

# Extending the Lifespan of Tires: Final Report

By

Shmuel L. Weissman and Jerome L. Sackman  
Symplectic Engineering Corporation

And

David Gillen and Carl Monismith  
Institute for Transportation Studies  
University of California at Berkeley

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## **Disclaimer**

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## Executive Summary

The number of waste tires generated in the State of California each year roughly equals its population, which is predicted to grow by about 30% over the next twenty years. Furthermore, motivated by improved performance and new safety oriented technologies, consumers are switching to heavier tires. As a result, over the next 20 years tire waste by tonnage will increase by about 40%. New tire technologies will also make it more difficult to recycle tires. Therefore, the importance of reducing the number of tires entering the waste stream will escalate with time.

In 1981 light-duty tires averaged about 28,000 life miles. By 2001 tire lifespan increased to 43,000 miles. During this twenty year period the average annual vehicle miles traveled (VMT) increased from about 9,000 to 12,000 miles. Thus, the average number of waste tires generated per light-duty vehicle each year declined from 1.29 in 1981 to 1.12 in 2001. This 15% reduction was achieved despite a 33% increase in annual VMT. This record demonstrates the importance of extending the lifespan of tires to reducing the number of waste tires.

Changing from bias ply tires to radial tires and improved rubber compounds brought about the increase in tire life noted above. However, gains in recent years have slowed as the radial tires technology matured. Something more is needed to enable the next leap in tire life mileage, and it is provided by smart tire systems that optimize tire operation.

Data provided by Michelin shows that 50% of all light-duty tires entering the waste stream do so because of abnormal wear, which is due to poor tire maintenance. An additional 10% enters the waste stream due to oxidation and separation, two processes that are accelerated when tires overheat, which is also a consequence of poor tire maintenance (*e.g.*, low air pressure). Thus, improving the maintenance of tires can extend the life of about 60% of light-duty tires.

In 2001 the National Highway and Traffic Safety Administration (NHTSA) conducted a nationwide survey of tire pressure maintenance for light-duty vehicles. This survey found that air pressure was, on the average, 6.1 pounds per square inch (psi) below placard pressure. (Placard pressure is the air pressure specified by automakers, and it is intended as the “cold” inflation pressure.) The survey examined air pressure in vehicles that were driven an unknown distance immediately prior to being tested. Consequently, the tires examined were “hot,” and the air pressure in them was 4 or 5 psi above the cold inflation pressure. Thus, it is possible to conclude that the national fleet averages about 10 or 11 psi below placard pressure. Goodyear, in a disclosure to NHTSA, indicated that tires lose about 1.78% of their tread life for each psi below placard pressure. Combining the (temperature-corrected) results of the NHTSA survey with the information provided by Goodyear leads to the conclusion that tires mounted on passenger vehicles lose, on the average, about 17.8% of their life miles potential (assuming an average of 10 psi below placard pressure). Many passenger tires feature a limited warranty of 80,000 miles, which means that the life mileage for these tires is reduced by 14,240 miles due to improper tire pressure maintenance. Thus, smart tire systems that continuously maintain air pressure at placard level can deliver a significant jump in the average tire life that can be achieved.

In August of 2000, Firestone recalled some 14.4 million tires that were primarily installed as original equipment (OE) on Ford Explorer sport utility vehicles (SUVs). This recall, which was

prompted by a number of tire blowouts that led to vehicle rollover resulting in injuries and fatalities, marks a major milestone for the tire industry. In the aftermath, the U.S. Congress passed the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000, which required NHTSA to establish a standard for tire pressure warning systems. In June of 2002 NHTSA issued its rule on tire pressure monitoring systems (TPMSs) that requires automakers to phase in TPMSs so that by the 2006 model year all vehicles will be equipped with such systems. Although smart tire systems predate this rule, it can be viewed as the start of the smart tire systems era.

