the change in the initial TPMS rule. Thus, no viable statistical survey errors can be assessed. The selection process would likely generate a survey sample that includes proportionally more high-end vehicles than make up the existing TPMS market. As a result, the reported response rate might be biased upward. However, at this time, the agency has no data to estimate the magnitude of the upward bias. Nevertheless, to consider the impact of response rate on the overall outcome and address this upward bias possibility, the analysis assumes that the response rate is normally distributed with a more conservative mean of 90 percent and a standard deviation of 1.7 percent. This indicates that the response rate is normally distributed between 85 and 95 percent with a mean of 90 percent. Figure X-2 depicts the normal distribution.

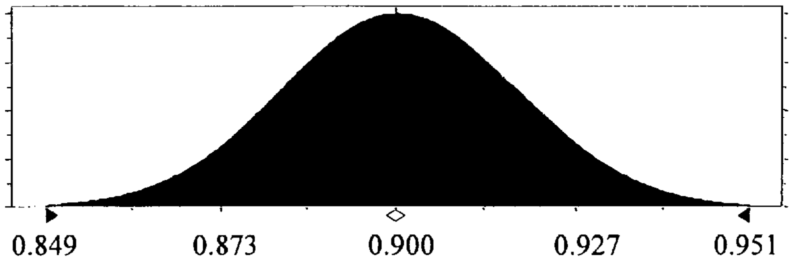


Figure X-2 Probability Distribution for Response Rate To TPMS Warnings

Flat Tires and Blowouts

The generalized fatal equivalent model (FE_2) for flat tires/blowouts is:

$$FE_2 = (\sum_{i=1}^{6} P_i * e_i * r_i) * d * a_1 * a_2$$

Where P_i = Target population with I = 1: MAIS 1; 2: MAIS 2; ...: and 6: fatality

e_i = the effectiveness of TPMS preventing flat tires and blowouts

r_i = injury-to-fatality equivalence ratios

d = cumulative lifetime discount factor (at 3 percent or 7 percent)

a_1 = adjustment factor for existing TPMS system

a_2 = adjustment factor for response rate to TPMS warning light

The generic form of FE_2 model is identical to that of FE_1 (for skidding/loss of control). So, FE_2 also contains the same six major uncertainty factors as those of FE_1. Of these uncertainty factors, only the values of the target population (P_i) and effectiveness of the TPMSs (e_i) against the corresponding safety population varied. The values of the remaining four major uncertainty factors, r_i, d, a_1, and a_2 do not change. These four factors are not discussed further.

The initial target fatal population is treated as a constant and the non-fatal target populations are treated as normally distributed using the survey errors as the proxy for standard deviation. The rationales of using these types of probability distributions were described in the skidding/loss of control section, and thus are not repeated here.

In addition to the survey errors, the analysis also considers two additional sources of variations for the target population. One is the assumed percentage of the flat tires/blowouts that were caused by underinflated tires. The other source is the percentage of flat tires/blowouts that would be corrected by new tire standards in FMVSS No. 139. Both variations would impact the spread of the population distribution. However, due to insufficient data, the analysis is unable to derive its variability. Instead, the analysis assumes that the percentage of flat tires/blowouts is uniformly distributed from 10 to 30 percent with 20 percent as the mean. Similarly, the analysis assumes that percent would be corrected by the new tire standards in FMVSS No. 139 is uniformly distributed from 40 to 60 percent with 50 percent as the mean. Figure X-3 depicts the final probability distributions for the target population, which take into account the three types of variations discussed above. As shown in Figure X-3, the non-fatal target populations are close to normal distributions but slightly positive skewed. The fatal target population distribution is a combination of two triangular distributions on both tails and a uniform distribution in between.

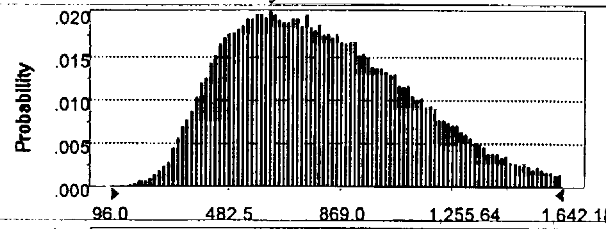
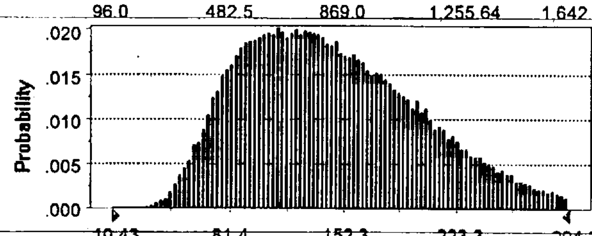
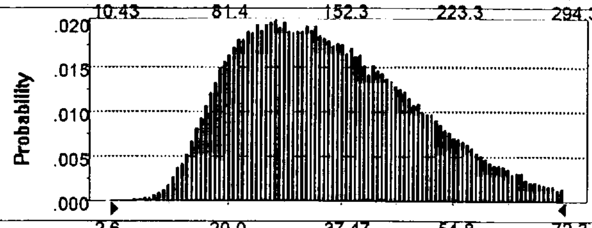
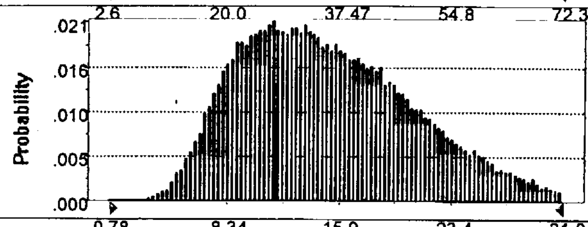
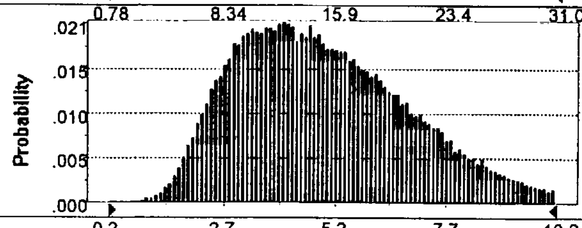
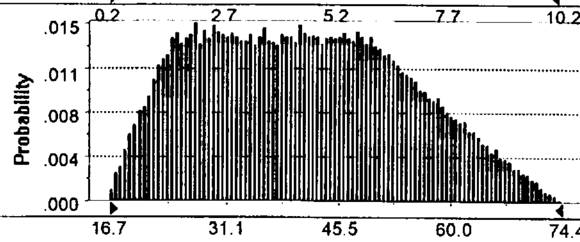
<table>
<tr><th>Injury Severity</th><th></th><th>Probability Distribution</th></tr>
<tr><td>MAIS 1</td><td>Mean: 810
SD: 300</td><td></td></tr>
<tr><td>MAIS 2</td><td>Mean: 146
SD: 54</td><td></td></tr>
<tr><td>MAIS 3</td><td>Mean: 36
SD: 34</td><td></td></tr>
<tr><td>MAIS 4</td><td>Mean: 15
SD: 6</td><td></td></tr>
<tr><td>MAIS 5</td><td>Mean: 5
SD: 2</td><td></td></tr>
<tr><td>Fatality
(Uniform
Distribution)</td><td>Mean: 41
Minimum: 16
Maximum: 74</td><td></td></tr>
</table>

Figure X-3
Probability Distributions for
Flat Tire/Blowout Target Population

The factor e_i is treated as a constant. As described in Chapter IV, the target flat tires and blowouts were narrowly defined in such a way that they would be completely prevented if the involved vehicles had the correct tire pressures. Thus, $e_i = 1$ for every i.

Stopping-Distance, Preventable Crashes

Maintaining proper tire inflation pressures can reduce stopping distance and thus prevent crashes or mitigate the severity of non-preventable crashes. Preventable crashes represent a portion of stopping distance related crashes that would be prevented if the involved vehicles had maintained the correct tire pressures to shorten its stopping distance. The benefits for this group were not only segregated by injury severity, but also by vehicle type (passenger cars, light trucks/vans) and roadway condition (wet, dry). In addition, a variety of adjustments were applied to represent factors relevant to the estimation of safety impacts. The following benefit model (FE_3) reflects the process for this subset of the target population:

$$FE_3 = [\sum_{i=1}^{6} (\sum_{j=1}^{2} \sum_{k=1}^{2} P_{i,j,k} * w_{i,k} * n_j * v_j) * r_i] * d * a_1 * a_2 * a_3$$

Where,

$P_{i,j,k}$ = target population with i = 1 to 6: MAIS 1 to fatality

j = 1: passenger cars, 2: light trucks/vans; and k = 1: wet roadway, 2: dry roadway

$w_{i,k}$ = adjustment factor for skidding on roadway with i = 1 to 6: MAIS 1 to fatality; and k = 1: wet, 2: dry

n_j = adjustment factor for average psi experience in the fleet prior to the TPMS been triggered by vehicle type with j = 1: passenger cars; 2: light trucks/vans

v_j = adjustment factor for no under-inflation and tire level above warning threshold by vehicle type with j = 1: passenger cars; 2: light trucks/vans

r_i = injury-to-fatality equivalence ratios

d = cumulative lifetime discount factor (at 3 percent or 7 percent)

a_1 = adjustment factor for existing TPMS systems

a_2 = adjustment factor for response rate to TPMS warning light

a_3 = adjustment factor for overlapping in target population

Based on the FE_3 model, there are 9 major uncertainty factors that would impact the benefit estimate for stopping-distance, preventable crashes: target population ($P_{i,j,k}$), adjustment factor for skidding state on roadway type ($w_{i,k}$), adjustment factor for average psi in a vehicle fleet before triggering a TPMS warning by vehicle type (n_j), adjustment factor for no under inflation and tire pressure above warning threshold (v_j), and injury-to-fatality equivalence ratios (r_i), cumulative lifetime discount factor (d), adjustment factor for existing TPMS systems (a_1), driver response rate to TPMS warnings (a_2), and adjustment factor for overlapping target population (a_3).

The target fatal population ($P_{6,j,k}$) is treated as a constant for every j (passenger car or light truck/van) and k (wet or dry roadway condition). The target non-fatal population ($P_{i,j,k}$) is normally distributed for every i, j, and k. The section on skidding/loss of control already explained the rationales for determining the probability distribution for target population. Thus, these rationales are not repeated here. Table X-2 lists the fatalities and the means and standard errors for deriving the normal distribution for the non-fatal target population.

Table X-2
Means and Standard Errors for Normal Distributions
Injuries Associated with Stopping-Distance, Preventable Crashes

		MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality*
PC – Wet	Mean	2,361	226	101	9	6	14
	SE	560	54	24	2	1	NA
PC – Dry	Mean	6,680	722	310	29	19	54
	SE	1,358	147	63	6	4	NA
LTV - Wet	Mean	1,133	111	50	4	3	10
	SE	324	32	14	1	1	NA
LTV - Dry	Mean	3,546	466	192	19	14	39
	SE	783	103	42	4	3	NA

* adjusted to the FARS level, thus was treated as a constant.

