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PRELIMINARY ECONOMIC ASSESSMENT

TIRE PRESSURE
MONITORING SYSTEM
FMVSS No. 138

Office of Regulatory Analysis and Evaluation
Plans and Policy
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Executive Summary

As required by the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act, the agency is proposing to require a Tire Pressure Monitoring System (TPMS) be installed in all passenger cars, multipurpose passenger vehicles, trucks and buses that have a Gross Vehicle Weight Rating of 10,000 pounds or less, effective in November 2003. Two alternatives are examined in this assessment:

Alternative 1 would require that the driver be given a warning when tire pressure is 20 percent or more below the placard pressure for one to four tires.

Alternative 2 would require that the driver be given a warning when tire pressure is 25 percent or more below the placard pressure for one to three tires.

There are two basic types of TPMS, direct measurement systems that have a tire pressure sensor for each tire, and indirect measurement systems that determine tire inflation pressure from wheel speeds. We assume that a direct measurement system would be required to meet Alternative 1.

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 diameter of a tire goes down slightly with low tire pressure. Since the indirect measurement system compares relative wheel speed, it cannot determine when all four tires lose air at about the same rate, thus Alternative 2 would require a warning when one to three tires lose pressure. We assume that vehicles which currently have an ABS system would use an indirect measurement system and vehicles without ABS would use a direct measurement system to meet Alternative 2.

The agency conducted a large study of tire pressure at 336 gasoline stations around the country and estimates that Alternative 1 would result in 38 percent of light vehicle operators being warned of low tire pressure, while Alternative 2 would result in 24 percent of light vehicle operators being warned.

Low tire pressure may have an influence on any crash that involves braking, since low tire pressure can result in reduced stopping distance. The quantified benefits, based on reduced stopping distance, have been estimated using two sets of data. One set of data indicates that benefits would be zero or insignificant. The second set of data indicates that there would be significant benefits from reduced stopping distance. Mid-point estimates from these two sets of data are:

Annual Full Fleet Benefits of TPMS

	Injuries Reduced (All AIS levels)	Fatalities Reduced
Alternative 1	10,635	79
Alternative 2	6,585	49

There are unquantified benefits related to crashes caused by blowouts, stopped vehicles with flat tires, handling characteristics, and hydroplaning. An estimated 23,000 crashes and 535 fatal crashes annually involve blowouts or flat tires. Since the agency does not collect tire pressure during its crash investigations, the agency cannot estimate how many crashes are caused by the influence that low tire inflation has on blowouts, vehicle handling, and hydroplaning. Theory and limited testing show that low tire pressure has a significant impact on all of these.

There are non-quantified costs and benefits that include the extra time it takes to inflate tires more frequently, the cost to replace batteries in some direct measurement systems, potential maintenance costs of TPMS, the property damage savings from avoiding crashes or reducing delta V in non-preventable crashes, and the savings in time and congestion from avoiding crashes.

The estimated consumer cost increase for an average new vehicle would be $66.33 for Alternative 1 and $30.54 for Alternative 2.

The net costs are estimated to be:

Net Costs per Vehicle
(2001 Dollars)

	Vehicle Costs	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Net Costs
Alternative 1	$66.33	$32.22	$11.03	$23.08
Alternative 2	$30.54	$16.40	$5.51	$8.63

The net costs per equivalent life saved are estimated at the 7 percent discount rate to be:

Net Cost per Equivalent Life Saved

Alternative 1	$1.9 million
Alternative 2	$1.1 million

These estimates are derived from the following:

Total Annual Costs for 16 Million Vehicles
(Millions of 2001 Dollars)

	Vehicle Costs	Present Value of Fuel Savings	Present Value of Tread Wear Savings	Net Costs
Alternative 1	$1,061	$516	$176	$369
Alternative 2	$489	$263	$88	$138

Present Discounted Value of Benefits

	Injuries Reduced (All AIS levels)	Fatalities Reduced
Alternative 1	7,038	52
Alternative 2	4,358	32

I. INTRODUCTION

The National Highway Traffic Safety Administration is evaluating a proposed new regulation that would require a tire pressure monitoring system (TPMS) on all passenger cars, light trucks (pickups, vans, and sport utility vehicles), and buses with a gross vehicle weight rating (GVWR) of 10,000 pounds or less (collectively this group is called "passenger vehicles" throughout this assessment). This is in accordance with the TREAD Act (H.R. 5164), **Sec. 13. Tire Pressure Warning**: "Not later than 1 year after the date of the enactment of this Act, the Secretary of Transportation shall complete a rulemaking for a regulation to require a warning system in new motor vehicles to indicate to the operator when a tire is significantly under-inflated. Such requirement shall become effective not later than 2 years after the date of the completion of such rulemaking." This means that the agency must issue a final rule by November 1, 2001 and the effective date would be before November 1, 2003.

II. BACKGROUND and ALTERNATIVES

There are two 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 other than tire pressure. The current ABS-based systems are an indirect measurements system. They measure wheel speed and then compare the variance in wheel speed from one wheel to another.

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 including the spare). Direct measurement systems advantages include: (1) much more 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

The 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 sensor and a pump. The current 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 cost 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 this system include: (1) driver convenience, they only need to worry about their tire inflation when they get 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 or taken off and put back on the rotated tire. These systems have not been installed on any light vehicles, although they have been used on a number of heavy trucks for several years.

Indirect measurement systems

The current indirect measurement system is based on Anti-lock Brakes (ABS). It takes information from the ABS wheel-speed sensors and looks 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 system works by comparing the relative speed of one tire to the other tires on the same vehicle.

The advantages for this system include low cost and 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. Regarding #3 and 4, current ABS systems cannot detect certain conditions of low tire pressure. To meet Alternative 2 requirements, the ABS systems would need to be upgraded. (5) it cannot check the spare tire; (6) the vehicle must be moving; (7) it requires significant time, sometimes hours, to calibrate the system and several minutes, sometimes tens of minutes, to detect a pressure loss; and (8) it 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.

Based on these technologies, NHTSA is proposing two different alternative requirements.

ALTERNATIVES

Alternative 1: Require activation of the tire pressure monitor system (TPMS) when one or more tires fall 20 percent or more below the recommended placard pressure, or as shown in Table II-1 below a minimum pressure activation floor (140 kPa or roughly 20 psi for p-metric tires), whichever is higher.

Alternative 2: Require activation of the TPMS when one, two, or three tires fall 25 percent or more below the recommended placard pressure, or as shown in Table II-1 below a minimum pressure activation floor (140 kPa or roughly 20 psi for p-metric tires), whichever is higher.

Table II-1
LTPM lamp activation floor

Tire type	Maximum Inflation Pressure (kPa)	Maximum Inflation Pressure (psi)	Activation Floor (kPa)	Activation Floor (psi)
P-metric - Standard Load	240, 300, or 350	34.8, 43.5, or 50.8	140	20.3
P-metric – Extra Load	280 or 340	40.6 or 49.3	160	23.2
Load Range C	350	50.8	200	29.0
Load Range D	450	65.3	260	37.7
Load Range E	600	87.0	350	50.8

The activation floor shown in Table II-1 shows the level below or at 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 above. If a vehicle has p-metric tires marked 240, 300, or 350 kPa, it is a standard load tire that will be tested at 20 or 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 20 or 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.

Currently, the lowest P-metric tire recommended placard pressure is 26 psi; thus, in all cases systems meeting Alternative 1's 20 percent below placard requirement would be activated above the 20 psi floor. However, for Alternative 2, the 20 psi floor would come into play for vehicles with a 26 psi placard (26 psi x 0.75 = 19.5 psi).

Rationales

The rationales for these alternatives are:

1. A 140 kPa 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 at 20 psi with a load for 90 minutes on a dynamometer. None of these tires failed. This leads the agency to believe that for safety, in terms of tire failures, warnings provided above that level will allow consumers to fill their tires back up before the tire fails.

   The lowest inflation pressure used in the 2000 Tire & Rim Association Yearbook is 140 kPa 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.

2. For Alternative 1, 20 percent below placard was chosen after considering several factors. First, there was no bright line at which the agency could declare that loss of air pressure definitely becomes a safety issue. The agency did not want to set the level so that the

warnings became a nuisance (the agency believes consumers would consider the warning at a nuisance level at about 10 percent below placard). The nuisance level comes in when consumers are warned too often. For example, a tire may lose air pressure due to cold weather overnight. But this does not necessarily indicate a need to inflate the tire. Frequent notifications for trivial reasons would lead consumers to disregard the warning. Our assessment of current TPMSs leads us to conclude that direct TPMSs can detect 20 percent under-inflation while indirect TPMSs can not.

3. For Alternative 2, the agency considered whether it should propose a level that is 30 percent below placard. The agency looked at the available technology and found that the current indirect measurement systems could not detect 30 percent below placard for all combinations of one to four tires. Many current ABS-systems can determine when one or three tires are 30 percent below the other tires, and can determine certain combinations (but not all combinations) of two tires being low. None can detect when all four tires are at equal under-inflation levels. The agency then used its judgment to estimate how good an indirect ABS-system could perform. We wanted the system to do better, and decided that one, two, or three tires that are 25 percent or more below the placard starting point in our tests was a reasonable goal for these systems.

Analytical Assumptions

1) We assume that a direct measurement system would be required to meet Alternative 1 that requires the TPMS to activate at 20 percent below placard pressure for one to four tires. The current indirect measurement system could not meet this criterion for all four tires since it compares the relative wheel speed of one tire to the other tires.