What is smart a tire system? Fundamentally, this is a conventional tire plus a smart system that helps optimize the performance of the tire-vehicle system. The following are three examples of smart tire systems. First, TPMSs noted above warn the driver whenever the air pressure in tires drops below a threshold specified by the NHTSA regulation. Thus, TPMSs can enhance the safety of vehicles. Second, auto-inflate systems monitor and maintain tire pressure at the placard pressure level at all times. The benefits from auto-inflate systems include extended lifespan of tires, enhanced safety, and improved effective fuel economy of vehicles. Third, Smart tire systems can also communicate information from tires to the vehicle suspension and braking systems to help reduce braking distances.

This study is primarily focused on light-duty tires because they form 80% of waste tires requiring secondary use or storage in landfills. This is primarily because more than 50% of replacement heavy-duty tires are retreads, whereas retreaded light-duty tires are almost nonexistent. However, some of the findings of this study can benefit heavy-duty tires, and these crossover benefits are pointed out when appropriate.

This report examines four different broad strategies to extend the lifespan of tires. Each of these strategies is presented and then analyzed from three points of view. First examined is the contribution of each strategy to the reduction of the number of waste tires. Second, a benefit cost analysis is undertaken to assess the economic effect of each strategy. Third, implementation issues pertaining to each strategy are reviewed. The four strategies are discussed below.

Each strategy is presented here as a stand-alone option. However, better results are likely to be achieved if these strategies are integrated. For example, adopting auto-inflate systems would resolve the acute problem of under-inflated tires noted above. However, these systems will most likely be installed only on new vehicles. Therefore, educating owners of existing vehicles to better maintain their tires is also needed.

The first strategy considered is advancing auto-inflate systems. The advantage of such systems is that they automatically maintain tire pressure at near placard at all times. As a result, tires equipped with auto-inflate systems can achieve in practice a life mileage closer to the one they are designed for than the average tire currently attains. Auto-inflate systems also contribute to reduce braking distance and the risk of tire blowouts, and improve fuel efficiency. As a result, the benefit cost analysis predicts a net benefit of \$1 billion over an eleven-year period for the California economy.

Two approaches to promote auto-inflate technology are considered. The first approach is to promote voluntary adoption of this technology. Under the voluntary adoption scenario the

California Integrated Waste Management Board (CIWMB) could educate the public about the advantages of auto-inflate systems including: extended tire life, improved safety, and improved vehicle fuel efficiency. At the same time the CIWMB could work with the auto-insurance industry to educate it about the safety advantages associated with this technology. Auto-inflate systems will become prevalent because automakers will be responding to both public and auto-insurance demands.

Mandating a phased adoption of auto-inflate systems is considered as an alternative to the voluntary adoption approach. (Both mandated and voluntary adoption address only new vehicles.) Mandating auto-inflate systems may result in a faster adoption of this technology in California. However, it will generate considerably more objections than the voluntary approach.

The second strategy considered is educating the public to better maintain their tires including: maintaining air pressure in tires at the placard level, rotating tires, and maintaining proper vehicle alignment. In pursuing this strategy the CIWMB could join forces with other entities already active in this area including the Rubber Manufacturers Association (RMA) “be smart play your part” campaign, and the web site launched by Bridgestone/Firestone [www.tiresafety.com](http://www.tiresafety.com).

The main advantages of the public education strategy are that it is easy to implement, relatively inexpensive, and would generate no objections. However, education is also not very effective in terms of reducing the number of waste tires. For example, the quick reaction of Congress to the Firestone recall noted above provides an indication of the high public awareness of the importance of maintaining proper tire pressure to its safety (otherwise why mandate a low pressure warning system). Yet, the poor state of maintenance revealed by the NHTSA study was found just three months after the passage of the TREAD Act of 2000.

The third strategy considered is to mandate that each tire producer sell in California a mix of light-duty tires that overall averages a given specified tread wear rating component of the uniform tire quality grading (UTQG). This strategy would allow tire makers to continue distributing high-performance tires without interference, which is where they get the highest profit margins. However, the total tire population would achieve longer lifespan, and thus reduce the number of tires entering the waste stream. This mandate would mimic the federal Corporate Average Fuel Economy (CAFE) standard, which led automakers to improve the fuel efficiency of new vehicles. The effectiveness of this rule in increasing the lifespan of tires would depend on the level set by the regulation. Therefore, no attempt to quantify the improved lifespan is attempted herein. However, the introduction of the CAFE standard was effective in increasing the number of miles per gallon delivered by new vehicles. In fact despite warning from automakers at the time when the CAFE standard was introduced, new vehicles are safer, deliver more horsepower and torque than their pre CAFE counterparts, and even exceed the demands of the standard.