The uncertainty factor $w_{i,k}$ represents the adjustment factor for skidding state for injury severity i and roadway type k. As described in the previous chapter on benefits, only the $w_{i,k}$ portion of the target population $P_{i,j,k}$ were skidding due to tires losing their friction capability. This portion of target population couldn't be compensated by drivers' action and thus was applicable to this TPMS rule. These adjustment factors were derived from 1995-1999 CDS. They are ratios of skidding to overall injuries. A ratio is sensitive to the frequency distribution of the survey counts. The derived ratios based on the 68 percent bounds of the CDS survey counts are similar to that from the mean survey population. Therefore, the analysis treats these adjustment factors as constants. Note that this loss of friction, can't be compensated by driver's action scenario would occur only on dry pavement (k=2). Since there is no adjustment on wet roadways, $w_{i,1}$ would be 1 for every injury severity i. Table X-3 lists these values. Also note that this factor is the same for all three compliance options.

Table X-3
Adjustment Factors for Skidding State*
Stopping Distance – Preventable Crashes

Roadway Type	Fatalities (i = 6)	Injuries (i = 1 to 5)
Wet (k=1)	1	1
Dry (k=2)	0.72	0.54

* same for all three compliance options.

The uncertainty factor n_j represents an adjustment factor for average psi in the whole vehicle fleet before triggering TPMS warnings. The average estimated psi(s) before triggering TPMS warnings were different among vehicle types and compliance options (see Table V-6). Therefore, the adjustment factors differed by vehicle types and compliance options. No data were available to bound this factor. This factor was treated as a constant. Table X-4 lists the values of the adjustment factor.

Table X-4
Adjustment Factor for Average PSI Before TPMS Warnings
Stopping-Distance, Preventable Crashes

Implementation Alternative	Passenger Cars (n_1)	Light Trucks/Vans (n_2)
Option 1	0.66877	0.68269
Option 2	0.62577	0.65503
Option 3	0.62577	0.65503

The uncertainty factor v_j represents an adjustment factor to exclude cases with no under inflation and tire pressure above warning threshold. The analysis treats the factor as normally distributed. Its mean value and SD differ by vehicle types. For passenger cars, the mean v_1 is 0.26 and SD is 0.013. For light trucks/vans, the mean v_2 is 0.29 and SD is 0.014. Figure X-4 depicts these distributions.

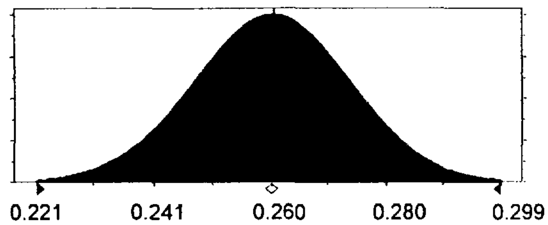
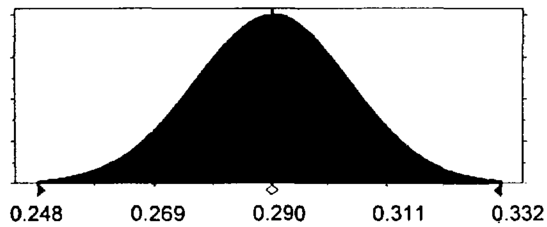
Vehicle Type	Parameters	Probability Distribution
Passenger Cars (v_1)	Mean: 0.260 SD: 0.013	
Light Trucks/Vans (v_2)	Mean: 0.290 SD: 0.014	

Figure X-4
Probability Distributions for
Adjustment Factor for Underinflation (v_j)

The uncertainty factors r_i (injury-to-fatality equivalence ratios), d (cumulative lifetime discount factor), a_1 (adjustment factor for existing TPMS systems), and a_2 (driver response rate to TPMS warnings) are the same as described in the previous subsection, thus are not repeated here.

The last uncertainty factor a_3 represents the adjustment factor to correct two cases of overlapping between target populations: overlapping between skidding/loss of control and stopping distance, and overlapping between injuries in passenger cars and in light truck/vans within the stopping distance group. Generally, a_3 is subject to survey errors inherited in the CDS systems since all the target populations were derived from 1995-1999 CDS. However, a_3 is a ratio, which can be reasonably represented by the ratio derived from the mean survey population. Thus, a_3 is treated as a constant. Its value is equal to 0.9588.

Stopping Distance, Non-Preventable

The non-preventable crashes are crashes that would still occur even after the tire pressure had been corrected. The benefit of TPMS for this group would come from crash severity reduction (as oppose to prevention). Crash severity is measured by delta v. Delta v reduction is sensitive to vehicle type, roadway condition, and traveling speeds. Therefore, the benefit process for this group is further segregated by three traveling speed categories (0-35, 36-50, 51+ mph). Basically, benefits are derived by comparing the would-be injury severity distribution (corrected tire pressure condition) to the initial injury severity distribution (underinflated tire pressure condition). Injury risk curves as functions of delta v are used to induce the injury severity distributions. The following benefit model (FE_4) describes the benefit process:

$$FE_4 = (\sum_{i=1}^{6} \{\sum_{j=1}^{2} \sum_{k=1}^{2} \sum_{\ell=1}^{3} \sum_{s=1}^{70} P_{i,j,k,\ell}(s) * [p_i(s) - p_i(s - \Delta v_{j,k,\ell})] * w_{i,k} * n_j * v_j\} * r_i) * A$$

Where $A = d * a_1 * a_2 * a_3 * a_4$, and

$P_{i,j,k,\ell}$ = target population with i = 1 to 6: MAIS 1 to fatality

j = 1: passenger cars, 2: light trucks/vans; k = 1: wet roadway, 2: dry roadway,

ℓ = 1: 0-35 mph, 2: 35-50 mph, 3: 51+ mph

$p_i(s)$ = probability risk of injury severity i, at delta v level s with $p_i(s) = 0$ for $s <= 0$.

$\Delta v_{j,k,\ell}$ = delta v reduction for roadway condition j, vehicle type k, and

travel speed ℓ mph

$w_{i,k}$ = adjustment factor for skidding on roadway with i = 1 to 6: MAIS 1 to fatality;

and k = 1: wet, 2: dry

n_j = adjustment factor for average psi experience in the fleet prior to the

TPMS been triggered by vehicle type with j = 1: passenger cars; 2: light trucks/vans

v_j = adjustment factor for no under-inflation and tire level above warning threshold by vehicle type with j = 1: passenger cars; 2: light trucks/vans

r_i = injury-to-fatality equivalence ratios

d = cumulative lifetime discount factor (at 3 percent or 7 percent)

a_1 = adjustment factor for existing TPMS systems

a_2 = adjustment factor for response rate to TPMS warning light

a_3 = adjustment factor for overlapping among target population

a_4 = adjustment factor for stopping distance distribution

Based on the FE_4 model, there are 12 major uncertainty factors that would impact the benefit estimate for stopping-distance, non-preventable crashes: target population ($P_{i,j,k}$), reduced dalta v ($\Delta v_{j,k,\ell}$), injury risk probability for severity i at s delta v ($p_i(s)$), adjustment factor for skidding state on roadway type ($w_{i,k}$), adjustment factor for average psi in a vehicle fleet before triggering a TPMS warning by vehicle type (n_j), adjustment factor for no under inflation and tire pressure above warning threshold (v_j), injury-to-fatality equivalence ratios (r_i), cumulative lifetime discount factor (d), adjustment factor for existing TPMS systems (a_1), driver response rate to TPMS warnings (a_2), adjustment factor for overlapped target population (a_3), and adjustment factor for stopping distance overestimation (a_4).

The probability distributions for the first uncertainty factor $P_{i,j,k}$, target population, are the same as those of previous three target populations. The fatal target population $P_{6,j,k}$ is a constant, for every j and k. While the target non-fatal injury population $P_{i,j,k}$ (i = 1 to 5) is treated as normally distributed. Table X-5 lists the target fatal population and the parameters (mean and standard errors) required to establish the normal distribution for target non-fatal injuries.

Table X-5
Means and Standard Errors for Normal Distributions
Injuries Associated with Stopping-Distance, Non-Preventable Crashes

		MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality*
PC - Wet							
0-35 mph	Mean	77,340	6,930	3,172	282	167	440
	SE	16,651	1,492	683	61	36	NA
36-50 mph	Mean	69,807	7,044	3,076	255	165	439
	SE	14,542	1,467	641	53	34	NA
51+ mph	Mean	24,126	2,446	1,088	96	72	177
	SE	4,690	476	212	19	14	NA
PC - Dry							
0-35 mph	Mean	184,795	17,408	7,790	669	448	1,175
	SE	46,430	4,374	1,957	168	112	NA
36-50 mph	Mean	224,077	20,930	9,332	879	490	1,549
	SE	58,309	5,447	2,428	229	128	NA
51+ mph	Mean	75,621	14,013	5,357	566	432	1,167
	SE	16,029	2,970	1,135	120	92	NA
LTV – Wet							
0-35 mph	Mean	27,756	2,670	1,178	103	67	164
	SE	5,410	520	230	20	13	NA
36-50 mph	Mean	43,201	3,733	1,762	123	96	257
	SE	8,603	743	351	24	19	NA
51+ mph	Mean	9,995	1,564	661	80	67	220
	SE	1,975	309	131	16	13	NA
LTV – Dry							
0-35 mph	Mean	100,964	11,504	4,890	475	299	847
	SE	22,477	2,561	1,089	106	66	NA
36-50 mph	Mean	100,620	12,242	5,078	469	348	1,104
	SE	22,218	2,703	1,121	104	77	NA
51+ mph	Mean	51,840	9,576	3,756	420	327	879
	SE	10,572	1,953	766	86	67	NA

SE: Standard Error; NA: Not Applicable
* constant numbers

The second uncertainty factor $p_i(s)$ represents the risk probability of injury severity i at the s delta v level. These probabilities were derived from MAIS+ injury curves, which were created through a statistical regression process. Thus, $p_i(s)$ is subject to the variations inherited in the regression process that was used to derive the MAIS+ injury curves. Table X-6 lists the mean and standard deviation for these MAIS+ injury curves.