2) None of the four current indirect measurement systems tested by NHTSA (see Chapter III) could meet Alternative 2. Not all the systems activated the warning when the pressure in one tire was reduced by 25 to 30 percent, nor did they activate the warning when all of the different groups of two tires were low compared to the other two tires. In addition, some pickup truck rear axle configurations have both rear tires using one ABS sensor and cannot individually sense wheel speed. Thus, these pickup trucks are not candidates for meeting the LTPM by using an ABS sensor, without changes that would allow individual wheel sensing. In essence, the agency believes that Alternative 2 will require an improvement in the indirect measurement systems that are currently in the fleet. Comments are requested as to whether such an improvement is economically feasible.

3) For Alternative 2, we assume an indirect measurement system would be provided for vehicles that have ABS-systems currently (about two-thirds of the fleet). For vehicles that don't 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. Comments are requested on whether those pickup trucks with ABS, but only one sensor on the rear axle, would add a direct sensor system rather than change the ABS configuration.

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.

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 manufacturer recommended placard pressure.

The issue addressed is how often drivers would get a warning from a low tire pressure monitoring system. Several scenarios were examined, as shown in Table III-1:

- Assume the driver would be warned anytime one or more tires fell 20%, 25%, or 30% below the placard recommended pressure, assuming a direct measurement system
- Assume the driver would be warned anytime one or more tires fell 6 psi (or 10 psi) below the placard recommended pressure, assuming a direct measurement system

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. For Alternative 1, an average of 38 percent of the passenger car and light truck drivers in the tire pressure survey would get a warning with a direct measurement system that activated at 20 percent or more below the placard pressure.

Table III-2 (a) shows, for example, the distribution of tire pressure when at least one tire is 20 percent or more below placard in terms of whether one, two, three, or all four tires were at least 20 percent below placard. Tables III-2 (b) and (c) show similar results for 25 percent and 30 percent below placard. The upgraded indirect measurement systems that work on relative wheel speed would not be able to pick up when all four tires have lost air at about the same rate.

Table III-3 shows that the tires on the rear axle are more likely to have a larger gap between actual tire pressure and the recommended level on the placard.

Table III-4 provides an analysis of what percent of the drivers would get a warning with an indirect measurement system that compares relative wheel speed of the four wheels. An assumption was made that if wheel speed were measured in all four wheels (an upgrade for some vehicles), then a comparison of wheel speed could be made for all situations except when all four tires lose air at about the same rate. For analytical purposes we used from our tire pressure survey (maximum tire pressure minus the minimum tire pressure) divided by the maximum tire pressure to get an average reduction. The maximum tire pressure was used as the denominator since supposedly we are starting at placard tire pressure and decreasing tire pressure from there. Since the indirect systems use a relative measurement, it cannot tell whether the tire pressure is over placard or under placard. For the benefit analyses done in this assessment, cases were not considered in which there were a relative differential in tire pressure of 25 percent or more, yet none of the tires were below placard. Thus, for example, if placard pressure was 30 psi, and the four tire pressures were 30, 30, 30, and 60 psi, this case was not included in the benefit calculations. For Alternative 2, an average of 24 percent of the passenger car and light truck drivers in the tire pressure survey would get a warning with an indirect measurement system that activated at 25 percent or more differential in wheel speed.

The current indirect measurement systems (which can determine relative differential in wheel speed of about 30%), give a warning less than 19 percent of the time. For this scenario, we use “less than 19 percent of the time”, since the current systems do not always provide a warning when two tires are high and two tires are low in pressure. Without knowing the various algorithms used by the manufacturers, this estimate could not be pinpointed closer.

In summary, based on the tire pressure survey the agency conducted:

Alternative 1: a direct measurement system would result in 38 percent of the light vehicles operators being notified of low tire pressure.

Alternative 2: an upgraded indirect ABS-based measurement system would result in 24 percent of the light vehicles operators being notified of low tire pressure. The current indirect ABS-based measurement systems being used today would result in less than 19 percent of the light vehicles operators being notified of low tire pressure. [Note that low tire pressure is defined differently for each system.]

Table III-1
Percent of Vehicles That Would Get a Warning
Assuming a Direct Measurement System

	Passenger Cars	Light Trucks
20% or more Below Placard	36%	40%
25% or more Below Placard	26%	29%
30% or more Below Placard	20%	20%
6 psi or more Below Placard	39%	46%
10 psi or more Below Placard	20%	25%

Table III-2 (a)
Distribution of the Number of Tires on Vehicles
That Have One or More Tires that are
20% or more Below Placard

Number of Tires 20% or more Below Placard	Passenger Cars	Percent	Light Trucks	Percent
1	994	46.5%	574	36.7%
2	548	25.7	440	28.1
3	275	12.9	223	14.3
4	319	14.9	327	20.9
Total	2,136	100%	1,564	100%

Table III-2 (b)
Distribution of the Number of Tires on Vehicles
That Have One or More Tires that are
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%

Table III-2 (c)
Distribution of the Number of Tires on Vehicles That Have One or More Tires that are 30% or more Below Placard

Number of Tires 30% or more Below Placard	Passenger Cars	Percent	Light Trucks	Percent
1	793	66.1%	454	57.6%
2	266	22.2	199	25.2
3	88	7.4	72	9.1
4	52	4.3	64	8.1
Total	1,199	100%	789	100%

Table III-3
Front versus Rear Axle Differences
Vehicles with one or more tires below placard

	Passenger Car Front Axle	Passenger Car Rear Axle	LT Front Axle	LT Rear Axle
20% or more Below Placard	20%	30%	23%	35%
30% or more Below Placard	8%	16%	9%	17%

Table III-4
Percent of Vehicles That Would Get a Warning Assuming an Indirect Measurement System

	Passenger Cars	Light Trucks
25% Differential	27%	21%
30% Differential	22%	16%

TPMS Test Results

The agency tested six direct measurement systems 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 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, the typical advisory level is given at 20 percent under placard pressure, while 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-5
Direct measurement systems
Driver information provided at (%) below placard

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 to determine when they provided driver information. The warning thresholds were determined by slowly leaking out air 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-6 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.

Table III-6
Indirect measurement systems
Driver warning provided at (%) below placard

Load	Axle	System A	System B	System C	System D	Ave. of 3
LLVW	Front	-31.4%	No Warning	-46.0%	-48.3%	-41.9%
LLVW	Rear	-24.7%	No Warning	-48.9%	-32.2%	-35.3%
GVWR	Front	-26.4%	No Warning	-23.3%	-41.4%	-30.4%
GVWR	Rear	-17.8%	No Warning	-31.8%	-37.7%	-29.1%

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. Two sets of data are available from different sources – Goodyear Tire and Rubber Company and NHTSA's Vehicle Research and Test Center (VRTC). The information provided by these sources do not lead to the same conclusions.

Table III-7 shows data provided by Goodyear on an ABS 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-7
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-8 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-8
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 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 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.

IV. TARGET POPULATION

Safety Problems associated with Low Tire Pressure

There is no direct evidence in NHTSA's crash files 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. 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 is more likely to cause loss of control or a skid initially. Skids can lead to tripping and then a rollover.

The 1977 Indiana Tri-level study associated low tire pressure with loss of control, on both wet and dry pavements. They never identified it as a "definite" cause of any crash, but did identify it as a "probable" cause of the crash in 1.4% of the 2258 crash investigations.[1] Note that more than one "probable cause" could be assigned to a crash. However, 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 1977 results may not be applicable in today's tire environment.

Low tire pressure probably causes crashes indirectly. Such tires wear prematurely and unevenly, making them more vulnerable to belt failure, punctures and skidding. Severe under-inflation coupled with an emergency steering maneuver could cause the tire to "de-bead," i.e., separate from the rim, which could "trip" the vehicle and cause it to roll over.

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[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

We will only be able to identify these indirect crashes after we can associate pre-crash tire pressures with crash types.

The target population for general tire-related caused crashes

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 that 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 the following information: 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-

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No. DOT HS 034-3-535). DOT HS 805 099. Washington, DC: U.S. Department of Transportation, NHTSA.

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%

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).

Geographic and Seasonal Effects

The FARS data were further examined to determine whether heat is a factor in tire problems (see Table IV-2). 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-2
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-3.

Table IV-3
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

Human Factors Issues

There are two human factors issues involved with Tire Pressure Monitoring Systems (TMPS). The first is what information is presented to the driver and how it is presented, and the second is whether the warning makes the driver pull into the next service area to check the pressure.

Regarding the information that the driver sees, the agency is proposing alternative display icons for comment. Some testing has been done on the understandability of these icons. The indirect measurement systems can only provide a warning light that tire pressure is low. 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 that manufacturers of direct measurement systems will display individual tire pressures because it will be helpful to drivers in terms of fuel economy, tread wear and safety.

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 underinflation may start to rely on the TPMS to indicate underinflation, rather than checking their tires frequently and filling them up whenever they were below the placard level. We believe this would happen more often for an indirect system, where only a warning light comes on when tire pressure goes below a specified threshold, rather than a direct system 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 no information that would help it estimate what percent of drivers would put to use the information on individual tire pressures.

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 TMPS telltale, which is amber or yellow, to be 100 percent. We have found no data with which we can predict compliance levels. We assume more than 50 percent of drivers will want to make sure they don’t get a flat tire and be stranded somewhere, so they will fill the low tire(s). Given just a telltale, some drivers will try to just fill one low tire. Given a reading of tire pressure on all four tires with a direct measurement system, the driver will know which tires are low and need to be filled.

