Final Report

Federal Motor Carrier Safety Administration
Washington, DC

For:

Task Order # 5

Commercial Vehicle Tire Condition Sensors

Under the

Commercial Vehicle Safety Technology Diagnostics and Performance Enhancement Program
Contract Number: DTFH61-99-C-00025

By

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November 2003

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ABSTRACT

This project focused on developing and documenting the impacts of tire inflation maintenance practices on commercial vehicle operating costs and safety, and providing a quantitative estimate of potential benefits of tire pressure monitoring sensors and automatic inflation systems. The work performed under the project included:

- Documenting and quantitatively characterizing the condition (pressure) of tires currently being used on a wide cross section of commercial vehicles operating in the United States. The project includes an examination of tractor, trailer, and motor coach applications.
- Estimating the economic impact of improper tire pressure on fuel economy, tire maintenance and replacement costs.
- Estimating the impact of improper tire pressure on commercial motor vehicle (CMV) safety and handling.
- Describing and discussing available and emerging devices and sensor technologies to address the problem of improper tire inflation.
- Calculating the value of technologies designed to improve tire inflation maintenance based on alternative assumptions regarding implementation and usage.

The results from this project can be used by a variety of motor carriers in helping evaluate their tire inflation maintenance practices and policies, and to determine if technologies and sensors designed to improve tire pressure maintenance provide an appropriate cost benefit and safety improvement in carrier operations.

Results of the project reveal that for a typical truckload (TL) or less-than-a-truckload (LTL) operator, improper tire inflation increases the total operating costs by about $750 annually per tractor-trailer combination. Cost penalties for other types of fleets are similar and range from about $600 to $800. In addition to the increased costs for new tires, retreads, fuel, and roadcalls caused by improper tire inflation, fleet operators also spend considerable effort in checking tire pressures and adjusting them as necessary.

There are numerous tire pressure monitoring and automatic inflation systems available from vendors that are specifically tailored to commercial vehicles. Based on current market pricing, and *if* such systems were effective in mitigating incidences of improper tire inflation, and, *if* they do not themselves become an off-setting maintenance item, (i.e., the systems are highly reliable), then the analyses presented shows that tire monitoring and automatic inflation systems could indeed be highly cost-effective for many types of fleets.

The challenge for the supplier community (for increasing market penetration) is to improve reliability and reduce or eliminate added maintenance for the systems themselves.

EXECUTIVE SUMMARY

Project Funding

Under provisions of Section 5117 of the Transportation Equity Act for the 21st Century of 1998 (TEA-21), Congress authorized the USDOT "to conduct research on the deployment of a system of advanced sensors and signal processors in trucks and tractor trailers to determine axle and wheel alignment, monitor collision alarm, check tire pressure and tire balance conditions, measure and detect load distribution in the vehicle, and adjust automatic braking systems."

As a result of a comprehensive technology scan, as well as numerous interviews with key industry stakeholders such as truck manufacturers, fleet operators, suppliers and regulators, a variety of research areas were identified, including the design, functionality, and performance of tire pressure monitoring and inflation systems for commercial vehicle applications.

Background

The load carrying capability of a tire is critically linked to the inflation pressure. Fleet operators will generally select a particular "target pressure" for their trucks based on the unique load, operating, and environmental conditions in which they operate. If not properly inflated the useful tire life, as well as safety, are compromised.

The act of tire pressure maintenance is labor and time intensive. An 18-wheeled vehicle can take from 20 to 30 minutes to check all of the tires and inflate perhaps 2 or 3 tires that may be low on air. To complete this task once each week on every tractor and trailer becomes a challenge for many fleet operators. As a result, tires are often improperly inflated.

Very little empirical data exists with regard to actual tire pressure maintenance practices on commercial vehicles, and the extent of the "problem" (i.e., improper inflation) is not well understood. Over the last several years, new approaches and technologies have been developed for the commercial vehicle market to help improve tire maintenance practices, including automatic tire inflation systems and various types of tire monitoring systems. However, fleet maintenance managers often lack the information to determine if such systems will offer a reasonable return on their investment.

Objectives of the research

The primary objectives of this project were to develop and document the impacts of tire inflation maintenance practices on commercial vehicle operating costs and safety, and to provide a quantitative estimate of potential benefits of tire pressure monitoring sensors and automatic inflation systems.

Overview of Project Approach

Work on this project consisted of the following sub-tasks:

- Gathered and synthesized existing research in order to characterize the impact of improper tire inflation upon fuel economy, tire wear, and safety (Chapter 2, Impacts of Tire Inflation On Operating Cost And Safety).
- Worked cooperatively with the Technology and Maintenance Council (TMC) to synthesize existing tire pressure survey data from a wide variety of fleets (Chapter 3, Data Sources).
- Conducted original research and tire inflation field data collection for the owner-operator segment (Chapter 3, Data Sources).
- Analyzed tire inflation survey data from the above two sources to statistically characterize the degree to which commercial vehicle tires are improperly inflated in the general commercial vehicle population (Chapter 4).
- Gathered information from numerous vendors and suppliers of tire pressure monitoring and automatic inflation systems (Chapter 5, Tire Monitoring Systems).
- Developed six different hypothetical fleet operating scenarios to use as a construct for evaluating the costs and benefits of tire pressure monitoring and inflation systems (Chapter 6, Economic Analysis).

Much of the information gathered for this project was obtained via computerized literature research, and through a review of technical material from organizations such as SAE, TMC, NHTSA, and other industry associations. In addition, numerous industry stakeholders were contacted and interviewed. In general, the companies and individuals contacted were extremely helpful in compiling the information contained in this report.

Commercial Vehicle Tire Maintenance Practices

The following summarizes the key observations and conclusions about tire inflation condition and maintenance practices of commercial motor vehicles as observed from the sample tire pressure data collected:

- Approximately 7.08% of all tires are underinflated by 20 psi or more. Only 44.15 percent of all tires are within ±5 psi of their target pressure.
  - For-hire carriers' (LTL, TL, and owner-operators) vehicles generally reflected better tire inflation maintenance practices than private carriers' vehicles. As a group, for-hire carriers sampled had 7.01% of all tractor tires underinflated by 20 psi or more. In contrast, the private carriers sampled had 13.21% of all tractor tires underinflated by 20 psi or more.

- Tire inflation maintenance practices correlate closely with the size of the fleet. For tractors, fleets with 50 power units or less have 19.07% of their tires underinflated by 20 psi or more, while fleets of greater than 3,000 power units have only 2.06% of their tires underinflated by 20 psi or more. Similarly, motor coach fleets with less than 50 power units have 11.75% of their tires underinflated by 20 psi or more, while fleets with over 500 power units have only 2.09% of their tires underinflated by 20 psi or more.

- Transit bus operators have better tire pressure maintenance than chartered motor coach operators based on the sample data. Only 3.09% of transit bus tires are underinflated by 20 psi or more, while 9.37% of chartered motor coach tires are underinflated by 20 psi or more. Additionally, 49.88% of transit bus tires are within ±5 psi of target (a very high percentage), compared with only 34.22% of chartered motor coach tires.

- Tractors and trailers have a significant challenge with mismatched dual tires. Approximately 20% of all tractor dual tire assemblies have tires that differ in pressure by more than 5 psi. One out of four trailer dual assemblies (25%) have tires that differ in pressure by more than 5 psi.

Economic Analyses Of Tire Pressure Monitoring & Inflation Systems

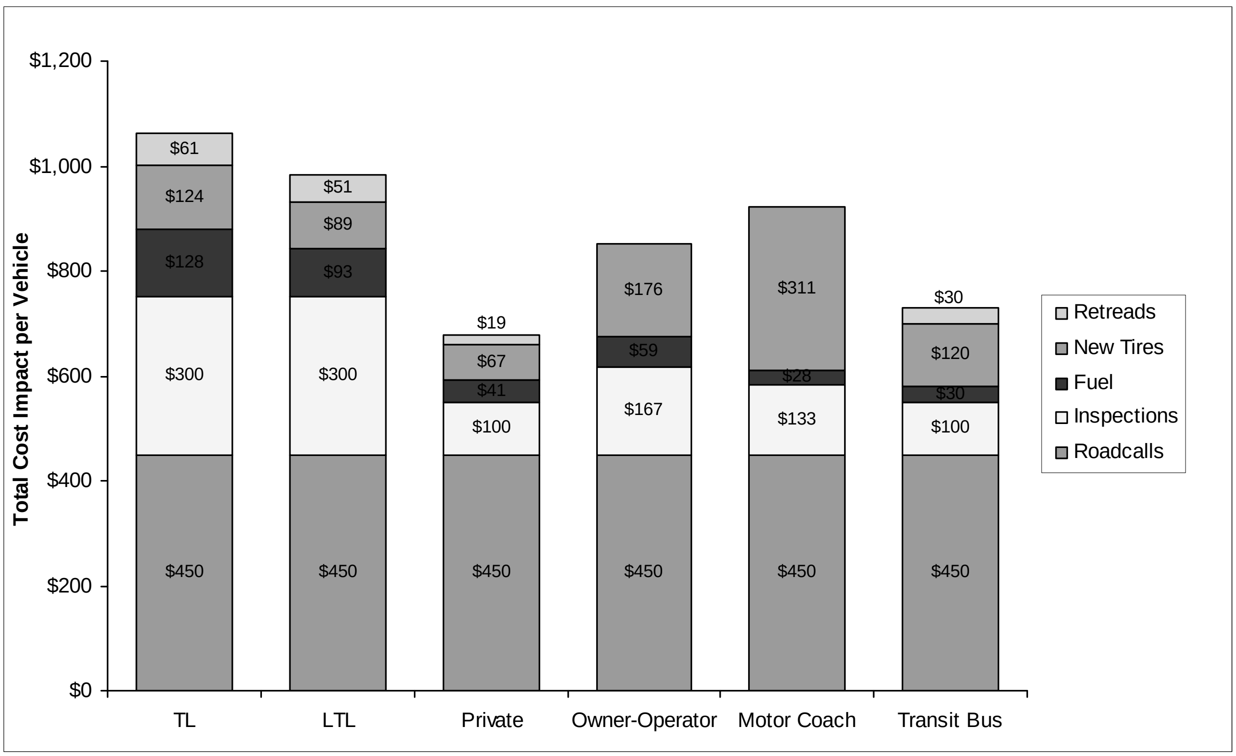
Key observations from the cost-benefit analyses are as follows:

- As reviewed in Chapters 1 and 2, tire related costs are the single largest maintenance cost item for commercial vehicle fleet operators. Nationwide, average tire related costs per tractor-trailer are about 1.9 cents per mile—or about $2,375 for a 125,000 annual mileage operation.
- For the average fleet operator in the United States, improper tire inflation increases the annual procurement costs for both new and retreaded tires by about 10 to 13% (see Exhibit 6.3).
- Fuel economy loss due to improper tire inflation is about 0.6% for typical TL and LTL operations.
- Improper tire inflation is likely responsible for about 1 roadcall per year per tractor-trailer combination due to weakened and worn tires.
- For a typical TL or LTL operator, improper tire inflation increases the total operating costs by about $750 annually per tractor-trailer combination. Cost penalties for other types of fleets are similar and range from about $600 to $800 (see Exhibit 6.3).
- One of the primary motivators for fleets to purchase automatic tire maintenance systems is that operators will not have to spend as much time checking tires for proper inflation. An average 18-wheel tractor-trailer could easily take 30 minutes to check the pressure of each tire and add air to 2 or 3 of the tires. Most fleet maintenance departments ask operators to check tire

pressures weekly. If however operators only check tires twice a month, the total annual labor would be approximately 12 hours (.5 hours/inspection (X) 24 insp.). At $25/hour, the cost would total $300 annually in tire inspection costs. This is likely a conservative estimate of tire pressure maintenance costs.

- The cost associated with routine tire pressure maintenance combined with the increased costs due to poor inflation arguably represents the total costs that could be addressed, (i.e., reduced), by tire pressure monitoring and automatic inflation systems. These cost items are shown below for the six "typical" commercial vehicle operating scenarios examined in this report.

Annual Increased Cost Due to Improper Inflation, Plus Annual Pressure Maintenance (Inspection) Costs



- There are numerous tire pressure monitoring and automatic inflation systems available from vendors that are specifically tailored to commercial vehicles. *If* such systems could be installed for approximately $1,000 per tractor-trailer combination, and *if* they were effective in mitigating incidences of improper tire inflation, such systems would indeed be highly cost effective. Return-on-investment periods even for an average fleet would be between 1 and 2 years (see Exhibit 6.4).

- Sensitivity analyses show that even for fleets with relatively "good" tire maintenance practices, (i.e., fleets which demonstrate a 25% reduction in total cost of improper inflation compared to "average"), the cost-effectiveness of tire monitoring and automatic inflation systems is still quite good with return periods of less than three years (see Exhibit 6.5).

- Tire pressure monitoring and automatic inflation systems become even more cost effective, if safety related benefits are explicitly considered. However, direct costs associated with a fleet's safety record, (such as injury claims, insurance premiums, workers compensation claims, as well as "goodwill" with customers and suppliers) are difficult to estimate, and even more difficult to determine what portion could be attributed to poor tire pressure maintenance. Therefore, while improved tire pressure maintenance will have an important and direct impact on reducing commercial vehicle related property damage, injuries, and fatalities; the economic benefits of such safety improvements have not been quantified.

- Tire pressure monitoring and automatic inflation systems have not achieved significant market penetration rates. Hindrances to increased usage appear to focus on fleet operators concerns over system reliability and required maintenance costs, as well as the initial costs of the systems.

The analyses presented in this report strongly suggests that the savings potential from tire pressure monitoring and automatic inflation systems could support the purchase prices of systems and products currently in the marketplace. The challenge for the supplier community is to prove reliability and reduce or eliminate added maintenance for the systems themselves.

1.0 INTRODUCTION

This chapter is organized as follows:

- Background on the Commercial Vehicle Safety Technology Diagnostics and Performance Enhancement Program
- Background and Rationale for the Research Study
- Project Objectives
- Overview of Process

1.1 COMMERCIAL VEHICLE SAFETY TECHNOLOGY DIAGNOSTICS AND PERFORMANCE ENHANCEMENT PROGRAM

The purpose of the Commercial Vehicle Safety Technology Diagnostics and Performance Enhancement Program, (i.e., "CV Sensor Study") was to define performance requirements, assess benefits, and accelerate deployment of driver and vehicle assistance products and systems and, in particular, advanced sensor and signal processors in trucks and tractor trailers with an emphasis in on-board diagnostic and improved safety related products.

The project solicited the input from key industry stakeholders (fleet operators, manufacturers, suppliers) regarding selection of areas of research, test and demonstration procedures, equipment specifications, and data collection and reporting methodologies. The project focused on conducting research that compliments (rather than duplicates) efforts by private industry. Objectives of the research included evaluating the probable impact of selected vehicle technologies on improving overall trucking safety, and to assess the cost savings potential and operational benefits helping to create market demand and encourage commercialization.

The following tasks were completed to help identify possible research areas:

- Extensive literature search of relevant technical journals and databases.
- Individual interviews and discussions with representatives from truck and trailer manufacturers, fleet operators, owner operators, industry suppliers as well as staff at NHTSA, FMCSA, and FHWA who are involved in commercial vehicle safety research.
- Convened a meeting of key industry stakeholders to review candidate research areas and make suggestions regarding future work under the CV Sensor study.

As a result of this background research and interview process, the following candidate areas of research were identified:

- Brakes and related controls,
- Tire inflation and condition monitoring systems,
- Truck and tractor alignment ("dynamic alignment"),
- Testing and analysis of high speed databus networks (J1939),
- Cost, benefits and implementation issues associated with Event Data Recorders,
- "Active Suspensions" and related suspension research,
- Advanced vehicle diagnostic and prognostic tools, and
- Issues related to implementation of "Smart Co-pilot" on-board systems.

The above list is meant to be a "work in process" and represents a starting point for directing the research. Contractor and government project team members continue to monitor and assess new technologies that could improve vehicle safety. The project team also continues to engage industry in discussions regarding the appropriateness of specific research projects. **[The focus of this report is on the second research area identified above, tire inflation and condition monitoring systems.]**

1.2 BACKGROUND AND RATIONALE FOR THE STUDY

The load carrying capability of a tire is critically linked to inflation pressure. For commercial applications, tire manufacturers publish data sheets that list the recommended inflation pressure for a particular tire type and application. Fleet operators will generally select a particular "target pressure" for tires based on tire size and load rating, anticipated weight to be carried by each tire (i.e., the number of axles and number of tires on each axle), maximum speed requirements, and other operational histories and/or environmental factors for that particular fleet. If not properly inflated, the useful life of the tire as well as safety is compromised (see Chapter 2 for additional discussion on impacts of improper inflation).

Commercial vehicle tires lose air pressure for a variety of reasons. Air can escape between the bead and wheel, as well as through improperly tightened valves, torn rubber grommets, or valve cores that have been blocked open by dirt and ice. Also, air molecules are small enough to diffuse through rubber (albeit very slowly) and an air pressure drop of up to 2 psi per month is not uncommon. Most tire companies recommend that tires be checked for correct air pressure once a week using properly calibrated tire gauges.

The act of tire pressure maintenance, however, is labor and time intensive. It takes approximately one minute per tire to check, adjust and record tire pressures. (see TMC Recommended Practice RP #233, *Guidelines for Tire Inflation Pressure Maintenance.* This publication details the importance of air pressure and is an agreed upon industry guide on the effects of tire inflation maintenance). An 18-wheeled vehicle can therefore take from 20 to 30 minutes to check all of the tires and inflate perhaps 2 or 3 tires that may be low on air. To complete this task once each week on every tractor and trailer becomes a challenge for many fleet operators. As a result, tires are often improperly inflated.

Most industry stakeholders intuitively recognize the importance of proper tire inflation maintenance and its impact on operating cost and safety. However, an examination of relevant literature and trade journals indicates that very little empirical data exists with regard to actual tire pressure maintenance practices on commercial vehicles. The extent of the "problem" (i.e., improper inflation), is not well understood, and the real cost of improper tire pressure maintenance (both in terms of safety and increased tire related operating costs) has not been well documented or analyzed.

Over the last several years, new approaches and technologies have been developed for the commercial vehicle market to help improve tire maintenance practices including automatic tire inflation and various types of tire monitoring systems. Most recently, much attention has been given to the potential of embedding electronic "tags" in the tire casing with the capability of monitoring pressure and temperature, as well as providing an inventory control function (see Chapter 5 for additional discussion). Fleet maintenance directors however often lack the information to determine if such systems will offer a reasonable return on their investment.

1.3 OBJECTIVES OF THE TIRE INFLATION RESEARCH STUDY

The primary objectives of this project were to develop and document the impacts of tire inflation maintenance practices on commercial vehicle operating costs and safety, and to provide a quantitative estimate of potential benefits of tire pressure monitoring sensors and automatic inflation systems. The work performed under this project included:

- Documenting and characterizing quantitatively the condition (pressure) of tires currently being used on a wide cross section of commercial vehicles operating in the United States (i.e., profile in-use tire pressures)
- Estimating the economic impact of improper tire pressure on fuel economy, tire maintenance, and replacement costs
- Estimating the impact of improper tire pressure on CMV safety and handling
- Describing and discussing available and emerging devices and sensor technologies to address the problem of improper tire inflation

- Calculating the value of technologies designed to improve tire inflation maintenance based on alternative assumptions regarding implementation and usage

The results from this project should be useful to a wide variety of motor carriers in helping evaluate their tire inflation maintenance practices and policies, and to determine if technologies and sensors designed to improve tire pressure maintenance provide an appropriate return in terms of cost reduction and safety improvement.

1.4 OVERVIEW OF PROCESS APPROACH

Work on this project consisted of the following sub-tasks:

- Gathering and synthesizing existing research in order to characterize the impact of improper tire inflation upon fuel economy, tire wear, and safety (Chapter 2, Tire Inflation Impacts on Safety and Cost).
- Working cooperatively with the Technology and Maintenance Council (TMC) to synthesize existing tire pressure survey data from a wide variety of fleets (Chapter 3, Tire Pressure Survey Data Sources). The tire pressure data supplied by TMC was originally gathered from tire manufacturers working with various customer fleets. The data was made “anonymous” before being forwarded to Booz Allen (that is, all information related to fleet names and locations was redacted).
- Conducting original research and tire inflation field data collection for the owner-operator segment (Chapter 3, Tire Pressure Survey Data Sources).
- Analyzing the tire inflation survey data from the above two sources to statistically characterize the degree to which commercial vehicle tires are improperly inflated in the general population (Chapter 4, Analysis of Tire Pressure Data).
- Gathering information from numerous vendors and suppliers of tire pressure monitoring and automatic inflation systems (Chapter 5, Overview of Tire Monitoring and Inflation Products).
- Developing six different hypothetical fleet operating scenarios to use as a construct for evaluating the costs and benefits of tire pressure monitoring and inflation systems (Chapter 6, Cost-Benefit Analysis).

Much of the information gathered for this project was obtained via computerized literature research, and through a review technical material, including, but not necessarily limited to, the following sources:

- Society of Automotive Engineering (SAE) papers,
- National Technical Information Service (NTIS),

- NHTSA, FHWA, TRB and NTSB technical papers and articles, including NHTSA rulemaking on Tire Pressure Monitoring Systems, (# NHTSA-2000-8572)
- Industry trade journals (*Commercial Carrier Journal, Fleet Owner, Transport Topics, Automotive Engineering, Diesel Progress*), and
- TMC Recommended Practices.

In addition, and more importantly, numerous industry stakeholders were contacted and interviewed, including the following:

- American Trucking Associations,
- National Private Truck Council,
- Owner-Operator Independent Drivers Association,
- American Bus Association,
- United Motorcoach Association,
- Technology and Maintenance Council (TMC),
- National Transportation Safety Board,
- Truck Manufacturers Association,
- Truck–Tractor manufacturers,
- Motorcoach manufacturers,
- Commercial tire manufacturers,
- Vendors and suppliers of tire monitoring and inflation systems,
- International Tire and Rubber Association,
- Tire Association of North America,
- Maintenance staff at commercial fleets, and
- Owner-Operators.

In general, the companies and individuals contacted were extremely helpful in compiling the information contained in this report.

2.0 TIRE INFLATION IMPACTS ON SAFETY AND COST

Tires represent the single largest maintenance cost item for commercial fleet operators and play a crucial role in vehicle safety. These issues are reviewed in the following sections:

2.1 SAFETY IMPACTS

It is well understood and accepted that tires play an important role in vehicle handling and braking performance, and that tire inflation pressure and tire wear levels impact vehicle performance characteristics. Tires also are subject to catastrophic failure (e.g., "alligators" from full or partial loss of tread), which significantly compromises vehicle handling. While loss of control is not an issue when a dual tire fails, catastrophic failure of a steer tire can cause the driver to immediately lose control of the vehicle. Also, the resulting debris from failed tires causes a hazard for other motorists. Further, it is well understood that excessive heat is a contributing factor in tire wear and tire failures and that low inflation leads to excessive heat buildup.

While there is clearly a strong relationship between tire condition, inflation pressure and safety, quantifying this relationship can be difficult. Nevertheless, data contained in the following databases was used to identify trends:

- The National Automotive Sampling System/General Estimate System (NASS/GES), operated and maintained by the National Highway Traffic Safety Administration (NHTSA); and
- The Motor Carrier Management Information System (MCMIS) Inspection File, operated and maintained by the Federal Motor Carrier Safety Administration (FMCSA).

The NASS/GES database is comprised of a nationally representative sample extracted from police traffic crash reports. For 1998, there were a total of 55,562 crash records in the GES database; of these, 10,511 records represented crashes involving large trucks.

Most crashes are not found to be the result of mechanical flaws or component failures, but rather are seen as involving driver error. Nevertheless, for each crash record within the GES database, the investigator makes an assessment about whether there were mechanical flaws that might have contributed to the cause of the crash. When a mechanical flaw is found to have potentially existed, an effort is then made to identify the pertinent defect category, such as tires, brake system, steering system, suspension, etc. These data are recorded in the GES under "Vehicle Contributing Factors" (V12).

Where vehicle defects on the truck were identified as possible contributing factors, these defects most frequently involved brakes or tires. As shown in Exhibit 2.1, when vehicle defect was a likely factor, an estimated 21% of 1998 NGA-reportable crashes involved tires.

Exhibit 2.1 Vehicle-based Contributing Factors in CV Crashes

VEHICLE FACTOR	1998 Estimated Reportable Crashes	Percent Reportable Crashes
Brake System	3,574	36.8%
Tires	**2,037**	**20.9%**
Steering System	538	5.5%
Power Train	384	4.0%
Wheels	307	3.2%
Trailer Hitch	231	2.4%
Other Lights	77	0.8%
Mirrors	38	0.4%
Signal Lights	38	0.4%
Suspension	0	0.0%
Other Vehicle Factors	1,576	16.2%
No Details	922	9.5%
TOTAL	9,722	100.0%

As shown in Exhibit 2.2, (and using this same data), crashes involving tires as a contributing factor accounted for 21% of all injuries associated with vehicle crashes.

Exhibit 2.2 Injuries in Crashes Where "Vehicle Defect" was a Contributing Factor

Vehicle Factor	1998 Estimated Injuries	Percent Injuries
Brake System	1,883	49.0%
Tires	**807**	**21.0%**
Steering System	115	3.0%
Suspension	0	0.0%
Other Vehicle Factors	653	17.0%
No Details	384	10.0%
TOTAL	3,842	100.0%

How prevalent are various vehicle defects among the population of large trucks? The MCMIS Inspection File contains the results of all driver-vehicle safety inspections of interstate commercial motor vehicles performed by States participating in the Motor Carrier Safety Assistance Program (MCSAP). In 1998, 1.9 million inspections of interstate vehicles were conducted.

It might be assumed that the prevalence of mechanical flaws and defects among inspected vehicles would roughly mirror the incidence of defects among all trucks involved in crashes. This expectation, however, must be tempered by these caveats:

- State selection of the particular vehicles subjected to driver-vehicle inspections is not a random process. Rather, most States employ one of several "selection algorithms" to determine precisely which vehicles to inspect. These algorithms are weighted towards "at-risk" carriers, such that in theory, carriers with poor previous inspection experience or higher-than-average crash rates are more likely to be inspected then are other carriers. To the extent then that the algorithms are weighted towards at-risk carriers, the actual aggregate incidence of vehicle defects among inspected carriers may be higher than for the carrier population at-large.

- If even occasional vehicle defects cause accidents, then it follows that large trucks with a preponderance of defects will more likely be involved in crashes than those with few or no defects. Hence, the incidence of defects among vehicles involved in crashes is very likely higher than for the large-truck population generally.

These cautionary notes notwithstanding, the pertinent MCMIS Inspection data may be summarized as follows:

Exhibit 2.3 MCMIS Inspection Data: 1998

Vehicle Defect	Number of Inspected Vehicles With Defects	Percent Total Vehicles
Brakes	355,814	18.7%
Tires	**180,703**	**9.5%**
Suspension	79,948	4.2%
Steering Mechanism	40,214	2.1%
Other Vehicle Defects	759,351	39.9%
Inspections with No Vehicle Defects	485,990	25.6%
TOTAL	1,902,020	100.0%

In 1998, three out of every four inspections resulted in the detection of one or more vehicle defects. Nineteen percent of all inspected vehicles (nearly one in five) were found to have one or more brake defects. Ten percent of all vehicles had tire defects.

In summary, although vehicle defects on large trucks could rarely be pinpointed as causative factors in crashes, when they did occur brakes, then tires, tended to be the culprit. And even though crashes involving mechanical defects generally were less severe than large truck crashes, the elimination or mitigation of key mechanical problems, including tire related issues, would likely save thousands of injuries.