Table X-6
MAIS+ Injury Probability Curves

Injury Severity	Injury Risk Curve As a Function of Delta V (%)	Parameters (Mean, Standard Deviation)
MAIS 0	$p^{+}_{0}(i) = 100 * e^{-\alpha * i}$	α: (0.0807, 0.0714)
MAIS 1+	$p^{+}_{1}(i) = 100 * \alpha * \sin(0.0049 * i)$	α: (93.2210, 5.4079)
MAIS 2+	$p^{+}_{2}(i) = 100 * \frac{e^{\alpha * i - \beta}}{1 + e^{\alpha * i - \beta}}$	α: (0.1683, 0.0128) β: (5.0345, 0.3362)
MAIS 3+	$p^{+}_{3}(i) = 100 * \frac{e^{\alpha * i - \beta}}{1 + e^{\alpha * i - \beta}}$	α: (0.1292, 0.0091) β: (5.5337, 0.3131)
MAIS 4+	$p^{+}_{4}(i) = 100 * \frac{e^{\alpha * i - \beta}}{1 + e^{\alpha * i - \beta}}$	α: (0.1471, 0.0093) β: (7.3675, 0.3344)
MAIS 5+	$p^{+}_{5}(i) = 100 * \frac{e^{\alpha * i - \beta}}{1 + e^{\alpha * i - \beta}}$	α: (0.1516, 0.0101) β: (7.8345, 0.3801)
Fatality	$p^{+}_{6}(i) = 100 * \frac{e^{\alpha * i - \beta}}{1 + e^{\alpha * i - \beta}}$	α: (0.1524, 0.0118) β: (8.2629, 0.4481)

The third uncertainty factor $\Delta v_{j,k,\ell}$ represents the delta v reduction if tire pressure was corrected. Delta v is sensitive to traveling speeds and the square root of traveling distance (i.e., stopping distance). Thus, $\Delta v_{j,k,\ell}$ – change or reduction in delta V - is also a function of speed and the square root of change in stopping distance. Given a traveling speed category, $\Delta v_{j,k,\ell}$ would only be a function of the square root of the change in stopping distance. Therefore, the analysis uses the variation in the square root of stopping distance from the agency sponsored testing of 10 vehicles[4] as a proxy for $\Delta v_{j,k,\ell}$. These 10 vehicles cover mid-size passenger cars, sports utility

[4] Transportation Research Center Inc., "Consumer Braking Information – Finalize Test Protocol – Phase 1

vehicles, vans, and pick-up trucks. Each vehicle was tested at 100 kph (62.1 mph) repeatedly about 10 or 20 times each on both wet and dry pavement. The mean of the square roots of these stopping distances and corresponding standard deviation is 7.4 meters and 0.3 meters on wet pavement and 7.0 meters and 0.3 meters on dry pavement. These translate to standard deviations of 4.3 percent and 3.7 percent of the mean for $\Delta v_{j,k,\ell}$ for wet and dry pavement, respectively. Since, the mean $\Delta v_{j,k,\ell}$ is small for each vehicle type and roadway condition, the small deviation does not perturb the delta v significantly. In addition, the $\Delta v_{j,k,\ell}$ was used to calculate $p_i(s)$. The small change in $\Delta v_{j,k,\ell}$ would thus alter the value of $p_i(s)$. However, these impacts are within the regression variations of $p_i(s)$. For these reasons, this analysis treats each $\Delta v_{j,k,\ell}$ as a constant. Table X-7 lists these values.

Table X-7 Delta V Reduction ($\Delta v_{j,k,\ell}$)

Passenger Car (k=1)	Wet Roadway (j=1)	Dry Roadway (j=2)
0-35 mph (ℓ=1)	3.018	1.952
36-50 mph (ℓ=2)	4.404	2.748
51+ mph (ℓ=3)	5.841	3.456
Light Truck Van (k=2)		
0-35 mph (ℓ=1)	3.358	2.187
36-50 mph (ℓ=2)	4.895	3.078
51+ mph (ℓ=3)	6.841	3.773

The remaining uncertainty factors, except for a_4, are the same as those described in the FE_3 model for stopping-distance, preventable crashes, and thus are not repeated here. The uncertainty factor a_4 adjusts for braking distance distributions. This factor adjusts for the variable impact on delta v of braking that occurs over different stopping distances. The sources of uncertainty for this factor come from vehicle types, traveling speed, roadway condition, and the uniform probability function used for describing crash occurrence. The sensitivity study presented in the Appendix indicates that the factor is relatively stable regardless of vehicle type, traveling speed, and roadway condition (Appendix A). The only uncertainty source left is the uniform distribution used in deriving the adjustment factor. At this moment, the agency does not have data to describe the likelihood of crash occurrence at a certain point between the initial braking and the final natural stopping distance. The agency considers the uniform distribution a logical choice and there are no data to prove otherwise, therefore, the analysis does not alter the uniform distribution to calculate the adjustment factor. This factor is treated as a constant of 0.07.

The above sections discuss the FE models. FE is the basic benefit measurement for estimating cost-effectiveness. The benefit measurement in net benefits is in total dollars, which is the product of cost per fatality and FEs. Let M denote the cost per fatality. The total benefit in the net benefit calculation is equal to M*FEs. M clearly is another uncertainty factor for net benefits. Recent meta-analysis of the wage-risk value of statistical life (VSL) shows that an individual's willingness-to-pay (WTP) for reduction in premature fatalities is from $1 million to $10 million[5]. Thus, the agency uses this as the range for M and assumes the value of M is normally distributed with its mean equal to $5.5 million. This value of $5.5 million represents a central value consistent with a range of values from $1 to $10 million. The characteristics of the remaining factors are the same as those described in the cost-effectiveness model.

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

Total Cost Model

The total net cost (TC) is the product of the net cost per vehicle (NC) and the total number of vehicles (V). The net cost per vehicle consists of six cost components: technology/ countermeasure cost (C_1), maintenance costs (C_2), opportunity and other costs (C_3), fuel savings (C_4), tread wear savings (C_5), and property damage/traveling delay savings (C_6). The total cost model has the following generic format

$$\begin{aligned} TC &= NC * V \\ &= (C_1 + C_2 + C_3 - C_4 - C_5 - C_6) * V \end{aligned}$$

Based on the TC mathematical model, the variability of these seven independent variables C_1, C_2, C_3, C_4, C_5, C_6, and V would perturb the estimated total costs. Thus, these seven variables are considered as major uncertainty factors. The uncertainties of these major factors come from the underlying assumptions, data sources, and statistical processing errors. Of these factors, C_2, C_3, C_4, C_5, and C_6, were the costs/savings over a vehicle life and need to be discounted at the 3 and 7 percent rates. As a result, the total costs are analyzed at these two discount rates. Note again, C_1 - C_6 are on a per vehicle basis and all the costs are in 2001 dollars.

Technology/Countermeasure Cost (C_1)

The first uncertainty factor C_1 is the technology/countermeasure cost per vehicle. Basically, $C_1 = C_{TMPS} * a_1$ where C_{TPMS} is the TPMS cost per vehicle and a_1 is the adjustment factor for existing TPMS market shares. C_{TPMS} varies depending on the implementation of the technologies (i.e., compliance options), the maturity of the technologies/countermeasures, and potential fluctuation in labor and material costs (e.g., due to economies of scale from production volume). Based on the professional judgments of NHTSA cost analysts and contractors, the cost of a TPMS generally falls within 10 percent of the point estimate as presented in the previous chapter on costs. Each cost value within this range would have an equal chance to be the true price. Thus, this analysis treats C_{TMPS} as uniformly distributed. Its generalized format can be represented as:

$$C_{TPMS}(x) = \frac{1}{C_{max} - C_{min}}, C_{min} \leq x \leq C_{max}$$
$$= 0, \text{otherwise}$$

Where C_{max} = the maximum TPMS cost per vehicle, and

C_{min} = the minimum TPMS cost per vehicle

Two parameters are required to establish its uniform distribution: the maximum and minimum costs. Table X-8 lists these costs for C_{TPMS}. These costs represent the investments paid now for future benefits. Therefore, there is no need to discount these costs.

Table X-8
Uniform Distribution for TPMS Cost Per Vehicle (C_{TPMS})
For Three Compliance Options*
(2001 Dollars)

	Maximum Cost (C_{max})	Minimum Cost (C_{min})	The Mean Cost (point estimate)
Option 1 Direct TPMS with Continuous Readings	$77.65	$63.53	$70.59
Option 2 Direct TPMS with Warning	$73.42	$60.07	$66.74
Option 3 Hybrid TPMS with Warning	$53.81	$44.04	$48.92

* no discounting

The uncertainty factor a_1, adjustment factor for existing TPMS, is treated as a constant. Currently, about 1 percent of passenger vehicles are equipped with a TPMS meeting the proposal. Thus, $a_1 = 0.99$ (= 1 - 0.01). The initial C_{TPMS} was adjusted down by this factor to estimate the true technology cost (i.e., incremental cost) per vehicle.

Of the two factors within C_1, a_1 is a constant, and thus influences only the range of the costs. The other factor C_{TMPS} dictates the type of probability distribution for C_1. As a result, C_1 is uniformly distributed with a range that is slightly smaller than C_{TMPS}. Table X-9 lists three costs (maximum, mean, and minimum) of C_1 that are used to establish its uniform distribution for the three compliance options.

Table X-9
Uniform Distribution for Technology/Countermeasure Costs (C_1)
For Three Compliance Options*
(2001 Dollars)

	Maximum Cost (C_{1max})	Minimum Cost (C_{1min})	The Mean Cost (point estimate)
Option 1 Direct TPMS with Continuous Readings	$76.88	$62.90	$69.89
Option 2 Direct TPMS with Warning	$72.69	$59.48	$66.08
Option 3 Hybrid TPMS with Warning	$53.28	$43.60	$48.44

* no discounting

Maintenance Costs (C_2)

The maintenance cost per vehicle C_2, is the cost for battery replacement over a vehicle's life, and thus was discounted at 3 and 7 percent. The cumulative discount factor (d) is equal to 0.8233 at 3 percent and 0.6600 at 7 percent. Obviously, C_2 depends on the design of the TPMS (with or without batteries). It also varies with the labor cost, the cost of the battery, and technologies (i.e., compliance options). Since the sources of its variations (e.g., labor and material costs, etc.) are similar to those cited for C_1, the analysis considers C_2 to possess the same type of probability distribution as C_1, i.e., C_2 is uniformly distributed with its values conforming within 10 percent of the point-estimated cost presented in the chapter on costs.

Table X-10 lists the cost parameters required for establishing the uniform distribution for C_2 at the 3 and 7 percent discount rates by TPMS design and three compliance options. As shown in Table X-10, under the with-battery scenario, C_2 is uniformly distributed between $36.45 and $44.55 for Options 1 and 2, and between $24.24 and $29.62 for Option 3. If batteries were not required, these values would all be 0.