For this analysis, we will assume that the equivalent of 80 percent of the drivers will react to a direct measurement system that gives them a continuous readout of tire pressure and to a continuous warning light when their tires get 20 percent below the placard and will inflate their tires the next time they refuel, given the gas station has the equipment. This takes into account the group that will fill their tires more frequently because they have continuous information, than those who would just fill their tires when given a warning. We assume that with an indirect measurement system 60 percent of the drivers will inflate their tires back up to the placard level when given a warning. Thus, for Alternative 1, we will be using 80 percent, and for Alternative 2, we will be using the weighted average of 66.6 percent (80% * 0.33 + 60% * .67).

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. An estimate will be made of the impact of TPMS on stopping distance, but other benefits from improved maneuverability cannot yet be quantified.

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. 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 are due to test track surface characteristics. The NHTSA track surface is considered to be extremely 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 be 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. On the other hand, crashes are more likely to occur under more hazardous conditions, which may mean the Goodyear data are less biased when applied to the actual crash involved population. Generally speaking, the Goodyear test results imply a significant impact on stopping distance from proper tire pressure, while the NHTSA tests imply these impacts would be minor or nonexistent at lesser water depths. This analysis will estimate stopping distance impacts using the Goodyear data to establish an upper range of potential benefits. A lower range of no benefit is implied by the current NHTSA test results.

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+, MAIS3+, MAIS4+, 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,

$I_{i,j}$ = 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-1 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-1
Injury Probability Risk Curve Formula

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

(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., $f_i = \frac{100}{\sum_j p_{i,j}}$ where j = 0…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-1. However, the general shape of each curve does not alter significantly. Table V-2 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-2
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-2

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- 3 for passenger cars and Table V-4 for LTVs. Table V-5 summarizes the target populations across all passenger vehicles.

Table V-3
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-4
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-5
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 (discussed in Chapter III) indicate that 74 percent of the on-road fleet has at least one tire that is under-inflated. For these vehicles, notification of this under-inflation would not be given until the system is triggered. For example, under Alternative 1, it is estimated that direct TPMS will trigger at roughly 20% below placard pressure, or roughly 6 psi for passenger cars and 7 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. Data from NHTSA’s tire pressure survey indicate that 36 percent of passenger cars and 40 percent of LTVs have at least one tire that is 20 percent or more below recommended placard pressure. However, in order to experience this reduction, the driver must respond to the warning. NHTSA has no data to indicate what portion of drivers will take action in response to this warning. For this analysis, it will be assumed that 80 percent would respond to direct systems. Eighty percent is chosen to represent a level that reflects the heightened consumer awareness that would come with systems that constantly monitor and display tire pressure levels. A lower response rate of 60 percent is assumed for indirect systems, which only provide information when the systems reach the warning level.

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 in a later section of this analysis. The results indicate that the existing passenger car fleet would, on average, experience a stopping distance of 137 feet, while the crash-involved LTV fleet experienced an average stopping distance of 131.5 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 132.1 feet, while for LTVs it would be 127.3 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 (137-132.1)/137 or 3.6 percent of all current crashes. For LTVs, this portion is (131.5-127.3)/131.5 or 3.2 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 Alternative 1 in Table V-6 . The combined results for all vehicles under Alternative 1 are shown in Table V-7, and for Alternative 2 in Table V-8. 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. An adjustment factor of .968 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.

The benefits from preventable crashes, shown in Tables V-6, 7, and 8, 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. Comments are requested on this assumption.

Table V-6
Potential Benefits from Preventable Crashes,
Passenger Cars Adjusted for Properly Inflated Vehicles,
20% Notification Level, 80% Response Rate, and Overlap

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	856	-756	-68	-31	-3	-2	-4
36-50mph	541	-682	-69	-30	-2	-2	-4
51+mph	222	-236	-24	-11	-1	-1	-1
DRY							
0-35mph	1959	-1806	-170	-76	-7	-4	-10
36-50mph	2188	-2189	-205	-91	-9	-5	-13
51+mph	584	-739	-137	-52	-6	-4	-10
Total	6349	-6407	-672	-291	-27	-17	-41

NOTE: Negative signs indicate reductions in injury levels.

Table V-7

Potential Benefits from Preventable Crashes, All Passenger Vehicles
Adjusted for Properly Inflated Vehicles,
Delta-V Distribution, 80% Response Rate, and Overlap

Alternative 1

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	1086	-1024	-94	-42	-4	-2	-5
36-50mph	882	-1100	-105	-47	-4	-3	-6
51+mph	303	-332	-39	-17	-2	-1	-3
DRY							
0-35mph	2932	-2783	-281	-123	-11	-7	-17
36-50mph	3047	-3164	-323	-140	-13	-8	-22
51+mph	1019	-1241	-230	-89	-10	-7	-17
Total	9268	-9645	-1072	-459	-43	-29	-69

NOTE: Negative signs indicate reductions in injury levels.

Table V-8

Potential Benefits from Preventable Crashes,
All Passenger Vehicles Adjusted for Properly Inflated Vehicles,
Delta-V Distribution, Response Rate, and Overlap

Alternative 2

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	724	-672	-61	-28	-2	-1	-3
36-50mph	554	-693	-67	-30	-2	-2	-4
51+mph	198	-216	-25	-11	-1	-1	-2
DRY							
0-35mph	1877	-1770	-176	-78	-7	-5	-10
36-50mph	1984	-2042	-204	-89	-8	-5	-14
51+mph	631	-774	-143	-55	-6	-5	-10
Total	5968	-6167	-676	-290	-27	-18	-43

NOTE: Negative signs indicate reductions in injury levels.

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, 3.6 percent of braking passenger cars and 3.2 percent of braking trucks could have avoided crashes with proper tire inflation. The remaining 96.4 percent of passenger car crashes and 96.8 percent of 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-2, 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. The Goodyear Tire and Rubber Company submitted a model they developed by testing tires under various circumstances 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 models are as follows:

$$Ms = 0.2339537+(0.0034537*ip)+(0.0003625*Vi)-(0.000049*Vi^2)$$

$$Mp = 0.4374907+(0.0024907*ip)+(0.003075*Vi)-(0.000095*Vi^2)$$

Where:

Ms = Mu slide value

Mp = Mu peak value

ip = inflation pressure (psi)

V_i = initial vehicle speed (mph)

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 the companies OEM customers). In order to relate them to real world surfaces, predicted values from the formulas were compared to actual test results on 2 surface types (asphalt and concrete). From this, a surface adjustment factor was obtained for each surface. For asphalt, the factor was 1.22. For Concrete, it was 2.00. Although most road surfaces are asphalt, the test surfaces tend to be slicker than roads that have experienced wear. NHTSA and Goodyear engineers both felt that the frictional qualities of the concrete test surface are most like those encountered on actual roads. Therefore, calculations of stopping distance will be based on the Concrete surface adjustment factor. The formulae thus become:

$$Ms = (0.2339537+(0.0034537*ip)+(0.0003625*Vi)-(0.000049*Vi^2))/2$$

$$Mp = (0.4374907+(0.0024907*ip)+(0.003075*Vi)-(0.000095*Vi^2))/2$$

The models provided by Goodyear were developed using wet traction test data, and are thus appropriate for wet surfaces only. Goodyear tested the tires with .05” of water on the track surface. 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. On the other hand, crashes are more likely to occur under more hazardous conditions, which may mean the Goodyear data are less biased when applied to the actual crash involved population With these caveats, this analysis assumes the data to be representative of the crash involved population on wet surfaces. To adjust for dry surfaces, NHTSA used data provided by Goodyear to develop models that predict adjustment ratios for dry surface conditions. The data on which these models are based is listed in Table V-9. The models take the following form:

$DFs = -0.022778*ip+.0485*Vi+1.437222$

$DFp = -0.0075*ip+0.03225*Vi+1.0575$

Where:

DFs = slide dry surface adjustment factor

DFp = peak dry surface adjustment factor

The formula for Mu peak and slide on dry surfaces thus become:

$Ms = ((0.2339537+(0.0034537*ip)+(0.0003625*Vi)-(0.000049*Vi^2))/2)*DFs$

$Mp = ((0.4374907+(0.0024907*ip)+(0.003075*Vi)-(0.000095*Vi^2))/2)*DFp$

Table V-9
Measured Mu Values by Surface Condition,
Speed and Inflation Pressure

	Dry		Wet		Ratio Dry/Wet	
psi,speed	Peak	Slide	Peak	Slide	Peak	Slide
35,40	0.949	0.66	0.454	0.244	2.09	2.70
35,60	0.936	0.646	0.343	0.182	2.73	3.55
17,40	0.995	0.7	0.448	0.234	2.22	2.99
35,40	1.036	0.7	0.499	0.285	2.08	2.46

Source: Goodyear Tire and Rubber Co.

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

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:

$$\text{DELTA-V} = (V(d)*3600/5280)/2$$

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 20% or 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 each alternative. For Alternative 1, these weights were drawn from the population that had at least one tire 20% or more under-inflated. For Alternative 2, these weights were drawn from the population that had at least one tire 25% or more under-inflated. In the case of Anti-lock Brake systems under Alternative 2, the population was also restricted to cases where the maximum inflation pressure of any tire exceeded the minimum pressure by at least 25%. The distribution of each level of under-inflation is shown in Table V-10 for both Alternatives.