2.2 QUANTIFYING THE COST OF IMPROPER TIRE INFLATION

From the fleet operators' perspective, tires represent the single largest maintenance cost item. Based on reports filed in 2001 with USDOT by carriers with $3 million or more in annual revenue, total tire related costs average about 1.9 cents per mile for a tractor-trailer combination vehicle.[1] Total annual tire related costs based on 125,000 miles per year are therefore approximately $2,375 for an 18-wheel tractor-trailer. The cost of new tires continues to increase with typical pricing in the $275 to $325 range for a 22-inch tractor tire and up to $350 to $400 for a premium motor coach tire. Costs associated with retreading range from perhaps $80 to $100 for a fleet operation.

Improper tire inflation increases operating costs through the following four mechanisms:

- Increased tire wear (miles between retreading),
- Reduced tire life (total useable miles including all retreads),
- Reduced fuel economy, and
- Tire failures from sudden loss of tire tread and blow-outs, leading to an out-of-service condition (roadcalls).

To quantify the affects of improper tire inflation, it was necessary to develop several "impact profile curves," which describe the correlation between the amount a tire is underinflated or overinflated and the percentage impact on tire life, tread wear, and/or fuel economy. TMC's recommended practice #233 Guidelines for Tire Inflation Pressure Maintenance was used as a starting point for the analyses presented in the following sections. In addition, the relationships between tire inflation and these operating parameters (tire life, tread wear, and fuel economy) were reviewed with engineering staff at tire manufacturers and with several fleet operators. In general, there is considerable agreement among industry experts on the impacts of improper tire inflation, and the data used in this study represents an average of the estimates and data received from industry stakeholders.

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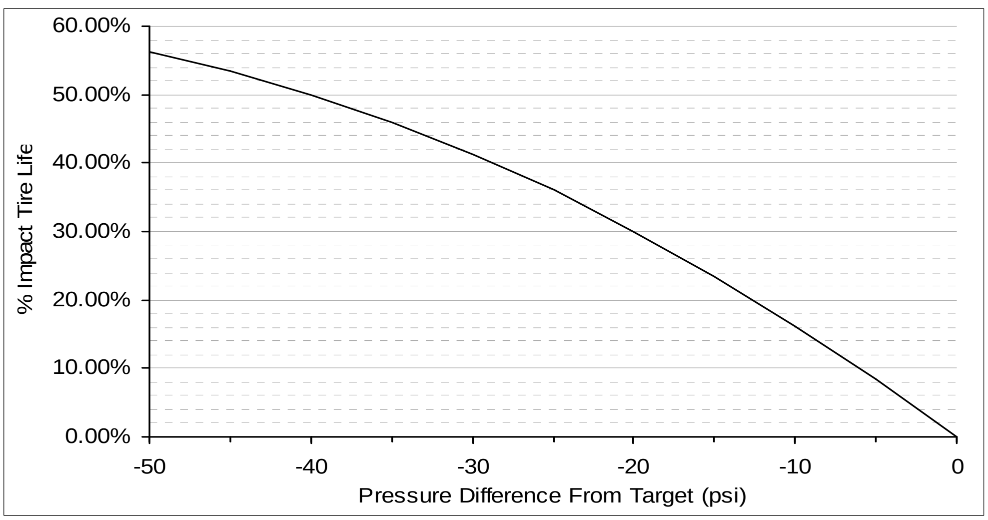
[1] ATA Economics & Statistics Group, *American Trucking Trends 2002*, Alexandria, VA: American Trucking Associations, 2001, 27.

2.2.1 Reduced Tire Life

Inadequate tire inflation, specifically underinflation, causes a reduction in the useable life of a tire because the tire is running in an overloaded condition. Overloading causes the sidewall of the tire to extend and contract, causing heat generation inside the tire. Excessive heat leads to fatigue of the rubber and cords thus further exacerbating the sidewall flexing. The weakened structure increases the likelihood of punctures and cuts, and the increased temperature leads to premature separation between the tire cords and the rubber. In effect, the increased heat and motion reduces the number of times that a tire could be safely retreaded. A common “rule-of-thumb” is that a constant 20% under-inflated condition will reduce the life of a tire by 30% and 40% under-inflation will reduce tire life by 50%. The impact profile curve shown in Exhibit 2.4 is offered as a basis for correlating tire life with tire pressure.

Exhibit 2.4 Underinflation Impact on Tire Life[2]



* no data available on the impact of over-inflation on tire life

2.2.2 Reduced Tread Wear

In addition to impacting the usable life of a tire, improper tire inflation also affects tread wear. Both over and under-inflation change a tire’s footprint thus affecting tire traction and leading to irregular wear. Under-inflation causes many types of irregular and accelerated wear patterns including shoulder wear, block-pumping wear, spot wear, diagonal wear, rib wear, and block-edge wear. Over-inflation also can cause shoulder and block-edge wear, and accelerates heel and toe wear. (TMC RP #233 provides details on such wear phenomena). A common rule of thumb is that a constant 20% underinflation will increase tread wear by 25%. Exhibit 2.5 presents a profile of the impact of tire inflation on tread wear for both over and under-inflated conditions.

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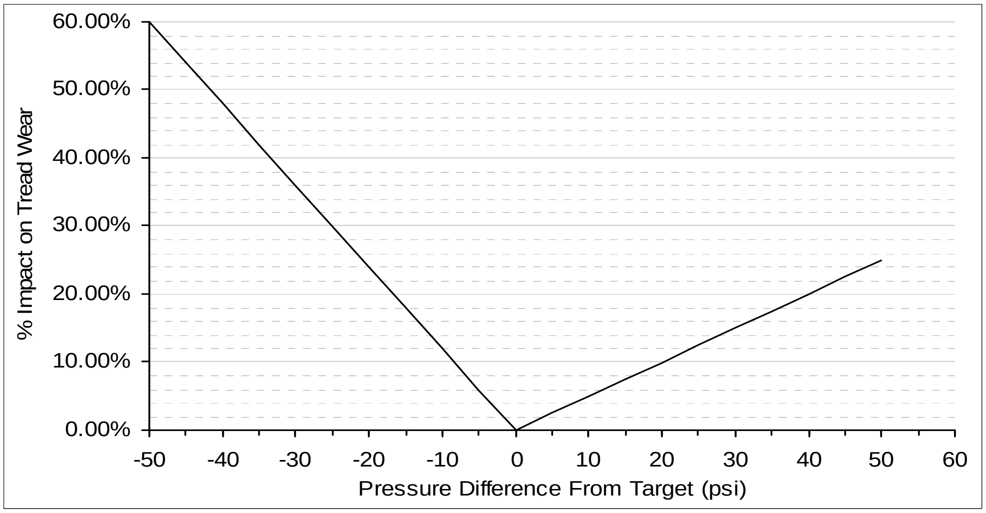
[2] Technology and Maintenance Counsel, *Recommended Practice #233 – Guidelines for Tire Inflation Pressure Maintenance,* Alexandria, VA: American Trucking Associations/TMC, 2002.

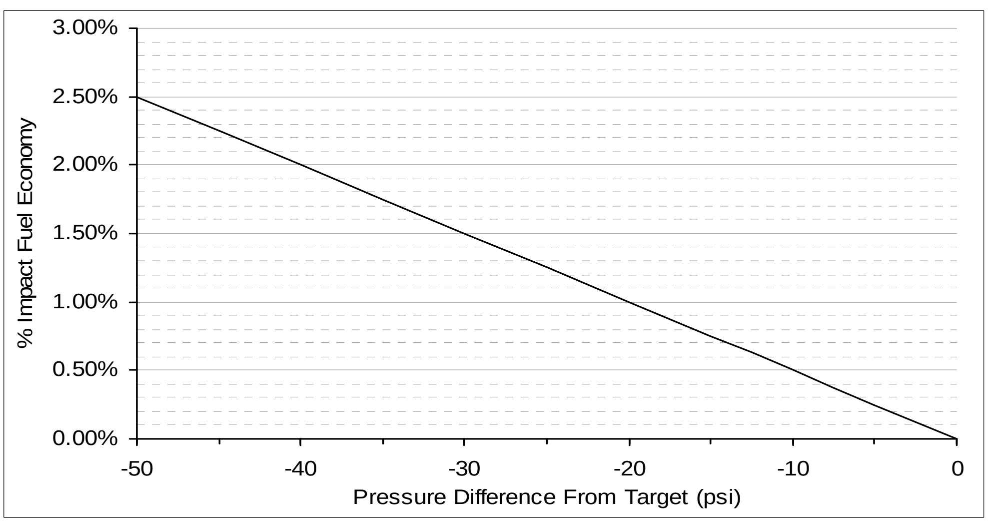
Exhibit 2.5 Inflation Pressure Versus Tread Wear[3]



2.2.3 Fuel Consumption

Fuel economy is also impacted by inadequate tire inflation. Increased flexing and the irregular footprint caused by underinflation, yields increased rolling resistance which leads to increased fuel consumption as more power is required to move the vehicle. In fact, for every 10 psi underinflated there is a 0.5% reduction in fuel economy. Exhibit 2.6 shows the impact profile of underinflation on fuel economy.

Exhibit 2.6 Underinflation Impact on Fuel Economy[4]



[3] TMC, *RP #233 – Guidelines for Tire Inflation Pressure Maintenance*
[4] TMC, *RP #233 – Guidelines for Tire Inflation Pressure Maintenance*

2.2.4 Roadcalls and Tire Failures

Improper tire inflation also increases the potential for tire failures from sudden loss of tire tread (the so-called "alligators" on highway shoulders). This severe tire damage can result in the CMV being placed out-of-service during a roadside vehicle inspection. Such an occurrence results in an expensive roadcall, and has obvious negative implications for safety. As noted, under-inflation causes excessive deformation of the sidewalls and heat built up, which weakens adhesion between the rubber and steel cords. Over-inflated tires also can lead to major tire failures since they are more vulnerable to tread surface cutting, impact breaks, punctures, and shock damage.

2.2.4.1 Tire Debris Survey Results

In 1995 and 1998, the Technology and Maintenance Council (TMC) of the American Trucking Associations surveyed tire debris found on and along roads to determine the cause of such rubble. [5] This work was done at 13 specific sections of various highway types in nine states across the country. The results provide insight necessary to prevent on-road tire failure and strongly suggest that tire air pressure maintenance is the key to safe tire use. This is true for original, as well as, retreaded tires and for both passenger and truck tires.

The survey consisted of gathering tire debris, examining it and determining its source and probable cause of failure. Key findings include the following:

- 64% of the tires were truck tires and 36% were passenger car and light truck tires,
- 28% more debris was collected in 1998 than was found in 1995. This resulted from Western state speed limit increases up to 75 mph and an extremely hot summer in the Southwest in 1998,
- 71% of the failed truck tires were of a type of tire used on trailers,
- 87% of the failed truck tires had been retreaded but retreaded tires were not over-represented,
- 90% of the tire failures examined were caused by underinflation, and
- 7% of the tires examined failed due to a retread problem.

There is a common misconception that the source of the tire debris found along the nation's highways is failed truck tire retreads. This study showed that while a majority of the scrap came from retreaded tires, the failures resulted from insufficient air pressure. Only 7% of the tires in these surveys failed due to problems related to retreading. This is easily determined by examining the scrap. When a tire fails due to a

[5] Technology and Maintenance Counsel, *1998 Tire Debris Survey*, Alexandria, VA: American Trucking Associations/TMC, 1998.

faulty retread, its tread separates and leaves a plain strip of rubber on the road. However, in 90% of the tires examined, the steel tire belts were attached to the tread rubber. These tires came entirely apart; they did not just fail at their retread bond lines. This type of failure is caused by underinflation.

Trailer tires are most susceptible to damage. This is because the tires on the tractor pulling the trailer tend to set up and align nails and other penetrating matter in their path. The trailer tires are then punctured by the objects and fail due to a loss of air. Since most trailer tires are retreaded, it is logical that these are the tires that most commonly fail.

The two TMC surveys show that the key to reducing tire failures is adherence to a comprehensive tire inflation maintenance program.

2.2.4.2 Roadcall Data

Unlike tread wear, tire life, and fuel economy, there is no well-documented relationship between the percentage of underinflation or overinflation and the increased propensity for roadcalls due to tire failures. To determine the cost associated with such failures, the following information is needed:

- Average total number of roadcalls per year per unit,
- Percentage of roadcalls attributable to tires, and
- Percentage of tire failures that were due to excessive heat, flexing, and/or fatigue (thus likely the result of improper inflation) versus those that were due to road hazards such as nails and other sharp objects (and are thus unaffected by inflation pressure).

Fortunately, such information can be obtained from companies specializing in providing independent road breakdown management services. Such companies establish contracts with commercial fleet operators to provide turnkey emergency towing and repair services. Conversations with these emergency road service contractors, as well as directly with fleet operators, reveal the following:

- There are approximately 2.0 to 2.3 breakdowns per "unit" (a combination tractor-trailer) per year,
- 45% to 55% of the total breakdowns per "unit" are related to tires during the cooler months of the year; 55% to 65% of the total breakdowns per "unit" during the hotter months of the year. Thus, on average, tire related problems account for just over half of all breakdowns,
- 15% of tire related breakdowns are a result of punctures/road debris; 85% are a result of excessive heat due primarily to poor maintenance, and
- 75% of tire related breakdowns occur on the trailer tires; 25% occur on the tractor tires.

The above data suggests that on average, a typical tractor-trailer will experience about 1.2 roadcalls per year related to tire failures (2.2 total breakdowns/unit multiplied by 55% due to tires), and that about 1 roadcall per year per tractor-trailer is directly attributable to improperly inflated tires (1.2 roadcalls due to tires x 85% caused by improper inflation).

One of the largest emergency road service operators in the United States is FleetNet America. FleetNet provides road assistance via a network of over 60,000 vendors nationwide. They currently service over 3,000 trucking clients, 3 OEM's, and 2 after-market and service companies. FleetNet maintains complete and accurate records on all roadcall occurrences they respond to in order to invoice customers, and to track trends in customer needs both geographically and seasonally. Exhibit 2.7 below presents statistics on the breakdowns that FleetNet handled for the years 2000 and 2001.

Exhibit 2.7 FleetNet Roadcall Data for years 2000 and 2001[6]

ATA Code	Description Of Repairs	Occurrences	Percent of Total	Downtime Hours	Direct Costs Billed	Downtime per Occurrence (hrs)	Cost per Occurrence
Year 2000 data							
117-01	TIRE FAILURE (CONSOLIDATED)	12,369	48.9%	31,560	$3,564,576	2.55	$288.19
132-01A	JUMP OR PULL START UNIT	2,030	8.0%	4,260	$249,869	2.10	$123.09
168-00	TOWING & OTHER	2,016	8.0%	10,837	$767,479	5.38	$380.69
113-19	R&R OR REP AIR LINE OR HOSE (EACH)	1,471	5.8%	3,934	$242,854	2.67	$165.09
134-03	R&R OR REPAIR: WIRING, PLUGS, LIGHTS	1,297	5.1%	3,146	$115,039	2.43	$88.70
131-02	REMOVE & REPLACE ALTERNATOR	1,024	4.1%	4,366	$492,041	4.26	$480.51
144-01	R&R FUEL FILTER OR FUEL ADDITIVE	1,012	4.0%	2,754	$133,869	2.72	$132.28
113-16E	R&R BRAKE CHAMBER	900	3.6%	5,584	$217,040	6.20	$241.16
Year 2001 data							
117-01	TIRE FAILURE (CONSOLIDATED)	14,260	55.3%	36,321	$3,788,146	2.55	$265.65
132-01A	JUMP OR PULL START UNIT	1,798	7.0%	3,621	$228,518	2.01	$127.10
168-00	TOWING & OTHER	1,637	6.4%	10,061	$615,929	6.15	$376.26
113-19	R&R OR REP AIR LINE OR HOSE (EACH)	1,591	6.2%	4,240	$276,534	2.67	$173.81
131-02	REMOVE & REPLACE ALTERNATOR	1,077	4.2%	5,796	$540,011	5.38	$501.40
144-01	R&R FUEL FILTER OR FUEL ADDITIVE	1,016	3.9%	2,803	$136,860	2.76	$134.70
134-03	R&R OR REPAIR: WIRING, PLUGS, LIGHTS	1,044	4.0%	3,258	$112,120	3.12	$107.39

This data suggests that the average lost time due to a tire related roadcall is about 2.5 hours and that the direct-billed costs are approximately $265.

Such cost do not, of course, encompass all of the costs incurred by the fleet operator due to tire related breakdowns, which may include:

- Additional driver wages due to driver delay,
- Lost revenue,
- Lost customer goodwill,
- Other penalties and costs associated with late delivery, and
- Purchase cost of a new tire.

[6] Warren Summer, FleetNet America, *FleetNet Roadcall Data for 2000, 2001,* Cherryville, NC: FleetNet America, 2002.

The real cost of a tire related breakdown therefore is almost certainly much higher than the "direct costs" paid to the emergency road service company. Considering the total cost/revenue to operate a combination vehicle to be about $1.25 per mile, and the average speed to be 60 miles per hour; a tire related breakdown results in a reduction of 153 miles traveled (60 mph x 2.55 hrs), and a total loss in revenue (or costs incurred depending on your perspective) of $191 (153 miles x $1.25 per mile.). Using this arguably conservative approach, the total estimated cost of a breakdown would be about $450 ($265 direct-billed by emergency road service + $191 in lost revenue). This cost estimate does not consider other penalties/costs associated with late delivery or the purchase cost of a new tire.

2.2.5 Dual Tire Assemblies

On a large majority of commercial vehicles (and with the exception of the steer tires), tires are most often operated in a dual or paired assembly. A mismatch in tire pressures on a dual assembly can exacerbate the previously described problems associated with improper inflation. Testing has shown that a five-psi difference creates a 5/16-inch diameter difference. Since the wheels holding the tires are physically bolted together, they must cover the same distance in a single revolution. Therefore, the larger tire drags the smaller one resulting in irregular and accelerated wear on both tires, but particularly on the tire with lower inflation. Because the properly inflated tire is also impacted, the cumulative negative impacts (in terms of tread wear, fuel economy, etc.) on a particular vehicle are therefore worse if they are mated with properly inflated tires than if the low inflation tires are mated together. In other words, mismatched tire pressures on dual-tire positions are particularly problematic; the relationships between inflation pressure and tread wear, tire life, and fuel economy presented in the previous exhibits implicitly recognize this reality. Furthermore, the relationships emphasize that across numerous trucks, (and over time), low inflation tires will inevitably be matched with both properly and improperly inflated tires. The relationships presented in Exhibits, 2.4, 2.5, and 2.6 represent an "average" degree of impact based on the degree of under- or over-inflation.

3.0 TIRE PRESSURE SURVEY DATA SOURCES

As noted in Chapter 1, a key objective of this research project was to profile actual in-use tire inflation pressures among a large cross section of commercial vehicle operations. Our initial approach to this task was to determine if adequate commercial vehicle tire pressure survey data already existed in the public domain. This work consisted of:

- A review of relevant technical journals and trade magazines,
- Interviews with industry trade associations,
- Interviews with tire manufacturers,
- Interviews with fleet operators, and
- A review of data available from various government sources.

This research revealed that limited tire pressure survey data was available (in the public domain), and the usefulness of the information was often compromised for a variety of reasons:

- The original source of the data could not always be identified,
- Sample sizes tended to be small and limited to a particular fleet's operation at a particular location, and
- Information and statistics were often "anecdotal" and conclusionary, (e.g., "one of 10 trucks is operated with at least one tire that is nearly flat"). The "raw" data to support conclusions was generally not available or verifiable.

In conducting the research, the Technology and Maintenance Council (TMC) was also contacted as a possible data source. While TMC did not have comprehensive tire inflation data on-hand, TMC's Tire Debris Prevention Task Force (Task Force) decided to take on the task of supplying data for this study to ensure that the data collected would be accurate and credible. The Task Force members were also interested in collecting this data for Task Force's own work to educate motor carriers on procedures and methods for improving tire maintenance.

Several large tire companies routinely conduct fleet surveys for their customers. These surveys entail inspecting tires on vehicles for tire wear and damage conditions, as well as, pressure status. Fleet surveys are also conducted when a fleet is testing a new brand or model of tire. Tire manufacturers perform these fleet surveys, often with compensation, to aid fleets with their tire maintenance programs, help fleets maintain their investment in tires, monitor tire tests, and acquire data to determine the performance of their tires in various applications. Field service engineers who are trained and skilled, and have the proper tools and accurate gauges to do this work, conduct these fleet surveys. They are usually performed on Saturdays or in the early morning before vehicles have run on the road. Therefore, tires are cold and the pressures reported are accurate.[7] This fleet survey data was sought and collected because it provides the most accurate way to assess the relationship between a motor carrier fleet's "target tire pressure" and the actual cold inflation pressure of tires in service. The data are considered representative of motor carriers that participate in this type of maintenance program.

3.1 OWNER-OPERATOR DATA

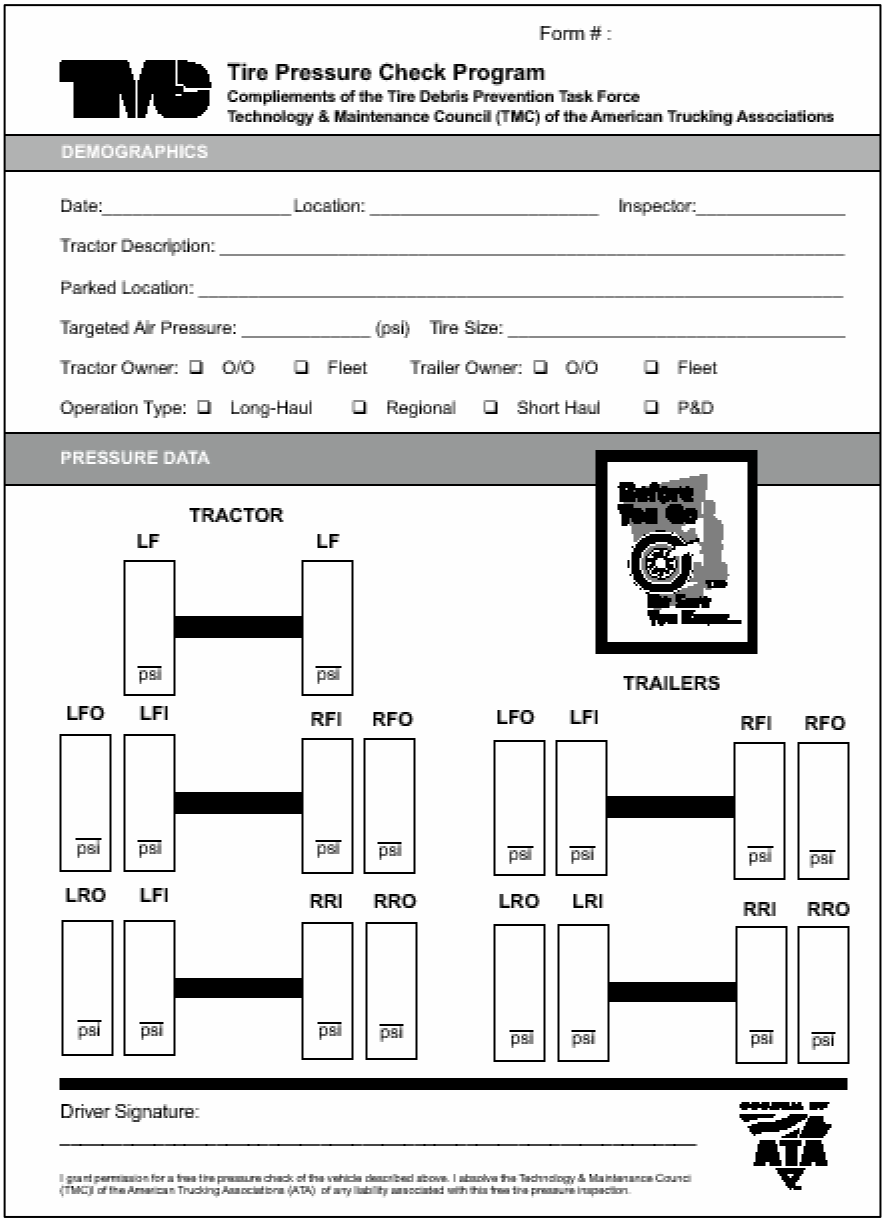
While fleet survey and tire pressure data were available on truck and bus fleet tires from tire company archives, no such data was available on owner-operators. Owner-operators usually own 1-5 tractors and drive them themselves. They often contract with a larger fleet operator and get paid by the mile. They are responsible for paying all of their own operating costs, including truck payments, fuel, insurance, maintenance costs, replacement tires, etc. The tire companies contacted did not have any significant sample tire inflation data on this segment of the trucking industry, and as noted, little to no data was available from any previous surveys. It was concluded that an original data collection effort would therefore be needed.

Due to the nature of the operations of owner-operators, the only way to obtain cold tire pressure data was to collect it at locations in which these drivers would be stopped for at least three (3) hours in order for their tires to cool down to ambient temperature. It was decided that "trucker appreciation events" held the most promise for data collection. These events last for at least two days and truckers are encouraged to stay overnight, or at least for several hours, to visit exhibit booths and enjoy the entertainment, food, and other activities that are provided. Two large events were selected: the Walcott Truckers Jamboree and the Reno Truckerfest 2001. The Walcott Truckers Jamboree was held at the Iowa 80 Truckstop in Walcott, IA on July 12-13, 2001 and the Reno Truckerfest 2001 was held August 17-19, 2001 at the Alamo Travel Center in Sparks, NV outside of Reno.

In preparation for this event, 10x10 booths were reserved at both events. Two-part carbon-copy forms were printed for collecting tire pressures and advising drivers of their tire conditions. The forms requested the following information: Date, Location, Name of Inspector, Tractor Description and Parked Location (for ease of identifying and finding the vehicle), Targeted Air Pressure, Tire Size, Owner of both the Tractor and Trailer, Operation Type (Long-Haul, Regional, Short- Haul, P&D), and the Driver's Signature (permission). (See Exhibit 3.1)

[7] Increased tire temperature (normally caused by side-wall flexing while the vehicle is in motion) increased the air pressure inside the tire. This leads to an inaccurate measurement of tire pressure when surveying tires on vehicle that have only recently stopped. In general, 2-3 hours are required before inspection after the vehicle has stopped in order to allow tire temperatures to cool.

Exhibit 3.1 Survey Form



Form # :

Tire Pressure Check Program

Compliements of the Tire Debris Prevention Task Force

Technology & Maintenance Council (TMC) of the American Trucking Associations

DEMOGRAPHICS

Date:__________ Location: __________ Inspector:__________

Tractor Description: __________

Parked Location: __________

Targeted Air Pressure: __________ (psi) Tire Size: __________

Tractor Owner: ❑ O/O ❑ Fleet Trailer Owner: ❑ O/O ❑ Fleet

Operation Type: ❑ Long-Haul ❑ Regional ❑ Short Haul ❑ P&D

PRESSURE DATA

Driver Signature:

I grant permission for a free tire pressure check of the vehicle described above. I absolve the Technology & Maintenance Council (TMC) of the American Trucking Associations (ATA) of any liability associated with this free tire pressure inspection.

New inflation gauges were obtained, as well as valve caps for installing on tires that were missing the caps. Other tire tools were acquired for removing inside valve caps on aluminum wheels and for repairing leaking valve cores. Educational literature, stickers, and buttons used in the booths as handouts were also sourced from TMC, the International Tire & Rubber Association (ITRA), and the Tire Retread Information Bureau (TRIB). The literature generally discussed the importance of keeping tires inflated and advocated checking tire pressure before starting a trip. Posters and signage were printed for distribution around the truck stops and for display at the booths. Coupons for free tire pressure checks were also printed and given out to drivers along with their free meal coupons (provided by the event sponsors) to encourage them to have their tire pressures checked.

The following TMC Tire Debris Prevention Task Force member companies participated in these events by sending field service engineers to take and record tire pressure data:

- Bridgestone/Firestone, Inc.
- Continental/General Tire, Inc.
- Fleet Tire Consulting
- Goodyear Tire & Rubber Co.
- Hankook Tire Co.
- Innovative Transportation Products
- International Marketing Inc.
- Michelin North America
- Yokohama Tire Corp.