Table X-10
Uniform Distribution For Maintenance Costs Per Vehicle (C_2)
TPMS With Batteries*
(2001 Dollars)

	Maximum Cost (C_{2max})	Minimum Cost (C_{2min})	The Mean Cost (point estimate)
At 3% Discount Rate			
Option 1 Direct TPMS with Continuous Readings	$61.58	$50.38	$55.98
Option 2 Direct TPMS with Warning	$61.58	$50.38	$55.98
Option 3 Hybrid TPMS with Warning	$40.95	$33.51	$37.23
At 7% Discount Rate			
Option 1 Direct TPMS with Continuous Readings	$44.55	$36.45	$40.50
Option 2 Direct TPMS with Warning	$44.55	$36.45	$40.50
Option 3 Hybrid TPMS with Warning	$29.62	$24.24	$29.63

* $0 if batteries were not required.

Opportunity and Other Costs (C_3)

The opportunity and other costs estimate the costs for additional tire pressure fill-ups and the air pump charges over the vehicle's life (C_3). C_3 varies with the estimated additional fill-up frequency (N), the time duration (in hour) for each fill-up (T), the number of occupants in a vehicle (O), the estimated cost per hour (C_h), air pump fee per vehicle over the vehicle's life (C_p), the cumulative lifetime discount rate (d), the existing TPMS market share (a_1), and the TMPS response rate (a_2). C_3 can be represented as:

$$C_3 = (N*T*O*C_h + C_p)*d*a_1*a_2$$

Where N = the number of additional fill-ups per vehicle over the vehicle's life

T = time needed for each fill-up

O = the number of occupants per vehicle

C_h = value of opportunity costs per hour

C_p = lifetime air pump fee per vehicle

d = cumulative lifetime discount factor (at 3 percent or 7 percent)

a_1 = adjustment factor for existing TPMS system

a_2 = adjustment factor for response rate to TPMS warning light

Of these eight factors within C_3, N, T, O C_h, and C_p are newly introduced. Their variations are discussed here. The variations of these factors are based on expert judgment. The analysis assumes that

- N is uniformly distributed between 8.02 and 9.08 with a mean of 8.91.

- T is normally distributed with 0.0833 hours (=5 minutes) as the mean and 0.0167 hours (= 1 minute) as SD.
- O is normally distributed with a mean of 1.3 occupants and a standard deviation of 0.1 occupants.
- C_h is normally distributed from \$8.10 to \$14.10 per hour with a mean of \$11.10 per hour.
- C_p is uniformly distributed from \$0.55 to 0.73 per vehicle over the vehicle's life with a mean of \$0.64 per vehicle.

The values and variability of uncertainty factor d (cumulative lifetime discount factor), a_1 (adjustment for existing TPMS), and a_2 (response rate to TPMS warnings) were discussed in the benefit model section, and thus are not repeated here. Figure X-5 depicts the probability distributions for the uncertainty factors within C_3.

After taking into account all these variations, the final outcome of C_3 is close to a normal distribution. At the 3 percent discount rate, C_3 has a mean of \$8.31 and a standard deviation of \$1.11. At the 7 percent discount rate, C_3 has a mean of \$6.66 and a standard deviation of \$0.89. Figure X-6 depicts the probability distributions for the final outcomes of C_3.

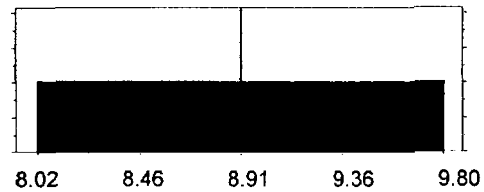
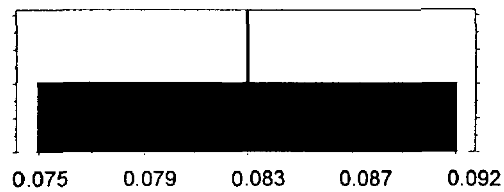
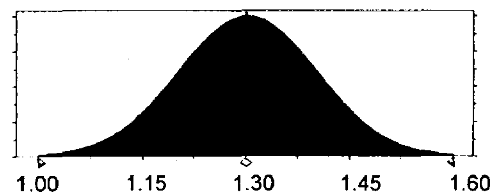
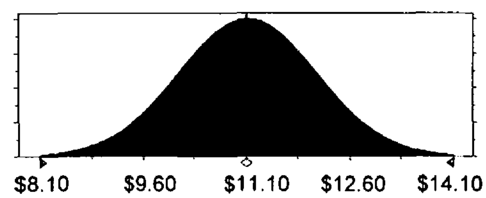
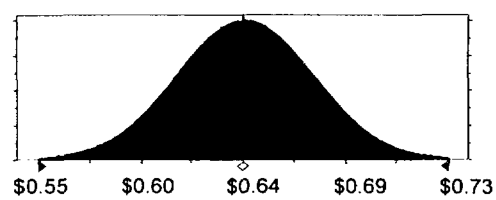
Factors	Parameters	Probability Distribution
Additional fill-ups per vehicle over the vehicle life (N)	Maximum: 8.02 Minimum: 9.80 Mean: 8.91	
Hours per fill-up (T)	Maximum: 0.075 Minimum: 0.092 Mean: 0.0833	
Occupants per vehicle (O)	Mean: 1.3 SD: 0.1	
Opportunity Cost per hour (C_h)	Mean: $11.10 SD=$1.10	
Lifetime Air Pump Fee per vehicle (C_p)	Mean: $0.64 SD=$0.03	
Cumulative lifetime discount factor (d)	NA	Constant At 3 % = 0.8233 At 7% = 0.6600
Adjustment factor for existing TPMS system (a_1)	NA	Constant a_1 = 0.99
Adjustment factor for response rate to TPMS warning light (a_2)	Mean: 0.90 SD: 1.7	Same as Figure X-2

Figure X-5
Probability Distribution for Factors Within The Opportunity and Other Costs (C_3)

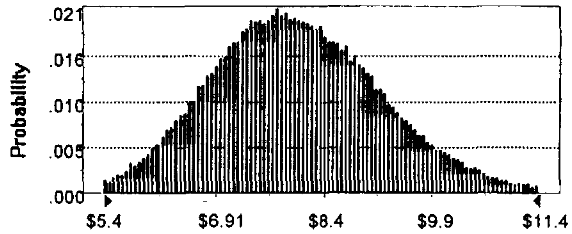
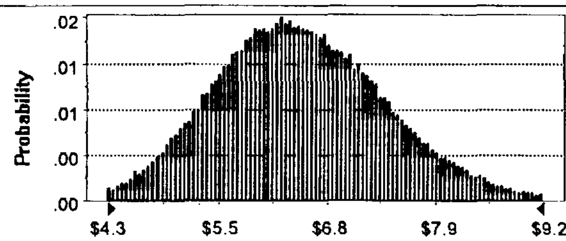
Discount Level	Parameters	Probability Distribution
At 3%	Mean: $8.31 SD: $1.11	
At 7%	Mean: $6.66 SD: $0.89	

Figure X-6
Probability Distributions for Opportunity and
Other Costs Per Vehicle Over the Vehicle Life (C_3)

Fuel Savings (C_4)

The saving from fuel consumption over a vehicle's life, C_4, also comes with certain variations. The sources of the variations come from, but are not limited to, fuel price, the 1 percent fuel efficiency equivalent psi, baseline mpg (CAFE standards), the discount factor, the existing TPMS, and the driver response rate to TPMS. Since, CAFÉ issues a different mpg standard for passenger cars and light trucks/vans and each compliance option has a different baseline mileage, C_4 would depend on the vehicle types and compliance options.

The fuel price fluctuates with demand and supply cycles. The 1949-2002 retail motor gasoline prices reported by the Department of Energy[6] were used to predict the future fuel price variations. The analysis used Crystal Ball as a tool to fit these historical data into 10 different continuous probability distributions (e.g., normal, lognormal, etc.). Three goodness-of-fit tests

Chi-square, Kolmogorov-Smirnov, and Anderson-Darling were used to rank each distribution[7]. None of the 10 probability distributions were found to be significant by all three of these measures. However, the logistic distribution has an overall consistent and relatively favorable ranking among these 10 probability functions. Thus, the logistic distribution was chosen to represent the variation of the fuel price. The general format of a logistic distribution is:

$$f(x) = \frac{e^{-(\frac{x-\mu}{\alpha})}}{\alpha(1+e^{-(\frac{x-\mu}{\alpha})})^2}, \text{ where } \mu = \text{mean and } \alpha = \text{scale.}$$

Mean represents the average fuel price and scale determines the spread and the shape of the probability curve. The historic motor gasoline price from 1949 to 2002 was logistically distributed with the scale equal to 9.2 percent of the mean fuel price. This mean and scale relationship was then applied to the logistic distribution used for the average fuel price, i.e., $\alpha = 0.092*\mu$. The mean pre-tax fuel price used (Chapter V) is \$1.06, i.e., μ = \$1.06. Based on the mean-scale relationship stated above, the scale, α, is equal to \$0.97. With this logistic probability distribution, the pre-taxed fuel price would range from \$0.48 to \$1.64. The estimated gasoline tax is \$0.38. Therefore, the after-tax fuel price is from \$0.86 to \$2.02. Figure X-7 depicts the logistic distribution for pre-tax fuel prices in 2001 dollars.

[6] Table 5.22 Retail Motor Gasoline and On-Highway Diesel Fuel Prices, 1949-2002, Annual Energy Review, 2002, Energy Information Administration (EIA), Department of Energy (DOE)

[7] Crystal Ball 2000 User Manual

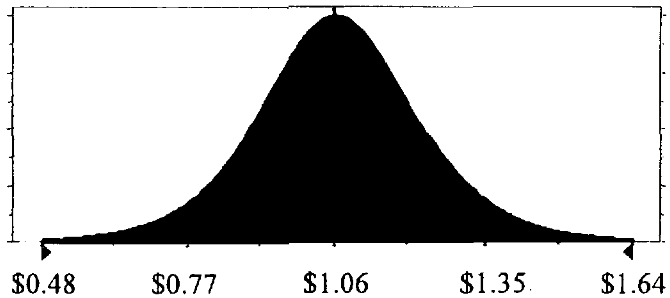


Figure X-7
Pre-Taxed Fuel Price Distribution
(2001 Dollars)

The 1 percent fuel efficiency equivalent psi power would also impact C_4. In Chapter V, we estimated that a mean of 2.96 psi is equivalent to one percent fuel efficiency. The agency does not have sufficient data to assess its variation. However, to somewhat assess its impact on C_4, the analysis assumes that the psi power is uniformly distributed with 10 percent variation from the mean 2.96 psi. In other words, 1 percent fuel efficiency would be equivalent to a range of psi from 2.66 to 3.26 psi.

Another factor, mpg , would be a constant which is based on the CAFE standards. The mpg standard is 27.5 and 22.2 mpg for passenger cars and light trucks/vans, respectively.