Table V-10
Percent of Vehicles Under-inflated Within Notification Levels

Alternative 1			Alternative 2			
20% or more below Placard pressure			25% or more below Placard pressure			
			Anti-lock Brakes		Non-Anti-lock Brakes	
Under-Inflated	Percent Under-Inflated		Percent Under-Inflated		Percent Under-Inflated	
Pressure (psi)	PCs	LTVs	PCs	LTVs	PCs	LTVs
-1	3.5%	1.2%	19.0%	14.6%	0.2%	0.2%
-2	8.8%	5.4%	13.1%	12.0%	7.4%	4.9%
-3	13.1%	8.1%	14.4%	10.4%	11.2%	6.0%
-4	13.5%	11.5%	12.0%	9.6%	11.8%	8.2%
-5	15.3%	11.7%	10.5%	10.0%	13.7%	8.4%
-6	12.2%	14.8%	7.5%	10.0%	12.3%	13.1%
-7	10.3%	11.1%	6.7%	6.7%	12.2%	11.2%
-8	7.4%	8.8%	4.9%	6.6%	9.7%	11.2%
-9	5.4%	6.5%	3.7%	4.0%	7.4%	8.5%
-10	3.5%	5.6%	2.2%	4.0%	4.8%	7.6%
-11	2.3%	3.8%	1.6%	3.6%	3.1%	5.1%
-12	1.8%	2.6%	1.8%	2.2%	2.4%	3.5%
-13	0.9%	1.6%	1.1%	1.3%	1.3%	2.2%
-14	0.5%	1.2%	0.4%	1.2%	0.6%	1.6%
-15	0.6%	0.7%	0.4%	0.4%	0.8%	0.9%
-16	0.3%	1.2%	0.3%	0.7%	0.4%	1.7%
-17	0.1%	0.7%	0.2%	0.4%	0.2%	1.0%
-18	0.1%	0.5%	0.1%	0.1%	0.1%	0.7%
-19	0.0%	0.3%	0.0%	0.1%	0.0%	0.4%
-20	0.1%	0.3%	0.1%	0.2%	0.1%	0.4%
-21	0.1%	0.3%	0.0%	0.2%	0.1%	0.4%
-22	0.1%	0.2%	0.1%	0.1%	0.1%	0.3%
-23	0.0%	0.3%	0.0%	0.4%	0.0%	0.4%
-24	0.1%	0.3%	0.1%	0.1%	0.1%	0.4%
-25	0.0%	0.2%	0.0%	0.1%	0.0%	0.3%
-26	0.1%	0.1%	0.0%	0.1%	0.1%	0.2%
-27	0.0%	0.2%	0.0%	0.1%	0.0%	0.3%
-28	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%
-29	0.1%	1.0%	0.0%	0.7%	0.1%	1.3%
Total	100.0%	100.0%	100.0%	100.0%	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 was assumed. The rates of under-inflation in Table V-10 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-11 for each passenger car and LTV target population category for 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. Similar results are summarized for Alternative 2 in Table V-12. 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. For Alternative 1, this analysis assumes a set point of 20 percent below the placard pressure, or 6 psi based on the assumption of a 30 psi recommended pressure. Benefits would only accrue to those tires that are more than 6 psi beneath their recommended pressure. For LTVs, benefits would accrue for those tires that are more than 7 psi beneath their recommended pressure. Alternative 2 assumes a set point of 25% below placard for non-anti-lock brake systems and this results in higher average delta-V changes for these systems under Alternative 2 than Alternative 1, due to the higher level of potential improvement within this more limited population of vehicles. However, for vehicles with anti-lock brakes, the systems would only operate in cases where the highest tire pressure exceeded the lowest tire pressure by 25% or more, and this less rigorous level of notification results in a lower average delta-V change under Alternative 2 than under Alternative 1.

Table V-11
Weighted Average Reductions In Delta-V from Improved Tire Inflation Pressure

Alternative 1

		Anti-lock	Non-Anti-lock	Combined
Passenger Cars				
Wet Pavement				
	0-35mph	2.836	4.399	3.352
	36-50mph	4.273	6.806	5.109
	51+mph	6.135	10.132	7.454
Dry Pavement				
	0-35mph	1.424	2.325	1.721
	36-50mph	2.953	5.032	3.639
	51+mph	4.978	8.707	6.208
LTVs:				
		Anti-lock	Non-Anti-lock	Combined
Wet Pavement				
	0-35mph	3.156	4.813	3.703
	36-50mph	4.745	7.400	5.621
	51+mph	6.785	10.877	8.136
Dry Pavement				
	0-35mph	1.499	2.224	1.738
	36-50mph	3.218	5.268	3.895
	51+mph	5.043	9.176	6.407

Table V-12
Weighted Average Reductions In Delta-V from Improved Tire Inflation Pressure

Alternative 2

		Anti-lock	Non-Anti-lock	Combined
Passenger Cars:				
Wet Pavement				
	0-35mph	2.457	4.681	3.191
	36-50mph	3.701	7.242	4.870
	51+mph	5.314	10.782	7.118
Dry Pavement				
	0-35mph	1.225	2.499	1.646
	36-50mph	2.551	5.377	3.484
	51+mph	4.304	9.289	5.949
LTVs:				
		Anti-lock	Non-Anti-lock	Combined
Wet Pavement				
	0-35mph	2.711	5.125	3.507
	36-50mph	4.076	7.880	5.331
	51+mph	5.829	11.581	7.727
Dry Pavement				
	0-35mph	1.275	2.420	1.653
	36-50mph	2.754	5.650	3.710
	51+mph	4.322	9.812	6.134

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 Tables V-11 and V-12. Functionally, 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-13 and V-14. Note that the revised distribution shown in Table V-14 represents a whole number delta-V change (in this case, 8 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-15. Table V-15 summarizes the results for all scenarios for passenger cars under Alternative 1.

Adjustments to Non-Preventable Crash Safety Benefits

A number of adjustments must be made to the benefit estimates in Table V-15. 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 would be about 11 percent of those based on maximum impact for passenger cars, and 10 percent for LTVs.

Table V-13
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	274	58	2	2	0	0	0	337
5	68	19	1	1	0	0	0	89
6	351	131	5	4	0	0	0	492
7	900	423	18	12	1	0	1	1356
8	4065	2360	99	73	7	0	7	6610
9	3678	2559	129	78	0	6	6	6463
10	1088	902	50	27	2	2	2	2073
11	3802	3715	221	118	8	8	8	7887
12	1341	1520	103	48	6	0	6	3028
13	2947	3864	284	146	7	7	15	7278
14	539	808	67	32	3	1	3	1453
15	715	1214	116	51	4	2	6	2108
16	516	983	108	43	5	2	5	1664
17	1142	2438	307	117	12	8	12	4037
18	0	0	0	0	0	0	0	0
19	138	361	59	22	2	1	3	587
20	79	226	43	15	1	1	2	368
21	259	806	177	59	7	4	8	1321
22	157	532	136	44	4	4	6	885
23	7	24	7	2	0	0	0	41
24	1	2	1	0	0	0	0	4
25	16	66	26	8	1	1	1	120
26	38	158	73	23	2	2	4	300
27	29	128	69	22	2	2	4	256
28	2	7	4	1	0	0	0	14
29	50	227	166	52	6	5	11	517
30	0	0	0	0	0	0	0	0
Etc.								
Total	22209	23586	2391	1064	94	70	146	49591

Table V-14
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
-7	0	0	0	0	0	0	0	0
-6	0	0	0	0	0	0	0	0
-5	0	0	0	0	0	0	0	0
-4	337	0	0	0	0	0	0	337
-3	89	0	0	0	0	0	0	89
-2	492	0	0	0	0	0	0	492
-1	1356	0	0	0	0	0	0	1356
0	6610	0	0	0	0	0	0	6610
1	6179	226	26	19	6	0	0	6463
2	1887	166	8	8	0	2	0	2073
3	6807	986	39	39	0	8	0	7887
4	2462	521	21	21	0	3	0	3028
5	5553	1594	65	51	0	0	7	7278
6	1036	387	15	12	1	0	1	1453
7	1400	658	27	19	2	0	2	2108
8	1023	594	25	18	2	0	2	1664
9	2297	1599	81	48	0	4	4	4037
10	0	0	0	0	0	0	0	0
11	283	276	16	9	1	1	1	587
12	163	185	13	6	1	0	1	368
13	535	701	52	26	1	1	3	1321
14	328	492	41	19	2	1	2	885
15	14	24	2	1	0	0	0	41
16	1	2	0	0	0	0	0	4
17	34	72	9	3	0	0	0	120
18	77	183	26	10	1	1	1	300
19	60	158	26	9	1	1	1	256
20	3	9	2	1	0	0	0	14
21	101	315	69	23	3	2	3	517
22	0	0	0	0	0	0	0	0
23	4	13	4	1	0	0	0	23
24	9	34	12	4	0	0	1	60
25	0	0	0	0	0	0	0	0
Etc.								
Total	39153	9253	673	386	26	28	40	49591
Difference	16944	-14333	-1719	-678	-68	-43	-106	0

Table V-15
Estimated Passenger Car Stopping Distance Impacts
Alternative 1, Unadjusted