The methodology for collecting data was exact yet simple. Tire pressure gauges were calibrated immediately upon setting up the booths. Driver permission to check tire pressures was obtained in the booths or in the truck parking lots by their signing the 2-part tire forms. The time the driver parked his rig was noted. Vehicles were required to be parked at least 3 hours before pressures were checked.

The TMC volunteers broke into 2-person teams. One person gauged the tire pressures and the other recorded them on the tire form. Once completed, a copy of the form was given to the driver or left on the windshield while the original was retained for data collection purposes.

A total of 144 tractors and 38 trailers owned by owner-operators were inspected, and 85 tractors and 61 trailers owned by fleets were inspected at these two locations. However, since the target pressure of the tires was a critical piece of information, tire pressure data was only used on vehicles that the drivers' owned or were responsible for maintaining. Most fleet drivers were not certain or even aware of the target pressures their respective companies were running. The data collection team felt that researching such data on the individual fleet trucks sampled would be very time consuming, and might raise possible privacy issues. Therefore, data collected on fleet equipment was not used (separate data for fleets was collected as discussed in section 3.2).

The TMC Tire Debris Task Force then entered the data on the two-part forms into an Excel spreadsheet, which was later downloaded to a database (ACCESS) for analysis (*See Chapter 4).*

3.2 FLEET DATA

Bridgestone/Firestone, Inc., Michelin North America, International Marketing, Inc., and various TMC motor carrier members contributed both truck and bus fleet tire pressure survey information for this study. Tire pressure survey data was gathered for the following categories of carrier operations:

- ***Truck Load Carriers (TL).*** For-hire carriers that typically contract shippers for full truck load shipments. Vehicles often can be "on-the-road" (and away from a company maintenance centers) for weeks. Tire pressure inflation maintenance tends to be performed by the operator, by an independent service center (truckstop), and occasionally by "in-house" maintenance and service personnel.
- ***LTL Carriers (LTL).*** For-hire carriers that are typically contracted to haul less than truck load shipments. Vehicles tend to frequent company service garages more often than TL trucks. Thus, tire inflation service is often performed by garage service personnel as well as by the operator.
- ***Private Fleets.*** These are trucking operations that are owned and operated by the shipper. In the sample data supplied by TMC, many of the private fleet vehicles are actually straight trucks.
- ***Owner-Operator.*** An individual or very small business that owns less than 5 tractors (and most often, a single tractor). Contracts directly with shippers, other TLs, and/or LTL carriers to haul their trailers. Inflation maintenance for the tractor will typically be done by the operator, while trailer tire inflation maintenance is the responsibility of the trailer owner.
- ***Chartered Motor Coach.*** These are large (8 tire), over-the-road motor coaches that are used in long distance chartered service. Tire inflation maintenance will be done by either the operator, an independent shop (truck stop), or by the company's maintenance shops.
- ***Transit Bus.*** The data in this category are predominantly transit buses (6-tire) that are used in commuter and suburban service. Tire inflation maintenance is typically performed by the transit agency's maintenance garage personnel.

The fleet survey data was submitted to the Tire Debris Task Force in several formats. Some of the data was submitted electronically. The nomenclature in this data designating fleet type and operation had to be standardized, fleet names were coded to mask the actual fleets, and tire pressures where checked to ensure they were placed in the proper wheel positions in the data base.

The remainder of the data was submitted on copies of the actual forms that were completed for the fleet surveys. This information had to be entered into the computer by hand and was checked for accuracy as it was entered. This was also done by a member of the Tire Debris Task Force to ensure that the data was entered correctly, since each company's forms were different and vehicle configurations varied between truck and motor coach fleets. These forms typically contained fleet name, location, fleet size, vehicle number, target pressure, tire size, gauged air pressures, and notes on tire conditions. Some forms contained vehicle mileage, tire model, and stated whether the tire was a retread, but this information was not included on all forms. The companies that submitted this data were contacted to clarify questions regarding fleet size, fleet type, type of operation, and vehicle configurations to ensure the data was input correctly.

All data used in this study was collected in fleet surveys performed between January 2001 and December 2001.

The following data from the various fleet surveys was entered into a "master" database:

1. Coded Designation for Fleet Name
2. Fleet Type (Less than Truckload, Truckload, Private, Chartered Motor Coach, Transit Bus)
3. Fleet Size
4. Operation: Long-Haul (over 500 miles), Regional (250-500 miles), Short-Haul (under 250 miles), Pickup and Delivery/Local
5. Tire Size
6. Targeted air pressure for steer, drive, and trailer tires
7. Gauged tire pressures by wheel position for tractor, trailer, and motor coach vehicle configurations

No data regarding fleet name (other than a reference code), tire make, model, retread number (new or number of retreads), tread depth, tire condition, or other comments were included in this data. This information was not requested and had no bearing on the purpose of this study.

3.3 SAMPLE SIZE INFORMATION (METADATA)

This section provides an overview of the sample population in terms of number of fleets, number of *units* (tractors, trailers, or motor coaches), and the number of tires sampled from the sources documented in Sections 3.1 and 3.2. A complete breakdown of the sample data and supporting statistics is attached in Appendix B.

A total of 6,086 units and 35,047 tires were sampled. Of these 6,086 units, 3,261 were tractors, 1,300 were trailers, and 1,525 were motor coaches. There were 18,039 tractor tires sampled, 7,501 trailer tires sampled, and 9,507 motor coach tires sampled. Exhibit 3.2 summarizes this data.

Exhibit 3.2 Survey Data Summary by Vehicle Type

Type of Unit	Number of Units Sampled	Number of Tires Sampled
All Tractors	3,261	18,039
All Trailers	1,300	7,501
All Motor Coaches and Buses	1,525	9,507
Total	6,086	35,047

The survey data collected included designation by carrier type. Of the 3,261 tractors sampled there were 144 owner-operator tractors, 1,093 LTL tractors, 1,083 TL tractors, and 941 private carrier tractors sampled. A similar stratification can be done for trailers, motor coaches, and the tires sampled. Exhibit 3.3 below summarizes the vehicles and tires sampled by carrier type:

Exhibit 3.3 Survey Data Summary by Carrier Type

Carrier Type	Number of Tractors Sampled	Number of Tractor Tires Sampled
Owner-Operator	144	1,411
For-Hire LTL	1,093	6,014
For-Hire TL	1,083	6,383
Private Carrier	941	4,231
Carrier Type	**Number of Trailers Sampled**	**Number of Trailer Tires Sampled**
Owner-Operator	38	303
For-Hire LTL	923	4,551
For-Hire TL	294	2,302
Private Carrier	45	345
Carrier Type	**Number of Vehicles Sampled**	**Number of Vehicle Tires Sampled**
Transit Bus	1,123	6,786
Chartered Motor Coach	402	2,721

It should be noted that a large portion of the owner-operators do not own their own trailers, but rather pull trailers owned by the company whose particular load they are contracted to carry. Therefore, target tire pressure data was not available during surveys and only trailers owned by the vehicle operator were surveyed. In addition, a significant portion of the private carrier fleets sampled operated 6-wheeled straight trucks, therefore there were relatively few private carrier trailers sampled.

In addition to stratifying the data by carrier type, the data can also be listed by fleet operation: long-haul, short-haul, regional, and pickup and delivery operations. For instance, there were 1,588 long-haul tractors, 191 short-haul tractors, 797 regional tractors, and 685 pickup and delivery tractors sampled. Exhibit 3.4 shows the number of vehicles and number of tires sampled for each of these fleet operations:

Exhibit 3.4 Survey Data Summary by Fleet Operation

Fleet Operation	Number of Tractors Sampled	Number of Tractor Tires Sampled
Long-Haul	1,588	8,996
Short-Haul	191	1,040
Regional	797	5,111
Pickup & Delivery	685	2,892
Fleet Operation	Number of Trailers Sampled	Number of Trailer Tires Sampled
Long-Haul	611	3,714
Short-Haul	0	0
Regional	615	3,276
Pickup & Delivery	74	511

Finally, the sample data can also be organized by fleet size based on the number of *power units* the fleet operates. A *power unit* is defined as a vehicle that provides power for motion (i.e., tractors or motor coaches, but not trailers or dollies). Six (6) fleet size categories were utilized to stratify the data collected: 1 to 50 power units, 51 to 100, 101 to 500, 501 to 1,000, 1,001 to 3,000, and more than 3,000 power units. Exhibit 3.5 summarizes the survey data by fleet size.

Exhibit 3.5 Survey Data Summary by Fleet Size

Fleet Size (Number of *Power Units*)	Number of Tractors Sampled	Number of Tractor Tires Sampled
50 and less (excluding O-O)	329	1,332
51 to 100	720	2,391
101 to 500	1,227	7,234
501 to 1,000	248	2,121
1,001 to 3,000	296	1,947
Greater than 3,000	297	1,603
Fleet Size (Number of Power Units)	**Number of Trailers Sampled**	**Number of Trailer Tires Sampled**
50 and less (excluding O-O)	30	225
51 to 100	34	246
101 to 500	213	1,692
501 to 1,000	0	0
1,001 to 3,000	603	3,189
Greater than 3,000	382	1,846
Fleet Size (Number of Power Units)	**Number of Motor Coaches & Buses Sampled**	**Number of Motor Coach & Bus Tires Sampled**
50 and less	247	1,642
51 to 100	37	198
101 to 500	1,201	7,428
501 to 1,000	40	239
1,001 to 3,000	0	0
Greater than 3,000	0	0

Based on a comprehensive review of existing literature, as well as on discussions with tire OEMs, Fleets, Government agencies, and TMC, the sample data set supplied for this study represents, by far, the most complete and accurate gathering of tire pressure inflation data for commercial vehicles that is publicly available.

4.0 ANALYSES OF TIRE PRESSURE DATA

This chapter presents an analysis of the survey data (introduced in Chapter 3) in order to characterize the extent to which commercial vehicles are operated in the United States with improperly inflated tires. This chapter is organized as follows:

- A discussion of the various statistical techniques used to analyze the data,
- Detailed presentation of results by vehicle type, fleet type, and by vocation, and
- Key observations and conclusions.

Supporting statistical analysis and data are also provided in Appendix B.

4.1 ANALYSIS TECHNIQUES

Due to the large quantity, diversity, and complexity of the data collected, it became necessary to utilize multiple analytical techniques to better understand tire inflation conditions and maintenance practices on commercial vehicles. This section reviews the statistical techniques used in analyzing the data, and includes a discussion of:

- Development of a relational tire pressure database which allowed data to be categorized and queried rapidly;
- Use of targeted tire pressures along with actual (measured) tire pressures to allow accurate comparisons across multiple vehicles, fleets, and market segments;
- Statistical tools and parameters used for profiling tire inflation conditions and practices; and
- Use of confidence levels and intervals to characterize the statistical significance of the sample data.

4.1.1 Survey Tire Pressure Database

The first step in this analysis was to develop a relational database to manage the large volume of data. Records were stored in the database on a per vehicle basis. The following information was recorded for each tire in the database:

- Targeted tire pressure (see next section),
- Actual tire pressure,
- Difference between targeted and actual tire pressures, and
- Wheel location.

Each vehicle was classified by:

- Type of vehicle (tractor, trailer, or motor coach),
- Category (owner-operator, TL, LTL, private fleet, transit bus, or chartered motor coach),
- Fleet operation (long-haul, short-haul, regional, or P&D), and
- Fleet size.

Queries were designed to quickly sort and extract data for various market segments.

4.1.2 Target Tire Pressures

Tires in general have a set of "standard" or recommended inflation curves that depict the proper inflation pressure for that tire at a given load. Tire brand, size, and construction all factor into these inflation curves, therefore, each tire model has a unique set of inflation curves. The "target" inflation pressure that is used generally varies from driver to driver or fleet to fleet depending on the average load they carry and the type of operation. This makes any direct analysis of the actual tire pressure difficult.

To assist in the accurate comparison of tire pressures it was therefore necessary to gather two data points for each tire: actual tire pressure and the targeted tire pressure. Since most operators specify a steer tire target pressure, a drive tire target pressure, and a trailer tire target pressure, these values were also included in the database and the difference between the target tire pressure and the actual tire pressure at each wheel location was used in the analysis**. Unless specified differently, the data in the following sections and the remainder of this report refers to the difference between the actual tire pressure and the target tire pressures recorded.**

4.1.3 Reported Statistics

In general, for any given subset of the sample population (or market segment), statistics can be reported in two broad ways:

1) based on the number of tires sampled (i.e., statistics that focus on reporting the proportion of tires that are improperly inflated to varying degrees), and
2) based on the number of vehicles sampled (i.e., statistics that focus on reporting the proportion of vehicles with improperly inflated tires, along the number and degree of improperly inflated tires).

It became clear early in the investigation that in order to focus the analysis and compare maintenance practices across various market segments, it would be important to provide various reference or "rule-of-thumb" statistics that are meaningful to fleet operators. Based on discussions with fleet operators and tire manufacturers, key useful "reference" statistics include the following:

Tire-based statistics:

- Proportion of tires that are 20% or more underinflated. In general, fleets accept small deviations from the targeted pressure as "normal," but if a tire is 20% or more under-inflated, it would indicate the problem is more serious and likely the result of inadequate maintenance or quality control procedures.
- Proportion of tires that are 50% or more underinflated. This degree of underinflation would indicate a major tire failure, and would generally be considered a "flat" tire. The percentage of such tires within a fleet could be an

indication of a tire product or tire mounting problem, or a poor tire inflation maintenance program as indicated above.

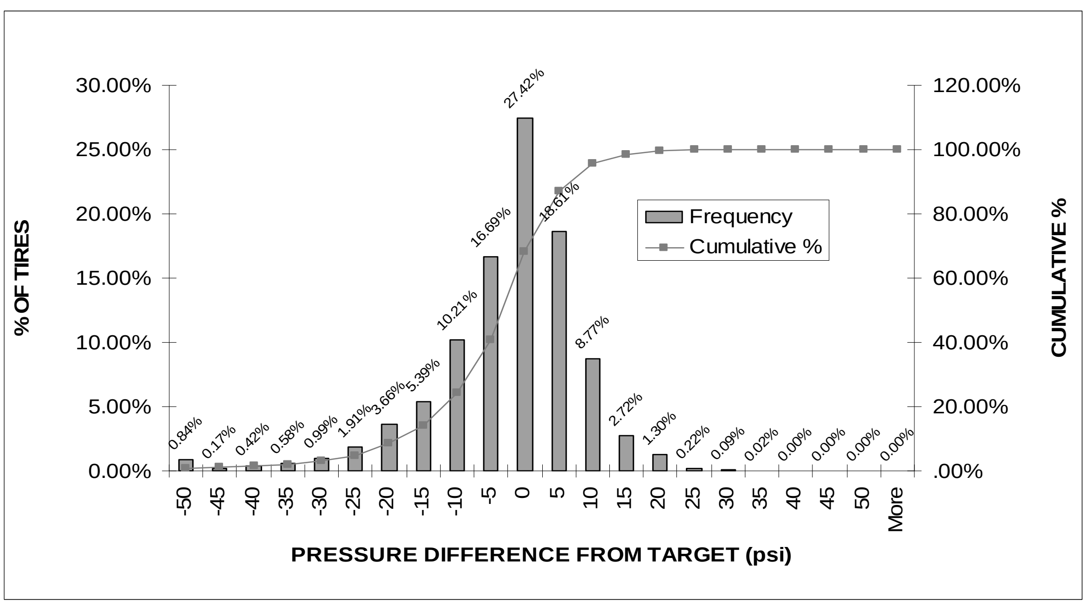
- <u>Proportion of tires that are within 5% of the targeted pressure</u>. Higher percentages indicate a well-executed tire maintenance program. It is generally accepted that a “good” fleet operator will have 70 percent or more of their tires within plus or minus 5% of the targeted pressure.
- <u>Proportion of tires that are 10% or more overinflated</u>. A high percentage of such tires might indicate that the fleet is systematically over inflating the tires to compensate for lack of a good quality control program. Since over-inflated tires also have negative impacts on tread wear, this is not considered a viable strategy.

Vehicle-based statistics.

- The proportion of vehicles which have one or more tires underinflated by 20 psi or more
- The proportion of vehicles which have four or more tires underinflated by 20 psi or more
- The proportion of vehicles which have one or more tires underinflated by 50 psi or more (considered flat)

These tire-based and vehicle-based statistics are simply convenient “point estimates,” which help quickly profile how well a fleet, or in the case of this study, a sub-segment of the market, is performing relative to tire inflation maintenance. In addition to these statistics we have also constructed complete inflation pressure histograms for various market segments as well as for the total sample population. Exhibit 4.1 below is an example histogram showing the distribution of tractor tire pressures surveyed:

Exhibit 4.1 Example Distribution Histogram of All Tractor Tires Surveyed



A complete record of the inflation statistics, histograms, and the supporting data used in this report can be found in Appendix B.

4.1.4 Confidence Levels and Statistical Significance

The previous discussion focused on how various reference point estimates (e.g., percentage of tires that are 20 psi or more under-inflated), as well as histograms and frequency distributions can be used to compare tire inflation results across various sets of data. A key question in any analysis involving sample data is how confident are we that the sample data is an accurate reflection of what is taking place in the actual (or total) population? In other words, how confident are we in the results of the analysis? In general, the level of confidence is linked to the total sample size as well as to the number of observations about a particular attribute of interest within the sample.

Sample distributions and sample proportions provide a clear method for analyzing sample data. However, they do not explicitly reveal the correlation between the sample data and the behavior or attributes of the actual population.

Properties of *normal* distributions can be used to relate survey data to the real-world population using a technique called *confidence interval estimation of the population proportion*. Using a measurement of a sample proportion, we will never be able to say what the exact population proportion is; however, we will be able to say that we have a certain confidence, defined as the *confidence level*, that the actual population proportion lies within a certain interval, the *confidence interval*. Unless otherwise specified, a *confidence level* of 95% is used throughout this report. Therefore, the *confidence interval* is equal to 1.96 times the standard deviation of the sample proportion; where the standard deviation of the sample proportion when discussing tire-based statistics, σ_P, is equal to:

$$\sigma_P = \sqrt{\frac{(1-f)}{n\overline{M}^2} \times \frac{\sum_{i=1}^{n}(y_i - \hat{p}M_i)^2}{n-1}}$$

Where p is equal to the sample proportion, n is equal to the number of units sampled, M_i is equal to the number of tires on vehicle i, M (with the bar) is equal to the average number of tires on each vehicle in the sample, y_i is equal to the number of tires on vehicle i which are match the inflation criteria of the sample (either 20 psi or more underinflated, within 5 psi of target, or 10 psi or more overinflated, and f is the sampling fraction equal to the sample size n divided by the size of the population N and is assumed to be 0 because N is very large. Therefore, the *confidence interval* estimate for a proportion, assuming a 95% *confidence level*, is equal to:

$$\pm\ 1.96 \times \sqrt{\frac{(1-f)}{n\overline{M}^2} \times \frac{\sum_{i=1}^{n}(y_i - \hat{p}M_i)^2}{n-1}}$$

For example, there were 3,261 tractors and 18,039 tractor tires sampled of which 8.46% (about 1 out of every 11 tires) are 20 psi or more underinflated. Using the equation above, the confidence interval of the population proportion is ± 0.70%, or:

$$8.46 \pm 1.96 \times \sqrt{\frac{(1-0)}{3261(5.53)^2} \times \frac{4122.78}{3261-1}}$$

A similar technique is followed for vehicle-based statistics with the standard deviation, σ_P, equal to:

$$\sigma_P = \sqrt{\frac{p\,(1-p)}{n}}$$

Where, *p* is equal to the sample proportion and *n* is equal to the number of vehicles sampled.

The remaining sections of this chapter profile tire inflation trends for various market segments using the "reference" proportion statistics described in section 4.1.3. Unless otherwise stated, each statistical point estimate is followed by the *confidence interval,* (e.g., 8.46 ±0.70%), where 8.46 is the proportion estimate and ±0.70 is the *confidence interval* around that proportion.

While specific confidence intervals are reported for all key statistics, the above sample analysis for the entire population of tires clearly demonstrates that the sample tire inflation data set used for this study is indeed very large, and allows for highly reliable analyses of the tire inflation conditions on commercial vehicles.

In addition to reporting the various reference statistics previously described, we also felt it was extremely important and relevant to list the standard deviations associated with the various point estimates. The standard deviation is essentially a measure of the variability of the data, and can therefore be useful for "qualifying" a point estimate. For example, two segments of the market may exhibit tire pressure statistics that are nearly identical in terms of average inflation rates. However one segment may have much more variability in the measured tire inflation pressures, and therefore experience greater negative impacts due to improper tire inflation, even though the average tire inflation pressure was identical. *Essentially, higher standard deviations (from the target pressure) indicate a lack of quality control (or consistency) in tire maintenance procedures.*

4.2 TIRE INFLATION SURVEY RESULTS

This section summarizes the statistical analysis of the sample data using the tools and techniques discussed in Section 4.1.

4.2.1 Overall Results: Tractors, Trailers, and Motor Coaches

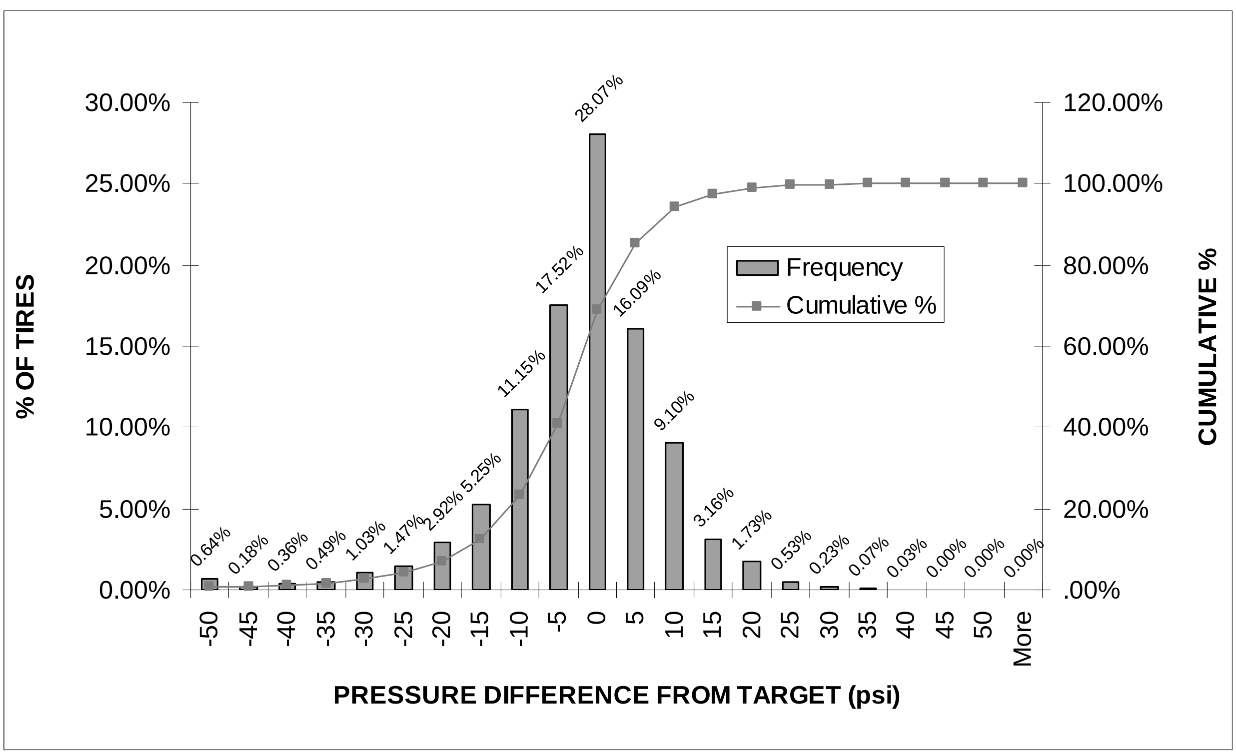
The survey sampled a total of 6,086 vehicles, which includes tractors, trailers, and motor coaches. The data shows that 19.68% of all vehicles, or approximately 1 out of 5, have at least one tire that is 20 psi or more underinflated and 3.14% of all vehicles have 4 or more tires underinflated by 20 psi or more. In addition, the survey data shows that 3.35% of all vehicles have one or more tires underinflated by 50 psi or more (considered flat). Exhibit 4.2 shows the percentage of tractors, trailers, and motor coaches that fall into one these three categories of improper inflation.

Exhibit 4.2 Vehicle-based Inflation Statistics

	Percentage of vehicles with 1 or more tires underinflated by 20+ psi	Percentage of vehicles with 4 or more tires underinflated by 20+ psi	Percentage of vehicles with 1 or more tires underinflated by 50+ psi
All Vehicles	19.68 ±1.00%	3.14 ±0.44%	3.35 ±0.45%
Tractors	21.62 ±1.41%	3.47 ±0.63%	3.68 ±0.65%
Trailers	18.69 ±2.12%	3.00 ±0.93%	2.92 ±0.92%
Motor Coaches	16.39 ±1.86%	2.56 ±0.79%	3.02 ±0.86%

A total of 35,047 tires were surveyed (including all tractor, trailer, and motor coach tires). Exhibit 4.3 shows a histogram chart for the total sample population.

Exhibit 4.3 Distribution of All Tires Surveyed



The mean (average) tire pressure was 3.58 psi below target, with a sample standard deviation of 11.51 psi, indicating a relatively large variation in tire inflation practices. Exhibit 4.3 also shows that 7.08% of all tires in the study, or 1 out of every 14, were 20 psi or more underinflated. In addition, only 44.15%, less than half, of all tires measured within ±5 psi of target. As previously noted on page 4-3, a "good" fleet will often have 70 percent or more of their fleet tires measure within ±5 psi of target. The data for the entire population also shows that 5.74% of all tires are overinflated by more than 10 psi, which leads to increased tread wear and vulnerability to tread surface cutting, impact breaks, punctures, and shock damage. Combined, these data generally point to a tire pressure maintenance issue among the commercial vehicle population. A detailed breakdown of the supporting data for Exhibit 4.3 can be found in Appendix B.

Exhibit 4.4 shows the proportions of tractor, trailer, and motor coach tires that are 20 psi and more underinflated, between ±5 psi of target, and overinflated by more than 10 psi.

Exhibit 4.4 Tire Inflation Statistics: All Vehicles

	Standard Deviation (PSI)	20+ psi Underinflated (percent)	±5 psi from Target (percent)	Greater Than 10 psi Overinflated (percent)
All Tires	11.51	7.08 ±0.45%	44.15 ±0.80%	5.74 ±0.44%
All Tractor Tires	11.69	8.46 ±0.70%	46.08 ±1.30%	4.35 ±0.70%
All Trailer Tires	11.26	6.55 ±0.95%	37.93 ±1.76%	5.49 ±1.16%
Motor Coach Tires	11.22	4.89 ±0.65%	45.40 ±1.54%	8.58 ±1.27%

Several conclusions can be drawn from Exhibit 4.4. Motor coaches show a tendency toward overinflation (with 8.58% overinflated by more than 10 psi and only 4.89% underinflated by 20 psi or more), while tractors and trailers show a tendency toward underinflation. The average tractor tire is underinflated by 4.26 psi and the average trailer tire is underinflated by 4.01 psi, while the average motor coach tire is only underinflated by 2.12 psi (shown in Appendix B, pages B-10, B-32, and B-50). Exhibit 4.4 also illustrates that tractors have a larger percentage of tires underinflated by 20 psi or more than do trailers, however, trailer tires have a larger degree of variability in their tire pressures than tractors, since only 37.93% of trailer tires are within ±5 psi of their target pressure compared with 46.08% for tractor tires.