The remaining uncertainty factors such as d (cumulative lifetime discount factor), a_1 (adjustment factor for existing TPMS), and a_2 (driver response rate to TMPS warning) were discussed earlier, and thus are not repeated here.

With the consideration of the variations from the factors discussed above, the simulated final outcome of C_4 is close to a normal distribution. Figure X-8 depicts these distributions by discount rates.

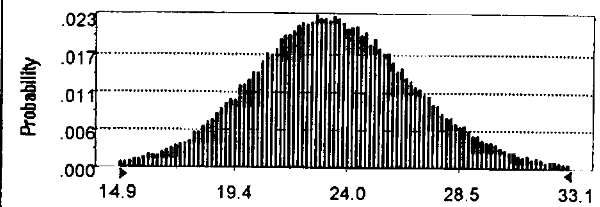
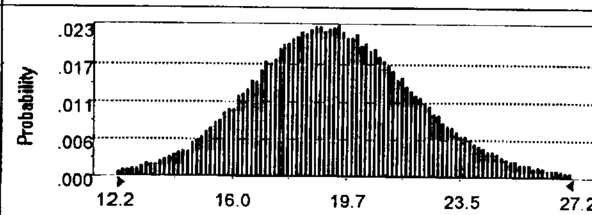
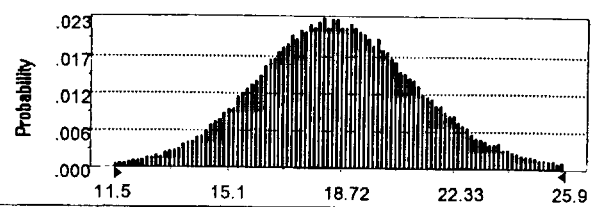
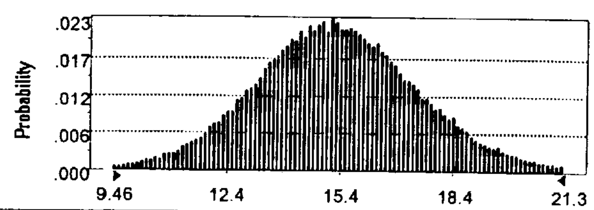
	Mean & SD	Probability Distribution
At 3% Discount Rate		
Option 1 Direct TPMS with Continuous Readings	Mean: $23.54 SD: $3.26	
Option 2 Direct TPMS with Warning	Mean: $19.39 SD: $2.69	
Option 3 Hybrid TPMS with Warning	Mean: $19.36 SD: $2.69	Same as Option 2
At 7% Discount Rate		
Option 1 Direct TPMS with Continuous Readings	Mean: $18.67 SD: $2.58	
Option 2 Direct TPMS with Warning	Mean: $15.37 SD: $2.13	
Option 3 Hybrid TPMS with Warning	Mean: $15.37 SD: $2.13	Same as Option 2

Figure X-8
Normal Distribution for Fuel Saving (C_4)
By Three Compliance Options and Discount Rates
(2001 Dollars)

Tread Wear Savings (C_5)

The saving from tread wear per vehicle over a vehicle's life, C_5, depends on the tire materials, technologies, and roadway types, miles traveled, and response rate to TPMS. The agency does not have information at this time to discern the trends for these sources except for the miles traveled. The average number of vehicle miles traveled by motor vehicles has increased each year[8]. Consequently, the estimated tread wear saving could potentially be higher than currently estimated. On the other hand, this increased saving might be offset by future tire improvements. With no adequate data to assess the possible trends and variations, the analysis treats C_5 as uniformly distributed with the overall range falling within 10 percent of the point estimate as presented in the previous chapter on costs. Figure X-9 depicts these distributions by compliance options and discount rates.

[8] Highway Statistics 2002, U.S. DOT, FHWA-PL03-010; Highway Statistics 2001, U.S. DOT, FHWA-PL02-008

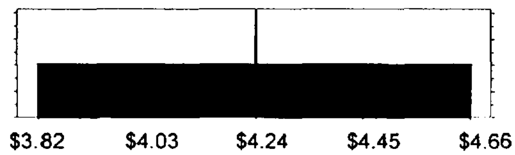
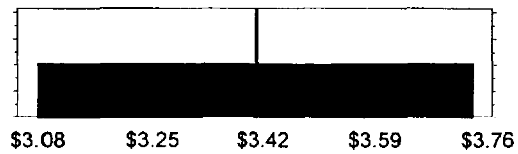
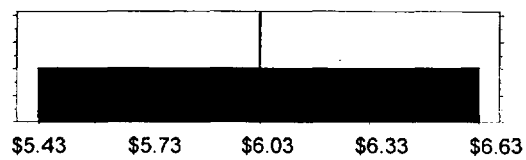
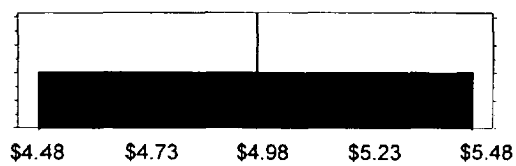
	Mean	Uniform Distribution
At 3% Discount Rate		
Option 1 Direct TPMS with Continuous Readings	$4.24	
Option 2 Direct TPMS with Warning	$3.42	
Option 3 Hybrid TPMS with Warning	$3.42	Same as Option 2
At 7% Discount Rate		
Option 1 Direct TPMS with Continuous Readings	$6.03	
Option 2 Direct TPMS with Warning	$4.98	
Option 3 Hybrid TPMS with Warning	$4.98	Same as Option 2

Figure X-9
Uniform Distribution for Tread Wear Savings Per Vehicle (C_5)
For Three Compliance Options
(2001 Dollars)

Property Damage and Traveling Delay Savings (C_6)

The property damage and travel delay savings per vehicle (C_6) over the vehicle life includes savings from three areas: preventable injury crashes, vehicles in preventable PDO crashes, and non-preventable crashes. The process of C_6 can be algebraically described as follow:

$$C_6 = \frac{(\sum_{i=0}^{6} BP_i * UC_i) + (\sum_{i=1}^{6} PDO_i * UC_{PDO}) + [\sum_{i=1}^{6} (BNP_i + BNP_{i-1}) * (UC_i - UC_{i-1})]}{V} * d$$

Where BP_i = net MAIS i benefits from preventable crashes with MAIS 6 = fatalities

BNA_i = net MAIS I benefits from non-preventable crashes with 6 = fatalities

PDO_i = PDO vehicles derived from MAIS i benefits with 6 = fatalities from preventable crashes.

UC_i = property damage/travel delay unit cost within MAIS i injuries with MAIS 0 = no injury and 6 = fatalities

UC_{PDO} = property damage/travel delay unit cost per PDO vehicle

d = cumulative lifetime discount factor

V = total number of vehicles

The variables BP_i, net injury and fatality benefits, were derived from the benefit models described earlier. Values of PDO_i were also derived from BP_i, i > 0. Basically, the initial BP_is were adjusted to its corresponding PDO vehicles by multiplying by a PDO/injury ratio. This PDO/injury ratio is a function of three variables: the number of occupants per crash involved vehicle (=1.35), property damage to injury vehicle ratio (= 5.70 for skidding/loss of control, 3.99 for others), and adjustment factor for underreporting (=1.92). These three variables were derived from NHTSA crash database such as FARS, CDS, and State Data Files. They are ratios, and thus are treated as constants. The formula for the PDO/injury ratio can be expressed as follow:

$$\text{PDO/Injury ratio} = \frac{\text{property damage to injury ratio} * \text{adjustment factor for underreporting}}{\text{occupant per crash involved vehicle}}$$

$$\begin{cases} = \dfrac{5.7*1.92}{1.35} = 8.11 \text{ for skidding/loss of control} \\ = \dfrac{3.99*1.92}{1.35} = 5.68 \text{ for other target crash types} \end{cases}$$

Based on the above mathematical formula, C_6 varies with the derived net benefits (BP_i and BNP_i) and the property damage/travel delay unit costs. Since C_6 was derived from BP_i and BNP_i, all the uncertainties for BP_i and BNP_i discussed in the benefit models would also apply to C_6. The variability of UC_i and UC_{PDO} would also impact C_6. However, as explained earlier in this chapter, the analysis does not consider its variability at this moment and treats these unit costs as constants. Table X-11 lists these unit costs. Please consult Chapter V for a detailed explanation. The factor V, the number of vehicles, also is treated as a constant of 17 million (see discussion below). Figure X-10 depicts the final outcomes of C_6.

Table X-11
Property Damage and Travel Delay Unit Costs by Injury Severity*

Injury Severity	Unit Costs
MAIS 0	$1,843
MAIS 1	$4,752
MAIS 2	$4,937
MAIS 3	$7,959
MAIS 4	$11,140
MAIS 5	$19,123
Fatality	$19,947
PDO Vehicle	$2,352

*adopted from Chapter V

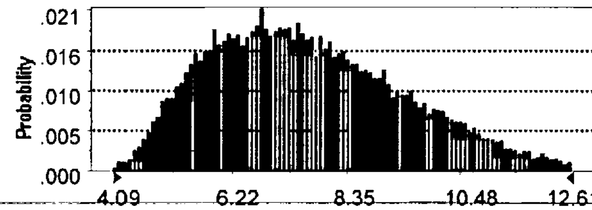
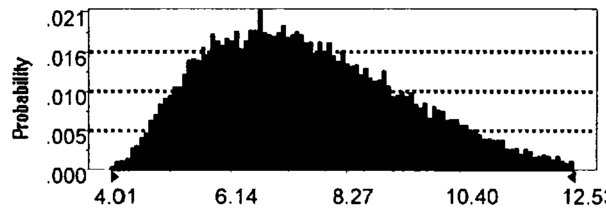
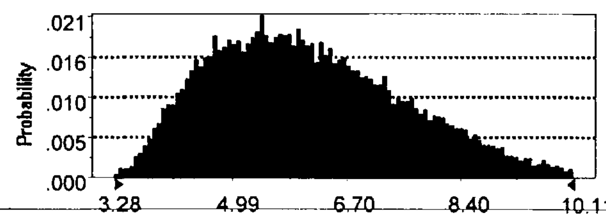
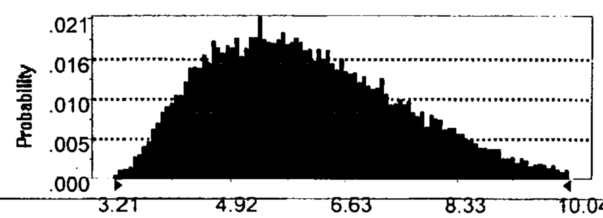
Discount Level	Parameters	Probability Distribution
At 3% Discount Rate		
Option 1 Direct TPMS with Continuous Readings	Mean: $7.67 SD: $1.67	
Option 2 Direct TPMS with Warning	Mean: $7.57 SD: $1.76	
Option 3 Hybrid TPMS with Warning	Mean: $7.57 SD: $1.76	Same as Option 2
At 7% Discount Rate		
Option 1 Direct TPMS with Continuous Readings	Mean: $6.15 SD: $1.42	
Option 2 Direct TPMS with Warning	Mean: $6.07 SD: $1.41	
Option 3 Hybrid TPMS with Warning	Mean: $6.07 SD: $1.41	Same as Option 2

Figure X-10
Probability Distributions for Property Damage and
Travel Delay Savings Per Vehicle Over the Vehicle Life (C_6)

Number of Vehicles (V)

The last uncertainty factor, the number of vehicles (V) is treated as a constant of 17 million. Of these, 8 million are passenger cars and 9 million are light trucks, vans, and sport utility vehicles. Although vehicle sales have gradually increased over time, they are subject to annual variation due to changes in economic conditions, which are difficult to predict.