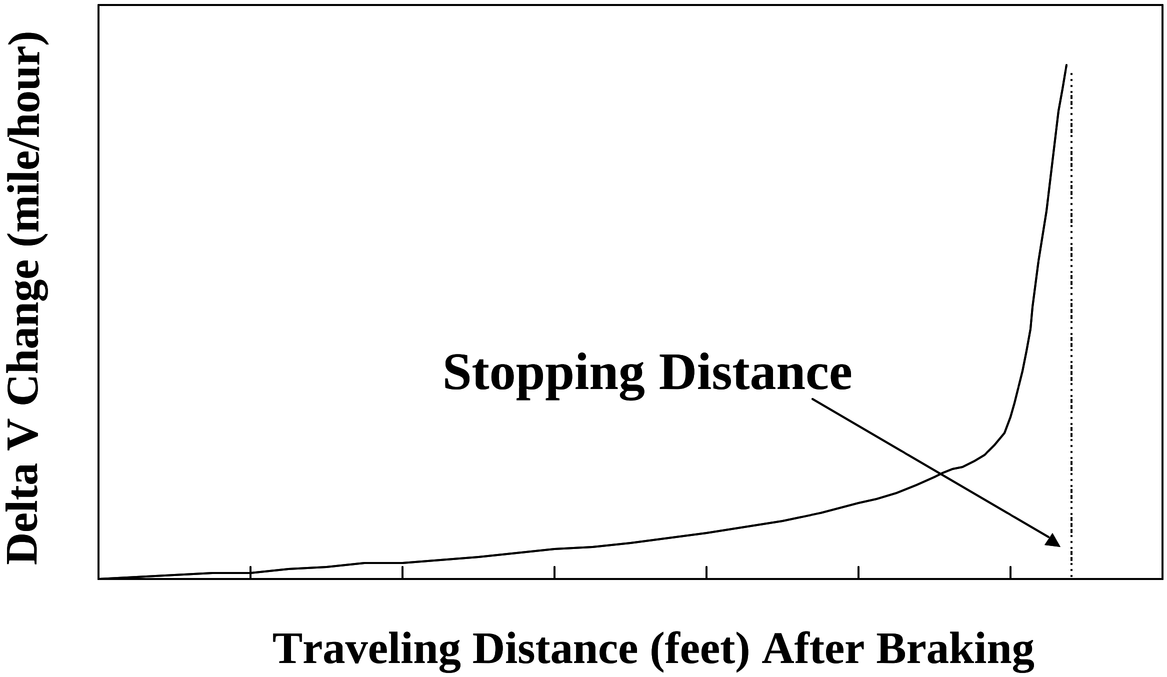
	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	24292	-20158	-2825	-1003	-117	-38	-155
36-50mph	27196	-21495	-3908	-1352	-105	-92	-198
51+mph	15759	-13277	-1644	-636	-61	-39	-102
DRY							
0-35mph	28148	-22352	-3984	-1339	-149	-90	-191
36-50mph	70450	-57226	-9097	-3062	-382	-148	-518
51+mph	35016	-24082	-7303	-2531	-314	-238	-571
Total	200860	-158590	-28761	-9923	-1128	-645	-1734

Braking Distance Distribution

Table V-15 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-1 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-1

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 11 percent of those based on maximum impact for passenger cars and 10 percent 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 under Alternative 1, only 36 percent of passenger cars and 40 percent of light trucks would potentially benefit from a TPMS. Under Alternative 2, 27 percent of passenger cars with anti-lock brakes, 26 percent of passenger cars without anti-lock brakes, 21 percent of light trucks with anti-lock brakes, and 29 percent of LTVs without anti-lock brakes would potentially benefit from a TPMS.

Driver Response

Table V-15 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. These rates vary for each alternative. For direct systems, a response rate of 80 percent is assumed. Eighty percent is chosen to represent a level that reflects the heightened consumer awareness that would come with systems that constantly monitor and display tire pressure levels. A lower response rate of 60 percent is assumed for indirect systems, which only provide information when the systems reach the set point. Since Alternative 1 involves only direct systems, the factor for that alternative is 80 percent. Alternative 2 involves both direct systems on vehicles with conventional brakes, and indirect systems on vehicles with anti-lock brakes. A weighted average of the two systems, 66.6%, was used for Alternative 2.

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.

The above 4 adjustments were accomplished by multiplying the results in Table 15 by factors of .11, .36, .80, and .9685. Similar adjustments were made for each vehicle type and Alternative. Table V-16 summarizes the total adjusted non-preventable crash benefits for passenger cars under Alternative 1. Table V-17 summarizes the benefits from non-preventable crashes under Alternative 1 for both passenger cars and LTVs. Table V-18 summarizes total benefits for all crashes and vehicle types under Alternative 1. Table V-19 summarizes total safety benefits for all crashes and vehicle types under Alternative 2. The results indicate a potential safety impact under Alternative 1 of 158 fatalities eliminated and roughly 21,000 nonfatal injuries prevented or reduced in severity from improved stopping distance. Under Alternative 2, an estimated 97 fatalities and 13,000 nonfatal injuries would be prevented or reduced in severity. Alternative 1 thus offers benefits that are potentially 60% higher than Alternative 2.

These estimates represent the upper bound of results based on the variety of test results currently available. As previously mentioned, other test data from NHTSA's VRTC indicate that stopping distance impacts may be insignificant. A lower range estimate of no impact is implied by the VRTC test results. Neither of these estimates can be considered to be a likely result because both are derived from test data that may be inadequate to represent real world crash situations. In Chapter III, the results from both Goodyear and VRTC tests are discussed. In tests conducted by Goodyear, 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 are due to test track surface characteristics. Moreover, the wet surface tests were conducted on a surface that was only sprayed with water. Given the unworn condition of the track, these tests may not have properly represented the slick conditions that result when road surfaces become wet. The Goodyear tests may also be biased. 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. On the other hand, crashes are more likely to occur under more hazardous conditions, which may mean the Goodyear data are less biased when applied to the actual crash involved population. Still, it is likely that the Goodyear tests represent a more extreme condition than would be expected under most wet driving circumstances. Thus, it is likely that the Goodyear tests produce estimates that overstate the impact of proper tire inflation pressure, while the VRTC tests produce estimates that understate these impacts. Although NHTSA is confident that the impacts lie within this range, there is no data to determine exactly where within this range the most likely impacts are. Therefore, the “best estimate” of impacts is assumed to be an average of the upper and lower estimate. These results are summarized in Tables V-20 and 21 below.

Table V-16

Estimated Passenger Car Stopping Distance Impacts
Adjusted for Properly Inflated Vehicles,
Delta-V Distribution, 80% Response Rate, and Overlap

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	745	-619	-87	-31	-4	-1	-5
36-50mph	834	-660	-120	-41	-3	-3	-6
51+mph	484	-407	-50	-20	-2	-1	-3
DRY							
0-35mph	864	-686	-122	-41	-5	-3	-6
36-50mph	2162	-1756	-279	-94	-12	-5	-16
51+mph	1074	-739	-224	-78	-10	-7	-18
Total	6163	-4866	-883	-304	-35	-20	-53

Table V-17
Estimated Non-Preventable Crash Stopping Distance Impacts, All Passenger Vehicles Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 80% Response Rate, and Overlap

Alternative 1

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	997	-818	-123	-43	-5	-2	-6
36-50mph	1531	-1243	-196	-71	-5	-5	-10
51+mph	572	-469	-68	-25	-3	-2	-5
DRY							
0-35mph	2610	-2110	-339	-121	-13	-7	-20
36-50mph	3123	-2484	-437	-148	-17	-9	-26
51+mph	1281	-869	-273	-95	-13	-9	-22
Total	10113	-7992	-1435	-504	-56	-34	-89

Table V-18
Total Estimated Stopping Distance Impacts, All Passenger Vehicles Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 80% Response Rate, and Overlap

Alternative 1

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	2083	-1842	-216	-86	-9	-4	-11
36-50mph	2413	-2343	-301	-118	-8	-8	-15
51+mph	875	-802	-107	-42	-4	-3	-9
DRY							
0-35mph	5541	-4893	-620	-244	-25	-14	-36
36-50mph	6169	-5648	-760	-288	-30	-17	-48
51+mph	2300	-2109	-503	-184	-22	-17	-39
Total	19381	-17637	-2507	-963	-99	-63	-158

Table V-19
Total Estimated Stopping Distance Impacts, All Passenger Vehicles Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 67% Response Rate, and Overlap

Alternative 2

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	1346	-1182	-138	-55	-6	-3	-7
36-50mph	1446	-1409	-186	-72	-5	-5	-10
51+mph	569	-521	-68	-27	-3	-2	-5
DRY							
0-35mph	3288	-2905	-364	-144	-14	-8	-21
36-50mph	3906	-3575	-471	-179	-19	-10	-29
51+mph	1460	-1336	-322	-117	-14	-11	-25
Total	12014	-10929	-1548	-594	-61	-38	-97

Table V-20

Mid-Point Estimate Total Stopping Distance Impacts, All Passenger Vehicles Adjusted for Properly Inflated Vehicles, Delta-V Distribution, 80% Response Rate, and Overlap

Alternative 1

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	1041	-921	-108	-43	-4	-2	-6
36-50mph	1206	-1172	-150	-59	-4	-4	-8
51+mph	438	-401	-53	-21	-2	-2	-4
DRY							
0-35mph	2771	-2446	-310	-122	-12	-7	-18
36-50mph	3085	-2824	-380	-144	-15	-8	-24
51+mph	1150	-1055	-251	-92	-11	-8	-19
Total	9690	-8818	-1253	-481	-49	-31	-79

Table V-21

Mid-Point Estimate Total Stopping Distance Impacts,
All Passenger Vehicles Adjusted for Properly Inflated Vehicles,
Delta-V Distribution, 67% Response Rate, and Overlap

Alternative 2

	MAIS0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
WET							
0-35mph	673	-591	-69	-27	-3	-1	-4
36-50mph	723	-705	-93	-36	-3	-2	-5
51+mph	284	-261	-34	-13	-1	-1	-3
DRY							
0-35mph	1644	-1453	-182	-72	-7	-4	-10
36-50mph	1953	-1788	-236	-89	-10	-5	-15
51+mph	730	-668	-161	-59	-7	-5	-12
Total	6007	-5464	-774	-297	-31	-19	-49

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). More recent data provided by Goodyear indicates that fuel efficiency is reduced by one percent for every 2.96 psi, fairly close to the 1978 estimate.