4.2.2 Results by Carrier Type

Tractor and trailer tires can further be subdivided into categories based on the type of carrier: Owner-Operator, LTL, TL, or Private Carriers. In addition, data was collected for the two categories of bus operations, chartered motor coach, and transit bus. Exhibit 4.5 summarizes the tire inflation statistics for these categories:

Exhibit 4.5 Tire Inflation Statistics by Carrier Type

	Standard Deviation (PSI)	20+ psi Underinflated (percent)	±5 psi from Target (percent)	Greater Than 10 psi Overinflated (percent)
Tractors	**Tractor Tires**			
Owner-Operator	11.45	4.11 ±1.29%	43.94 ±4.67%	8.93 ±3.06%
LTL Carrier	12.18	7.27 ±1.21%	48.67 ±1.82%	3.81 ±0.73%
TL Carrier	9.92	7.41 ±0.98%	46.98 ±2.24%	1.35 ±0.61%
Private Carrier	13.13	13.21 ±1.83%	41.76 ±2.42%	8.13 ±1.54%
Trailers	**Trailer Tires**			
Owner-Operator	10.26	3.63 ±2.73%	39.27 ±8.23%	12.21 ±6.33%
LTL Carrier	11.20	5.19 ±0.89%	39.86 ±1.95%	6.86 ±1.28%
TL Carrier	10.56	8.69 ±2.28%	32.67 ±3.23%	2.35 ±0.81%
Private Carrier	13.92	12.75 ±5.92%	46.38 ±7.47%	2.61 ±2.53%
Motor Coach & Bus	**Motor Coach & Bus Tires**			
Transit Bus	9.52	3.09 ±0.58%	49.88 ±1.48%	4.72 ±0.87%
Chartered Motor Coach	14.54	9.37 ±1.63%	34.22 ±2.41%	18.23 ±2.42%

In Exhibit 4.5 above, 13.21% of private carrier tractor tires were underinflated by 20 psi or more, compared to 4.11% of owner-operator tractor tires, 7.27% of LTL carrier tractor tires, and 7.41% of TL carrier tractor tires. The survey data illustrate that private carriers, in general, have significantly worse tractor tire inflation than TL carriers, LTL carriers, and owner-operators.

The motor coach survey data in Exhibit 4.5 also show that transit bus operations have significantly better tire pressure maintenance than chartered motor coach operations. Exhibit 4.5 shows that chartered motor coaches have a higher proportion of tires than transit buses, 9.37% compared to 3.09%, which are 20 psi or more under-inflated, and chartered motor coaches have only 34.22% of tires between ±5 psi of target, while transit buses have 49.88%.

4.2.3 Results by Fleet Operation

Exhibit 4.6 shows tractor and trailer tire inflation statistics categorized by fleet operation: pickup and delivery, regional, short-haul, and long-haul.

Exhibit 4.6 Tire Inflation Statistics by Fleet Operation

	Standard Deviation (PSI)	20+ psi Underinflated (percent)	±5 psi from Target (percent)	Greater Than 10 psi Overinflated (percent)
	Tractor Tires			
Pickup & Delivery	13.36	14.21 ±1.99%	40.15 ±2.58%	3.18 ±0.85%
Regional Fleet	11.31	6.34 ±1.17%	53.28 ±2.16%	3.97 ±0.87%
Short-Haul Fleet	11.79	4.52 ±1.28%	53.94 ±4.77%	8.08 ±2.76%
Long-Haul Fleet	11.04	8.28 ±1.03%	43.00 ±1.81%	4.51 ±0.91%
	Trailer Tires			
Pickup & Delivery	7.79	1.17 ±0.86%	41.68 ±7.29%	16.05 ±6.54%
Regional Fleet	10.43	8.15 ±1.31%	37.48 ±2.30%	0.76 ±0.40%
Long-Haul Fleet	11.32	5.87 ±1.51%	37.80 ±2.36%	8.21 ±1.34%
	Motor Coach & Bus Tires			
Local Fleet	10.78	3.95 ±0.72%	40.27 ±1.48%	6.34 ±1.14%
Regional Fleet	8.25	2.37 ±0.95%	62.71 ±2.75%	7.91 ±1.70%
Long-Haul Fleet	15.37	11.50 ±2.19%	33.47 ±3.15%	16.05 ±3.24%

Exhibit 4.6 shows that pickup and delivery fleets have a significantly larger proportion of tractor tires 20 psi or more underinflated (14.21%) than long-haul (8.28%), short-haul (4.52%), and regional (6.34%) fleets. Pickup and delivery fleets also show the lowest percentage of tractor tires within ±5 psi of target, 40.15%, and the highest standard deviation of 13.36 psi. Combined, this data indicates that pickup and delivery fleets' tire inflation maintenance is not as rigorous as regional, short-haul, and long-haul fleets operations.

Long-haul motor coach tires appear to have very poor tire pressure maintenance programs, with 11.64% of their tires underinflated by 20 psi or more, only 33.47% of their tires within ±5 psi of target, and 16.05% of tires overinflated by more than 10 psi. Additionally, the standard deviation of measured tire pressures for long-haul motor coach fleets (15.37) was significantly larger than any other category.

4.2.4 Results by Fleet Size

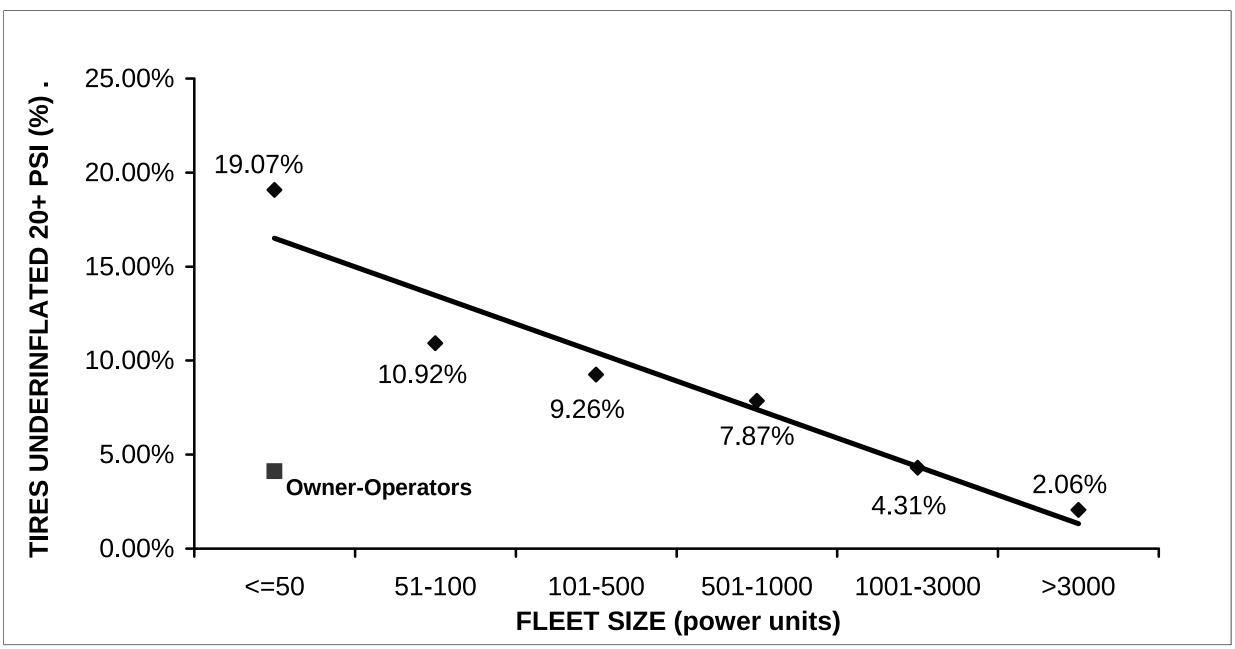
Another important factor, which impacts tire inflation maintenance practices, is fleet size (i.e., the total number of power units operated by a fleet). Exhibit 4.7 on the following page shows tractor tire statistics stratified by fleet size.

Exhibit 4.7 Tractor Tire Inflation Statistics by Fleet Size

Number of Power Units	Standard Deviation (PSI)	20+ psi Underinflated (percent)	±5 psi from Target (percent)	Greater Than 10 psi Overinflated (percent)
Owner-Operators	11.45	4.11 ±1.29%	43.94 ±4.67%	8.93 ±3.06%
50 and less	15.72	19.07 ±4.31%	37.09 ±3.86%	5.11 ±1.44%
51 to 100	11.79	10.92 ±2.05%	36.97 ±2.93%	2.05 ±1.00%
101 to 500	11.41	9.26 1.04%	44.91 ±1.99%	3.86 ±0.93%
501 to 1,000	11.74	7.87 ±2.30%	54.46 ±3.43%	7.17 ±1.81%
1,001 to 3,000	8.46	4.31 ±1.20%	52.03 ±3.70%	0.72 ±0.50%
Greater Than 3,000	9.69	2.06 ±0.74%	56.02 ±3.39%	6.01 ±1.87%

Exhibit 4.7 shows a clear pattern between low tire inflation and the size of the fleets. Small fleets, less than 50 power units, have 19.07% of their tires underinflated by 20 psi or more, while fleets with more than 3,000 power units have lowest percentage of tires underinflated 20 psi or more, 2.06%. Exhibit 4.8 shows a graphical representation of this data and the associated trend line.

Exhibit 4.8 Fleet Size Relationship To Underinflation



Data collected in this study appears to indicate a strong correlation between fleet size and tire pressure maintenance. In addition to the proportion of tires underinflated decreasing as fleet size increases, the proportion of tires maintained to within ±5 psi of target increases as fleet size increases. This also suggests that larger fleets in general have better tire pressure maintenance practices. It should be noted that since the maintenance practices of owner-operators are significantly different than those of most fleets, for clarity, owner-operator tires have been excluded in the statistics (and not included in calculating the trend line) for fleets of 50 or fewer power units in Exhibits 4.7 and 4.8 but are shown separately.

Bus tire inflation trends (both transit bus and motor coaches) behave in a similar manner to that of tractors relative to fleet size. Exhibit 4.9 below shows that bus fleets with less than 50 power units have 11.75% of tires underinflated by 20 psi or more, while bus fleets with 501 to 1,000 power units have only 2.09% of their tires that are 20 psi or more underinflated.

Exhibit 4.9 Bus Tire Inflation Statistics by Fleet Size
(Transit buses and over-the-road motor coaches)

Number of Power Units	Standard Deviation (PSI)	20+ psi Underinflated (percent)	±5 psi from Target (percent)	Greater Than 10 psi Overinflated (percent)
less than 50	14.92	11.75 ±2.31%	35.51 ±3.37%	15.16 ±3.46%
51 to 100	16.22	5.56 ±3.45%	26.26 ±6.78%	16.67 ±4.79%
101 to 500	10.10	3.45 ±0.60%	47.90 ±1.44%	7.19 ±0.99%
501 to 1,000	8.94	2.09 ±1.62%	51.46 ±6.81%	0.00 ±0.00%

It is interesting to note that trailers (Exhibit 4.10) do not show a similar pattern with regard to the impact of fleet size on tire pressure maintenance practices. It should be noted that the data in Exhibit 4.10 was assembled for trailer tires, but the fleet size designation was based on the number of power units (tractors) operated by the fleet.

Exhibit 4.10 Trailer Tire Inflation Statistics by Fleet Size

Number of Power Units	Standard Deviation (PSI)	20+ psi Underinflated (percent)	±5 psi from Target (percent)	Greater Than 10 psi Overinflated (percent)
Owner-Operator	10.26	3.63 ±2.73%	39.27 ±8.23%	12.21 ±6.33%
50 and less	14.92	19.11 ±8.25%	34.67 ±9.74%	0.00 ±0.00%
51 to 100	8.88	1.22 ±1.26%	61.38 ±8.02%	3.66 ±3.45%
101 to 500	7.79	1.36 ±0.50%	35.46 ±3.95%	2.36 ±0.97%
1,001 to 3,000	10.69	11.98 ±1.88%	33.77 ±2.29%	0.53 ±0.30%
Greater than 3,000	9.82	1.57 ±0.71%	44.42 ±3.14%	16.74 ±2.72%

4.2.5 Results by Tire Location

It was also possible to analyze tires based on their location on the vehicle: steer vs. drive, left-side vs. right-side, and tires located on the inner position of duals vs. tires located at the outer position of the duals. These results are summarized in Exhibit 4.11 (trailers) and 4.12 (tractors).

Exhibit 4.11 Trailer Tire Statistics By Wheel Location

	Standard Deviation (PSI)	20+ psi Underinflated (percent)	±5 psi from Target (percent)	Greater Than 10 psi Overinflated (percent)
Trailer Tires (all)	11.26	6.55 ±0.95%	37.93 ±1.76%	5.74 ±0.44%
Left-Side	11.11	6.31 ±1.11%	37.34 ±1.74%	5.40 ±0.96%
Right-Side	11.41	6.78 ±0.98%	38.51 ±1.66%	5.58 ±0.95%
Inner Dual Position	11.36	7.27 ±1.10%	37.72 ±1.69%	4.98 ±0.91%
Outer Dual Position	11.16	5.84 ±0.98%	38.13 ±1.61%	6.00 ±0.97%

Exhibit 4.12 Tractor Tire Statistics By Wheel Location

	Standard Deviation (PSI)	20+ psi Underinflated (percent)	±5 psi from Target (percent)	Greater Than 10 psi Overinflated (percent)
Steer Tires	11.06	8.45 ±0.89%	45.44 ±1.23%	3.72 ±0.61%
Drive Tires	11.95	8.47 ±0.91 %	46.37 ±1.40%	4.63 ±0.73%
Left-side	11.56	8.40 ±0.76%	46.23 ±1.23%	4.40 ±0.61%
Right-side	11.82	8.53 ±0.74%	45.94 ±1.22%	4.31 ±0.61%
Inner Dual Position	12.44	8.99 ±1.00%	46.50 ±1.41%	4.26 ±0.74%
Outer Dual Position	11.43	7.96 ±0.91%	46.23 ±1.40%	4.99 ±0.80%

One common hypothesis about tire inflation is that steer tires are better maintained than drive tires. Exhibit 4.12 suggests that there is not a significant difference in maintenance and monitoring of steer tires vs. drive tires with 8.45% of steer tires and 8.47% of drive tires being underinflated by 20 psi or more and 45.44% and 46.37% of steer and drive tires between ±5 psi respectively.

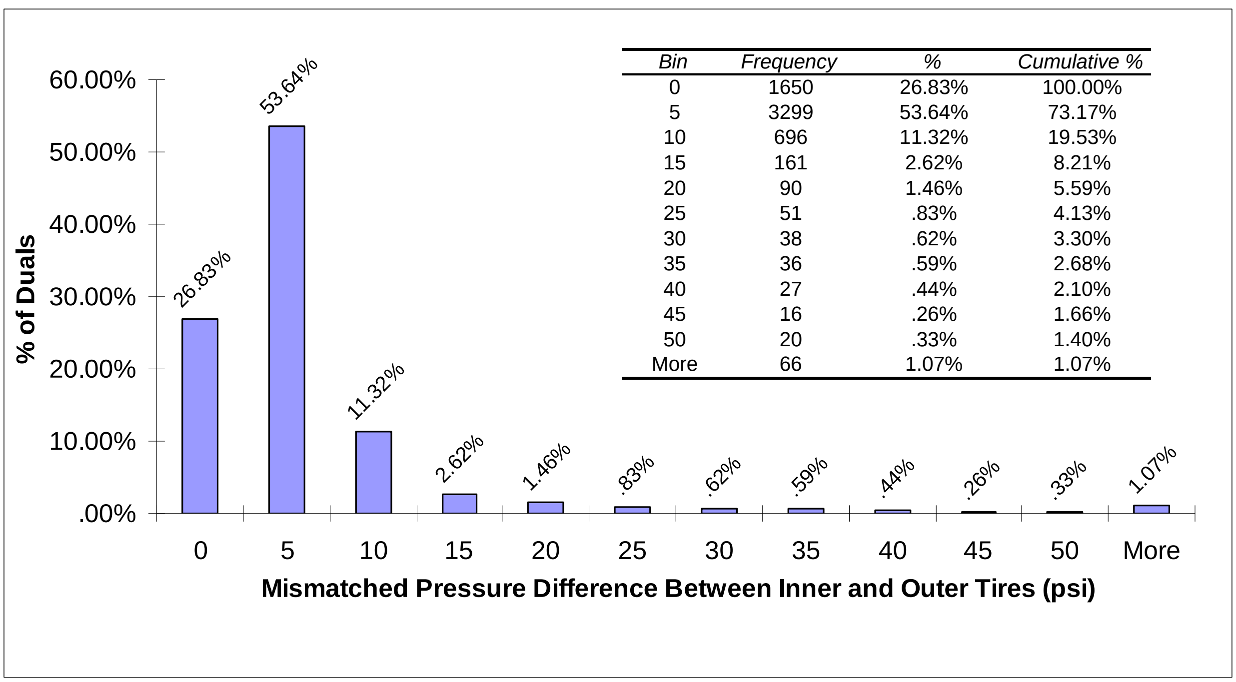
In addition, the proportion of tractor-trailer left-side tires, which are underinflated by 20 psi or more, are very similar to the proportion of tractor-trailer right-side tires, which are also 20 psi or more underinflated, dispelling another hypothesis that left-side tires have better tire pressure inflation because they are on the driver’s side of the vehicle and are monitored more closely. The proportion of tires between ±5 psi and the proportion of tires that are overinflated by more than 10 psi does not vary significantly between left and right locations.

Finally, another common belief is that inside tires (on a dual assembly) are not maintained as well as the outer tires because they are more difficult to monitor and service. However, survey data indicates that for both tractor and trailer dual assemblies, only a slight difference in tire pressure conditions exists between tires located on the outer versus inner position. For tractors, the inside position showed 8.99% of the tires were 20 psi or more underinflated, while the outside position showed 7.96% of tires to be 20 psi or more underinflated. In addition, the proportion of tires that are between ±5 psi of target is almost identical, at 46.50% and 46.23% for inners and outers respectively. Data for trailers shows a similar trend.

4.2.6 Unbalanced Inflation on Dual Tire Assemblies

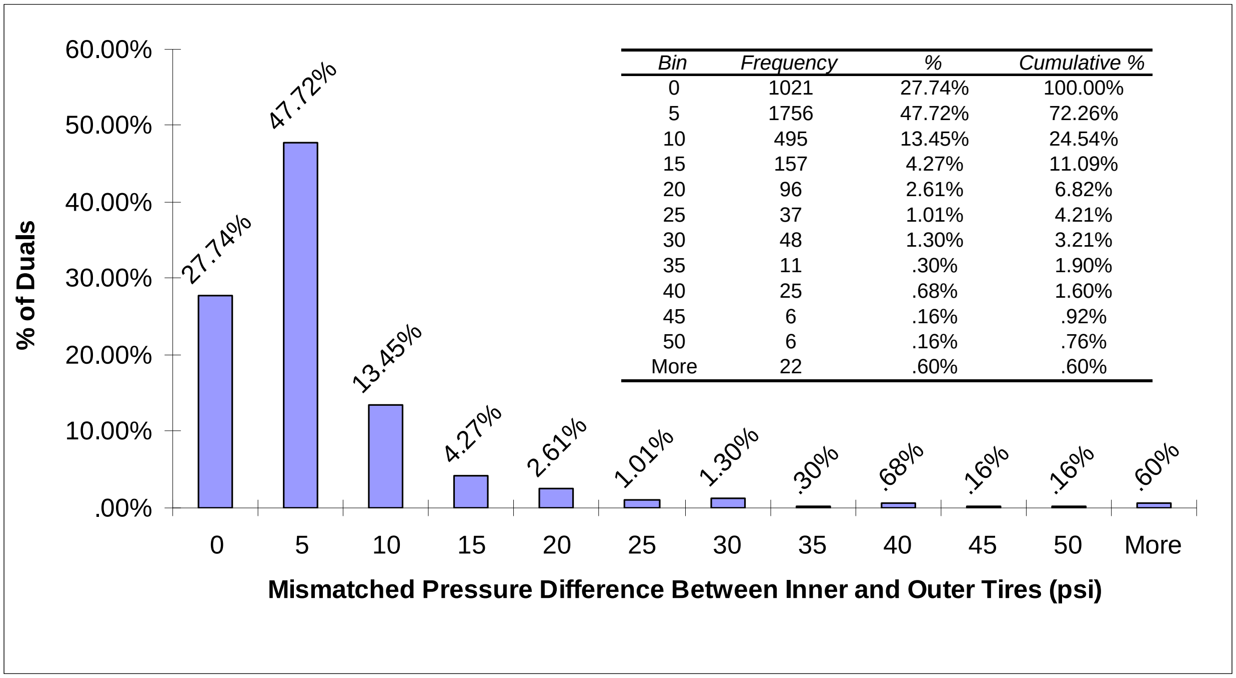
To further examine the tire inflation characteristics of duals, it was necessary to analyze the inflation differences between tires located on the same dual assembly. Exhibits 4.13 and 4.14 show histograms of the difference in inflation pressure of dual assemblies on tractors (drive axle duals) and trailers (trailer axle duals) respectively.

Exhibit 4.13 Distribution of Tractor Tire Duals



Bin	*Frequency*	*%*	*Cumulative %*
0	1650	26.83%	100.00%
5	3299	53.64%	73.17%
10	696	11.32%	19.53%
15	161	2.62%	8.21%
20	90	1.46%	5.59%
25	51	.83%	4.13%
30	38	.62%	3.30%
35	36	.59%	2.68%
40	27	.44%	2.10%
45	16	.26%	1.66%
50	20	.33%	1.40%
More	66	1.07%	1.07%

Exhibit 4.14 Distribution of Trailer Tire Duals



Bin	*Frequency*	*%*	*Cumulative %*
0	1021	27.74%	100.00%
5	1756	47.72%	72.26%
10	495	13.45%	24.54%
15	157	4.27%	11.09%
20	96	2.61%	6.82%
25	37	1.01%	4.21%
30	48	1.30%	3.21%
35	11	.30%	1.90%
40	25	.68%	1.60%
45	6	.16%	.92%
50	6	.16%	.76%
More	22	.60%	.60%

Exhibit 4.13 shows that almost 20% (1 in 5) tractor dual-tire assemblies have tires with mismatched air pressures by more than 5 psi. The exhibit also shows that only 26.83% of dual assemblies have tires that measure equal pressure in both tires. This data suggests that the use of pressure equalizing devices could significantly reduce the problem of mismatched duals. In addition, exhibit 4.14 shows that trailer dual assemblies have a similar problem (actually slightly worse) with mismatched tire pressures. Exhibit 4.14 shows that almost 25% of trailer-dual assemblies have tires with mismatched air pressures greater than 5 psi. This means that, on average, <u>every</u> trailer (with 4 dual assemblies) has one dual assembly where the tire pressures are mismatched by more than 5 psi.

4.3 Tire Pressure Survey Observations And Conclusions

The following summarizes the key observations and conclusions regarding tire inflation condition and maintenance practices of commercial motor vehicles:

- Just under half (44.15 percent) of all tires are within ±5 psi of their target pressure. Approximately 7.08 percent of all tires are underinflated by 20 psi or more,
- For-hire carriers' (LTL, TL, and owner-operators) vehicles generally reflected better tire inflation maintenance practices than private carriers' vehicles. As a group, for-hire carriers sampled had 7.01% of all tractor tires underinflated by

20 psi or more. In contrast, the private carriers sampled had 13.21% of all tractor tires underinflated by 20 psi or more,

- Tire inflation maintenance practices correlate closely with the size of the fleet. For tractors, fleets with 50 power units or fewer have 19.07% of their tires underinflated by 20 psi or more, while fleets with more than 3,000 power units have only 2.06% of their tires underinflated by 20 psi or more. Similarly, motor coach fleets with less than 50 power units have 11.75% of their tires underinflated by 20 psi or more, while fleets with over 500 power units have only 2.09% of their tires underinflated by 20 psi or more,

- Transit bus operators have better tire pressure maintenance than chartered motor coach operators based on the sample data. Only 3.09% of transit bus tires are underinflated by 20 psi or more, while 9.37% of chartered motor coach tires are underinflated by 20 psi or more. Additionally, 49.88% of transit bus tires are within ±5 psi of target (a very high percentage), compared with only 34.22% of chartered motor coach tires, and

- Tractors and trailers have a significant challenge with mismatched dual tires. Approximately 20% of all tractor dual tire assemblies have tires that differ in pressure by more than 5 psi. One out of four trailer dual assemblies (25%) have tires that differ in pressure by more than 5 psi.

5.0 OVERVIEW OF TIRE MONITORING AND INFLATION PRODUCTS

There are numerous commercially available products designed to simplify or automate tire inflation maintenance. The majority of these are for the passenger/light truck market, but there are many that are engineered specifically for the heavy, commercial truck market as well. (The TREAD Act has mandated the use of Tire Pressure Monitoring Systems, TPMS, for the light-duty market, and NHTSA has conducted extensive research on the operation, accuracy, and reliability of such products. See Docket No. NHTSA 2000-8572 for additional information on tire pressure monitoring products for light-duty vehicles.)

A fairly large selection of products and systems targeted at enhancing tire pressure maintenance have been available to fleet operators for many years and have been deployed with varying degrees of success. This section reviews the major categories of products available to carriers, and provides summary comments regarding carriers' experiences with using such products. This section is organized as follows:

5.1 Dual Tire Pressure Equalizers
5.2 Tire Pressure Monitors
5.3 Integrated "Tire Tags"
5.4 Tire Inflation Systems
5.5 Fleet Experience with Tire Pressure Monitoring and Inflation Products

Note: Appendix A presents brief descriptions of specific products and systems from various manufacturers. These descriptions are offered to help generally categorize and describe the type of products available in each of the respective categories. The listings are not meant to be 100% comprehensive, nor should they be taken as an endorsement of any particular product. The information presented in Appendix A is gathered from manufacturers sales literature, and no independent testing of the products have been performed as part of this study.

5.1 DUAL TIRE PRESSURE EQUALIZERS

Tire pressure equalizers are designed to simplify tire pressure maintenance by equalizing the pressure between two tires of a dual assembly, thus reducing irregular tire wear and rolling resistance and improving fuel economy.

Tire pressure equalizer systems equalize dual tire pressure by allowing air to transfer from one tire to another as they run down the road. This is accomplished by the use of two hoses that are plumbed to a check valve and each attaches to the valve stem of a dual tire. The check valve is attached to the hub. The valve opens to allow airflow between the tires, but closes and shuts the air off in case of an instantaneous air loss, which prevents both tires from going flat. In a slow leak situation, the valve isolates both tires after a pressure drop of approximately 10 psi. Since a central valve is located in these devices, a single airing point is provided that eliminates the need to remove the hoses to add air to the tires and makes airing the tires easier, since both tires in the assembly are aired at the same time.

Theses systems also provide a visual indicator of air pressure conditions in the tires that can be seen from about 20 feet away. They do not provide actual inflation pressures, but provide different types of "go/no-go" gauges that can easily display whether the tires are underinflated, over-inflated or at the correct pressure. This display feature is the primary difference between these systems.

The problem with tire pressure equalizers is that after one or two years, the accuracy of the valves deteriorates as their internal diaphragms wear. Hose breakage can also be a maintenance issue. Pressure equalizer systems from Dual Dynamics, Link Manufacturing, and Shrader-Bridgeport are reviewed in Appendix A.

5.2 TIRE PRESSURE MONITORS

There are several types of tire pressure monitoring systems that have been available to carriers for several years. These systems can be categorized into the following types:

- Valve Stem Mounted Tire Pressure Monitors, and
- Wheel Mounted Tire Pressure Monitors.

All of these systems monitor tire pressure through a device that senses the pressure and forwards a radio frequency (RF) signal to a display of some kind, which may be located in the tractor cab, a hand-held unit, or in a more remote location. Many systems also monitor temperature and convert the actual hot tire pressure to cold pressure so that meaningful data is related to the user. Available products cover a wide range of feature and price points. Typical costs for such systems range from about $400 to $1,200 to outfit an 18-wheel commercial vehicle.