Mandating a corporate average tread life standard would force tire makers that specialize in economy light-duty tires that deliver low life mileage to either improve their tires to meet the standard, or to exit the California marketplace. If these tire producers chose the first alternative then the objective of extending the average life mileage of tires is achieved. If they chose to withdraw from the California market, then the light-duty retread industry may be rekindled,

which would reverse its demise that was caused by the appearance of low-cost light-duty tires. Diverting light-duty tire to be retreaded would further reduce the number of tires that need to be recycled or stored in landfills.

The fourth strategy considered is to employ a combination of taxes and rebates to replace the uniform \$1 tire disposal tax with an *ad-valorem* tax. The idea here is that a tire that weighs 30 lb. (a typical SUV tire) should pay more than a 20 lb. tire (a typical sedan tire). The tax/rebate, however, should also take into account the expected average tire life mileage, as indicated by the limited warranty provided or the UTQG tread wear rating, so that pounds per mile would be the actual measure on which the tax and rebates are based. Additionally, credits should be given for smart tires (*e.g.*, rims equipped with auto-inflate systems) and tires that have a retread warranty.

The underlying idea of the *ad-valorem* tax is that it would divert consumers to longer life tires. However, the benefit cost analysis predicts a significant cost to the California economy, and indicates only a small improvement in terms of extending the life of tires.

The CIWMB can act immediately on either of the proposed strategies. Additional strategies require further study. First among these evaluations should be further review and analysis of smart tire systems with the objective of identifying possible advances. Additionally, tires are the link between the road and the vehicle. Therefore, road design is important to the lifespan of tires. For example, a study of the effect of road roughness on tire cost per mile for trucks found that the cost is 30% higher for roads with high roughness index. (Note that roughness is a property of the pavement, and does not necessarily refer to the condition of the pavement.) It is also important to note that at the moment, the effect of the road on tire longevity is practically ignored during road design.

Finally, the California Energy Commission (CEC) recently issued a report advocating reduced rolling resistance tires. Unfortunately, reducing rolling resistance comes at the expense of other tire attributes including tread wear. Therefore, the CEC report is analyzed herein, emphasizing the implications of reducing rolling resistance on tread wear. The main conclusions are that the goal set by the CEC of improving vehicle fuel efficiency by 3% is overly optimistic, and promoting such tires would negatively affect average tire life mileage. Additionally, the laboratory studies proposed by the CEC are focused on identifying the rolling resistance of new tires. However, the *average* tire rolling resistance *throughout the life of the tire* should be determined in order to identify fuel savings. Therefore, even after the proposed CEC studies are performed, the actual fuel savings achieved in practice will remain unknown.

## Glossary

ABS	Antilock Brake System
<i>Ad-valorem</i> tax	Value based tax
Alliance	Alliance of Automobile Manufacturers
Alignment	Front wheels settings
Auto-inflate system	a system that combines a TPMS with a unit that delivers pressurized air to tires, and maintains the tire pressure near placard at all times.
ARB	California Air Resources Board
B/C	The ratio of the present value of benefits to the present value of costs
CEC	California Energy Commission
CIWMB	California Integrated Waste Management Board
CAFE	Corporate Average Fuel Economy, a standard that requires each automaker to produce light-duty vehicles that as a group average a specified number of miles per gallon
CATL	Corporate Average Tire Life, a standard considered in this report to require each tire producer selling light-duty tires in California to average, across all their tires sold in California (aftermarket and OE) a specified UTQG tread wear rating
IRI	International Roughness Index
NPV	Net Present Value is the difference between the present value of the benefits and that of the costs.
NHTSA	National Highway and Traffic Administration
Placard	The (cold) tire inflation pressure specified by automakers, usually found in the vehicle user manual.
RMA	Rubber Manufacturers Association
Retreaded tire	A used tire with a new tread
Tire rotation	Rotating the tires every few thousand miles to avoid uneven wear due to different forces that are applied to different tires
TPMS	Tire Pressure Monitoring System
Direct TPMS	a TPMS that uses sensors in the tire to determine tire pressure
Indirect TPMS	a TPMS that compares the relative angular velocity between tires to identify tire pressure.
TRIB	Tire Retread Information Bureau
UTQG	Uniform Tire Grade Rating