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 under Alternative 1 at 24 psi (20 percent below placard), no benefits are

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

assumed for those vehicles that have tires with lowest pressure above 24 psi. For Alternative 1 and 2, 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-22 provides the average under-inflation and the percentage of the fleet that would get a warning by the TPMS by alternative.

Table V-22

Analysis of Fleet Tire Pressure Survey

	Passenger Cars		Light Trucks	
	Average psi below placard of those vehicles warned	Percent of Fleet Affected	Average psi below placard of those vehicles warned	Percent of Fleet Affected
Alternative 1	6.1 psi	36%	7.7 psi	40%
Alternative 2 Direct Measurement System	6.8 psi	26%	8.7 psi	29%
Alternative 2 Indirect Measurement - ABS-based System	4.9 psi	27%	6.1 psi	21%

Tables V-23 and V-24 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. Year 1 for these gasoline prices is estimated to be 2004, when the TPMS requirements

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[2] DOE Energy Information Administration, Annual Energy Outlook 2001, Table A3, Energy Prices by Sector.

will be in place. Obviously, these gasoline prices are much lower than the current prices at the pump ($1.70 in May 2001, or $1.32 excluding taxes). However, the projections are for gasoline prices to steadily decline from 2001 through about 2005 when they will level off.

Table V-23

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	0.96	0.9667
2	12,989	0.988	12,833.1	0.95	0.9035
3	12,466	0.978	12,191.7	0.96	0.8444
4	11,964	0.962	11,509.4	0.97	0.7891
5	11,482	0.938	10,770.1	0.98	0.7375
6	11,020	0.908	10,006.2	0.98	0.6893
7	10,577	0.87	9,202.0	0.99	0.6442
8	10,151	0.825	8,374.6	0.98	0.602
9	9,742	0.775	7,550.1	0.98	0.5626
10	9,350	0.721	6,741.4	0.97	0.5258
11	8,974	0.644	5,779.3	0.97	0.4914
12	8,613	0.541	4,659.6	0.97	0.4593
13	8,266	0.445	3,678.4	0.96	0.4292
14	7,933	0.358	2,840.0	0.96	0.4012
15	7,614	0.285	2,170.0	0.96	0.3749
16	7,308	0.223	1,629.7	0.96	0.3504
17	7,014	0.174	1,220.4	0.96	0.3275
18	6,731	0.134	902.0	0.96	0.326
19	6,460	0.103	665.4	0.95	0.286
20	6,200	0.079	489.8	0.95	0.2673
			126,678		

Table V-24
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	0.96	0.9667
2	12,469	0.995	12,407	0.95	0.9035
3	12,067	0.989	11,934	0.96	0.8444
4	11,678	0.980	11,444	0.97	0.7891
5	11,302	0.967	10,929	0.98	0.7375
6	10,938	0.949	10,380	0.98	0.6893
7	10,585	0.924	9,781	0.99	0.6442
8	10,244	0.894	9,158	0.98	0.602
9	9,914	0.857	8,496	0.98	0.5626
10	9,594	0.816	7,829	0.97	0.5258
11	9,285	0.795	7,382	0.97	0.4914
12	8,985	0.734	6,595	0.97	0.4593
13	8,696	0.669	5,818	0.96	0.4292
14	8,415	0.604	5,083	0.96	0.4012
15	8,144	0.539	4,390	0.96	0.3749
16	7,882	0.476	3,752	0.96	0.3504
17	7,628	0.418	3,189	0.96	0.3275
18	7,382	0.364	2,687	0.96	0.326
19	7,144	0.315	2,250	0.95	0.286
20	6,913	0.217	1,500	0.95	0.2673
21	6,691	0.232	1,552	0.95	0.2498
22	6,475	0.196	1,269	0.95	0.2335
23	6,266	0.169	1,059	0.95	0.2182
24	6,064	0.143	867	0.95	0.2039
25	5,869	0.121	710	0.94	0.1906
			153,319		

The baseline miles-per-gallon figure for cars was 27.5 mpg at perfect inflation, and for light trucks was 20.7 mpg at perfect inflation. A sample calculation for passenger cars for Alternative 1 is:

The average of all four tires on a passenger car that would be warned based on our survey would be 6.1 psi lower than placard. Since 1 percent fuel efficiency is equivalent to 2.96 psi lower, the average passenger car with a warning would get 2.060811 percent higher fuel economy. 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 * 1.02060811 = 28.0667 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 $3,631.32 present value for fuel over its lifetime. Those drivers warned who filled up to placard pressure and achieved 28.0667 mpg (discounted by 15 percent to account for real on-road mileage) would spend $3,558.00 for fuel over their lifetime. The difference is $73.32. Since 36 percent of the fleet get a warning, and it is assumed that 80 percent of the drivers would fill their tires to placard, the average benefit is $21.12 ($73.32*0.36*0.80). The estimated benefit for each subgroup under the different alternatives is shown in Table V-25.

Table V-25
Fuel Economy Benefits Compared to the Baseline Fleet
Present Discounted Value over Lifetime
(2001 Dollars)

	Passenger Cars	Light Trucks
Alternative 1	$21.12	$43.32
Alternative 2 Direct Measurement System	$16.96	$35.37
Alternative 2 Indirect Measurement - ABS-based System	$9.58	$13.58

Weighting the Alternative 2 fuel economy benefit by the percent of the fleet with ABS-based systems (67 percent) and direct measurement systems (33 percent) results in an estimated $12.02 for passenger cars and $20.77 for light trucks. Weighting light trucks (50 percent) and passenger cars (50 percent) results in the following overall benefit in fuel economy shown in Table V-26.

Table V-26
Fuel Economy Benefits Compared to the Baseline Fleet
Present Discounted Value over Lifetime
(2001 Dollars)

	Average Passenger Vehicle
Alternative 1	$32.22
Alternative 2	$16.40

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 tire 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 costs is $61 per tire (in 2001 dollars).

For Alternative 1

Assuming a direct measurement system, the TPMS warns the driver anytime a tire is 20 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 2,136 out of 5,967 passenger car tires (36 percent) had at least one tire under-inflated by 20 percent or more below the placard level. The average under-inflation of the 4 tires for these vehicles was 6.1 psi. Thus, on average, passenger cars lose an estimated 4,880 miles (6.1 * 800 miles) of tread life for each tire due to the way they are currently under-inflated that could be remedied under Alternative 1 if everyone filled all their tires back up to the placard pressure when they were notified by a TPMS. If we assume that 80 percent of the people actually inflate their tires properly, then on average about 3,900 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 48,900 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 48,900 miles, and at 97,800 miles). The benefit to consumers is the delay in purchasing those tires and getting interest on that money at an assumed 7 percent rate of return. Using a mid-year 7 percent discount rate, the discounted present value of these delayed tire purchases is estimated to be $14.62 for those passenger cars that would be notified by a TPMS that they are under-inflated. Since 36 percent would be notified, the present discounted benefits are $5.26 ($14.62 * 0.36) and 1,404 miles (3,900 * 0.36) of tread life.

For light trucks, data from our tire pressure survey indicated that 1,564 of 3,950 light truck tires (40 percent) had at least one tire under-inflated by 20 percent or more compared to the placard. The average under-inflation of the 4 tires for these vehicles was 7.7 psi. Thus, on average, light trucks lose an estimated 6,160 miles (7.7*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 80 percent of the people actually inflate their tires properly, then on average 4,930 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 49,930 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 49,930 miles, at 99,860, and at 149,790 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 $42.00. Since in 40 percent of the vehicles at least one tire is under-inflated by 20 percent or more, the average benefit for light trucks is estimated to be $16.80 ($42.00 * 0.40) and 1,972 miles (4,930 * 0.40) of tread life.

<u>For Alternative 2</u>

We have to consider both ABS-based vehicles and non-ABS-based vehicles since they are represented by a different group of vehicles in the tire pressure survey. For Alternative 2, we assume that two-thirds (67%) of the vehicles would have ABS-based indirect measurement systems and one-third of the vehicles (33%) would have a direct measurement system. For the ABS-based vehicles we assume the TPMS warns the driver anytime there is a 25 percent or more psi differential between tires. For the non-ABS-based vehicles, we assume a direct measurement system will provide a driver warning anytime one or more tires is 25 percent or more below placard. If we assume 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.

For direct measurement systems

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. Thus, on average, passenger cars lose an estimated 5,440 miles (6.8 * 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 80 percent of the people actually inflate their tires properly, then on average 4,350 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 49,350 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 49,350 miles, and at 98,700 miles). The benefit to consumers is the delay in purchasing those tires and getting interest on that money at an assumed 7 percent rate of return. Using a mid-year 7 percent discount rate, the discounted present value of these delayed tire purchases is estimated to be $16.30 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 $4.24 ($16.30 * .26) and 1,131 miles (4,350 * 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. Thus, on average, light trucks lose an estimated 6,960 miles (8.7*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 80 percent of the people actually inflate their tires properly, then on average 5,570 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 50,570 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 50,570 miles, at 101,140, and at 150,710 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 $47.71. 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 $13.84 ($47.71 * 0.29) and 1,615 miles (5,570 * 0.29) of tread life.