In the past, reliability has been a problem with many of these systems. Drivers have reported that occasional false readings may result and the alarms must be reset to see if they repeat. There is the fear that tire pressure monitoring systems are less reliable than the tires they monitor. If these systems give excessive false readings, drivers may just ignore them.

Our review of such products, however, suggests that manufacturers continue to heavily invest in research and development to improve reliability, enhance functionality, and reduce costs. Products from Advanced Maintenance Technologies, Dana Spicer, Fleet Specialties, REA Technologies, Sensatec, SmarTire Systems, and WABCO are briefly reviewed in Appendix A.

5.3 INTEGRATED "TIRE TAGS"

While they are not yet commercially available, the most advanced approach for monitoring tire pressures involves the use of so-called electronic "tags" that would be imbedded directly into the carcass of a tire. All major tire manufacturers are actively engaged in research and development related to these devices. Key targeted features of the tire tag concept include:

- Complete integration of a sensor/transmitter/receiver in a single electronic device,
- Extremely lightweight and small packaging,
- Ability to withstand high temperature, shock, and vibration environment,
- No batteries—"powered" by an external electronic signal,
- Ability to sense pressure and temperature, and monitor these parameters continuously, and
- Ability to "permanently" record various tire related data such as; a unique ID number for each tire, incidences of low and high pressure, incidences of low and high temperature, and other service related data that a fleet user may choose to record on the tag, such as retread number, retread DOT code, tread design, and repair data.

For most fleet operators, an electronic tag imbedded directly into the tire carcass that was reliable, accurate, did not require batteries, and required no maintenance would represent a near ideal technical solution for tire monitoring as long as the cost impact was "reasonable."

For competitive reasons, tire manufacturers are unable to share details concerning the design features, costs, and availability of electronic tire tags. The most publicly available information is offered by a UK company called Transense Technologies. Transense is a "technology transfer" firm that is often contracted to perform specialized R&D and product development for other larger companies. Transense claims to be the originator of the concept of using Surface Acoustic Wave (SAW) devices to remotely, and in a non-contact manner, measure torque, temperature, and strain in objects. They are actively engaged in the development of electronic tags and have joint venture agreements with tire manufacturers, as well as large-scale electronics suppliers.

The SAW device is basically a small chip impregnated on a piece of quartz. The circuit is physically configured similar to the shape of two combs with the "fingers" of each comb interlaced and parallel to each other at precise distances. The SAW device can be affixed to an object such that the distances between the "fingers" of the circuit are distorted by changes in pressure, temperature or strain. The SAW device is then electronically excited by a very low power external signal (less than 10 millivolts). The SAW device then acts as a resonator and reflects back a signal proportional to the arrangement of the "fingers" of the circuit. The relative distances between the "fingers" of the circuit impacts the resonance frequency and hence alters the characteristics of the reflected wave. This relationship can be mapped for various stimuli, so that difference in the reflected wave can be used to measure pressure, temperature, strain, torque, or any other input that would cause the SAW to physically distort.

For the tire tag application, one or more SAW devices (one for temperature, another for pressure, and another to act as a reference signal) would be packaged into an integrated circuit about the size of a common shirt button. This would then be integrated into the tire carcass. An external excitation signal would be generated by a small transmitter/receiver that may be located in the wheel-well. The transmitter/receivers (from multiple wheel-wells) could then be linked together and the information routed to an in-cab display. Alternatively, the system could be designed to be queried by a hand-held device, a gate reader, or, the information could be off-loaded from the vehicle to a central location using satellite, cell phone, or 802.11 technology.

The SAW devices themselves are inexpensive (less than $1.00), but the packaging, calibration, and circuit integration along with the associated transmitters/receivers will drive up the price of a complete system. As noted, no systems are commercially available, but tire manufacturers have suggested that prototype testing is underway and products are likely to be available in the near future.

5.4 TIRE INFLATION SYSTEMS

There are basically two types of tire inflation systems. The first type uses air from the vehicle's air system to inflate the vehicle's tires. These systems are generally referred to as central tire inflation systems. The second type uses a pump of some kind that is separate from the vehicle's air system to generate air. These systems are referred to as continuous tire pressure pumps.

Central tire inflation systems take the air that is stored in the air brake wet tanks on a vehicle and use it to supply air to the tires. This can be done on demand or automatically triggered through sensors that monitor tire pressure. These systems can be broken down into two types: constant and variable. Constant systems maintain tire pressure at a single preset level. They eliminate the need to check tire pressure manually and allow a vehicle to remain in-service despite small air leaks in one or more of its tires. Constant tire inflation systems have no involvement from the driver. They automatically sense the pressure in the tires and inflate as necessary when they lose air. A drawback to these systems is that the external hoses can get damaged and render the systems ineffective, and could cause the tires to deflate.

Variable central tire inflation systems can raise or lower tire pressures during vehicle operation to compensate for varying load and road conditions in addition to maintaining tire pressure. These systems allow the driver to interact with the system and change tire pressure on demand. They are expensive and are usually used for on/off-road operations such as logging, construction, mining, gravel hauling, concrete, exploration, and military activities.

In general, automatic tire inflation systems as described above appear to operate as promised as have been well received by fleets that have purchased them. As with tire monitoring systems, there is a large range of features and prices among this group of products. Prices range from about $700 for a simple tractor-only system to just over $3,000 for sophisticated systems that serve a tractor-trailer combination. Appendix A includes a review of products from the following companies: CM Automotive Systems, Tire Pressure Control International, Dana Spicer, Air Fender Systems, Arvin Meritor, Gio Set Corporation, Innovative Transportation Products, and The Cycloid Company.

5.5 FLEET EXPERIENCE WITH TIRE PRESSURE MONITORING AND INFLATION PRODUCTS

As previously discussed, various types of tire pressure monitoring and inflation systems have been available to fleet operators for many years, with battery powered, valve stem mounted sensors/transmitters being the most common type of system in use. Tire pressure monitoring and inflation systems have been given very mixed reviews by fleet operators, and tend to be the type of products that fleets either swear by, or enthusiastically despise. Overall, this category of product has not been widely accepted by fleet operators as being cost-effective. While reliable market share data is difficult to obtain, knowledgeable industry experts, as well as suppliers of tire monitoring and inflation systems, estimate the market share penetration to be less than 2 percent among commercial fleet operators. As discussed in the previous section, typical complaints are that the systems themselves require too much maintenance and management attention. Perhaps most importantly, the benefits of such systems are difficult to measure and verify.

While not attaining broad market acceptance, there are numerous examples of major fleets that have implemented tire monitoring and inflation systems and experienced very good results:

- A large private fleet operator in the southwest implemented an automatic tire inflation system and reports the following results:
  - "Began testing the systems in 1993—it is installed on all (1,100) of our trailers. Tread wear is improved by 15%…and it saves considerable labor expense. Before, we had 5 or 6 people spending an entire week trying to check every one of our tires…we don't do that anymore."
  - "On the downside, it is a mechanical system, so hoses and connections need checking…but we do that when we change tires."

- A large long-haul fleet implemented an automatic inflation system and reports the following results:
  - "Began testing the units in 1994—all 2,000 of our trailers are now equipped."
  - "It eliminates what would be a road-call."

- "Rolling resistance is reduced and the tractor's fuel economy is better."
- "A careful analysis of tire expenses determined that the system provides an improvement in tire costs of 53% …this is a statistically correct study with three different trailer manufacturers."

- A very large LTL carrier implemented a tire maintenance system with the following results:

  - "After more than a year of tracking (the group of test trailers) we found that the on-board inflation system had cut total tire-related costs by a whopping 60%….Big savings also resulted from eliminating the need for time-consuming monthly manual gauging of trailer tires…. We anticipate that retreadability also will improve."

It should be pointed out that in general, fleet operators who have implemented a new technology are biased toward wanting it to work and tend to report good results. In other words, there is a built in bias for the literature to be populated more by "good news" about such technologies than by "bad news." In conducting interviews with fleet operators, tire OEMs, and truck OEMs, the consensus among industry stakeholders was that tire pressure monitoring and automatic inflation systems generally operate as promised, but that the economic benefits of such systems are simply not clear (or at least not verifiable) to fleet operators. Many fleet operators do not have a good feel for whether they are above average or below average relative to their tire pressure maintenance activities. They do not know how much improper tire maintenance is costing them—hence they don't know how much they should be spending to fix the problem.

6.0 COST–BENEFIT ANALYSIS

Chapter Four quantified the actual in-use tire inflation characteristics of various segments of the commercial vehicle industry. The data suggests that tire inflation maintenance practices are less than optimal, however, the question remains: what is the real world cost impact of improper inflation? This chapter addresses that question for each of the market segments examined, (i.e., TL, LTL, Private, Owner-Operator, Chartered Motor Coach, and Transit Bus). The economic costs of improper inflation can then be compared with the purchase and operating costs of tire pressure maintenance products (Chapter Five), to determine the potential economic return of such systems.

6.1 METHODOLOGY

A "scenario-based" approach is used to evaluate the cost impacts of improper inflation and the potential return of tire inflation products and systems. For the scenarios involving combination vehicles (TL and LTL), such an approach allows for separately estimating operating cost savings versus system implementation costs (purchase price) for fleets owning more trailers than tractors, which is in fact usually the case. This is necessary since cost savings will be linked to the miles traveled by combination vehicles (i.e., one trailer for each tractor) but, the actual tire monitoring technology implementation costs are linked to the total number of tractors and total number of trailers in the fleet.

Scenarios are developed for each of the six market segments for which survey data was gathered including a truckload carrier, LTL carrier, private carrier, owner-operator, chartered motor coach operation, and a transit bus operation. For each of these market segments a set of "typical" operating assumptions have been defined relative to number of vehicles in the fleet, mileage accumulation, tire costs, fuel costs, baseline tire life (assuming tires are inflated at target), and other operating parameters. The degree of improper inflation assumed for each scenario reflects exactly the overall distribution developed from the sample data. It is important to recognize, therefore, that the cost impacts (from improper inflation) calculated for each scenario represent an ***average*** fleet for that particular market segment. It is also important to recognize that the terminology "average fleet" does not mean the same thing as "most fleets." Because of the high confidence level obtained from the actual survey data, it is safe to conclude that there is considerable variation among fleets with regard to tire inflation maintenance. As a fleet operator, it is important to recognize that not all fleets can exhibit tire inflation conditions that are average or better; there are some fleets that must be below average.

After estimating the cost impacts of improper inflation, a cost range for implementing tire inflation maintenance systems is established based on in the information listed in Chapter 5. The benefits of such systems in terms of reducing the incidence of improper inflation can then be estimated and the costs and benefits of advanced tire monitoring and automatic inflation systems can then be compared.

6.2 FLEET OPERATING SCENARIOS

The following six scenarios were chosen to represent a range of carrier operations:

- Scenario #1: A truckload carrier operating long-haul tractor-trailer combinations across the continental United States,
- Scenario #2: An LTL carrier operating regional double, 28 foot trailers,
- Scenario #3: A private fleet of single axle (6-wheel) trucks operating in a large metropolitan area,
- Scenario #4: An owner-operator operating a long-haul tractor across the continental United States (no costs or savings for trailers are estimated in this scenario),
- Scenario #5: A chartered motor coach fleet operating in long-haul service, and
- Scenario #6: A transit bus service operating in a large metropolitan area.

Each scenario was designed to simulate a typical carrier operating in the respective market segments. An ancillary benefit of this approach is that it allows for an examination of the cost and benefits of tire inflation maintenance products across a wide range of operating conditions. The following assumptions/conditions were specified in constructing the six scenarios:

- The number of power units (tractors, van trucks, motor coaches) each carrier operates, including the configuration (axle layout) of these vehicles,
- The number of trailers and converter dollies in the fleet and the configuration of these vehicles,
- The average number of miles per year that each power unit operates,
- The baseline tire life in miles (i.e., the expected tire life if the tires were maintained at the proper inflation level throughout the life of the tire),
- The baseline number of retreads performed on a tire during its usable tire life,
- The baseline fleet fuel consumption in miles per gallon,
- The average cost of a tire and the average cost to perform a retread;,
- The average price of diesel fuel.

Exhibit 6.1 on the following page summarizes the specific assumptions used to define the six scenarios. The scenarios in exhibit 6.1 offer a wide cross-section of the motor carrier industry in terms of the type of vehicle (tandem drive axle tractor/trailer combination to single drive axle truck), fleet size (750 power unit fleets to 100 power unit motor coach fleets and owner-operators), average miles per year (40,000 to 150,000 miles), and baseline tire life (50,000 to 650,000 miles).

Exhibit 6.1 Scenario Assumptions and Conditions

Fleet Characteristics	Scenario #1: TL Carrier	Scenario #2: LTL Carrier	Scenario #3: Private Carrier
Power Unit Configuration	Tandem Drive Axle Tractor	Single Drive Axle Tractor	Single Drive Axle Truck
Number of Power Units	400	750	200
Trailer Configuration	53′ Van Trailer	28′ Van Trailer with Single Axle Converter Dollies	none
Number of Trailers	600	1,875 Trailers with 750 Dollies	none
Average Miles Per Year Per Power Unit	125,000	100,000	60,000
Baseline Tire Life (miles)	650,000	500,000	200,000
Baseline Number of Retreads Performed During Life of Tire	2	2	1
Baseline Fleet Fuel Consumption (mpg)	6.5	6.3	5.9
Average Tire Cost	$300	$300	$300
Average Cost For Each Retread	$90.00	$90.00	$90.00
Average Price of Diesel	$1.40	$1.40	$1.40
Fleet Characteristics	**Scenario #4: Owner-Operator**	**Scenario #5: Chartered Motor Coach**	**Scenario #6: Transit Bus**
Power Unit Configuration	Tandem Axle Drive Tractor	45′ Steerable Tag Axle Motor Coach	Single Drive Axle Transit Bus
Number of Power Units	1	100	150
Trailer Configuration	none	None	none
Number of Trailers	none	None	none
Average Miles Per Year Per Power Unit	150,000	75,000	40,000
Baseline Tire Life (miles)	200,000	75,000	50,000
Baseline Number of Retreads Performed During Life of Tire	0	0	1
Baseline Fleet Fuel Consumption	6.1	9.0	3.5
Average Tire Cost	$325	$375	$325
Average Cost For Each Retread	$90.00	$90.00	$90.00
Average Price of Diesel	$1.40	$1.40	$1.40

Each scenario defines a set of "typical" operating assumptions relative to the average tire cost, average cost of retreads, price of diesel fuel, baseline tire life, and the baseline fuel consumption for the respective market segment. These assumptions are not intended to be direct industry averages, but are "best judgments" based upon research and discussion with industry. While these figures may not be common for *every* fleet in a given market segment, they are "typical" of what is likely for a fleet operating in that segment. The rational for the above assumptions is discussed below.

Average Tire Cost

The cost of new commercial truck tires vary greatly depending on the size, tread type/thickness, casing, and manufacture– typically between $275 to $325 for a 22-inch tractor tire and up to $350 to $400 for a premium motor coach tire. For large fleets, an average of $300 for a commercial truck tire would not be uncommon. Owner-operators only purchase a small number of tires at a time, likely from a truck stop or other retail outlet, and therefore do not receive the volume discounts a large fleet might. A slightly higher cost of $325 might be typical for new owner-operators' tires. Premium over-the-road motor coach tires, which have a tire life of around 75,000, would typically cost around $375, while transit bus tires, typically lower cost and only lasting around 50,000 miles, would likely cost around $325.

Average Cost For Retreads

According to the Tire Retread Information Bureau, the cost of a retread for commercial on-highway trucks is approximately 1/3 of the cost of a new tire.[8] The actual retread cost is dependent on the size of the tire, the type/depth of the tread, and the method of the retreading process. In addition, a fleet might have a service contract with a particular retreading company, providing a slightly discounted rate. The information from the Tire Retread Information Bureau and from various retread companies place the costs associated with retreading in the range from perhaps $80 to $100 for a fleet operation.

Average Price of Diesel Fuel

The average price of diesel fuel, $1.40 per gallon, was derived from the United States Department of Energy Information Administration's weekly survey of retail on-highway diesel prices over the past two years. [9] This is the United States national average retail fuel price as surveyed by the Energy Information Administration.

Baseline Tire Life

The baseline life of a tire varies greatly, depending on the tire design, material, casing construction, manufacturing method, tread type/depth, and the intended application.

[8] Tire Retread Information Bureau, *Retreads – Best Buy In Recycling*, Pacific Grove, CA: Tire Retread Information Bureau, 2002.

[9] DoE Energy Information Administration, *Weekly Retail On-highway Diesel Prices*, 9/02/2002. (Washington, DC: Department of Energy, 2002).

It is not uncommon to obtain perhaps 650,000 miles from a well-maintained tire operating in long-haul service and undergoing 2-3 retreads. Often, throughout the tire's 650,000-mile lifetime, it will be used for roughly 150,000 miles as a steer tire, 250,000 as a drive tire, and an additional 250,000 miles as a trailer tire.

Based on these industry estimates, baseline tire life in Scenarios # 1-6 would not be uncommon for their respective market segments. According to fleet maintenance experts, an LTL carrier, operating a regional service, such as Scenario #2, might obtain 500,000 miles of service per tire with two retreads. Private carriers only performing 1 retread per tire might expect to get 200,000 miles per tire. Owner-operators who do not retread but do purchase premium tires would only expect to get 200,000 miles per tire. Over-the-road motor coaches operating in revenue passenger service might only get 75,000 per tire, while transit bus fleets operating in urban environments perhaps only get 50,000 miles per tire.

<u>Baseline Fuel Consumption</u>

According to the 1997 Economic Census Vehicle Inventory and Use Survey, 53% of all heavy-duty commercial trucks get between 5 and 6.9 miles per gallon. In addition, according to the same survey, 56% of all trucks operating more than 75,000 miles per year get between 5 and 6.9 miles per gallon.[10]

Actual fuel consumption varies greatly depending on the route, distance between stops, average speed of the vehicle, and the type and weight of the vehicle. A long-haul TL carrier might expect to have a baseline fuel consumption of perhaps 6.5 miles per gallon, while an LTL carrier, averaging slightly fewer miles per year, may only get 6.3 miles per gallon. Private carriers, often carrying oversized/heavy loads might only get 5.9 miles per gallon. Owner-operators, while often traveling similar distances to that of TL carrier vehicles, typically run at higher speeds (to maximize their revenue miles), and generally have a slightly higher fuel consumption rate, around 6.1 miles per gallon.

Over-the-road motor coaches generally have lower fuel consumption than commercial trucks; a fuel consumption of between 7.5 and 10.0 miles per gallon would not be uncommon. For Scenario #5, a fuel consumption of 9.0 was used as a baseline for over-the-road motor coach fleets. The fuel consumption for transit bus operations in large metropolitan areas varies greatly, but typically is between 3.5 and 4.5 miles per gallon. A baseline fuel consumption of 3.5 miles per gallon was selected for Scenario #6 - Transit Bus.

[10] United States Census Bureau, *1997 Economic Census – Vehicle Inventory and Use Survey,* Washington, DC: United States Census Bureau, 1999.

6.3 COST IMPACT CALCULATIONS

As reviewed in Chapter 4, improper tire inflation increases the total costs associated with the procurement, maintenance, and operation of tires through the following mechanisms:

- Reduced tread wear. An improperly inflated tire will cause the tread to wear quicker thus increasing the number of retreads needed for a given tire life,
- Reduced tire life: The improperly inflated tire will also increase flexing of the tire causing heat and internal stresses to build up. The structure of the tire is damaged and the actual life of the tire (as measured by the total number of miles that can be accumulated on the tire including all retread operations) is thus reduced,
- Reduced fuel economy. Tires that are inflated below their target pressure will cause increased surface contact, friction, and heat and thus increase fuel consumption, and
- Increased incidence of tire failures.

As the difference between actual and target inflation pressure increases, so do the negative cost impacts related to tread wear, tire life and fuel economy (these relationships are reviewed in detail in Chapter 2). It is therefore possible to determine (using the survey data) the percentage of tires that fall into various categories of improper inflation, and then apply the associated performance degradation estimates (relative to tire life, tread wear and fuel economy as stated in Chapter 2, Exhibits 2.4, 2.5, and 2.6) to the number of vehicles (or tires) falling into that category. For example:

Exhibit 6.2 on the following page shows a sample table from the cost analysis for Scenario #1 – Truckload Carrier. (Detailed Cost Analysis spreadsheets for each scenario are included in Appendix C). The first two columns (labeled A and B) define ranges or "bins" of measured inflation levels relative to target pressures. Column C shows the percentage of tires falling within each bin. Column D lists the percentage that tire life is reduced when tires are inflated within the corresponding bin. For example, for tires underinflated between 20 and 25 psi, the tire life is reduced by 30%. Column E (*Tread Wear Increase)* and column F (*Fuel Economy Reduction)* follow a similar pattern; for tires underinflated between 20 and 25 psi, tread wear is increased by 24% and fuel economy is reduced 1.00%.

Using these assumptions it is possible to calculate: (1) the additional new tires required as a result of decreased tire life, (2) the additional number of retreads that are required, and, (3) the impact on fuel economy as a result of underinflation. Sample calculations for each of these three statistics are presented in the sections following Exhibit 6.2.

Exhibit 6.2 Sample Cost Analysis Summary Table: Truck Load Fleet Scenario

A	B	C	D	E	F	G	H	I
Measured PSI from Target		*Percentage of*	*Tire Life*	*Tread Wear*	*Fuel Econ.*	*Additional New*	*Additional*	*Impact on Fuel*
Lower Limit	Upper Limit	*Tire within BIN*	*Reduction*	*Increase*	*Reduction*	*Tires Required*	*Retreads Req.*	*Econ.*
	-50	0.53%	56.25%	60.00%	2.50%	27.4	63.9	0.01%
-50	-45	0.17%	53.50%	54.00%	2.25%	7.9	16.2	0.00%
-45	-40	0.19%	50.00%	48.00%	2.00%	7.5	13.9	0.00%
-40	-35	0.28%	46.00%	42.00%	1.75%	9.6	16.3	0.00%
-35	-30	0.56%	41.25%	36.00%	1.50%	15.8	25.4	0.01%
-30	-25	1.63%	36.00%	30.00%	1.25%	36.7	55.9	0.02%
-25	-20	4.04%	30.00%	24.00%	1.00%	69.3	102.1	0.04%
-20	-15	6.92%	23.50%	18.00%	0.75%	85.1	121.6	0.05%
-15	-10	12.64%	16.25%	12.00%	0.50%	98.1	137.9	0.06%
-10	-5	20.88%	8.50%	6.00%	0.25%	77.6	106.6	0.05%
-5	0	34.01%	0.00%	0.00%	0.00%	0.0	0	0.00%
0	5	12.97%	0.00%	2.50%	0.00%	0.0	26.6	0.00%
5	10	3.81%	0.00%	5.00%	0.00%	0.0	16.0	0.00%
10	15	0.77%	0.00%	7.50%	0.00%	0.0	5.0	0.00%
15	20	0.41%	0.00%	10.00%	0.00%	0.0	3.6	0.00%
20	25	0.09%	0.00%	12.50%	0.00%	0.0	1.1	0.00%
25	30	0.06%	0.00%	15.00%	0.00%	0.0	0.9	0.00%
30	35	0.02%	0.00%	17.50%	0.00%	0.0	0.3	0.00%
35	40	0.00%	0.00%	20.00%	0.00%	0.0	0.0	0.00%
40	45	0.00%	0.00%	22.50%	0.00%	0.0	0.0	0.00%
45	50	0.00%	0.00%	25.00%	0.00%	0.0	0.0	0.00%
	More	0.00%	0.00%	27.50%	0.00%	0.0	0.0	0.00%
		TOTAL				435	713	0.26%

Additional New Tires Required: The first step in calculating the additional new tires required is to determine the number of affected tires for each bin. This is equal to the percentage of tires within each bin times the total number of tires. For Scenario #1, the example in Exhibit 6.2, there are 4,000 tractor tires. Therefore there are 4,000 tires x 4.04% = 161.6 tires that are between 20 and 25 psi underinflated.

The second step is to determine the baseline number of miles these 161.6 tires are expected to go during their lifetime (Scenario #1 assumes 650,000 miles per tire). This is equal to 161.6 tires x 650,000 mile per tire = 105,040,000 miles.

Next, given a reduction in tire life of 30% for tires underinflated between 20 and 25 psi, these tires will not be able to go all 105,040,000 miles; additional new tires will be required. The 161.6 tires will only be able to go 650,000 miles x (1 – 30%) = 455,000 miles each or 73,528,000 total.

This means that additional new tires will be needed to go the remaining 105,040,000 – 73,528,000 = 31,512,000 miles. At 455,000 miles per tire, (31,512,000 /455,000 = 69) additional tires will be required to go the same distance 161.1 properly inflated tires would go.

To calculate the total additional new tires required, this same calculation must be completed for each of the bins in Exhibit 6.2, and results totaled. For this example, an additional 435 new tractor tires are required due to improper tire inflation on the 400-tractor fleet over the 105,040,000 total miles.

Additional Retreads Required: A similar method is followed for calculating the additional tire retreads that would be required. The first step is to calculate the number of effected tires for each bin. This is exactly the same number as presented above (4.04% x 4,000 tires 161.6 tires between 20 and 25 psi underinflated).

The next step is to determine the base number of retreads required. For example, Scenario #1 assumes that a properly maintained tire has 2 retreads during its lifetime. Therefore, the 161.6 tires will have 161.6 x 2 = 323.2 retreads total during their lifetime.

Due to increased tread wear from both overinflation and underinflation, the number of retreads a tire will need increases. Exhibit 5.2 shows that tread wear increases 24% for tires between 20 and 25 psi underinflated. The total number of retreads required is equal to 323.2 retreads/(1 – 24%) = 425.6 total retreads required for those 161.6 tires. Therefore, additional (425.6 – 323.2 = 102) retreads will be required during the lifetime of those 161.6 tires.

To calculate the total additional retreads required, this same calculation must be completed for each of the bins, and the results totaled. For this example, 713 additional retreads are required for the 400-tractor fleet due to improper tire inflation maintenance.

Impact on Fuel Economy: The impact of improper tire inflation on fuel economy is equal to the total of the percentage of tires in each bin multiplied by the associated percentage fuel economy reduction. For example, in Exhibit 6.2, 4.04% of tires are underinflated between 20 and 25 psi and there is a 1.00% reduction in fuel economy for tires in that range. Therefore, there is a 4.04% x 1.00% = 0.04% impact in fuel economy for tires between 20 and 25 psi underinflated. To calculate the total impact in fuel economy, the same calculation must be made for each of the bins and the results totaled. For this example there is a 0.26% total impact on fuel economy due to improper tire inflation maintenance on the 400-tractor fleet.

The previous examples demonstrate how the cost of improper inflation impacts fuel usage, required number of retreads, and additional new tires needed for an average TL fleet. It is also well understood that improper tire inflation will lead to an increased incidence of complete tire failure, and data on tire failures due to improper inflation is also presented in Chapter 2. However, there is no exact relationship (that the project found) that correlates the probability of tire failure with varying degrees of improper inflation levels. The available data supplied by industry sources is simply presented for all fleets, or for "average" fleet operations. Based on the data presented in Chapter 2, it is evident that an average combination vehicle operated by an average fleet operator experiences about one roadcall each year due to improper tire inflation, and that the cost of such a roadcall is about $450 (see Chapter 2).

Based on the methodology described above, the total direct costs of improper inflation have been calculated for all six scenarios, see Exhibit 6.3.