## 1. Introduction

The number of waste tires generated in the State of California each year is roughly equal to its population size (CIWMB [2003a]). These tires are either diverted to secondary use such as crumb rubber, or end up in landfills. Unfortunately, landfills may be hazardous to the environment due to fires, and insects and rodents that breed there (CIWMB [1992]). To date the California Integrated Waste Management Board (CIWMB), the public body responsible for dealing with waste tires in California, has focused its efforts primarily on diverting tires from landfills (CIWMB [2003b]). These efforts resulted in 74.8% of scrap tires being diverted in 2001 (CIWMB [2003b]).

The California Department of Finance projects a 31% increase in the California population over the next 20 years (CDOF [2002]). Additionally, the weight of tires is increasing. For example, according to CIWMB reports the weight of the average passenger tire increased from 18 pounds in 1990 to 20 pounds in 2001 (see *e.g.*, CIWMB [1992] and CIWMB [2003b]). Because of trends in the tire industry discussed below the weight of tires is expected to continue to grow. Moreover, the same tire evolution trend could make it harder to recycle tires. Therefore, the CIWMB is facing an escalating challenge, and it has become even more necessary now than in the past to try to stem the flow of scrap tires entering the waste stream.

In 1981 light-duty tires averaged about 28,000 life miles (RMA [2002b]). By 2001 tire lifespan increased to 43,000 miles (RMA [2002b]). During this twenty year period the average annual vehicle miles traveled (VMT) increased from about 9,000 to 12,000 miles.<sup>1</sup> Thus, the average number of waste tires generated per light-duty vehicle each year declined from 1.29 in 1981 to 1.12 in 2001. This 15% reduction was achieved despite a 33% increase in annual VMT. This record demonstrates that extending the lifespan of tires is effective in decreasing the number of tires entering the waste stream.

Because there are literally thousands of tire-models it is impractical within the scope of this study to address each and every tire model. Therefore, tires are grouped into two major categories: heavy- and light-duty tires. The logic for this division is the large disparity between members of the two groups. These differences include: weight (a typical weight ratio of heavy- to light-duty tire is about five), rubber compounds, amount of reinforcement, design objective (due to different operating conditions), and percentage of retreaded tires among replacement tires. The differences between the two categories are further discussed in Section 2. As will become apparent from the discussion below, concentrating on extending the lifespan of light-duty tires is likely to yield a much better return in terms of reducing the tonnage of waste tires entering the waste pipeline. Therefore, this report primarily focuses on light-duty tires.

The objective of this report is to identify strategies that lead to extending the overall average life mileage of tires, without compromising safety. Tires provide the link between vehicles and roads. Consequently, tire longevity is a function of the design and maintenance of the tire, the vehicle, and the road. Therefore, this report examines the entire vehicle-tire-road system.

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<sup>1</sup> Source: <http://ceq.eh.doe.gov/nepa/reports/statistics/tab10x3.html>

The report is organized as follows. First, background information ranging from contributors to reduce the average life of tires, to technology, to legislative initiatives is provided in Sections 3 through 9. Second, the foundation for a benefit cost analysis is laid down in Sections 10 through 13.

Four different strategies to extend the lifespan of tires are presented in Section 14. The four strategies are: (1) using auto-inflate systems (i.e., technology that automatically maintains tire pressure at placard level); (2) public education to better maintain their tires; (3) requiring producers of light-duty tires to meet a corporate average tire life standard; and (4) replacing the uniform tire disposal tax with an *ad-valorem* tire disposal tax/rebate.

The underlying assumptions for predicting the effectiveness of each strategy in reducing the number of waste tires are given in Sections 15 through 17. These sections also provide the basic measured subsequently used in the benefit cost analyses of the proposed strategies.