For ABS-based systems

Data from our tire pressure survey indicated that 1,622 out of 5,967 passenger car tires (27 percent) had a 25 percent or more tire pressure differential. The average under-inflation of the 4 tires for these vehicles was 4.9 psi. Thus, on average, passenger cars lose an estimated 3,920 miles (4.9 * 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 60 percent of the people actually inflate their tires properly, then on average 2,350 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 47,350 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 47,350 miles, and at 94,700 miles). The benefit to consumers is the delay in purchasing those tires and getting interest on that money at an assumed 7 percent rate of return. Using a mid-year 7 percent discount rate, the discounted present value of these delayed tire purchases is estimated to be $8.84 for those passenger cars that would be notified by a TPMS that they are under-inflated. Since 27 percent would be notified, the present discounted benefits are $2.39 ($8.84 * 0.27) and 635 miles (2,350 * 0.27) of tread life.

For light trucks, data from our tire pressure survey indicated that 831 of 3,950 light truck tires (21 percent) had a 25 percent or more tire pressure differential. The average under-inflation of the 4 tires for these vehicles was 6.1 psi. Thus, on average, light trucks lose an estimated 4,880 miles (6.1*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 60 percent of the people actually inflate their tires properly (some of them might only fill some tires and not all of their tires), then on average 2,930 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 47,930 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 47,930 miles, at 95,860, and at 143,790 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 $24.63. Since in 21 percent of the vehicles there is a tire pressure differential of 25 percent or more, the average benefit for light trucks is estimated to be $5.17 ($24.63 * 0.21) and 615 miles (2,930 * 0.21) of tread life.

In summary, assuming that half of the vehicle sales in the future are passenger cars and half of the sales are light trucks, the average present discounted value benefit for tread wear savings for Alternative 1 is $11.03 ([$5.26 + $16.80]/2) and 1,688 miles ([1,404 + 1,972]/2) of tread life. For Alternative 2, the average benefit for tread wear savings for direct measurement systems is $9.04 ([$4.24 + $13.84]/2) and 1,373 miles ([1,131 + 1,615]/2) of tread life. The average benefit for tread wear savings for the ABS-based indirect measurement system is $3.78 ([$2.39 + $5.17]/2) and 625 miles ([635 + 615]/2) of tread life. Assuming that 33 percent of the fleet uses the direct measurement system and 67 percent of the fleet has ABS, the average present discounted value benefit for tread wear for Alternative 2 is $5.51 ($9.04*0.33 + $3.78*.67) and 872 miles (1,373*.33 + 625*.67) of tread life.

There are other potential unquantified 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.

Unquantifiable Benefits

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

1. an increase in stopping distance,
2. flat tires and blowouts
3. 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
4. skidding and/or loss of control of the vehicle in a lane change maneuver,
5. hydroplaning on a wet surface, which can affect both stopping distance and skidding and/or loss of control.
6. overloading the vehicle

The agency can quantify the effects of under-inflation in a crash involving the reduction in stopping distance. However, it cannot quantify the effects of under-inflation in the five other types of crashes. 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 does not collect tire pressure in its crash data investigations.

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 the tire pressure and doesn't know whether these blowouts occur before the crash or during the crash.

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. So, when under-inflation is a contributing factor to a crash, it is hard to know whether correcting this one problem area could result in the collision being avoided or reduced in severity. Certainly, reducing under-inflation is an important area and a move in the right direction. 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, as a result of under-inflation, 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. Figure V-2 shows the results of lefthand turns plotted 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 graph shows 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 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 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:

Figure V-2

Hydroplaning speed $= 10.35 \times \sqrt{\text{inflation pressure}}$[3]

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.

Non-quantified benefits

Property Damage and Travel Delay

TPMS will impact safety by reducing both the incidence and severity of crashes. When crashes are prevented, the property damage and travel delay that would have occurred are prevented as well. In a 1996 report[4], NHTSA estimated that property damage costs averaged over $3000 per crash and travel delay averaged $260 per crash ($1994). These savings would accrue to crashes

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[3] "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.

[4] "The Economic Cost of Motor Vehicle Crashes", 1994, DOT HS 808 425, NHTSA, July 1996.

VI. COSTS and LEAD TIMES

Systems Costs

These preliminary estimates are NHTSA-derived estimates mainly based on confidential discussions with a variety of suppliers and manufacturers about how their systems work and the various components in their systems. In addition, NHTSA has the preliminary results of a tear-down study of costs by a contractor of two direct measurement 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, since these systems will be required to go on 16 million vehicles. For this analysis, we estimate there will be sales volumes of 16 million light vehicles per year, 8 million passenger cars and 8 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 is estimated to be approximately $12 per vehicle. Currently about two-thirds of all new light trucks and passenger cars have ABS systems. NHTSA tested four current 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 tires" being low. They had problems detecting two tires low on the same axle or when two tires on the same side of the vehicle were low. The agency anticipates changes in the algorithms at a cost of $2 per vehicle to compare relative wheel speeds could be used to determine when one, two, or three tires are different from the others. However, the system wouldn't be able to detect when all four tires slowly lose air at about the same time and are low. The agency does not know whether there will be additional costs to improve the accuracy of the current ABS indirect measurement systems from roughly 30 percent below placard to the proposed upgraded 25 percent below placard. Comments are requested on the cost estimates.

If the agency decides it is important to also measure when all four tires are low, then the current ABS indirect measurement system would have to add another feature to independently determine vehicle speed (independent of the speedometer that works off wheel speed), so that individual tire speeds could be compared to vehicle speed. Although the agency has not tried it to determine its accuracy, a GPS system is the least costly possible method of independently determining vehicle speed. Other measures the agency could think of, adding a fifth wheel or a radar system, are either impractical or too costly.

Pickup trucks comprise about 40 percent of light truck sales. Some proportion of pickup trucks (comments are requested on this percent) that have ABS, have only one wheel speed sensor for the rear axle. In order to pass the proposal that the system be able to detect when one, two, or three tires are low, the agency believes these trucks would have to add a fourth wheel detector at a cost of $20 per vehicle. The agency assumes for this analysis that about 10 percent of all light trucks, or 7.5 percent of all light vehicles with ABS, would be in this category.

For those vehicles without ABS, there are two ABS-based indirect measurement choices. The first is not adding a full ABS system, but just those parts of the system needed for a TPMS system. Essentially, this would require adding TPMS and wheel speed sensors, which will cost approximately $130 per vehicle. (The agency won't discuss this option further, since it is more costly than a direct measurement system.)

To add the full ABS system (a manufacturer's marketing decision, not a NHTSA requirement) and a TPMS will cost approximately $240 per vehicle. (Again, the agency won't discuss this option further, since it is more costly than a direct measurement system, and it is a marketing decision by the manufacturer to spend more money to get a full ABS-system.)

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 some 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 can be two main costs of these systems (sensors and a receiver/central processor).

There is a wide disparity in costs for the sensors depending upon what type of information is sensed. Providing just the information proposed to be required by the NPRM (tire pressure) would cost in the range of $5 to $10 per wheel (or $20-40 per vehicle for this analysis). Some systems can sense tire pressure and air temperature inside the tire.

The cost for the receiver/central processor depends upon whether the current vehicle already has a receiver capable of receiving/processing the information coming from the sensors or not. It is estimated that about 60 percent of vehicles currently have the capability to receive the information (some in the form of a keyless remote entry system) and process the information. With some software changes and adding a display, showing tire pressure for all four tires individually, at a cost of about $25 per vehicle, these systems with the added cost of sensors could meet the proposal. Other vehicles that currently don't have a receiver/central processor (about 40 percent of the vehicles), would have to add them and the software and a display at an estimated cost of about $40 to $50 per vehicle.

An additional cost is the installation of the direct measurement system to the vehicle, which is estimated to cost about $4 per vehicle.

The agency also has a teardown study in progress performed by its contractor Ludtke & Associates.[1] Two direct measurement systems, the Beru tire pressure warning system and the Johnson Controls system, have been torn down and costed out to date.

The Beru system is an expensive system that goes beyond the bare minimum needed to pass the alternative. 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 $130, 4 wheels electronic modules to measure tire pressure and transmit the data at $33, 4 reception antenna at $26, 4 valves at $1, assembly at $4, and miscellaneous costs at $6, for a total of $200).

The costs of the Johnson Controls direct measurement system are broken into the following categories (1 control unit at $31, 4 wheels electronic modules to measure tire pressure and transmit the data at $33, 1 reception antenna at $1, 4 valves at $1, assembly at $2, for a total of $68).

A direct measurement system with a pump:

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

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.

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

Table VI-1

Cost Summary of TPMS Costs

(2001 Dollars)

Indirect Measurement System	
Add to Existing ABS	$12
Adding Wheel Sensors	$130
Adding Full ABS	$240
Changing Algorithms of Current ABS-TPMS	$2
Adding Fourth Wheel Speed Sensor Capability for Some Pickups	$20
Direct Measurement System	
With Current Receiver/central processor	$49 to $69 (we will use the mid-point $59)
Without Current Receiver/central processor	$64 to $94 (we will use the mid-point $79)
With a Pump, with current receiver/central processor	$89 to $109
With a Pump, without current receiver/central processor	$114 to $134

Current TPMS Systems in New Vehicles

Current 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, or 6 percent of the ABS fleet has a TPMS, and 1 percent of the fleet has a direct measurement system. While there are cost implication to make the current indirect TPMS comply with Alternative 2 (estimated at $2), the agency believes the direct systems could be changed at no cost to meet Alternative 1.