Exhibit 6.3 Total Direct Cost Impacts of Improper Tire Inflation

	Annualized Costs Data	TL Fleet			LTL Fleet		
		Tractor	Trailer	Fleet Total	Tractor	Trailer/Dolly	Fleet Total
	# of vehicle	400	600	1,000	750	2,625	3,375
New Tires	Basline new tires needed	769	923	1,692	900	2100	3000
	Additional tires needed due to reduced tire life	84	123	207	88	195	283
	Percentage increase in new tires needed	10.88%	13.33%	**12.22%**	9.76%	9.30%	**9.43%**
Retreads	Basline retreads	1,538	1,846	3,385	1,800	4,200	6,000
	Additional retreads due to increase tread wear	137	200	338	170	377	547
	Percentage increase in retread operations	8.91%	10.85%	**9.97%**	9.42%	8.98%	**9.11%**
Fuel Impacts	Basline fuel usage			7,692,308			11904762
	Additional fuel due to low inflation	20,192	24,586	44,778	26,971	26,642	53,613
	Percent increase in fuel usage			**0.58%**			**0.45%**
Incremental Fleet Costs Due to Improper Inflation	New tires	$25,096	$36,923	$62,019	$26,340	$46,848	$73,188
	Retreads	$12,340	$18,035	$30,375	$15,264	$27,158	$42,422
	Fuel	$28,269	$34,420	$62,689	$37,759	$37,299	$75,059
	Road calls			$180,000			$337,500
	Total fleet costs due to improper inflation	**$65,705**	**$89,378**	**$335,083**	**$79,363**	**$111,306**	**$528,169**
	Average annual cost penalty per vehicle			Combination Tractor + Trailer			Combination Tractor & 2 Trailer w/ Dolly
	Fuel	$71	$57	$128	$50	$14	$93
	New tires	$63	$62	$124	$25	$18	$89
	New retreads	$31	$30	$61	$20	$10	$51
	Road calls			$450			$450
	Total cost penalty per vehicle	**$164**	**$149**	**$763**	**$106**	**$42**	**$683**

	Annualized Costs Data	Private Fleet	Owner Operator	Motor Coach	Transit Bus
	# of vehicle	200	1	100	150
New Tires	Basline new tires needed	360	8	800	720
	Additional tires needed due to reduced tire life	45	1	83	55
	Percentage increase in new tires needed	**12.42%**	**7.22%**	**10.38%**	**7.67%**
Retreads	Basline retreads	360	0	0	720
	Additional retreads due to increase tread wear	42	0	0	50
	Percentage increase in retread operations	**11.58%**	**N/A**	**N/A**	**6.89%**
Fuel Impac ts	Basline fuel usage	2,033,898	24,590	833,333	1,714,286
	Additional fuel due to low inflation	5,855	42	1,991	3,214
	Percent increase in fuel usage	**0.29%**	**0.17%**	**0.24%**	**0.19%**
Incremental Fleet Costs Due to Improper Inflation	New tires	$13,410	$176	$31,125	$17,940
	Retreads	$3,753	$0	$0	$4,464
	Fuel	$8,197	$59	$2,787	$4,500
	Road calls	$90,999	$450	$45,000	$67,500
	Total fleet costs due to improper inflation	**$115,360**	**$685**	**$78,912**	**$94,404**
	Average annual cost penalty per vehicle				
	Fuel	$41	$59	$28	$30
	New tires	$67	$176	$311	$120
	New retreads	$19	$0	$0	$30
	Road calls	$450	$450	$450	$450
	Total cost penalty per vehicle	**$577**	**$685**	**$789**	**$629**

It is important to note that the above analysis does not consider the more difficult to quantify, but nonetheless very real, costs associated with compromised safety and handling due to improper tire inflation. As reviewed in Chapter 2, excessive and irregularly worn tires contribute to:

- Reduced stopping distances (particularly on wet pavement);
- Reduced handling and maneuverability;
- Possible vibration in the steering system (and associated driver fatigue); and
- Increased incidence of catastrophic tire failures (blow outs), which can lead to loss of vehicle control.

While tires are rarely the direct, or the first and most identifiable, cause of an accident, the above consequences of improper tire inflation clearly contribute to the likelihood of a crash event, and to the severity of the event. The ability of the operator to avoid the crash event in the first place is compromised due to reduced stopping performance and handling characteristics. The costs associated with crash events have a very real and significant impact on the bottom line profits of carriers. Properly maintained tires could clearly provide safety, operational reliability, and economic benefits.

6.4 COST-BENEFIT ANALYSIS

The analysis presented in the previous section clearly demonstrates that improper tire inflation, even for the average fleet operator, significantly increases direct costs associated with tire procurement and operations. Appendix A reviews numerous products and systems designed to improve the tire maintenance function; however, there are two issues for the fleet operator: are they worth it and what is the associated return period? To address these questions, the total annualized cost savings from having implemented a particular tire maintenance system must be compared with the total procurement and maintenance costs of the systems themselves. These issues are reviewed in the following sections.

6.4.1 Total Cost Savings

The following cost elements and cost drivers are needed to calculate the total estimated savings:

- <u>Total direct costs avoided if tires were maintained at target pressure</u>. This is the sum of costs associated with new tires, additional retreads, additional fuel and roadcalls as listed in Exhibit 6.3.

- <u>The percentage reduction in the above costs if a tire pressure monitoring and/or an automatic tire inflation system were implemented</u>. In other words, this would be a measure of the effectiveness of the tire maintenance system in eliminating the problem of improper inflation. Chapter 5 reviews the industry's experience with implementing a variety of tire maintenance systems. As discussed in that Chapter, fleets that have implemented tire monitoring and automatic inflation systems have generally reported very good results. While the authors of this study have not located any rigorously controlled "before and after" studies of the effectiveness of various systems and technologies, the anecdotal evidence suggests that fleet operators nearly eliminate problems associated with improper inflation. A properly functioning automatic inflation system would, by design, keep tires properly maintained.

- Tire pressure monitoring systems automatically notify the operator of an improper pressure condition. Based on interviews with fleet operators conducted as part of this study, when an operator is made aware of the improper inflation condition via the tire monitoring system, he or she will very quickly correct the problem at the nearest opportunity, such as the next stopping point, or before they begin a trip. In any event, the majority of operators do not simply ignore the warning, and most often take quick corrective action. For purposes of this cost-benefit analyses,the authors will make a baseline assumption that automatic tire inflation and tire monitoring systems are 80 percent effective in eliminating incidences of improper tire inflation. This represents a plausible average degree of benefit based on discussions with industry experts and fleets which operate such systems. A sophisticated system, which perhaps includes an automatic inflation system, might prove to be 90-95% effective, while a more limited system (perhaps a product which alters the color of a valve cap based on pressure) might not have as great of an improvement on efficiency. (Sensitivity analyses of these rates of effectiveness are described in Section 6.4.)

- Avoided tire inspection and maintenance costs. One of the primary motivators for fleets to purchase automatic tire maintenance systems is that operators will not have to spend as much time checking tires for proper inflation. An average 18-wheel tractor-trailer could easily take 30 minutes to check the pressure of each tire and add air to 3 or 4 of the tires. Most fleet maintenance departments ask operators to check tire pressures once a week. Total annual inspection labor would be approximately 24 hours (.5 hours/inspection x 48 inspections/yr). At $25/hour, the cost would total $600 annually in tire inspection costs. If the use of automatic tire maintenance systems could reduce these costs by just 50%, total savings would be around $300 per year.

- Avoided tire installation costs and associated downtime. As reviewed in Section 6.3, improper inflation will require the purchase of additional tires, as well as additional retreads. The calculated costs in Section 6.3 only include the direct costs of purchasing the new and/or retreaded tire. However, because the additional tires will need to be mounted, the vehicle will be lost from service during this time and overall availability of the fleet vehicles will be slightly reduced, plus the vehicle will not be generating revenue. Because of the difficulty of estimating this loss of revenue, and the variability among fleets, the authors of this study did not attempt to quantify this cost, and the study has assumed zero avoided costs for purposes of this analysis. Nevertheless, it is worth noting that properly inflated tires will result in less time in the shop (for tire replacement) and more time in revenue-generating service.

- Avoided costs from improved safety. As noted, properly maintained tires would likely result in a reduction in the number and severity of crash events. The costs associated with crashes including civil lawsuits and liability costs, insurance premiums, injury and employee claims, lost revenue and lost customer goodwill would all be reduced. Because of the difficulty of estimating such costs, they are assumed to be zero for purposes of this analysis.

6.4.2 Total Implementation Costs

The following are the key drivers of system implementation costs:

- System procurement costs. Procurement costs vary substantially, and tire maintenance systems are available in several configurations and often with various options. However, in general, many of the systems consist of a single "readout/receiver/control unit" type of device, along with sensors that are purchased and installed on a per tire basis. In order to complete the cost-benefit analyses, a "representative" total system cost must be selected. For illustrative purposes only, the following costs are assumed for a "generic" type of tire maintenance system:

  - Single unit "readout/receiver/transmitter/control unit": $300 per vehicle,
  - Tire pressure sensor/transmitter: $40 per tire, and
  - Total system cost for an 18-wheel tractor-trailer: $1,020.

- System maintenance costs. A significant hurdle that vendors of tire maintenance systems have faced is the perception that the systems themselves require "too much" maintenance. Comments such as, "I will be trading off one type of (maintenance) problem for another," are not uncommon. Many of the currently available systems are battery powered. The batteries must be maintained and replaced periodically. Some systems also require additional wiring harnesses to be added to the tractor and/or trailer that could complicate various types of routine maintenance and electrical system diagnosis. Because of the large variation in product designs and maintenance requirements among available products it is difficult to quantify "representative" or average annual maintenance costs. Our interviews with vendors suggest that very little maintenance is actually required. At the same time, fleets do not maintain reliable data on how much they spend on system maintenance. For illustrative purposes only, we will assume that the average annual maintenance cost is 25 percent of the initial purchase cost—or about $255 per year for a system installation cost of $1,020 assumed in Scenario #1.

6.4.3 Results of Cost-Benefit Analysis

Based on the previously listed assumptions, the total cost savings from improved tire inflation maintenance is compared with the total system implementation costs for each scenario in Exhibit 6.4. A "Years Return" calculation is also presented.

Exhibit 6.4 Cost- Benefit Analysis for Fleet Scenarios

	TL Scenario 1	LTL Scenario 2	Private Scenario 3	Owner-Operator Scenario 4	Motor Coach Scenario 5	Transit Bus Scenario 6
Total Powered Units	400	750	200	1	100	150
Total Trailers	600	2,625	0	0	0	0
Total Tires	8,800	15,00	1,200	10	800	900
Representative Tire Monitoring System Implementation Costs (per unit)						
Readout/Receiver	$300	$300	$300	$300	$300	$300
Device Cost per Tire	$40	$40	$40	$40	$40	$40
Cost per Powered Vehicle	$400	$240	$240	$400	$320	$240
Cost per Trailer	$320	$160	$0	$0	$0	$0
Per Combination Vehicle	$1,020	$1,020	$540	$700	$620	$540
Fleet Implementations Costs						
Readout/Receiver	$120,000	$225,000	$60,666	$300	$30,000	$45,000
Sensors – Tractors	$160,000	$180,000	$48,000	$400	$32,000	$36,000
Sensors – Trailers	$192,000	$420,000	$0	$0	$0	$0
Total	**$472,000**	**$825,000**	**$108,000**	**$700**	**$62,000**	**$81,000**
Cost Avoidance Calculations						
Total cost of improper inflation (see Exhibit 6.3)	$335,083	$528,169	$115,360	$685	$78,912	$94,404
Assumed percentage improvement from tire monitoring and/or automatic inflation systems	80%	80%	80%	80%	80%	80%
Reduced tire replacement, retreading, and fuel costs	$268,066	$422,535	$92,288	$548	$63,130	$75,523
Cost/unit avoided due to reduced manual inspections	$300	$300	$100	$167	$133	$100
Total annual cost avoided due to reduced manual inspection	$120,000	$225,000	$20,000	$167	$13,333	$15,000
Annual maintenance costs per Tire Monitoring System	-$255	-$255	-$135	-$175	-$155	-$135
Total annual maintenance cost for Tire Monitoring Systems	-$102,000	-$191,250	-$27,000	-$175	-$15,500	-$20,250
Total annual cost savings	**$286,066**	**$456,285**	**$85,288**	**$540**	**$60,963**	**$70,273**
Years return	**1.65**	**1.81**	**1.27**	**1.30**	**1.02**	**1.15**

6.4.4 Sensitivity Analysis

In an effort to better understand how key cost, benefit, and scenario assumptions influence cost-effectiveness of tire pressure monitoring/inflation systems, a sensitivity analysis was performed. **It should be noted that this sensitivity analyses is presented primarily to provide the reader with a framework for evaluating tire inflation systems, and not to speculate on the actual cost-effectiveness of specific products, or even various categories of products offered in the marketplace.**

There are three key cost and operating assumptions that effect the return period for commercial vehicle tire pressure monitoring and/or automatic inflation systems:

(1) The initial cost of the system (capital costs),
(2) The anticipated benefit from implementing the system (i.e., how much does the system improve tire maintenance practices),
(3) The existing tire pressure maintenance practices of the carriers (i.e., how well is the fleet currently performing relative to tire maintenance).

<u>Implementation Costs</u>
To review, the baseline cost-effectiveness analyses presented in Exhibit 6.4 is based on a "generic" tire monitoring system, which is assumed to provide an 80% reduction in the directly avoidable costs, if tires were maintained at target pressure. In other words, the tire monitoring system is assumed to be 80% effective in eliminating improper inflation. This represents a plausible average degree of benefit based on discussions with industry experts and carriers that operate such systems. However, it is certainly possible that more sophisticated tire pressure monitoring systems that incorporate automatic inflation might produce even greater benefits, potentially up to 90-95% of the costs due to improper tire inflation. Conversely, it is also reasonable to assume that more limited systems, for example, a product that simply changes the color of the valve stem in response to pressure changes, may not improve the fleet's tire maintenance practices to the same degree as more sophisticated systems, since this type of system still requires diligence by the drivers or maintenance personnel to inspect each valve stem at regular intervals. However, such a product presumably could be purchased at much lower cost.

<u>System Benefits</u>
For the sake of completing a cost-effective sensitivity analyses, it was assumed that in a developed market, the benefit a system might provide is directly linked to the cost of the system. For this sensitivity analyses, a system that costs 50% less than average is assumed to reduce avoidable tire costs by 50% (i.e., the "Low Cost/Limited Benefit" scenario), and a system that costs 50% more than average is assumed to reduce avoidable tire costs by 90% (i.e., the "High Cost/High Benefit" scenario). For example, for the TL fleet scenario, a "low cost" system would be $510 per tractor-trailer (half of the $1,020 amount listed in Exhibit 6.4), while a "high cost" system would be $1,530. Similarly, a "limited benefit" system would reduce the avoidable costs due to improper inflation from $765/tractor-

trailer (see Exhibit 6.3) to $382.50, while a "high benefit" system would reduce such costs by $688.50.

Tire Pressure Maintenance Practices Among Commercial Carrier Fleets.
Again, the baseline cost-effectiveness analyses summarized in Exhibit 6.4 assumes an average motor carrier fleet with regard to tire maintenance practices. That is, a carrier whose tire maintenance practices exactly match the sample data collected and discussed in Chapter 4. In actuality, there are many carriers that have maintenance conditions worse than the average, while other carriers perform better than average relative to maintaining proper tire inflation.

For this sensitivity analyses, a carrier with "poor tire maintenance practices" is represented by a 25% increase in total costs associated with improper inflation, while a carrier with "good tire maintenance practices" is represented by a 25% reduction in total cost of improper inflation, (compared to average). For example, for the TL Scenario the baseline cost of improper inflation is assumed to be $765.00, while for a "poor tire maintenance practices fleet" such costs will amount to $956.25, and a "good tire maintenance practices" fleet will only lose $573.75 to poor tire maintenance.

Exhibit 6.5 below shows how the initial system purchase cost, anticipated benefits, along with varying assumptions regarding the extent of the problem (i.e., poor vs. good tire maintenance) impact the cost-effectiveness (as measured in terms of years return) of tire pressure monitoring and inflation systems.

Exhibit 6.5 Return Period (in years) Based on Alternative Product Cost, Benefit, and Fleet Assumptions

Product Cost, Benefit, and Fleet Tire Maintenance Assumptions	Market Segment					
	Truckload	LTL	Private	Owner-Operator	Motor Coach	Transit Bus
Low Cost/Limited Benefit						
Poor Maintenance Condition	1.04	1.13	0.83	0.83	0.66	0.75
Average Maintenance Condition	1.27	1.38	1.07	1.05	0.83	0.97
Good Maintenance Condition	1.64	1.78	1.49	1.41	1.13	1.34
Average Cost/Moderate Benefit						
Poor Maintenance Condition	1.34	1.47	1.00	1.03	0.81	0.91
Average Maintenance Condition	1.65	1.81	1.27	1.30	1.02	1.15
Good Maintenance Condition	2.15	2.35	1.74	1.74	1.37	1.58
High Cost/High Benefit						
Poor Maintenance Condition	2.01	2.20	1.50	1.55	1.21	1.36
Average Maintenance Condition	2.47	2.71	1.90	1.95	1.53	1.73
Good Maintenance Condition	3.23	3.53	2.60	2.61	2.06	2.36

The following observations can be made from the cost-effectiveness sensitivity analyses presented in Exhibit 6.5:

- "Low cost/Limited benefit" systems appear to offer the potential for better cost effectiveness than "High cost/High benefit" systems. This observation is of course directly linked to the assumptions used in the analyses, and no specific brands or products have been evaluated. Nevertheless, the sensitivity analysis suggests diminishing returns with "expensive" systems (in this case, "expensive" is defined as 50% higher costs than an "average" priced system).

  It also should be pointed out that "cost-effectiveness" calculations used in these analyses are based solely on economic benefits that can be linked to directly quantifiable and avoidable costs (such as reduced tread wear, tire life, and fuel economy). They do not consider the clear and important safety benefits that could be derived from improved tire maintenance, such as improvements in vehicle stability and handling, and avoidance of crashes related to tire failure. If a fleet owner were to explicitly associate a cost with reduced safety then more expensive systems begin to improve their overall cost-effectiveness (assuming of course that more expensive systems result in better tire maintenance than lower priced systems).

- Tire monitoring and automatic inflation systems offer the potential for a reasonable return period even for fleets with relatively good tire pressure maintenance practices. The return period for such carriers range from about 1.6 years (for a low cost/low benefit system) to 3.5 years (for a high cost/high benefit system)

In addition to the key system attributes examined above (i.e., initial product cost, effectiveness of systems in improving tire maintenance, and baseline severity of the tire maintenance problem), there are a variety of operating assumptions that can also impact the cost-effectiveness of tire monitoring and automatic inflation systems. Such parameters include annual vehicle mileage, costs of new and retread tires, and fuel cost. The LTL market segment was selected to demonstrate how these assumptions might impact cost-effectiveness. Exhibit 6.6 presents three different sets of operating assumptions examined.

Exhibit 6.6 LTL Sensitivity Analysis
Alternative Operating Assumptions

	Low	Average	High
Miles per Year per Unit	60,000	100,000	125,000
Tire Cost /retread cost	$250/$70	$300/$90	$350/$110
Diesel Fuel Price (gal)	$1.20	$1.40	$1.60

It should be noted that these scenario assumptions were selected simply to show how variations in annual mileage, tire costs, and fuel cost might impact the savings that could be associated with tire monitoring and automatic inflation systems. Exhibit 6.7 shows how return years are impacted by each of these three operating assumptions. It should also be noted that trend lines shown were developed by varying only the parameter in question and holding all other variables constant at their average levels.

Exhibit 6.7 Impact of Mileage Accumulation, Tire Costs, and Fuel Costs on the Cost-Effectiveness of Tire Monitoring and Inflation Systems

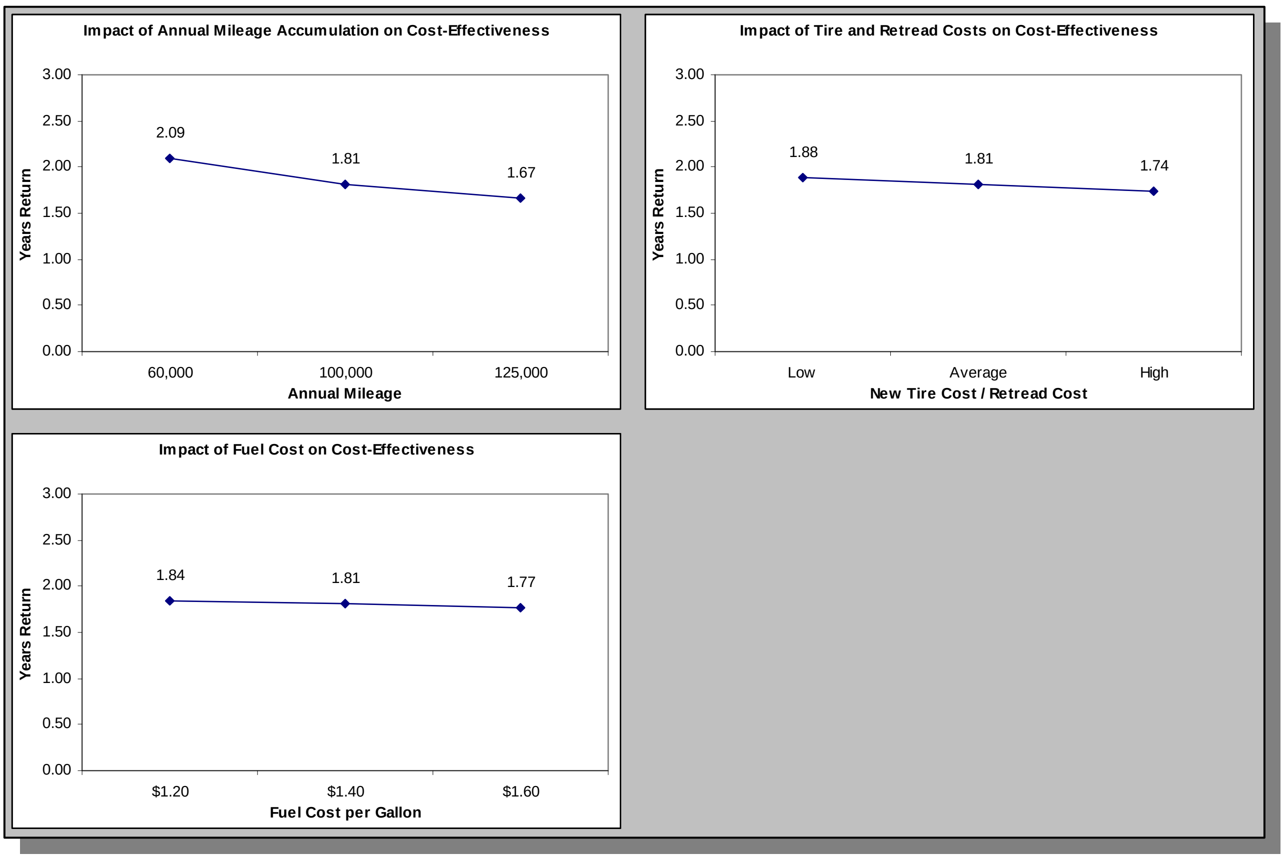


Exhibit 6.7 demonstrates that annual mileage accumulation has a marginal impact on the cost effectiveness calculations. This is true of nearly all vehicle innovations that are targeted at reducing costs—namely that the more the vehicle is driven the greater the savings generated. However, the analyses shows that tire and fuel costs have relatively little impact (within the range of values examined), on the return period for tire monitoring and/or automatic inflation systems.

7.0 OBSERVATIONS AND CONCLUSIONS

Key observations and conclusions presented in the previous chapters are outlined as follows:

- As reviewed in Chapters 1 and 2, tire related costs are the single largest maintenance cost item for commercial vehicle fleet operators. Nationwide, average tire related costs per tractor-trailer are about 1.9 cents per mile, or about $2,375 for a 125,000 annual mileage operation.

- For the average fleet operator in the United States, improper tire inflation increases the annual procurement costs for both new and retreaded tires by about 10 to 13 percent (see Exhibit 6.3).

- Fuel economy loss due to improper tire inflation is about 0.6 percent for typical TL and LTL operations.

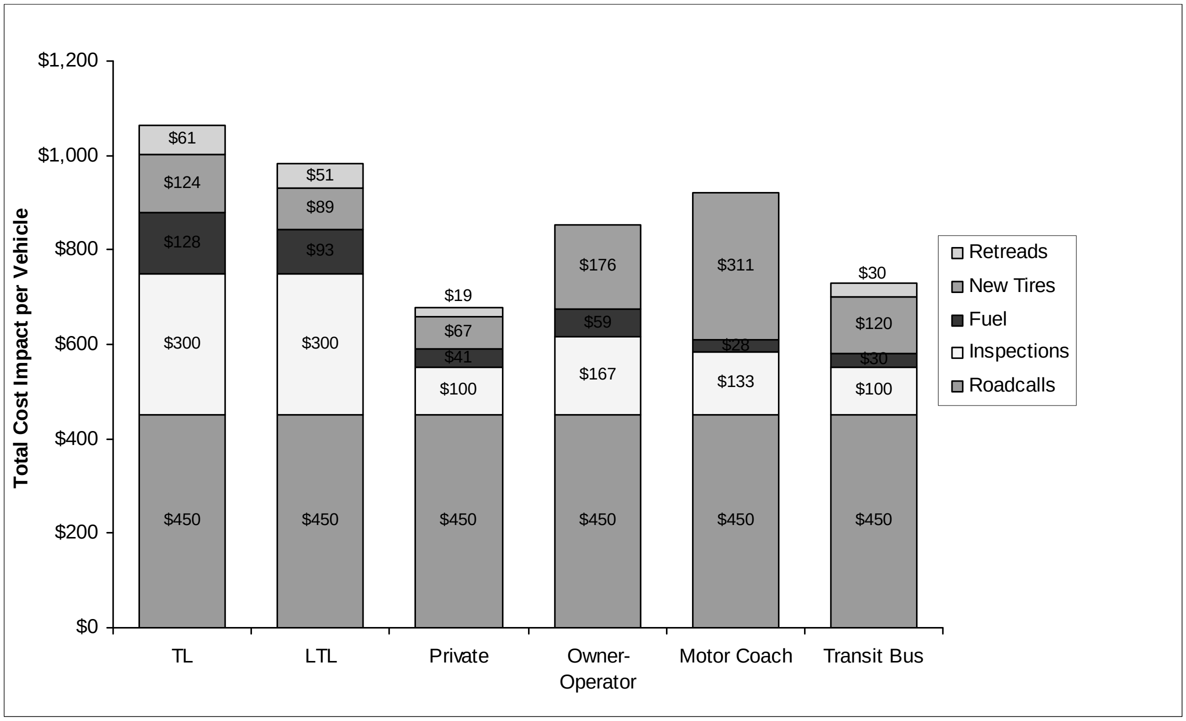
- Improper tire inflation is likely responsible for about 1 roadcall per year per tractor-trailer combination due to weakened and worn tires.

- For a typical TL or LTL operator, improper tire inflation increases the total operating costs by about $750 annually per tractor-trailer combination. Cost penalties for other types of fleets are similar and range from about $600 to $800 (see Exhibit 6.3).

- One of the primary motivators for fleets to purchase automatic tire maintenance systems is that operators will not have to spend as much time checking tires for proper inflation. An average 18-wheel tractor-trailer could easily take 30 minutes to check the pressure of each tire and add air to 3 or 4 of the tires. Most fleet maintenance departments ask operators to check tire pressures once a week. Total annual inspection labor would be approximately 24 hours (.5 hours/ inspection x 48 inspections/yr). At $25/hour, the cost would total $600 annually in tire inspection costs. If the use of automatic tire maintenance systems could reduce these costs by just 50%, total savings would be around $300 per year.

- The costs associated with routine tire pressure maintenance combined with the increased costs due to poor tire inflation management (increased fuel consumption, reduced tire life) represent the total costs that could be addressed, (i.e., reduced), by tire pressure monitoring and/or automatic inflation systems. These cost items are shown on the following page (Exhibit 7.1) for the six "typical" commercial vehicle operating scenarios examined in this report.