The effect of each strategy on the rate of tire disposal is tabulated in Section 18, and the results of the benefit cost analyses are contained in Section 19. (No predictions are made for the third, legislating an average tire life, strategy which is treated like a state variable instead.) When assessing which strategy it is important to know the reliability of the outcome of pursuing a given strategy. Therefore, Section 20 provides a risk analysis for each of the three strategies analyzed.

Sections 21 through 25 consider the implementation of each of the four strategies. These include identifying the key barriers to implementing each strategy, and proposing ways to overcome these barriers. For example, two alternatives to implement the auto-inflate strategy are considered. First, pursuing voluntary adoption that the CIWMB would promote through a public education campaign and working with automakers, tire producers, and auto insurance companies. Second, mandating that all new vehicles be equipped, after a phase-in period, with auto-inflate systems.

Additional research projects are proposed in Section 26. These research projects fall into two categories. The first set of studies take an in-depth look at smart tire systems. The second set of studies considers tire-pavement interaction effect on tire wear. Finally, concluding remarks are offered in Section 27.

Finally, the California Energy Commission (CEC) recently issued a report advocating reduced rolling resistance tires. Unfortunately, reducing rolling resistance comes at the expense of other tire attributes including tread wear. Because of the risk of different parts of the California Government issuing conflicting demands, the CEC report is analyzed in Appendix A emphasizing the implication of pursuing reduced rolling resistance tires to reduce the average tire life mileage.

## 2. Heavy- and Light-Duty Tires

Thousands of tire models are marketed in the United States each year (a list of all passenger and light-truck tire models is available at <http://www.nhtsa.dot.gov/cars/testing/utqg/index.htm>). These tire models employ different rubber compounds and reinforcement, and are designed to emphasize different performance aspects (*e.g.*, high tire life mileage, reduced rolling resistance, and wet and/or dry traction). Moreover, materials, designs, and production techniques are considered trade secrets that are closely guarded by each tire producer. Therefore, working within the time and budget limitations of this study, it is more effective to address the characteristics of tire categories rather than individual tires. For the purposes of the present study tires are divided into two categories: heavy- and light-duty tires.

There are numerous differences between the two categories. From the standpoint of waste management, the most important difference is weight. A typical heavy-duty tire weighs about five times more than the typical light-duty tire. For example, the Goodyear G397 LHS 11R22.5 G, a commercial tire intended for line hauls, weighs 120 lbs; whereas the Michelin Energy MXV4 Plus P205/60R16 passenger tire weighs only 22 lbs. This weight disparity reflects both the difference in wheel diameter and number of plies. In the above example, the passenger tire is mounted on a 16-inch diameter rim and has four plies, while the commercial tire has fourteen plies and is mounted on a 22.5-inch diameter rim.

The two tire categories also differ dramatically in their average life mileage. In 2001 light-duty tires averaged 41,000 (Michelin [2002a]). Aided by retreading, heavy-duty tires can reach more than a quarter million miles (see Section 4 for a discussion of tire retreading). The cost of tires is also very different between the two categories. For example, the Goodyear WeatherHandler LS P215/60R16 passenger tire costs \$86.99 whereas the Goodyear G397 LHS 11R22.5 G costs \$320.36.<sup>2</sup>

An important difference between heavy- and light-duty tires is the fact that heavy-duty tires are commonly warranted to be retreadable, while light-duty tires are not. For example, one of the main benefits noted by Goodyear's website for the G397 LHS 11R22.5 G commercial tire is "excellent retreadability," and the specifications include information on retreaded buffing radius and base width range (<http://www.goodyear.com/truck/products/G397LHS.html>).

Heavy-duty tires are required to support much heavier loads. For example, the Goodyear Conquest P225/60R16 passenger tire is rated for a maximum load of 1,609 lbs. at an inflation pressure of 35 pound per square inch (psi); whereas the maximum load that the Goodyear G397 LHS 11R22.5 G is rated for 6,175 lbs. at an inflation pressure of 105 psi. In this example the maximum allowed load per tire is 3.84 times larger for the heavy-duty tire. It is also worthwhile noting the large difference in operating pressures. Heavy-duty tires are commonly operated at about 100 psi whereas a typical pressure for light-duty tires is 30 psi.