System Cost Summary by Alternative

Alternative 1: Assuming a direct measurement system is required, the incremental cost would be an estimated $66 per vehicle ($59 with current receiver/central processor * 60 percent with receiver/central processor + $79 without receiver/central processor * 40 percent without receiver/central processor = $67 per vehicle * 99 percent to account for the 1 percent of sales in the current fleet = $66.33)

Alternative 2: An indirect measurement system for all passenger cars and light trucks with ABS, is estimated to cost an average ABS-equipped light vehicle $12.90 per vehicle ($12*0.94 + $2*.06 + $20 *0.075 = $12.90). This accounts for 94 percent of the ABS systems have no TPMS, 6 percent have TPMS and 7.5 percent need a fourth wheel sensor. The overall cost for Alternative 2 assuming that an indirect system would be provided for the 67 percent of the fleet that is already equipped with ABS, and that a direct measurement system will be installed in the remaining 33 percent of the fleet is estimated to be $30.54 ($12.90 * .67 + $66.33*.33).

Non-Quantified Costs

Maintenance Costs

The agency anticipates that there will be maintenance costs associated with both a direct and an indirect measurement system. Most notable to consumers for most ABS-type indirect systems is a reset button that must be pushed whenever the tires have been rotated and perhaps when tires have been inflated. There is the potential for the reset button to be misused, just to get the warning light to go out, before inflating the tires and then forgetting to inflate the tires. In addition, the agency is aware of problems with wheel speed sensors with mis-adjustment, maintenance, and component failures.

The direct measurement systems also have maintenance concerns. Because there are sensors in the wheel, they can be damaged when tires are changed, etc. Furthermore, there is a battery in the sensor in most systems, which has a finite life of about 10 years currently, that will have to be eventually replaced to keep the system functioning.

The agency has not attempted to estimate these maintenance costs and requests comments on them. These costs are real, but they will decrease as improvements keep being made to the systems.

More frequent tire inflation costs

In order to benefit from the TPMS, drivers must respond by maintaining the air pressure in their tires. To accomplish this, they must either make a separate trip to a service station to get the air, or spend additional time to fill their tires when they are at the station getting gasoline. The process of checking and filling tires is relatively simple and would probably take from 3-5 minutes. The time it takes to make a separate trip to a gas station would vary depending on the driver's proximity to a station at the time they were notified. Presumably, the greater the distance to the station, the less likely the driver would be to make a separate trip.

It is likely that drivers who take action to fill their tires would consider this extra time to be fairly trivial. Since the action is voluntary, by definition, they would consider it to be worth the potential benefits they derive from properly inflated tires. However, when tallied across the entire driving population, the total effort involved in terms of man hours may be significant. Tires lose an estimated 1 psi per month, which means they lose 6 psi every 6 months. Therefore, people who otherwise would never fill their tires would be notified about twice a year. However, since many people do check their tires more frequently than that, the average number of extra fill ups would be considerably less than 2 per year. NHTSA has no data to indicate what portion of drivers would make a separate trip, or wait to fill their tires when they next filled their gas tanks.

Testing Costs

The test to show compliance may be broken down into the following sets of tests. Initially the vehicle would be set up for the test with each of the four wheels being instrumented. The vehicle would be run for a specified time to check out the system. Then, 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 agency has not worked out the calibration procedure yet, but for these estimation purposes, assumes it would take several hours. Finally, the agency is considering running a system failure test, if required by the standard, where some part of the system would be disconnected to determine whether there was an indication of system failure. 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, the test costs for light trucks would essentially double.

Lead Time

The act requires that the effective date of the rule be two years after the final rule. If Alternative 1 is selected then the manufacturers would be required to provide direct measurement systems in all vehicles. Comments are requested on whether there would be enough supply of direct measurement systems for 16 million vehicles at one time. However, if Alternative 2 is selected for the final rule, the agency believes that both suppliers and vehicle manufacturers can be ready to provide TPMS given the two-year lead time.

VII. COST EFFECTIVENESS

This section combines costs and benefits to provide a comparison of the estimated injuries and lives saved per net cost. Costs occur when the vehicle is purchased, but the benefits accrue over the lifetime of the vehicle. Benefits must therefore be discounted to express their present value and put them on a common basis with 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 fatalities and nonfatal injuries prevented converted into fatality equivalents. This conversion is accomplished using the relative values of fatalities and injuries measured using a Awillingness 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 0.0038 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	1994 Relative Value* per injury
MAIS 1	.0038
MAIS 2	.0468
MAIS 3	.1655
MAIS 4	.4182
MAIS 5	.8791
Fatals	1.000

* includes the economic cost components and valuation for reduced quality of life

Source: AThe Economic Cost of Motor Vehicle Crashes, 1994", NHTSA, 1996.

Table VII-2 shows the estimated equivalent fatalities for the two different alternatives. 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

	Fatality Benefits	Injury Benefits	Equivalent Fatalities
Alternative 1	79	10,635	300
Alternative 2	49	6,585	184

Net Costs

The average vehicle costs are estimated to be $66.33 per vehicle for Alternative 1 and $30.54 for Alternative 2. Multiplying these by 16 million vehicles results in $1,061 million for Alternative 1 and $489 million for Alternative 2. These costs are offset somewhat by reduction in costs for fuel economy and tread wear (See Table VII-3).

Table VII-3
Net Costs per Vehicle
(2001 Dollars)

	Vehicle Costs	Present Value of Fuel Savings	Present Value for Tread Wear	Net Costs
Alternative 1	$66.33	$32.22	$11.03	$23.08
Alternative 2	$30.54	$16.40	$5.51	$8.63

For 16 million vehicles, the net costs are estimated to be $ 369 million annually for Alternative 1 and $138 million annually for Alternative 2.

Net Cost/Equivalent Fatality Before Discounting

Alternative 1 $369 mil./300 equivalent fatalities = $1.2 million per equivalent life

Alternative 2 $138 mil./184 equivalent fatalities = $0.8 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. Historically, the agency has discounted future benefits and costs when they were monetary in nature. For example, the agency has discounted future increases in fuel consumption due to the increased weight caused by safety countermeasures, or decreases in property damage crash costs when a crash avoidance standard reduced the incidence of crashes, such as with center high-mounted stop lamps. The agency has not assigned dollar values to the reduction in fatalities and injuries, thus those benefits have not been discounted. The agency performs 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. 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.

Four different discount values are shown as a sensitivity analysis. The 2 and 4 percent rates represent different estimates of the social rate of time preference for health and consumption. The 10 percent figure was required by OMB Circular A-94, until October 29, 1992. The 7 percent figure is the current OMB requirement, which represents the marginal pretax rate of return on an average investment in the private sector in recent years.

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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 <u>Discounting for Time and Risks in Energy Policy</u>, 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.

[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.

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 (300 x .8766 = 263). The net costs per equivalent life saved for passenger cars and light trucks are then recomputed and shown in Table VII-6 using the net cost figures from Table VII-3 times 16 million vehicles and the discounted equivalent lives saved from Table VII-5 (e.g., for Alternative 1 @ 2 percent discount rate; $369 million/263 equivalent lives saved = $1.4 million per life saved).

Table VII-4
Discounting Multipliers

	2 Percent	4 Percent	7 Percent	10 Percent
Passenger Cars	0.8906	0.8004	0.6921	0.6078
Light Trucks	0.8625	0.7545	0.6315	.05409
PC/LT Average	0.8766	0.7775	0.6618	0.5744

Table VII-5
Discounting of Equivalent Lives Saved

	Base Equivalent	2 Percent	4 Percent	7 Percent	10 Percent
Alternative 1	300	263	233	199	172
Alternative 2	184	161	143	122	106
		x .8766	x .7775	x .6618	x .5744

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

	2 Percent	4 Percent	7 Percent	10 Percent
Alternative 1	$1.4	$1.6	$1.9	$2.1
Alternative 2	$0.9	$1.0	$1.1	$1.3

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.

Small Vehicle Manufacturers

Currently, there are about 4 small motor vehicle manufacturers in the United States. 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 is not considering any alternatives for the small vehicle manufacturers.

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 107, a final stage manufacturer would primarily rely upon the chassis manufacturer's incomplete vehicle document.

Low Tire Pressure Monitoring System Suppliers

There are several suppliers of radio frequency transmission technology (Beru, Johnson Controls, Schrader-Bridgeport, Pacific Industrial Company, SmarTire, Rayovac, and Fleet Specialties Company). Suppliers of ABS integrated technology include Continental Teves, 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). 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 $100 million annually. However, it is estimated to result in the expenditure by automobile manufacturers and/or their suppliers of more than $100 million annually. The agency has estimated that compliance with this proposed rule would cost from $30.54 to $66.33 per vehicle. Since approximately 16 million vehicles are produced for the United States market each year, this proposal will have a greater than a $100 million effect (16 million * $30.54 = $489 million). 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

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	4,570 - 9,110	AIS 2-5 85,930 - 155,090	None
Compared to 46.1% Usage in 1991	2,842 - 4,505	63,000 - 105,000	
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*

* 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 301, Fuel Tank Integrity Upgrade	TBD – first model year starting 3 years after final rule	$5.00	$2.30
FMVSS 202, Head Restraint Upgrade	TBD – first model year starting 3 years after final rule	$8.10 to $17.15	$10.70

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 301, Fuel Tank Integrity Upgrade	4 to 11	none	none
FMVSS 202, Head Restraint Upgrade	none	12,395	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

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*

* 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 301, Fuel Tank Integrity Upgrade	TBD – 3 years after final rule	$5.00	$2.30
FMVSS 202, Head Restraint Upgrade	TBD -	$8.10 to $17.15	$10.70

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 301, Fuel Tank Integrity Upgrade	4 to 10	none	none
FMVSS 202, Head Restraint Upgrade	none	1,852	None

prevented by TPMS. However, most benefits from TPMS would accrue from crashes that still occur but with a reduced severity. It is unclear what the impact would be on travel delay and property damage from these reductions.