Exhibit 7.1 Annual Increased Cost Due to Improper Inflation Plus Annual Pressure Maintenance (Inspection) Costs



- There are numerous tire pressure monitoring and automatic inflation systems available from vendors that are specifically tailored to commercial vehicles. *If* such systems could be installed for approximately $1,000 per tractor-trailer combination, and *if* they were effective in mitigating incidences of improper tire inflation, such systems would indeed be highly cost-effective. Return periods, even for an average fleet, would be between 1 and 2 years (Exhibit 6.4).
- Sensitivity analyses shows that even for fleets with relatively "good" tire maintenance practices (i.e., fleets which demonstrate a 25% reduction in total cost of improper inflation compared to "average"), the cost-effectiveness of tire monitoring and automatic inflation systems is still quite good with return periods of less than three years (Exhibit 6.5).
- Tire pressure monitoring and automatic inflation systems become even more cost-effective if safety related benefits are explicitly considered. However, direct costs associated with a fleet's safety record, (such as injury claims, insurance premiums, workers compensation claims, as well as "goodwill" with customers and suppliers), are difficult to estimate, and even more difficult to determine what portion could be attributed to poor tire pressure maintenance. Therefore, while improved tire pressure maintenance will have an important and direct

impact on reducing commercial vehicle related property damage, injuries, and fatalities, the economic benefits of such safety improvements have not been quantified.

- Tire pressure monitoring and automatic inflation systems have not achieved significant market penetration rates. Hindrances to increased usage appear to focus on fleet operator concerns over system reliability and required maintenance costs, as well as the initial costs of the systems.

The analyses presented in this report strongly suggests that the savings potential from tire pressure monitoring and automatic inflation systems could support the purchase prices of systems and products currently in the marketplace. The challenge for the supplier community is to prove reliability and reduce or eliminate added maintenance for the systems themselves.

7.1 TOPICS FOR FURTHER RESEARCH

While the impact of improper inflation on tire life and tread wear cited in the preceding sections represent the best available information in the public domain, it became clear during the research on this project that impacts of tire pressure on both safety and operating costs is not fully understood. The following additional research could better quantify these parameters:

- The relationship between improper inflation and its impact on vehicle handling and braking is not well documented.
  - How does under-inflation impact stopping distance?… at various speeds”… at various loads?…and on various types of pavement conditions?
  - How is “handling” impacted? There does not appear to be a generally accepted and repeatable test procedure to measure “handling” and/or “responsiveness” of tractor-trailer combination vehicles. If such a test were developed, how would improperly inflated tires impact vehicle handling?
- The impacts of varying tire pressures, vehicle speeds, and vehicle loads on tread wear, tire life, and fuel economy are derived from fleet experience and anecdotal data. There does not appear to be well documented, and publicly available, test data taken under carefully controlled test track conditions to measure such parameters. Further, complex relationships involving how the number and location of improperly inflated tires on a particular vehicle affect operating costs and handling is not well understood.

- Empirical data related to the effectiveness of automatic tire inflation and pressure monitoring systems for commercial vehicles is lacking. The data that is available is anecdotal and often limited to a small number of vehicles. Information related to the actual savings (from improved tire life, fuel economy and /or reduced roadcalls) is not well documented or tracked by fleet operators. Also, the real procurement, installation, and maintenance costs of such systems are not well understood. Essentially there has not been a controlled fleet field testing program for such devices and systems.

- The overall performance, reliability, and accuracy of various types of commercial vehicle tire pressure monitoring and automatic inflation systems is not well documented, and such information is not available in the public domain. The capability of systems to detect small changes in pressure at individual wheels, and under varying speed, load, temperature, and other operating conditions is not well understood. Testing of such systems under controlled test track and/or laboratory conditions, that explicitly control for such variables as part of the experimental design, would help verify, characterize and differentiate the operational benefits as well as the limitations of systems available in the marketplace.

APPENDIX A: TIRE INFLATION PRODUCTS FOR COMMERCIAL VEHICLES

Included in sections A.1 through A.4 are brief descriptions of specific products and systems from various manufacturers. These descriptions are offered to help generally categorize and describe the type of products available in each of the respective categories. The listings are not meant to be 100% comprehensive, nor should they be taken as an endorsement of any particular product. The information presented is gathered from manufacturers sales literature, and no independent testing of the products has been performed as part of this study.

A.1. DUAL TIRE PRESSURE EQUALIZERS

Dual Dynamics manufactures the **CrossFire**. This system uses a valve that has a bar that changes colors when inflation conditions change. When the bar is yellow, the dual tires have the proper inflation pressure. This bar turns black when an underinflation problem arises and red when an overinflation situation results. This product currently sells for about $60 an axle end. Dual Dynamics estimates that it has sold around 800,000 units in its 21 years of marketing the Crossfire. Its annual sales are around 50,000 units. Dual Dynamics, PO Box 80436, Lincoln, NE 68501 (800) 228-0394, Scott Kuck, President www.dualsynamics.com

Link Manufacturing, Ltd. produces the **Cat's Eye Tire Pressure Maintenance System**. The Cat's Eye Tire Gauge works in the same manner as the Crossfire but its display for inflation condition is different. A highly visible yellow display on the air valve indicates the tire pressure is +/- 2% of the recommended inflation level. As pressure drops a vertical black line appears in the center of the display. This is the "Cat's Eye". As pressure drops further, the line widens until an all black display indicates that tire pressure is approximately 10 psi below the specified level. The display is factory set for a specific pressure and is non-adjustable. This system currently costs about $50.00 an axle end with rubber hoses and $60.00 an axle end when stainless steel hoses are used. The company has been marketing the Cat's Eye Tire Pressure Maintenance System since 1990 and has sold conservatively 125,000 units to date. It sells approximately 30,000 annually now. No numbers were available for R&D costs. Link Manufacturing, Ltd., 223 15th Street, N.E., Sioux Center, IA 51250-2120 (800) 222-6283, Pat Coghlan, National Sales Director www.linkmfg.com

Schrader Bridgeport International produces the **Visualizer II**. This system is also a dual tire pressure-equalizing device. Schrader's Visualizer features a color-coded pressure gauge that shows green for proper inflation, red for underinflation, and yellow for overinflation. Schrader calibrates the accuracy of this mechanism at the factory to within +/- 3 psi. This product costs about $75.00 an axle end. Schrader Bridgeport, 500 South 45th Street East, Muskogee, OK 74403, (800) 331-4062, www.schraderelectronics.com

Stemco, LLC is developing the **TPMM (Tire Pressure Maintenance & Monitoring) System**. This tire pressure monitoring system includes a Dual-Tire sensor that attaches to the axle end with a hub cap bolt. The unit has two air fill valves for each tire of the dual assembly and hoses attach the valve stems to the unit. It has a blinking LED light that advises the user of low and high tire pressure conditions at the axle end. The user can select 5%, 10% 15% or 20% levels at which to set the visual alarm. This unit does not equalize pressure but simply monitors it. The sensor transmits pressure information to a handheld reader that can store up to 400 RF tag reads in its internal memory. Mileage can also be read and logged with the use of the Stemco RF DataTRAC. This data can be downloaded to a PC system via a serial port attachment from the handheld reader. The sensor is operated with a battery that has a 5-year life. Field trials are in place today and product release is expected at the end of 2004. A Single-Tire sensor is also under development for steer positions that will provide a blinking LED light for low and high pressure conditions at the axle end and will transmit exact pressure data to the hand held reader. It will have a safety valve incorporated into the hoses so that if the hose is severed or broken, airflow out of the valve stem will be cut off. Field trails are scheduled to begin the third quarter of 2004. Product release date is unknown at this time. The Dual –Tire Equalizer/Sensor equalizes air pressure as well as monitors its. The equalizing unit is attached to the hub with a hub cap bolt and a single air fill valve is incorporated into the sensor. The unit will also include a blinking LED light on the axle end for low and high tire pressure conditions as well as transmit exact pressures to the hand held reader. Field trials of this product are to begin the third quarter of 2004. Product release date is unknown at this time. Stemco expects to develop a gate reader for this system by 2005 or 2006. The price of a Dual Tire sensor is expected to in the $27 range or $216 for 16 wheel positions. Stemco, LLC, 300 Industrial Blvd., P.O. Box 1989 Longview, TX, 75602-4720, (903) 758-9981, Ken Veit, Director of Business Development, www.stemco.com

V-Tech International, Inc. produces the **Tire-Knight-S** for dual truck tires. It is similar to equalizer systems in that the valve is mounted on the wheel and hoses are attached to the valve stems of both dual tires. However, each tire is connected to its own chamber and has its own valve for individual inflating and pressure checking in the unit. A bypass connects and equalizes the pressure in both tires when a piston opens or closes the bypass. (The piston is the only moving part in the unit.) The piston opens the bypass if both tires have a pressure greater than 85-90 psi. It closes the bypass if one tires blows out, one hose is unhooked or cut, or if both tires have a pressure of less than 80-85 psi. The position of the piston can be checked at a glance, although the indicator is not very clear. However, a switch is in development that will be connected to the main power supply and produces a transmission signal or optical signal. The signal would be sent to a gate reader or in-cab monitor. The prototype for this RF device will be available in June. The bypass is designed to allow minimal air flow. In case of a leak there will be a pressure difference between the dual tires. Both tires would have to be gauged to determine which tire is leaking. V-Tech has sold around 100 units locally in the Wisconsin area including some to Schneider National. The price per unit is $80 or $640 for 16 positions. V-Tech International, Inc., 227 Barbie Drive, West Bend, WI 53090 (262) 306-1708, Gottfried Hoffmann, President, www.vtechint.com

A.2. TIRE PRESSURE MONITORS

There are several types of tire pressure monitors. These systems can be categorized into the following types:

- Valve Stem Mounted Tire Pressure Monitors
- Wheel Mounted Tire Pressure Monitors
- Tire Mounted Tire Pressure Monitors

A.2.1 Valve Stem Mounted Tire Pressure Monitors

Advantage Pressure Pro LLC markets **Pressure Pro** (formerly Tire Mate). The company began its entry into the tire pressure monitor market with Tire Mate, a product that fits over the valve stem like a valve cap in 1992. The product was not reliable, as it frequently failed to work in high humidity and rainy conditions. It had a 2% failure rate on the sensors and did not have the ability to advise the user when it wasn't working. The company was able to further develop the product to ensure a good signal was transmitted and received in the on-board reader.

The new product, is called Pressure Pro and it is 1" in diameter and ¾" in length, weighs .25 oz., is completely sealed and fits over the valve stem. The sensors weigh approximately ½ ounce. There is no "cross-talk" between systems as each sensor is identified by its own individual code. The sensors check tire pressure every 15 seconds. The product can monitor 1-34 tires with pressure from 10 to 150 psi. The receiver/monitor can be operated by battery or plugged into the cigarette lighter. The monitor is 6" wide x 3" tall and .5" thick and weighs just under 8 ounces. Whenever tire pressure drops below the low trigger pressure set by the user, it triggers an alert which displays tire location, low pressure reading, and battery power in the sensor on the receiver display. An audio and visual alert comes on when a tire is 10% low and a more serious alert identifies a tire that is 20% low. The driver can scroll through the display and check all tires on demand as well. The battery life in the sensors is expected to be 5 years in automobiles, 3-3 ½ years in RV applications and 2 years on commercial trucks. The life of the battery is dependent upon mileage since the sensor is activated by tire rotation. Trailer tires are linked to the tractor receiver with a relay box that fits on the nose of the trailer and sends an RF signal to the cab. A hand held receiver called the Pressure Pro Wand can read sensors within one foot of the tire. A gate reader will be added to the product line as well. Pressure Pro is currently being field tested. The company has 600 units installed on 4,6,8, and 18-wheeled commercial vehicles. The company has found that some vehicles present unique problems with receiving a transmission. To correct this problem it may be necessary to install an antenna under the rig that is connected to the monitor with coaxial cable. Advantage Pressure Pro is also in the process of developing a "Repeater" unit. This unit would be used when a tractor drops off a trailer and picks up another trailer. The Repeater would send the sensor codes for the new trailer to the monitor so it would recognize the new trailer's sensors and not get cross talk between vehicles. This should be available in July, 2004. The cost for an 18 wheel tractor-trailer combination will be around $1,075 for the sensors and on-board receiver. A hand held reader will be priced about $150 and the gate reader should retail for $150-$200. Between 35,000 and 40,000 Tire Mate units were sold primarily to the RV industry and owner operators. Advantage has about 600 of the new Pressure Pro units operating at this time. Advantage Pressure Pro LLC, Inc., 205 Wall Street, Harrisonville, MO 64701 (800) 959-3505 Phil Zaroor, President www.advantagepressurepro.com

The **ACE Company dba AIR CHEX Equipment Co., Inc.** is developing the **Air Chex** system, which is a monitoring system that includes a pressure sensor/transmitter, pressure gauge, valve stem and connecting braided hoses. The hose connects to the valve stem and has a pressure sensor attached to the end. Air pressure is constantly monitored. The sensor can be fitted with either a red LED that lights when the battery is low or a buzzer that sounds on the wheel. A display is attached to the dash. The Aero Disc is designed for dual wheels and has pressure gauges on the disc face and valve stems. Behind the disc is the pressure sensor/transmitter and connecting braided hoses to the valve stems. The company claims the disc reduces turbulence around the wheel and improves fuel economy by 4%. These products are not on the market yet but the company expects to introduce them to the market in 2004. The cost of this system will be under $30/wheel. AIR CHEX Equipment Co., Inc. 27 New Street, Nyack-on-Hudson, NY 10960 (845) 358-8179, Fax (845) 358-4804 Mark Wallach, CEO

The **Bigfoot Tire Alert Company** sells a pressure monitor system it calls the **Bigfoot Tire Alert** that attaches large dial gauges to the ends of the valve stems with hoses. The gauges are attached to the outside of the wheels with the wheel studs. Adaptors are available for hub piloted, stud piloted and spoke wheel/demountable wheel systems. Tire pressure is monitored by walking around the vehicle. The company has been manufacturing and selling this product since June 2003 and has sold approximately 450 units to date. The cost of the Bigfoot Tire Alert is $100.00 Canadian. The monitors are sold in packages of 4 to a box. Bigfoot Tire-Alert Co., 4532 6th Street, N.E., Calgary, Alberta, Canada T2E 327 (403) 276-7948 www.bigfoot-tirealert.com.

Colorado Enterprise International is developing a remote tire pressure sensor for medium-duty trucks called the **C.E.I. Tire Monitor**. Its remote pressure sensor continually monitors the pressure of each tire on a vehicle and provides the driver with a real time display of this information. The device is made up of two components. The first is a small radio transmitter assembled into a modified tire valve assembly. This valve is also equipped with a simple pressure switch that is configured to activate at a predetermined threshold. Once activated by low pressure, the transmitter will immediately transmit to the unit on the dash the unique sensor identity code for that wheel position. The unit on the dash will receive the code and match it against the codes it has stored for the tires on that vehicle. If a match is found an enunciator will sound and an indicator will show which wheel is generating the signal. A small standard lithium coin cell battery that is estimated to provide more than four years of operation powers the transmitter module. Once depleted it can be replaced by the user. (The company is exploring the possibility of powering the unit with centrifugal force.) To provide notification of sensors that have failed, are missing, or whose batteries have been depleted, the transmitters are configured to periodically send a brief message to the dash unit to confirm they are operational. If the dash unit does not receive the periodic update, a different warning message is provided to the driver. The company claims that the sensors attached to wheel assemblies on doubles trailers can successfully transmit their signals to the dashboard receiver. This product is not yet on the market but will be introduced to the trucking industry in 2004. List price for this system is about $500 ($27/monitor) for an 18-wheeled vehicle. Colorado Enterprise International, 20 Lanning Blvd., Suite 215, East Windsor, NJ 08520 (609) 918-9646 Edward Neefeldt, President.

Doran Manufacturing LLC sells the **Doran Tire Pressure Monitoring System**. This system is made up of a sensor that screws onto the valve stem of each tire and a receiver that fits into a standard gauge hole in the dash. The sensors weight 25.7 grams and require the user to adjust the pressure setting. The sensor comes apart to show a pressure scale that has a range from 18 to 125 psi. The desired pressure is set using a screwdriver. The sensor sends a “soft” alarm when the pressure drops to 10% below the setting and a more urgent audible alarm when the pressure drops 25%. Each sensor on the truck/tractor is marked with the wheel position so that the system can tell the driver which tire has low pressure. In addition the system has unique codes for each sensor so that trucks don’t receive signals from each other in the yard. However, all trailer sensors are coded the same which allow for drop and hook operations. Sensor batteries normally last 2-3 years since the sensor only sends a signal when there is a low pressure tire. However, if no action is taken to correct the underinflation condition, the sensor sends the alarm continuously and the battery will last only to 2 weeks. The receiver in the dash indicates which tire is low with a graphic display. The appropriate position is indicated visually, a “Low Tire” signal is shown and an audio signal is heard. The receiver needs three wires that attach to the battery, ignition, and ground. An antenna is required to receive signals from trailer tire sensors. This antenna is a wire that attaches to the back of the receiver and runs under the cab to the back of the tractor. The Doran Tire Pressure Monitoring System can monitor up to 34 tires. This product has been available for two months and the company is actively selling it with a dedicated sales force. So far many units have been put in place on test within many fleets. The price to equip an 18-wheeled unit is around $900 and a 6-wheeled unit is

$300. The company anticipates that they will develop a gate reader in the near future. Also anticipated in the future is the use of a "Repeater" unit (like that used by Advantage Pressure Pro) that will send the new codes for a new trailer hooked up to a tractor to the monitor so it will recognize the new trailers sensors. Doran Mfg., LLC, 2851 Massachusetts Avenue, Cincinnati, Ohio 45225 (8656) 816-7233, Fax (513) 681-5604 www.doranmfg.com

Fleet Specialties Company produces **Tire Sentry** for all classes of trucks, buses, and RVs. Microchip wheel sensors attach to each valve stem to continuously monitor tire pressure mechanically and transmit a coded signal to the dash instrument when a loss of tire pressure is detected. A warning light and audible alarm on the dash display shows which tire is losing pressure. The Tire Sentry wheel sensors incorporate a pressure sensor and a microchip transmitter powered by 2 standard watch batteries and are set to the user's individual tire pressure requirements. The user can change pressure settings when desired without the need of special equipment. The wheel sensors that are installed on each tire valve stem weigh less than 1 ounce and can transmit their coded signal up to 50 feet to the antenna located near the drive axle of the tractor. Tire Sentry's coding system prevents "cross-talk" to other vehicles. The display module is wired into the vehicle's power source Tire Sentry's operating range is 50 feet, it operates on 303 or 418 MHz frequency, has an air pressure range of 18 to 125 psi, and a battery life of 2-3 years. Depending on the fleet size the cost of a Tire Sentry system is about $750-$965 for an 18-wheeled vehicle and $395.00 or less for a 6-wheel bus. Fleet Specialties has been developing Tire Sentry since 1995 and has been marketing it since 1997. It has sold "several thousand" units. Fleet Specialties Co., PO Box 4575 Thousand Oaks, CA 91361 (818) 889-1716 Bill James or Bill Shore www.tiresentry.com

REA Technologies has patented the **Integrated Tire Pressure Audio Alarm**. Although not yet on the market this tire pressure warning device consists of a long life battery, a pressure sensing switch and an audio alarm. The device can be designed as either a discrete thread-on (to an existing valve stem) unit or as a unit that would replace completely a standard valve stem. Either design could be made with a replaceable battery or could be made as a throwaway unit after the battery is completely drained. In the thread-on version, the device would simply thread onto an existing valve stem, replacing the valve cap and would provide an intermittent audio warning which could be heard within a few feet of the device when a pre-determined, low pressure threshold is reached. The device is cylindrical, about 3/8" in diameter and approximately 1" long that essentially looks like a valve stem extension. The valve stem version is designed to completely replace the standard valve stem. This unit would perform just like a standard valve stem except it provides the appropriate low-pressure warning. Both units incorporate a small sensor/switch at its base and a battery/sounder module. Since the units are under pressure, pressure is constantly monitored. It does not have an in-cab display but could provide an LED display on the end of the valve stem. The company believes that depending on the specific production model, pressure range, and features the product can be priced in the $4.00 to $8.00 per unit range, or $72.00 to $144.00 for a tractor-trailer combination. REA believes that the product is ready for field testing now and after that will be released into the market perhaps at the end of 2004 or early 2005. REA Technologies, Inc., 815 Brookmead Drive, O-Fallon, MO 63366 (636) 272-3770 Stephen Blakely, Director, Technology Commercialization.

Sensatec, LLC is developing the **Tire Safe** tire pressure and temperature sensor system. The Tire Safe system alerts drivers to impending tire, bearing and brake problems by generating an audible, visual and digital alert when any increase in tire temperature or decrease in tire pressure occurs. It provides constant monitoring of changes in tire pressure and temperature on any vehicle. Tire Safe can be coupled to a satellite transmitter to relay information to a central control facility. The system includes sensors on each tire valve and a portable dash unit that consists of a liquid-crystal display that is either battery powered, wired into the vehicle's electrical system or plugged into the cigarette lighter. The tire sensor is a 1" x 2" cylinder that has a special universal mounting sleeve which allows it to fit on most valves stems. The sensors are battery powered and battery life is between 9-24 months depending on battery type, frequency of interrogation and amount of use. The user can accept factory default conditions or have the capability to program a variety of performance monitoring features such as variable pressure, temperature, frequency of reading, and alarm settings. The operator can set the level at which the tire pressure and temperature measurements will activate the audible and visual warning and alarm features. The display unit continuously displays each tire's position and its conditions. Green is normal, amber is a warning condition and red is an alarm condition. The display unit includes buttons for power and setup menus and an optional computer connection for downloading of tire condition history. A communication control relay box is available for trailers that allows a single tractor to connect to any so equipped trailer. The system operates on 900-950 MHz frequency. Market introduction is expected in 2005. The price for the Tire Safe system will be about $1,200 for an 18 wheeled tractor-trailer unit and $400 for a 6 wheeled bus. Sensatec, LLC, 4 Woodbine Avenue, Greenwood Lake, NY 10925 (845) 477-0200 Keith Yeates www.sensatecllc.com

TireGuard has a valve stem mounted tire pressure monitor called the **TireGuard**. The valve cap-like monitor is available in pressure ranges from 26 psi to 120 psi and as such is being marketed to the automobile/light truck and motorcycle markets as well as the recreational vehicle and commercial vehicle markets. The cost is $7.50 per wheel retail with discounts being offered to fleets. A typical fleet can equip all their wheels for around $4.00/wheel or $72 for an 18-wheeled tractor-trailer unit. This product has had problems with leakage that causes tires to lose air and go flat as experienced by the author. TireGuard, 1501 E. Orangethorpe Ave., Suite 170, Fullerton, CA 92831 (714) 773-4300, Fred Wiseman www.tireguard.net

A.2.2 Wheel Mounted Tire Pressure Monitors

Beru Group introduced its **Tire Safety System** (TSS) as standard OEM equipment for commercial vehicles in July 2003 in Europe. The TSS consists of a central control unit and a set of battery powered wheel electronics attached to each wheel as well as a high frequency receiver for each axle group. The sensors measure the tire pressure and temperature at frequent intervals. These values are sent by radio communications to the antennas where they are then converted into a digital signal and sent to the central control unit for analysis. The control unit analyzes the data, converts tire air pressure to standard pressure. The target tire pressure is set by the driver at the press of a button or at the factory. Should a sudden drop in tire pressure occur, a warning appears in the instrument panel display that says "Flat tire, stop immediately. In the case of a slow loss of pressure, a warning is displayed for the driver who is then reminded to increase the tire pressure at the next opportunity and repeated each time the ignition is turned on. This warning first appears when pressure has dropped 6 psi. If the pressure falls 12 psi, the warning is displayed at a higher urgency level in red instead of yellow. If the pressure loss occurs when the vehicle is stationary, the driver is warned before he starts his trip. The service life of the wheel electronics is three years and they operate at tire temperatures ranging from -40□ to 120□. This system has been linked to satellite aided telemetry in Europe. It is understood that Beru has recently been talking to truck OEMs in the U.S. Beru Group, Morikestr. 155, D-71636 Ludwigsburg, Germany, 49 7141 132 233 www.beru.com.

HCI Corporation sells the **Tire-SafeGuard** tire pressure monitoring system. This system alerts trucks and buses of low-pressure situations with a location, temperature, and pressure reading display and an audible signal. It monitors tire pressure around the clock with detection of abnormal tire pressure even while the vehicle is parked. The Tire-SafeGuard product for commercial vehicles, the TPM-S206, uses an internal rim-mounted sensor. The sensor-transmitter is mounted to the rim and monitors pressure up to 145 psi. The low-pressure and temperature warning is user adjustable and has a range of 18 to 130 psi. The sensor transmitter automatically switches on to monitor the tire of a vehicle moving faster than 15 mph and reports pressure readings to the receiver. Pressure measurement accuracy is +/- 1 psi. The module has an operating temperature range of -40□ to 250□ and a battery life of over 5 years. The receiver for the display can be plugged into the auxiliary power outlet or can be directly hardwired to the main power source. It is 3 1/2" x 1 1/8" x 5/8" in size and weighs 1.5 ounces. The cost to equip a tractor (10 positions) is $650. The company is developing a receiver to mount on trailers that will transmit signals from the trailer tires to the in-cab monitor in the tractor. This should be available in July, 2004. At present it must use an antenna that is connected to the tractor through the 7-way pin connector to get the trailer tire signals to the in-cab monitor. HCI has sold about 100 of these systems. It is working with the Reineke Company to provide tire pressure monitoring with its central tire inflation system. HCI Corporation, 11245 E. 183rd Street, Cerritos, CA 90703 (562) 926-7123 x 212 Tim Glassford, Sales Manager www.tiresafeguard.com.

SmarTire Systems, Inc.'s **SmarTire** currently marketed passenger/light truck technology uses wireless communications to monitor the air pressure and temperature in tires. A small sensor is strapped on each wheel and collects temperature and pressure data every 7 seconds. This data is transmitted via radio frequency to a receiver display located inside the vehicle that indicates individual tire pressure and temperature. When tire pressure drops below a pre-set level, a red warning light and audible alarm warns the driver of the pressure loss and indicates the wheel location. Should the situation worsen, a second warning involving a flashing red light and an audible alarm will be activated and repeated every minute until the problem is resolved.