Comfort and noise level demands from light- and heavy-duty tires are also very different. To address the functional differences noted above, different technologies are used for the two tire

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<sup>2</sup> The cost for the light-duty tire is from <http://www.sears.com> and the cost for the heavy-duty tire is from <http://www.premiertire.com/truck.htm>.

categories. These differences range from the amount of reinforcement to the type of rubber compounds used. Therefore, categorizing tires as light- or heavy-duty is an effective way to address tires and, consequently, this classification is often used (see *e.g.*, CIWMB [1992]).

### **3. Contributors to tire longevity**

The most direct approach to reduce the number of tires entering the waste stream is to increase the average life mileage of tires, while maintaining safety. Either employing new tire models that are designed for longer life, or extending the life of existing tire models can achieve this objective. The wisdom of mandating new tire designed for longer life mileage is deferred to Section 5. In this section attention is focused on the later strategy. The premise for this approach is that some service conditions prevent tires from achieving their full life potential. These conditions are investigated in this section.

Before proceeding, however, it is important to determine what is the design life of tires. Fortunately, tire producers provide two such measures: a limited warranty provided with some tires, and the tread wear component of the Uniform Tire Grade Rating (UTQG), a government mandated standard. These two measures are discussed in Section 3.1. Operating conditions contributing to reducing the life mileage of tires are addressed in Section 3.2.

Consumers' choice of tires also affects the average life mileage of tires. The effect of high performance tires on the average life mileage is discussed in Section 3.3, and that of budget tires is addressed in Section 3.4. As shown in Section 3.5, the choice of original equipment (OE) tires by automakers also affects the average tire life mileage. Section 3.6 considers consumer choice of vehicles, which can also increase the number of waste tires.

The ratio of light- to heavy-duty replacement tires in the United States is roughly fifteen (RMA [2002a]), and the weight ratio of heavy- to light-duty tires is about five. Thus, light-duty tires constitute about seventy five percent of the total tire waste by weight. Therefore, this section is primarily focused on light-duty tires. However, some issues pertaining to heavy-duty tires are addressed in Section 3.7.

#### ***3.1 Tire design life***

Tire producers disclose the expected tire life in two ways. The first measure of tire life is the tread wear component of the UTQG, which, by law, is embossed on the sidewall of each tire. The tread wear grade compares the performance of the tire, when tested under controlled conditions on a specified government test course, against that of a government issued "standard" tire. For example, a UTQG tread wear rating of 420 indicates a tire that would last 4.2 times longer than the tire provided by the government.

The UTQG tread wear value, however, reflects a projection of the life expectancy of tires based on their performance during a 6,400-mile long test, conducted on a standard 400-mile long test track (49 CFR 575-104, 10-1-99 edition). For most light-duty tires the projected life-mileage is an order of magnitude more than the length of the test. Therefore, the accuracy of this projection is questionable.

It is also important to note that the UTQG tread wear embossed on the tire is not the actual test result. Rather the UTQG tread wear rating is influenced by the tire maker's marketing strategy, and as a result the value provided may be lower than the actual test result. This appears at first to

present somewhat of a contradiction because, at least for replacement tires, longevity is an important criteria for the public. Here it is important to note that tire producers often ascribe a single UTQG tread wear rating to a tire model, which may consist of twenty or thirty tire sizes all bearing the same name (*e.g.*, Michelin Energy MXV4 plus). Moreover, as discussed in Section 3.5, if a tire model is also provided as original equipment (OE) with a few different vehicles, each size may consist of a number of different designs (in terms of compounds and tread thickness). Thus, the tire maker wants all “family members” of a tire model to meet the specified UTQG value.