After the fatal equivalent (FE) and cost models were established, the cost-effectiveness model (CE) simply is the ratio of total costs (TC) to fatal equivalents. It has the format: CE = TC/FE. The net benefits (NB) has the format: NB = M*FE – TC, where M is the cost per fatality.

Modeling Results

The uncertainty analysis conducted a total of 25,000 trials before the forecasted mean results reached 99 percent precision. Even if the later criterion was reached first, the trial numbers generally are very close to 25,000. These criteria were chosen to ensure that the simulation errors ($\approx \frac{1}{25,000}$) would be very close to 0.

Tables X-12 and X-13 summarize the modeling results. Table X-12 lists the results for the scenario that all the TPMSs require batteries. Table X-13 is for the no-battery scenario, which is the direction that the industry is expected to take. Therefore, the agency believes that the modeling results reported in Table X-13 are a more realistic assessment of the rule in the future than those in Table X-12.

With Batteries

As shown in Table X-12 – with battery scenario, at the 3 percent discount rate, the estimated costs range from $1,391 to $1,973 million for Option 1, $1,426 to $1,975 million for Option 2, and $851 to $1,313 million for Option 3. These three options would save 98 – 296, 96 – 291, and 96 – 291 equivalent lives, respectively. As noted in Chapter VII, the most recent NHTSA study relating to the cost of crashes on valuing fatalities indicate a value of life of about $3.5 million (in 2001 dollars). Based on the statistics, there is almost no chance for these compliance options to produce a cost per equivalent fatality of less than $3.5 million. If a higher $5.5 million threshold was used (based on the midpoint of the range previously discussed), Option 3 would have 47 percent chance to meet this threshold. There is almost no chance for Options 1 and 2 to meet the $5.5 million threshold. All three options would produce positive net benefits with different levels of certainty: 6 percent for Option 1, 5 percent for Option 2, and 44 percent for Option 3.

At the 7 percent discount rate, the estimated costs range from $1,208 to $1,711 million for Option 1, $1,237 to $1,705 million for Option 2, and $763 to $1,136 million for Option 3. At this discount rate, these three options would save 79 – 237, 77 – 233, and 77 – 233 equivalent lives, respectively. Option 3 is the only option that would produce a cost per equivalent fatality less than $5.5 million with 32 percent certainty. The chance that each option would produce positive net benefits at this discount rate is: 3 percent for Option 1, 2 percent for Option 2, and 35 percent for Option 3.

No Batteries

For the no-battery scenario, the total compliance cost would be one-third to one-half of those with batteries. Because the compliance costs were significantly reduced, the three compliance options become much more cost-beneficial than assessed under the with-battery scenario. As shown in Table X-13, at the 3 percent discount rate, the estimated costs range from $477 to $977 million for Option 1, $509 to $986 million for Option 2, and $247 to $657 million for Option 3. The three options would produce a cost per equivalent fatality less than $3.5 million with 41 percent, 34 percent, and 93 percent certainty, respectively. If the threshold were raised to $5.5 million, all three options would have more than 90 percent chance to meet it. All three Options would also generate positive net benefits with relatively high certainty levels, 82 percent for Option 1, 79 percent for Option 2, and 97 percent for Option 3.

At the 7 percent discount rate, the estimated costs range from $557 to $999 million for Option 1, $577 to $997 million for Option 2, and $327 to $679 million for Option 3. The three options would produce a cost per equivalent fatality less than $3.5 million with 8 percent, 5 percent, and 65 percent certainty, respectively. If the threshold were raised to $5.5 million, the certainty levels for these three Options would be 68 percent, 62 percent and 99 percent, respectively. Options 1 and 2 would produce positive net benefits with about 55 percent certainty. Option 3 would have a 90 percent chance to produce positive net benefits.

Summary

The three compliance options would save a similar number of equivalent lives. However, due to its relatively low costs, Option 3 (a hybrid TPMS) is the most cost-beneficial among these three options. With technology advances, the cost of the TPMS would be reduced significantly as demonstrated in the no-battery scenario (Table X-13). This scenario probably reflects the future of TPMS design. Under this assessment, the TPMS rule is increasingly more favorable. At a 3 percent discount rate, Options 1 and 2 would have less than 50 percent chance to produce a cost per equivalent fatality less than $3.5 million. The certainty level increased significantly to 93 percent for Option 3 to meet the $3.5 million threshold. All three options would have a very high probability to produce a cost per equivalent fatality less than $5.5 million and positive net benefits. Not surprisingly, with a higher discount rate of 7 percent, these options would meet the same cost-effectiveness ($3.5 and $5.5 million) and net benefit (>0) thresholds with less certainty. But, all three options would still produce a cost per equivalent fatality less than $5.5 million and positive net benefits with high certainty levels.

This analysis of TPMS involved numerous data sources, methods and assumptions, most of which involve some degree of uncertainty. As a result, this uncertainty analysis includes over 100 probability distributions, comprised of a variety of uniform distributions, normal distributions, logistic distributions, and a combination of uniform and triangular distributions. Considering all of these distributions simultaneously results in very wide ranges for cost-effectiveness and net benefits as shown in Tables X-12 and X-13.

Table X-12
Simulated Cost-Effectiveness and Net Benefits
With Batteries

	Compliance Option		
At 3% Discount Rate	**1**	**2**	**3**
Range of Total Costs	$1,391 - $1,973 M	$1,426 - $1,975 M	$851 - $1,313 M
Mean Net Total Cost	$1,678 M	$1,700 M	$1,081 M
90% Certainty for Total Costs	$1,498 - $1,861 M	$1,528 - $1,868 M	$941 - $1,219 M
Range of Equivalent Lives Saved	98 – 296	96 – 291	96 – 291
Mean Equivalent Lives Saved (present value)	197	193	193
90% Certainty for Equivalent Lives Saved (present value)	140 – 263	142 – 265	142 – 265
Range of CE	$4.6 - $14.9 M	$5.0 - $15.1 M	$2.8 - $9.9 M
Mean CE	$8.8 M	$9.1 M	$5.8 M
90% Certainty for CE	$6.5 – $14.2 M	$6.7 - $14.5 M	$4.2 - $9.6 M
Certainty that CE <= $3.5 M	0.0%	0.0%	1.4%
Certainty that CE <= $5.5 M	1.4%	0.7%	47%
Range of Net Benefits	-$1,552 to $371 M	-$1,536 to $366 M	-$989 to $943 M
Mean Net Benefits	-$610 M	-$650 M	-$34 M
90% Certainty for Net Benefits	-$1,135 to $95 M	-$1,156 to $76 M	-$534 to $679 M
Certainty that Net Benefits > $0	6%	5%	44%
At 7% Discount Rate			
Range of Total Costs	$1,208 - $1,711 M	$1,237 - $1,705 M	$763 - $1,136 M
Mean Net Total Cost	$1,464 M	$1,475 M	$945 M
90% Certainty for Total Costs	$1,306 - $1,617 M	$1,328 - $1,620 M	$830 - $1,065 M
Range of Equivalent Lives Saved	79 – 237	77 – 233	77 – 233
Mean Equivalent Lives Saved (present value)	158	155	155
90% Certainty for Equivalent Lives Saved (present value)	112 – 211	112 – 209	112 – 209
Range of CE	$5.0 - $15.9 M	$5.3 - $16.1 M	$3.2 - $10.6 M
Mean CE	$9.5 M	$9.8 M	$6.3 M
90% Certainty for CE	$7.1 - $15.4 M	$7.3 - $15.7 M	$4.6 - $10.5 M
Certainty that CE <= $3.5 M	0%	0%	0.2%
Certainty that CE <= $5.5 M	0.2%	0.1%	32%
Range of Net Benefits	-$1,381 to $192 M	-$1,405 to $154 M	-$880 to $686 M
Mean Net Benefits	-$607 M	-$634 M	-$104 M
90% Certainty for Net Benefits	-$1,031 to -$19 M	-$1,050 to -$60 M	-$508 to $474 M
Certainty that Net Benefits > $0	3%	2%	35%

M: million; CE: cost per fatal equivalent

Table X-13
Simulated Cost-Effectiveness and Net Benefits
No Batteries*

	Compliance Option		
At 3% Discount Rate	**1**	**2**	**3**
Range of Total Costs	$477 – $977 M	$509 – $986 M	$247 – $657 M
Mean Net Total Cost	$726 M	$748 M	$449 M
90% Certainty for Total Costs	$570 - $883 M	$600 - $889 M	$323 - $573 M
Range of Equivalent Lives Saved	98 – 296	96 – 291	96 – 291
Mean Equivalent Lives Saved (present value)	197	193	193
90% Certainty for Equivalent Lives Saved (present value)	140 – 263	142 – 265	142 – 265
Range of CE	$1.6 - $6.9 M	$1.5 - $7.0 M	$0.5 - $4.5 M
Mean CE	$3.8 M	$4.0 M	$2.4 M
90% Certainty for CE	$2.6 - $6.4 M	$2.8 - $6.6 M	$1.5 to $4.2 M
Certainty that CE <= $3.5 M	41%	34%	93%
Certainty that CE <= $5.5 M	94%	92%	100%
Range of Net Benefits	-$634 to $1,344 M	-$653 to $1,276 M	-$319 to $1,556 M
Mean Net Benefits	$343 M	$300 M	$599 M
90% Certainty for Net Benefits	-$173 to $1,069 M	-$204 to $1,017 M	$101 to $1,302 M
Certainty that Net Benefits > $0	82%	79%	97%
At 7% Discount Rate			
Range of Total Costs	$557 – $999 M	$577 – $997 M	$327 – $679 M
Mean Net Total Cost	$775 M	$787 M	$488 M
90% Certainty for Total Costs	$634 - $916 M	$655 - $916 M	$381 - $599 M
Range of Equivalent Lives Saved	79 – 237	77 – 233	77 – 233
Mean Equivalent Lives Saved (present value)	158	155	155
90% Certainty for Equivalent Lives Saved (present value)	112 – 211	112 – 209	112 – 209
Range of CE	$2.1 - $9.0 M	$2.3 - $9.1 M	$0.8 - $5.8 M
Mean CE	$5.1 M	$5.2 M	$3.2 M
90% Certainty for CE	$3.6 - $8.5 M	$3.7 - $8.6 M	$2.2 – $5.6 M
Certainty that CE <= $3.5 M	8%	5%	65%
Certainty that CE <= $5.5 M	68%	62%	99%
Range of Net Benefits	-$701 to $889 M	-$708 to $835 M	-$373 to $1,113 M
Mean Net Benefits	$81 M	$54 M	$352 M
90% Certainty for Net Benefits	-$337 to $672 M	-$358 to $626 M	-$50 to $911 M
Certainty that Net Benefits > $0	59%	55%	90%