SmarTire is currently developing tire-monitoring products for the commercial vehicle market. These products will monitor pressures up to 187 psi and accommodate up to 20 wheel positions. The commercial products will have the ability to integrate with fleet management systems and on-board computers. SmarTire's commercial vehicle system is not being marketed at this time but is expected to be introduced in May 2004. It is expected to cost $620 for an 18-wheeled vehicle, $210 for a 6-wheeled bus, operate on 300 MHz frequency, and measure temperature and pressure. SmarTire Systems, Inc., Suite 150 – 13151 Vanier Place, Richmond, BC, Canada V6V 2J1, (604) 276-9884 x 308, John Bolegoh, Product Manager, www.smartire.com

WABCO and **Michelin** developed the **WABCO Integrated Vehicle Tire Pressure Monitoring** (IVTM) system for commercial vehicles. Each tire and wheel assembly is equipped with a wheel module that is attached to the outside of the wheel rim using two wheel bolts and nuts. It is connected to the tire valves using pneumatic hoses. It checks pressure constantly and transmits tire pressure data periodically every 15 minutes to the ECU and every 30 seconds in case of a significant pressure variation. The wheel module remains on the same position on the vehicle even when tires are changed. The power supply is provided from a built-in lithium battery with a 5-year service life. The IVTM ECU is mounted on the vehicle chassis and contains a built-in antenna to receive the pressure data from all tires eliminating the need for additional antennas in the wheel modules. Trailers are equipped with their own ECU which sends the tire inflation pressures measured on the trailer to the ECU on the tractor. The display on the dashboard warns the driver optically and acoustically whenever the inflation pressure of a tire on the tractor or trailer has reached a critical value. A yellow lamp indicates a slight pressure loss, a red lamp indicates a critical pressure loss. The position of the concerned tire and its current inflation pressure can be called up on the display at the push of a button. Before a trip, the driver can check pressures by using this system and pressing a button. Under normal circumstances there is no pressure display as this system only displays exceptions. Operating frequency is 433 MHz. This product was supposed to be introduced in May 2003 in the European aftermarket and in mid- to late 2003 with truck OEMs. In the third quarter of 2003 MAN, a leading European truck and bus manufacturer began equipping trucks with wide base tires and the IVTM. In March 2004 WABCO launched the IVTM system for retrofitting buses and coaches in Europe. WABCO is currently field testing its tractor-trailer system. Market introduction for retrofitted tractor-trailers is expected to be summer, 2004 in Europe. A second truck OEM will offer this system on its tractors in August 2004 and will offer the trailer retrofit system through its dealer network. The company is also modifying the radio transmission and the CAN interfaces for United States vehicle architecture. It is planning to introduce the IVTM system to OEMs and the United States aftermarket, but cannot disclose any dates at this time. No prices are available for the IVTM System either at this time. WABCO has sold several hundred systems in Europe. WABCO GmbH, Vehicle Control Systems, Am Lindener Hafen 21, D-30453, Hanover, Postfach 91 21 62, Germany 49 (511) 922-2144 www.ivtm.com

Yokohama Tire Corp. has developed a chip technology as well for truck and bus tires. Yokohama's has named its tire pressure monitoring system **HiTES**, an acronym **for Hi-Technology Tire Engineering System**. This system uses a sensor that is mounted on the tire rim and reports pressure and temperature to a receiver and display unit in the cab of the truck. Also near the driver is an LED indicator that uses color changes to show air pressure status. This allows drivers to confirm air pressure in real time, reducing the time needed to conduct checks before they begin a trip. Yokohama also has a hand held monitor as well. Data is automatically transmitted to Yokohama's host computer where it is managed along with information gained through periodic checks of tire wear, damage, and distance traveled. This information can be analyzed and provided to the customer via the Internet, enabling customers to precisely calculate the appropriate times for tire changes and rotations. According to Yokohama it has been testing this technology in both OTR tires as well as medium truck tires for several years. No price is yet available for this system. HiTES was commercialized in Japan in July 2003 and is expected to be marketed in limited quantities to trucking firms and bus companies through Yokohama's tire sales subsidiaries throughout the world including the United States. The system is being offered exclusively to users of Yokohama tires. To date the product has not been introduced to the United States market. (One vehicle was equipped for test at the Port of Tauranga, New Zealand in January 2004.) Yokohama plans to develop a range of systems and products as part of its Tire Management System (TMS) program. Yokohama Tire Corp. 1500 Indiana Avenue, PO Box 3250, Salem, VA 24153 (540) 389-5426 www.yokohamatire.com

A.2.3 Tire Mounted Tire Pressure Monitors

Bridgestone/Firestone, Inc., Goodyear Tire & Rubber Co., Michelin North America, and Yokohama Tire Co. have all been developing tire condition sensors that are installed inside the tire on the tire liner with the use of a tire patch to adhere the sensor to the tire. To date, they have concentrated their efforts in the Off-the-Road market due to the complexity of developing these systems, the high costs of technology, and the pricing flexibility that large, $30,000 off-road tires offer. Long-term plans call for the possibility of bringing this technology to the truck tire market. Currently, the sensors that have been developed for this market are about the size of a pack of cigarettes, which is too large to work in typical commercial truck tire sizes. Some smaller prototypes have been running in the truck market in limited field trials, but none are commercially available. Descriptions of these products as they currently exist in the Off-the-Road market are provided as follows:

Bridgestone/Firestone Inc. is working on a PC-based active tag system that consists of a tiny battery-powered sensing and sending chip that is installed on a patch inside the tire. A stationary "gate" reader receives the signals broadcast by the unit up to 30 feet away. This receiver is connected to a PC with special software to record the information. Ultimately, this active tag system will be able to provide tire temperature and pressure readings every 10 to 15 minutes, provide tire pressure histories for each tire that is given an identification number and report to an in-cab monitor or through a broadcast link with a satellite dispatch system. Data is transmitted to a network server and placed on a secure Web site where it can be accessed from anywhere in the world. No prices have been established for this system at this time. Bridgestone/Firestone America, 1200 Firestone Pkwy., Akron, OH, (330) 379-3844, www.bridgestone-firestone.com.

Goodyear Tire & Rubber Co. has an **Intelligent Tire System for off the road vehicles**. It monitors and reports tire pressure and temperature for tires on large haul trucks used in mining and other off-highway, heavy-duty applications. This system utilizes an active tire sensor that operates on the 902-927 MHz frequency. The size of the sensor is 3" in diameter and 1.3" high, about the size of a hockey puck. It samples pressure and temperature every 3 minutes and communicates this information to a receiver in the cab, which sends data upstream to the mine management system. The data can be viewed at mine dispatch, downloaded into a laptop computer, or viewed in the truck. It also can interface with a satellite dispatch system. The sensor screws onto a ¼" threaded stud in a patch that is affixed to the liner of the tire in the center of the crown. The cost for this system is $4,700/vehicle. Goodyear Tire & Rubber Co. 1144 East Market Street, Akron, OH 44316, (330) 796-8365, www.goodyear.com.

Michelin North America introduced its **eTire** system for medium-duty trucks in October, 2002. Michelin worked with Texas Instruments for around three years to develop this system. The eTire system utilizes Michelin's battery-less InTire Sensors that can be applied to any commercial truck tire using the sidewall mounted SensorDocks, which are molded rubber pieces that chemically cure to the inside of the sidewalls in the same fashion as tire repair units. The sensor unit slips over a knob on the rubber dock and locks into place. Once installed, the sensors remain through the entire life of the tire including retread processes. The sensor is removable and can be reattached to a new truck tire with a new SensorDock. The sensors measure temperature and pressure on demand from a reader and communicate this information along with wheel position, a unique identification code and a programmable identification number for its respective tire, to drive-by and hand held readers that power the sensors. Other sensors located on the tractor and trailer provide vehicle identification information at the same time. The sensors include a radio frequency transmitter, pressure and temperature sensors and an antenna, which are encased in impact- and heat-resistant plastic. The unit measures 4x1.5 inches and weighs less than an ounce. The vehicle must only be traveling about 5 mph past a gate reader for it to receive the information from all the tires including the inside duals. The reader picks up about 95% of the sensor information when a vehicle drives by. The readers convert hot pressure to cold equivalent pressure. The information gathered is reported in a fleet specific manner via an Internet server to Michelin's BIBTRACK web site which is home to BIBTRACK software that tracks tires and provides recommended actions to be taken on problem tires. Fleets can get up-to-date information on their tires, track tire costs, and monitor inventories around the clock by going on-line. No data is stored on InTire Sensors. This system does not have an in-cab display nor is it capable of having one designed for it in the future. The InTire Sensors do not have 360° read capability so the hand held reader must be positioned over the sensor to read it. Michelin has an eTire label that is installed on the outside of the tire that visually locates the sensor. Each sensor unit costs about $30 but actual fleet cost will vary based on fleet size. Hand held readers are approximately $6,000 and gate readers are approximately $10,000-$12,000. No unit sales numbers are available. Michelin North America Inc., PO Box 19011, Greenville, SC 29602 (864) 458-5476 Randy Clark, Vice President of Marketing, Truck Tire Unit www.michelintruck.com

Yokohama Tire Corp. is developing chip technology as well. It can be used for tire identification applications and to monitor and indicate temperature, inflation pressure and other data. As with the other systems, Yokohama's works with an embedded ship within the tire structure that sends a signal to a transponder. The actual readout of the information takes place within the cab of the truck. Yokohama also has a hand-held monitor as well. According to Yokohama, it has been testing this technology in both OTR tires as well as medium truck tires for several years. No price is yet available for this system. Yokohama Tire Corp. PO Box 3250, Salem, VA 24153, (540) 389-5426, www.yokohamatire.com.

CrossLink, Inc. After five years of development, **CrossLink** was licensed by Bridgestone/Firestone to market the TreadLink system that is designed for trucks and other heavy equipment vehicles. The TreadLink system uses 1" square 915 MHz passive tags which have a read range of up to 30 feet. Each tag hold 8 kilobits of data, including a unique serial number, temperature and pressure readings, and the maximum temperature of a tire during its lifetime. The pressure-sensing chip is permanently installed on a patch inside the tire. The RFID transponder sends data on the temperature-adjusted pressure of each vehicle's tires to readers placed on the truck or at a terminal entrance or exit. These readers are connected to PCs with special software to record the information. Fleet operators can also scan the tags with a handheld reader. The company says it is working on reusable tags as well as a similar system that tracks tires and links them to the truck as part of a larger vehicle-monitoring system. The TreadLink system will be available in early 2004 for trucks, buses, tankers, trailers and off-road heavy equipment vehicles over 6,000 pounds gross vehicle weight rating. The tags are expected to be priced at around $30 each. Fixed readers will run about $1,000. On-board and handheld readers will cost about $300-$400. CrossLink,Inc., 6185 Arapahoe Avenue, Boulder, CO 80303 (303) 473-9232 Gary Zarlengo, President www.crosslinkinc.com

D H Products is developing a tire pressure monitoring system called the **Flat Alert System** that is placed inside the tire although not mounted to the tire. This system uses a silicone covered 2" ball that weighs 2 ounces, which rolls inside the tire as the tire runs. It has an expected life of 250,000 miles. A hand held reader is used to read the pressure and a display/receiver is also located in the cab of the vehicle. This product is expected to be introduced to the market in June, 2004 for recreational vehicles and commercial vehicles. It is expected to retail at $612 for an 18-wheeled unit ($450 for fleets). D.H. Products, 2231 Riviera Place, Longmont, CO 80501 (303) 772-7902 Dusty Hill, President.

A.3 TIRE INFLATION SYSTEMS

A.3.1 Central Tire Inflation Systems

A.3.1.1 Variable Central Tire Inflation Systems

CM Automotive Systems, Inc. manufactures the **Central Tire Inflation System (CTIS)** which is designed for all terrain operations more so than over-the-road operations. CM Automotive's targeted market is military trucks and transports, fire and rescue vehicles, logging operations, and dump trucks. The CTIS allows the driver to maintain traction and mobility over wide variations of terrain by adjusting the tire pressures. The tire adjustments can be made while the vehicle is in motion. The system components are the manifold, controller, wheel valve, and harness. The manifold adjusts pressure that goes to or out of the system, the controller is the display located in the cab that allows the driver to operate the system, the wheel valve attaches to the valve stems and allows for the air to enter or escape the tires, and the harness provides the electronic controls to the system. The cost of this system on a tractor–trailer combination ranges from $1,200 to $2,500 depending on the vehicle/axle configuration. CM Automotive Systems, Inc., 120 Commerce Way, Walnut, CA 91789, (909) 869-7912, www.cmautomotive.com.

Tire Pressure Control International, LTD. manufactures and distributes the **TIRENBOSS Tire Pressure Control System**. The Redline-Eltek Tire Pressure Control System integrates with the existing air supply on the vehicle. It is comprised of five component assemblies: a priority valve that protects air brake system integrity, control air valves, air lines to and from the control valves, and axle end rotary union hardware that transmits air into and out of the rotating tires. In use, the driver selects an appropriate setting on the operator control panel, which then sends a signal through the computer to open either the inflate or deflate control valve as needed. Air from the vehicle brake wet tank is drawn into the tire pressure control system to inflate tires through the inflate valves, while air from the tires is exhausted through the deflate valves. Priority safety switches make sure that air is available for tire inflation only when the vehicle system air brake pressure is above a safe level, typically 90 psi. The computer continuously monitors tire pressure and controls the inflating, deflating or maintaining of a pre-selected target tire pressure. The system also monitors vehicle speed. If it detects the rig is going too fast for the selected tire pressure and risking tire damage, visual and audible alerts warn the operator to reduce speed or choose another pressure setting. Should the driver fail to respond to these alerts, the computer is programmed to automatically select a pressure suitable for higher speeds. The operator control unit is easy to read allowing the driver to monitor the status of the TPCS at a glance. Four buttons control and program the system's functions, which include four driving modes: highway loaded, highway unloaded, off-highway loaded and off-highway unloaded, as well as three secondary function modes. This system is used primarily in on/off road applications, such as forestry and concrete operations where mobility in sand or soft ground is required. The cost for this system starts at about $8,000 to equip the tandem drive axles on a tractor. Tire Pressure Control International Ltd., 15803 – 121 A Avenue, Edmonton, Alberta, Canada, T5V 1B1, (888) 338-3587, www.tirepressurecontrol.com.

Dana Spicer markets the **Tire Pressure Control System**. Dana's Tire Pressure Control System is designed specifically to allow the operator to adjust tire pressure to match the conditions on and off the road while the vehicle is in motion or is stationary. This system is the commercial version of the Eaton Central Tire Inflation System (CTIS) used in military applications. This system regulates tire pressures through a series of electro-pneumatic controls that feed air to each wheel end through wheel valves. The driver operates a dash-mounted graphic control panel, which commands the system to adjust tire pressures, and tells the driver what functions the system is currently performing. A pressure switch prevents the system from consuming air unless the vehicle's brake system is fully charged. This system has three distinct settings: a highway setting for high speed travel on paved surfaces, an off-highway setting for operation on secondary roads, and an emergency setting to help free vehicles that are stuck in muddy terrain or to help drivers negotiate difficult grades. Two modes accommodate both loaded and unloaded trucks. The cost for this system on a tractor-trailer unit is about $7,000-$13,000. Dana Corporation, Spicer Heavy Axle & Brake Division, Advanced Chassis Control Unit, PO Box 4097, Kalamazoo, MI, 49003-4097, www.roadranger.com.

A.3.1.2 Constant Central Tire Inflation Systems

Air Fender Systems, Inc. has just developed its **Rotary Air Chamber**. This system is designed for tractor (including steer tires) and trailer tires and supplies air to them while traveling down the road. The Rotary Air Chamber does this by taking air from the brake system air tank and passing it into an internal air chamber that is bolted on to the axles and rotates with the tires. The air then passes through a small tunnel hole in the rotator shaft and comes out a tee connection that has two hoses that are connected to the valve stems of the dual tires. The housing of the air chamber is held stationary by Air Fender's fender panel. Tire pressure can be visually read by examining a small pressure gauge on the hose lines that constantly measures the actual tire pressure. Pressure is maintained at 100 psi and air is exhausted from the tires when pressures exceed 120 psi. This system costs about $80.00 an axle end. This system is expected to be introduced to the market in 2004. Air Fender Systems, Inc., 322 Northpoint Parkway, Suite J, Acworth, GA 30102 (800) 527-7729, John Becker, President www.airfenders.com

AIRGO Systems Inc. brought out a new central tire inflation system in July, 2003 called the **AIRGO System**. The company founder, Tony Ingram was formerly with Pressure Systems International. The trailer central tire inflation system it is bringing out has a light on the trailer nose that indicates when the system is supplying pressure to the tires. The AIRGO System offers constant tire monitoring and when necessary automatic re-inflation. When a tire loses pressure due to a puncture or other leakage, the system's sensor check valve automatically detects the loss. It immediately draws air from the vehicle's reserve pneumatic system, and directs air flow to each tire requiring air. This air pressure is delivered via the trailer's hollow axle housing, through the hub assembly and into the tires. The system uses an externally located rotation design for venting outside of the hub which eliminates potential internal pressure leaks and debris that can cause damage to internal hub components. Eight cubic feet per minute of air flow is supplied to a leaking tire via a large transfer tube. The external location of the rotating unit allows for fast installation and service and no custom hubcaps are required. The rotary seal this system uses is guaranteed to last five years. The suggested retail price is $795 for a tandem axle trailer. OEM and distributor pricing is available. AIRGO Systems, PO Box 727, Edmond, OK 73034 (405) 844-5825 Tony Ingram, CEO, Julie Leidner Marketing (617) 422-0045.

Arvin Meritor distributes **Pressure System International's (PSI) Tire Inflation System**. This system currently addresses only trailer tires but the company is working on developing a system for tractors as well. The Tire Inflation System uses compressed air from the trailer to inflate any tire that falls below the system's air pressure specifications. Air from the existing trailer air supply is routed to a control box and then into each axle. Acting as a conduit, the axles carry the air through a rotary union assembly at the spindle end, which then distributes the air to each tire as needed. Tire pressure is constantly monitored. When a tire experiences a leak, an indicator light mounted on the trailer comes on to signal air delivery and charging. A one-way check valve located in the hose connected to the valve stem protects each tire against air pressure loss. If a tire is punctured during operation and loses air pressure, the check valve prevents loss of pressure in the other tires. A pressure protection valve located between the shut-off valve and the reservoir allows air to the tire inflation system only when the brakes have sufficient pressure to operate correctly. The cost for this system is approximately $700. PSI entered into a distribution agreement with Arvin Meritor in 1998. This has resulted in international sales and closer ties with OEMs. PSI has sold 500,000 units since 1994. Its current annual sales are between 30,000 and 40,000 units. PSI estimates that 18% of new trailers are equipped with central tire inflation systems. It expects to introduce a system for commercial tractors in 2004. Arvin Meritor Commercial Vehicle Systems, Meritor Heavy Vehicle Systems, LLC, 2135 West Maple Road, Troy, MI 48084 (800) 435-5560 www.arvinmeritor.com Pressure Systems International, 3023 Interstate Drive, San Antonio, TX 78219 (210) 222-1926 Frank Sonzala, Executive Vice President.

Dana Spicer produces the **Tire Maintenance System for Trailers**. This system constantly monitors tire pressure and provides air pressure automatically to trailer tires that experience air loss. (It does not address tractor tires.) This system detects and responds to low tire pressure by directing air as needed and alerting the operator with a yellow light located on the left front corner of the trailer. It also retains evidence of low pressure tires in its memory for recall during vehicle maintenance. The system uses a main power harness, an ECU and a pneumatic control valve to regulate air pressure to the tires. Air flows through conduits inside the axle to wheel end seals. The price for this system on an eight-wheeled trailer is $900. This system was introduced in 1999-2000. No unit sales numbers are available for this product. Dana Corporation, Spicer Heavy Axle & Brake Division, Advanced Chassis Control Unit, PO Box 4097, Kalamazoo, MI 49003-4097 www.roadranger.com

Gio-Set Corporation produces the **VIGIA Automatic Tire Pressure System** for tractors-trailer combinations and RVs. This system continuously reports and automatically regulates the tire pressure. When the pressure falls minimally in one or more tires, the VIGIA system reports the existence and location of the problem to the driver. At the same time the inflation process starts to maintain the appropriate pressure in the tires. In case of a tire blowout, the equipment automatically shuts down to protect the operation of the other air-powered components on the vehicle such as the brakes, clutch, suspension, etc. VIGIA is fed from the auxiliary air reservoir. A dedicated air filter absorbs the impurities in the air. Once the air is filtered, it reaches the control panel and from there it is redistributed to the tires. A small control panel in the truck cab controls all the functions in the system. The lights indicate the normal function of the equipment, the loss of pressure in tires, the air circuit where the loss is taking place, and the low air pressure of the compressor. A separate control panel is placed on the front corner of the trailer so that the driver can readily see it. This system costs $2,300-$3,200 depending on the axle setup for a tractor and trailer combination. The VIGIA Automatic Tire Pressure System was developed 27 years ago in Argentina and is used in 20 countries around the world. Only one distributor has been marketing this product in the United States for the past two years. To date he has only sold 32 units on recreational vehicles, 275 on trailers, 50 on tractors and 10 on buses. Marketing efforts have been restricted by finances. Gio-Set Corporation, 37 Landing, Laguna Niguel, CA 92677 (949) 412-9393 Ruben Giosa, Distributor. www.gio-set.com

Hendrickson International began marketing its **Hendrickson Tire Inflation System (HTIS)** for its INTRAAX and VANTRAAX trailer suspension systems in 2002. This responsive tire maintenance system maintains inflation to a specified level. The system checks tire pressure every 10 minutes, detects low tire pressure, and alerts the operator to the occurrence. It responds by directing air when a tire dips below a predetermined pressure level. HTIS activates only when needed, constant air pressurization to the tires is not required – reducing air demand and prolonging system life. Air travels from the supply tank through air lines inside the axle to the wheel-ends. A rotary union allows air to flow from a non-rotating axle spindle to the rotating hubcap fitting. Hoses connect from a hubcap tee to the tires. A warning light alerts the operator to system status and maintenance activity and the system records episodes of low tire pressure for retrieval during servicing. Check valves help prevent tire pressure loss back through the system. Manual fill and pressure checks may be accomplished at the hose end. HTIS connects all tires to the trailer air supply and may be combined with any of an extensive array of wheel end configurations and spindles available for INTRAAX and VANTRAAX suspensions only. A laptop computer can be used to download tire inflation history from the system. The system was jointly developed by Hendrickson and Spicer over a 2 ½-3 year period and was introduced to the market in May 2002. Approximately 1,000 systems are currently in use. Hendrickson sells this system only to trailer OEMs who price it competitively with other similar systems on new trailers. As a result, Hendrickson does not control the price.

Hendrickson introduced a new tire inflation system in 2003 that has less record keeping features but is less costly called TIREMAXX. This system is governed by an electronic control unit (ECU) that detects low tire pressure and signals the operator. It responds by directing air from the trailer tank to one or more tires when the pressure dips below the pre-set level. It only pressurizes the air lines when needed which protects seals and wheel ends. A lamp is mounted on the trailer to alert the driver to the system status. An optional hand-held programmer featuring a 32-character display accesses status information and using convenient system-check routines, reduces guesswork when troubleshooting. This convenient maintenance tool reprograms target pressure to settings from 70 to 130 psi in five-psi increments and helps prevent system tampering. Hendrickson International, Trailer Suspension Systems, 2070 Industrial Place SE, Canton, Ohio 44707-2641 (866) 743-3247, Rick Bevington, Marketing Mgr. Tire Inflation Systems, www.hendrickson-intl.com

Reineke Company Inc. manufactures the **PressureGuard Automatic Tire Maintenance System** (which it purchased from Innovative Transportation Products Inc. in 2003). The PressureGuard system routes air from the trailer's supply tank through the axle to the hub and then to the tires so they maintain pressure at preset levels. The system is always under pressure so tire pressure is constantly monitored. If there is a tire blowout or system leak, PressureGuard's valve stem-mounted check valve keeps air in the remaining tires. If a sudden drop in pressure occurs, the system protection valve closes to prevent air loss out of the reservoir so the rest of the trailer air system including brakes remains unaffected. When a sudden loss of air occurs a trailer-mounted warning indicator alerts the driver. The cost of the PressureGuard System for one trailer is about $600. ITP worked on developing this product for over a year before it introduced it to the market in October of 1999. Since then it has sold around 20,000 units. Reineke Company has been working with Tire-SafeGuard to offer a tire monitoring system that will work in conjunction with the Pressure Guard Automatic Tire Maintenance System that will include a display in the cab that advises the driver of individual tire air pressures. This is expected to be available the third quarter of 2004.

Reineke is also developing a drive axle tire inflation system. The Drive Axle TIS utilizes a rotary union that can be adapted to fit an array of drive shaft designs. The system was designed for use without complicated electronic components and to maintain correct tire pressure at a preset level (inflate only). While the system is till in development, the Company expects to have prototypes installed for field testing by the fourth quarter, 2004 and commercially available in 2005. The cost for this system is expected to be between $2,000 and $3,000.

PressureGuard TIS for wide base tires is also under development. This system uses a valve stem adapter that is inserted in a hole drilled into the wheel and eliminates the need for hoses. Reineke expects to be testing these units on field applications by the fourth quarter of 2004 and have it commercially available in 2005. The cost of this system is expected to be $600-$700/trailer. Reineke Company Inc. 1025 Faultless Drive, Ashland, Ohio 44805 (419) 281-5800 Matt Reineke, President www.pressureguard.com.

A.3.2. Continuous Tire Pressure Pumps

The Cycloid Company produced the **Cycloid Model 2000 Continuous Tire Pressure Maintenance System**. This system was different from the other tire inflation systems as it did not use the air system on the vehicle to supply air to the tires, but rather generated its own compressed air with a small pump mounted to the end of each axle. The rolling motion of the wheel (centrifugal force) continuously powered the Cycloid self-contained pump compressor. It attached to the hub of a dual wheel assembly and hoses connected the pump to the tire valve stems. Inner and outer tire pressures could easily be checked from a centralized hub mounted valve stem. An option was available that provided visible pressure gauges to indicate the exact pressure in the tire assemblies. The pump was set at the factory with the maximum pressure that the tire would be inflated to so it would not overinflate or deflate the tires. The pump constantly monitored tire pressure. When a tire experienced an air leak, the pump supplied air independently to that tire. It did not equalize pressure between the dual tires. Due to overall width limitations on commercial vehicles the pump could only be installed on dual wheel combinations and could not be placed on steer axle ends. The pump weighed 2 lbs. and pumped 6 psi an hour to tires that experienced air loss. The cost of a Cycloid Model 2000 Pump ranged from $200-$250 an axle end depending upon the accessories chosen.

In 2001 Cycloid signed an exclusive distribution contract with Euclid Industries for sale of their truck tire pump. However, on the same day, Euclid was purchased by Arvin Meritor which already had an exclusive agreement with Pressure Systems International for distribution of its Tire Inflation System. As a result, Cycloid decided to concentrate on the automotive market with its pump through its ties with Arvin Meritor and exit the commercial truck market. At this moment the company does not sell pumps for commercial trucks. Cycloid plans to introduce a new, electronic version of its pump for commercial trucks in 2005. Cycloid began developing its Continuous Tire Pressure Maintenance System in 1992 and introduced it to the market in 1997. It has sold 7,000 pumps in the trucking industry. Cycloid Company, 301 Commerce Park Drive, Cranberry Township, PA 16066 (724) 742-1780 Mervyn Carse President & CEO www.cycloid.com

A.4 OTHER TYPES OF SYSTEMS

With the advent of the Firestone recall in 2000, engineers in all types of technologies have focused on addressing the problem of tire failures. Coming to market are technologies that do not fit the general category of tire pressure monitors but do address detection of tire failures. The authors have identified one such technology that is described below, however, there may be more currently under development that are unknown to the authors of this report at the present time.

Radian Inc. has developed the **Thermal Imaging Inspection Station (TIIS)**. This system uses thermal imagery to detect tire faults that result in tire failures as a result of heat buildup inside a tire. In tires, most tire failures begin with separation in the plies. Air eventually seeps into these areas of separation and heats up and expands when the vehicle is moving. The air trapped in the separations becomes hotter than the air in the tire, which causes the separations to expand until a chunk of rubber breaks off and causes a blowout. The pattern of heat that builds up can be viewed with a thermal imager (camera) that takes temperature sensitive snap shots of tires. The TIIS detects these separations that show up as red in the photographs and is programmed to recognize the thermal signatures associated with separations to give advanced warning of an impending failure. The TIIS can be used in any location where vehicles have been in operation at highway speeds. Weigh stations on Interstate Highways and the entrance into motor pools or maintenance yards are good sites for inspecting tires. Vehicles can be moving at speeds up to 15 mph while going through the TIIS inspection. The TIIS can also be mounted in a vehicle and a hand-held unit may be available in the future too. This system can also be used to detect overheating brakes and bearings. The cost of the Thermal Imaging Inspection Station is currently about $90,000-100,000. Radian, however, is working on making a smaller, hand-held version that will have a target price of around $20,000. Radian, Inc., 5845 Richmond Highway, Alexandria, VA 22303, (703) 329-9300, www.radianinc.com.