* no maintenance costs
M: million; CE: cost per fatal equivalent

APPENDIX A

Appendix A explains how to derive an adjustment factor for non-preventable crashes in Chapter V Benefits. Chapter V uses the change in delta v to estimate benefits from correcting the under-inflated tire pressures. Change in delta v at a given traveling distance is defined to be one half of the velocity difference between two scenarios: a vehicle with correct tire pressure and without. The total traveling distance of a vehicle after braking under the correctly inflated tire pressures is defined as the correct stopping distance. The incorrect stopping distance is the total traveling distance of a vehicle with under-inflated tire pressures. Change in delta v increases with the traveling distance. Figure A-1 depicts a simplified curve relationship between change in delta v and the traveling distance for illustration. The curvature varies with initial speed, deceleration, and traveling distance. For non-preventable crashes, the maximum change in delta v occurs at the correct stopping distance. Therefore, applying the change in delta v at this level to the total applicable baseline population would overestimate the benefits from correcting tire pressures for non-preventable crashes.

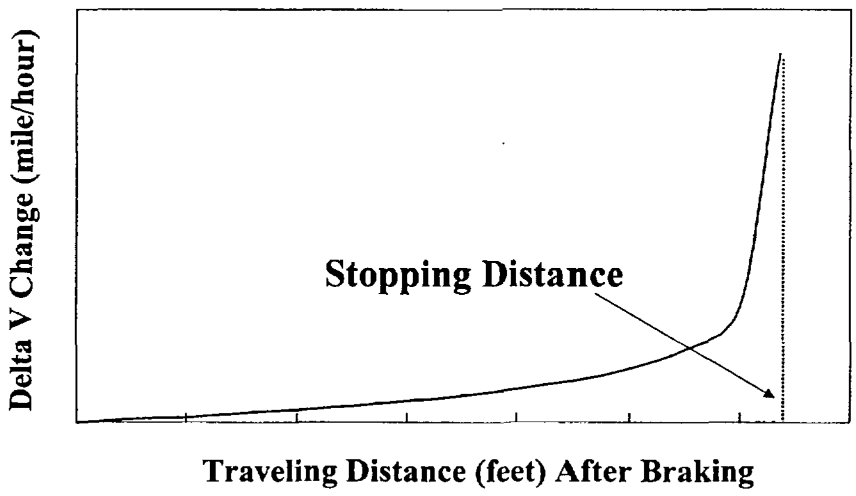


Figure A-1 Generalized Relationship Between Change in Delta V and Traveling Distance

Ideally, the benefits would be estimated by applying the change in delta v at any given traveling distance to the corresponding baseline population. However, the change in delta v varies with the initial traveling speeds, deceleration, and traveling distance. There are too many initial traveling speeds and deceleration (or stopping distance) combinations to be exhaustively analyzed. Less ideally, the benefits would be estimated by applying the expected changes in delta v to the applicable baseline population. This approach, too, encounters the same obstacles as in the ideal approach. In addition, the expected changes in delta v might be fractions of 1 mile/hour, e.g., 0.1, 0.01 mile/hour. This would result in infinite ways to segment the measurement units for the delta v based injury probability curves. Thus, this analysis only uses a weighted average initial speed, correct stopping distance, and incorrect stopping distance to estimate the expected change in delta v with respect to the traveling distance. The expected change in delta v can be considered as the mean for continuous variables (i.e., traveling distance). The adjustment factor is the ratio of the expected change in delta v and change in delta v at the correct stopping distance. The following two sections describe the process in detail. In the last section, the sensitivity analysis examines several scenarios to estimate the impact of different initial traveling speeds, decelerations, and stopping distances on the adjustment factors. Note that all the equations and functions were derived assuming constant decelerations.

Expected Change in Delta V

The expected change in delta v is an integral of the product of two functions: the probability density function of a non-preventable crash occurrence and the change in delta v at any given traveling distance d. The change in delta v function is one half of the velocity change function. The expected change in delta v (EDV) is:

$$\begin{aligned} EDV &= \int_0^{SD_c} u(d) * \left(\frac{1}{2} * DV(d)\right) dd \\ &= \frac{1}{2} \int_0^{SD_c} u(d) DV(d) dd \end{aligned} \qquad \text{--------} \ (1)$$

Where, SD_c= the correct stopping distance

u(d) = the probability density function of a crash occurrence

DV(d) = the velocity change function.

The function $\frac{1}{2} * DV(d)$ is the change in delta v by definition. Note that the measurement unit among variables has to be consistent for Equation 1 and the rest of the equations. For example, if "feet-second" measurement is used, then the velocity, deceleration, and traveling distance have all been based on feet-second unit.

Probability Density Function

Assuming that the non-preventable crashes occurred uniformly at any traveling distance between the initial braking (d=0) and the correct distance, the probability density function u(d) has the property that $u(SD_c) = \int_0^{SD_c} dd = 1$. By solving this equation, u(d) is a constant function:

$$u(d) = \frac{1}{SD_c}, \forall d, 0 \le d \le SD_c \qquad \text{--------- (2)}$$

where, SD_c = the correct stopping distance

Change in Delta V Function

Change in delta v function between two tire pressure conditions is half of the velocity change function at any traveling distance d. The velocity change function is

$$DV(d) = v_i(d) - v_c(d), \forall d, 0 \le d \le SD_c \qquad \text{-------- (3)}$$

Where, v_i = velocity with incorrect tire pressure

v_c = velocity with correct tire pressure

SD_c = the correct stopping distance

At any given traveling distance d, the velocity under a constant deceleration can be derived based on the following formula: $v(d) = \sqrt{v_0^2 + 2 * ad}$, where v_o is the initial traveling speed and a the deceleration. Let variables a_i and a_c represent the deceleration under incorrect and correct tire pressure, respectively. Then,

$$v_i(d) = \sqrt{v_0^2 + 2 * a_i d}$$

-------- (4)

$$v_c(d) = \sqrt{v_0^2 + 2 * a_c d}$$

At the stopping distance, a braking vehicle has 0 velocity. Thus, for incorrect tire pressure:

$$0 = \sqrt{v_0^2 + 2 * a_i SD_i} \text{ and}$$

$$a_i = \frac{-v_0^2}{2 * SD_i} \qquad \text{--------(5)}$$

where:

a_i = the deceleration with incorrect tire pressure

SD_i = the stopping distance with incorrect tire pressure.

Similarly, the deceleration formula for braking vehicles with the correct tire pressure is

$$a_c = \frac{-v_0^2}{2 * SD_c} \qquad \text{-------- (6)}$$

where:

a_c = deceleration with correct tire pressure

SD_c = the stopping distance with correct tire pressure

By substituting the right side of Equations 5 and 6 for a_i and a_c into Equation 4, the velocity change function can be rewritten as a function of initial traveling distance.

$$
\begin{aligned}
DV(d) &= v_i(d) - v_c(d) \\
&= \sqrt{v_0^2 + 2a_i d} - \sqrt{v_0^2 + 2a_c d} \\
&= \sqrt{v_0^2 + 2 * (\frac{-v_0^2}{2 * SD_i})d} - \sqrt{v_0^2 + 2 * (\frac{-v_0^2}{2 * SD_c})d} \\
&= \sqrt{v_0^2 - \frac{v_0^2}{SD_i}d} - \sqrt{v_0^2 - \frac{v_0^2}{SD_c}d} \qquad \text{-------- (7)} \\
&= v_0\left(\sqrt{1 - \frac{d}{SD_i}} - \sqrt{1 - \frac{d}{SD_c}}\right)
\end{aligned}
$$

Change in delta v at any given traveling distance d would be

$$
DV(d) = \frac{v_0}{2}\left(\sqrt{1 - \frac{d}{SD_i}} - \sqrt{1 - \frac{d}{SD_c}}\right) \qquad \text{------- (8)}
$$

For passenger cars, the weighted average initial traveling speed, correct stopping distance, and incorrect stopping distances are:

V_0 = 45.078 mile/hour = 66.114 feet/second

SD_c = 85.273 feet

SD_i = 86.464 feet

At any given traveling distance, the change in delta v is calculated by substituting these numbers into Equation 8. Figure A-2 shows the change in delta v by traveling distance. At the correct stopping distance of 85.273 feet, for example, the change in delta v DV(85.273) is:

$$DV(85.273) = \frac{66.144}{2}\left(\sqrt{1-\frac{85.273}{86.464}} - \sqrt{1-\frac{85.273}{85.273}}\right)$$

$$= 3.878 \text{ feet/second}$$

$$= 2.644 \text{ miles/hour}$$

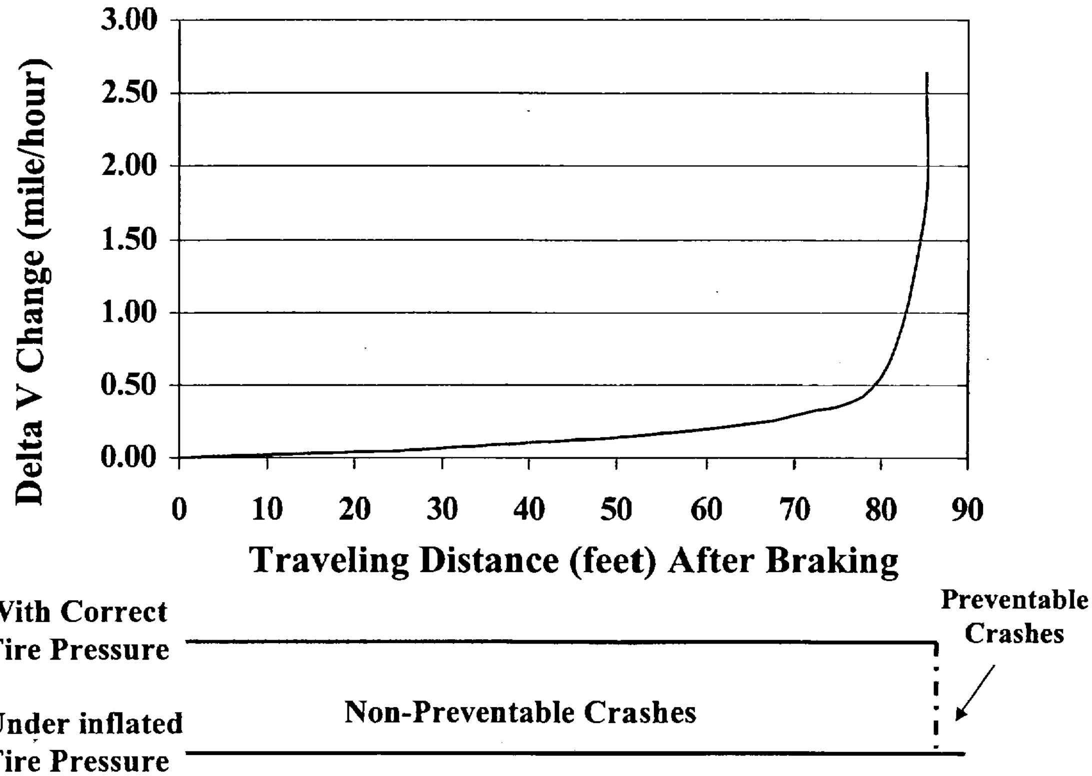


Figure A-2. Change in Delta V by Traveling Distance
Passenger Cars

For light trucks and vans, the weighted average initial traveling speed, correct stopping distance, and incorrect stopping distances are:

V_0 = 45.078 mile/hour = 66.114 feet/second

SD_c = 90.726 feet

SD_i = 91.979 feet

Figure A-3 shows the change in delta v by traveling distance. At the correct stopping distance of 90.726 feet, the change in delta v DV(90.726) is:

$$\begin{aligned} DV(90.726) &= \frac{66.144}{2}\left(\sqrt{1-\frac{90.726}{91.979}}-\sqrt{1-\frac{90.726}{90.726}}\right) \\ &= 3.859 \text{ feet/second} \\ &= 2.631 \text{ miles/hour} \end{aligned}$$

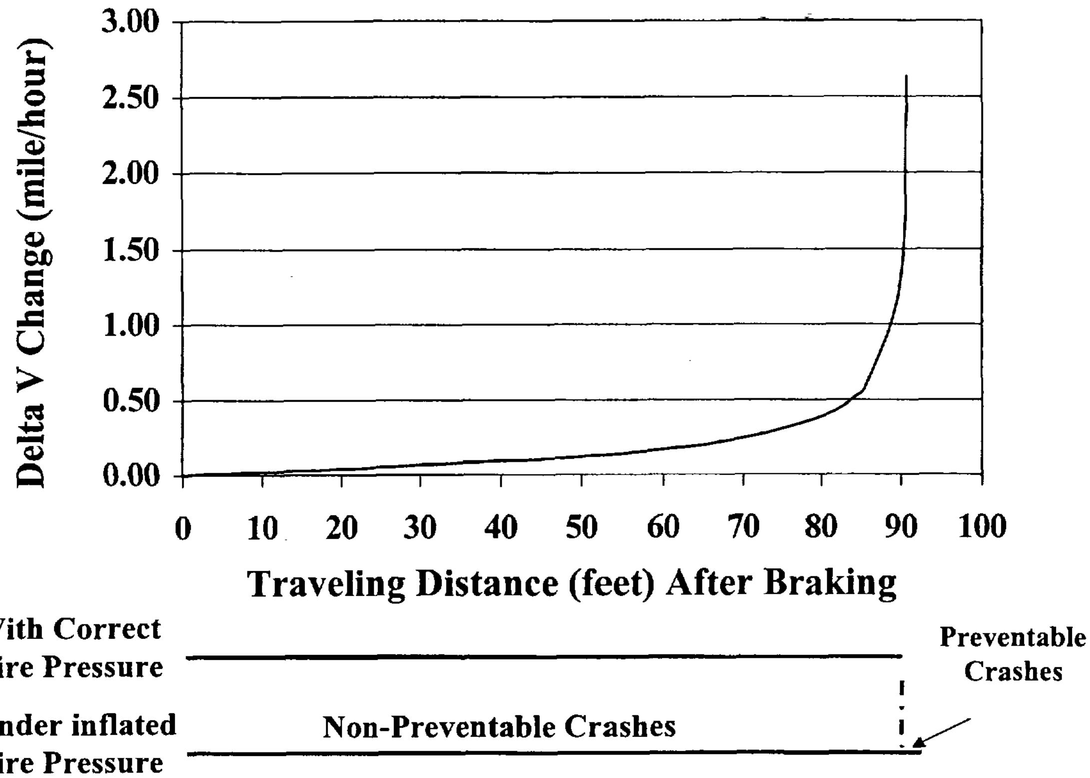


Figure A-3. Change in Delta V by Traveling Distance
Light Trucks/Vans

After calculating the change in delta at the correct stopping distance, the expected change in delta v must be derived to calculate the adjustment ratio.

Expected Change in Delta V

The expected change in delta v is an integral of the product of the probability density function of a non-preventable crash occurrence and the change in delta v at any given traveling distance d. The crash probability density function (Equation 2) is a constant function as described in the previous section. With known correct and incorrect stopping distances and under a constant deceleration condition, the change in delta v function is a function of the traveling distance (Equation 8). Substituting these two equations back to Equation 1, the expected change in delta v function can be rewritten as:

$$EDV = \frac{1}{2}\int_0^{SD_c} u(d)DV(d) \quad dd$$

$$= \frac{1}{2}\left[\int_0^{SD_c} \frac{v_0}{SD_c}\left(\sqrt{1-\frac{d}{SD_i}} - \sqrt{1-\frac{d}{SD_c}}\right)dd\right]$$

$$= \frac{v_0}{2*SD_c}\left(\int_0^{SD_c}\sqrt{1-\frac{d}{SD_i}}dd - \int_0^{SD_c}\sqrt{1-\frac{d}{SD_c}}dd\right)$$

$$= \frac{v_0}{2*SD_c}\left\{\left[\frac{-2*SD_i}{3}\left(1-\frac{d}{SD_i}\right)^{\frac{3}{2}} + c_0\right]_0^{SD_c} + \left[\frac{2*SD_c}{3}\left(1-\frac{d}{SD_c}\right)^{\frac{3}{2}} + c_1\right]_0^{SD_c}\right\}$$

$$= \frac{v_0}{2*SD_c}\left(\frac{-2*SD_i}{3}\left(1-\frac{SD_c}{SD_i}\right)^{\frac{3}{2}} + \frac{2*SD_i}{3} - \frac{2*SD_c}{3}\right)$$

$$= \frac{v_0}{3*SD_c}\left(-SD_i\left(1-\frac{SD_c}{SD_i}\right)^{\frac{3}{2}} + SD_i - SD_c\right) ----(9)$$

Where, c_0 and c_1 are constants.

For passenger cars, the expected change in delta v is:

$$EDV = \frac{66.114}{3*85.273}\left(-86.464*\left(1-\frac{85.273}{86.464}\right)^{\frac{3}{2}} + 86.464 - 85.273\right)$$

= 0.271 feet/second

= 0.185 miles/hour

For light trucks/vans, the expected change in delta v is:

$$EDV = \frac{66.114}{3*90.726}\left(-91.979*\left(1-\frac{90.726}{91.979}\right)^{\frac{3}{2}}+91.979-90.726\right)$$

= 0.269 feet/second

= 0.183 miles/hour

Adjustment Factors

The adjustment factor is the ratio of expected change in delta v and change in delta v at the correct stopping distance, i.e.

$$\text{Adjustment Factor} = \frac{EDV}{DV(SD_c)}$$

For passenger cars, under the following set of conditions:

the initial traveling speed V_0 = 45.078 mile/hour = 66.114 feet/second,

the correct stopping distance SD_c = 85.273 feet, and

the incorrect stopping distance SD_i = 86.464 feet,

EDV = 0.185 mile/hour and DV(85.273)= 2.644 mile/hour.

The adjustment factor is 0.07 (= 0.185/2.644).

For light trucks and vans, under the following set of conditions:

the initial traveling speed V_0 = 45.078 mile/hour = 66.114 feet/second,

the correct stopping distance SD_c = 90.726 feet, and

the incorrect stopping distance SD_i = 91.979 feet,

EDV = 0.183 mile/hour and DV(90.726) = 2.631 mile/hour.

The adjustment factor is 0.07 (= 0.183/2.631).

Sensitivity Study

The sensitivity study examines the variations of the adjustment factors under 12 different scenarios – combinations of three initial traveling speeds (35, 49, and 62 mph), two vehicle types (passenger cars, light trucks/vans), and two roadway conditions (dry, wet). Table A-1 lists the criteria of these 12 scenarios and the associated stopping distances and case weights. Readers can refer to Chapter V for detailed explanations on how the initial traveling speeds, stopping distances, and weights were derived for these 12 scenarios. Table A-1 also lists the calculated change in delta v at the correct stopping distance, the expected change in delta v, and the adjustment factor for each scenario. The adjustment factors range from 6 to 10 percent. It's not surprising that the adjustment factors are smaller for dry pavement roadways. As expected, the overall weighted adjustment factor is about 7 percent which equals to the overall 7 percent.

Table A-1. Adjustment Factors and Related Statistics

Initial Traveling Speed (mile/hour)		Correct Stopping Distance (feet)	Incorrect Stopping Distance (feet)	Change in Delta V at the Correct Stopping Distance (mile/hour)	Expected Change in Delta V (mile/hour)	Case Weights	Adjustment Factor
Passenger Cars, Dry Pavement							
1	35	46.430	46.840	1.639	0.093	0.2920	0.06
2	49	91.097	91.926	2.324	0.135	0.3404	0.06
3	62	142.364	143.671	2.956	0.172	0.1110	0.06
Passenger Cars, Wet Pavement							
4	35	53.389	54.587	2.594	0.223	0.1245	0.09
5	49	114.159	117.045	3.845	0.348	0.0963	0.09
6	62	202.678	208.722	5.276	0.511	0.0359	0.10
Light Trucks/Vans, Dry Pavement							
7	35	49.120	49.551	1.630	0.093	0.2920	0.06
8	49	96.391	97.260	2.315	0.133	0.3404	0.06
9	62	150.704	152.076	2.947	0.170	0.1110	0.06
Light Trucks/Vans, Wet Pavement							
10	35	57.552	58.817	2.566	0.219	0.1245	0.09
11	49	123.065	126.110	3.806	0.341	0.0963	0.09
12	62	218.405	224.748	5.206	0.499	0.0359	0.10