Tire producers provide a second, and more direct, measure of expected tire longevity through limited warranties that they provide with some tires. Limited warranties provide a good indication of expected life mileage, when the tire is well maintained, because the tire producers are willing to back their claim with money (*i.e.*, if a well maintained tire does not achieve the specified life mileage, the tire manufacturer will issue some credit to the consumer). For example, the Michelin limited warranty reads as follows (Michelin [2002b]):

“Tires which wear out evenly before delivering the warranted mileage will be replaced on a *pro rata* basis only if:

1. You are the original purchaser of the tires, you own the vehicle on which they were originally installed, and the tires have been used only on that vehicle;
2. The tires have been rotated and inspected by a participating Michelin tire retailer every 7,500 miles, and the attached Mounting and Rotation Service Record has been fully completed and signed;
3. The completed Service Record form, Original Owner/Tire Installation Information form, and the Original Invoice are presented to a participating Michelin tire retailer at the time of adjustment claim, and
4. The tires have not become unserviceable due to a condition listed under WHAT IS NOT COVERED (see page 3).”

The above quote clearly demonstrates that the warranty depends on proper maintenance. For example one of the criteria is even wear which would not be achieved if the tires were used while under-inflated for a significant period.

Before proceeding further, it is important to know the dependencies of the limited warranty. The tire industry contends that the warranty provided depends on numerous factors, including tread wear, aging, and speed rating. To prioritize the relative importance of the different factors, it is instructive to compare the limited warranty with the tread wear grade component of the UTQG standard. Table 3.1 provides a comparison of the tread wear grade and the limited warranty provided. This table clearly indicates that there is a strong correlation between the two parameters, thus suggesting that tread wear is a dominant factor in determining the limited warranty. Also, this correlation suggests that tire producers regard tread wear as the main cause leading to consumers replacing their tires.

Table 3.1: Sample of limited warranty vs. tread-wear grade for several major brand tires.

Manufacturer	Tire Type	Tire Size	Tread-wear grade	Limited Warranty (miles)
Bridgestone	Potenza S-02	205/50ZR16	140	N/A
Bridgestone	B420	P205/75R17	460	65,000
Goodyear	Aquatred 3	P205/70R15	620	80,000
Goodyear	Eagle T/R	P215/60R16	420	50,000
Michelin	MX4	205/70R15	420	50,000
Michelin	X-one	P205/70R15	620	80,000

### **3.2 Operating Conditions that Reduce Tire Life Mileage**

This subsection considers operating conditions that reduce the actual life mileage delivered by tires including: tire maintenance (Section 3.2.1); pavement design and condition (Section 3.2.2); road congestion (Section 3.2.3); and driving habits (Section 3.2.4).

#### **3.2.1 Maintenance**

Michelin periodically reviews scrap tires to determine why they are removed from vehicles. Its findings for the years 1992 through 1999 are presented in Figure 3.1. The main finding for that period is that an average of about fifty percent of scrap tires were discarded due to abnormal wear, which is caused primarily by poor tire and vehicle maintenance. The Michelin study also found that no obvious cause was determined for roughly nine percent of the tires. One explanation for removing these tires is that they were removed together with other tires that required replacement. Therefore, one can conclude that roughly 55% of scrap tires are discarded because of poor maintenance. Consequently, tire life can indeed be extended through better maintenance.

Proper tire maintenance includes three components: maintaining air pressure at placard (Section 3.2.1.1); rotating tires every few thousand miles (Section 3.2.1.2); and keeping the wheels of the vehicle aligned (Section 3.2.1.3).

##### **3.2.1.1 Tire inflation pressure**

Virtually all tire maintenance literature identifies proper inflation as the most important aspect of tire maintenance. For example, the Bridgestone-Firestone web site states: “proper inflation pressure is essential for achieving maximum performance and mileage.”<sup>3</sup> The Bridgestone-Firestone site further states that “improper inflation pressure may result in rapid or irregular wear.” Goodyear’s web site reads as follows: “Proper tire inflation is a key ingredient in driving

<sup>3</sup> <http://www.tiresafety.com>

safety and long tire life.”<sup>4</sup> Michelin’s web site states, “Air pressure – Nothing else is more important.”<sup>5</sup> Michelin further elaborates: “Keeping your tires properly inflated is essential for the proper performance and longevity of the tire.”<sup>6</sup> The Rubber Manufacturer’s Association (RMA) web site states: “Under-inflation is tire’s #1 Enemy. It results in unnecessary tire stress, irregular wear, loss of control and accidents.”<sup>7</sup>

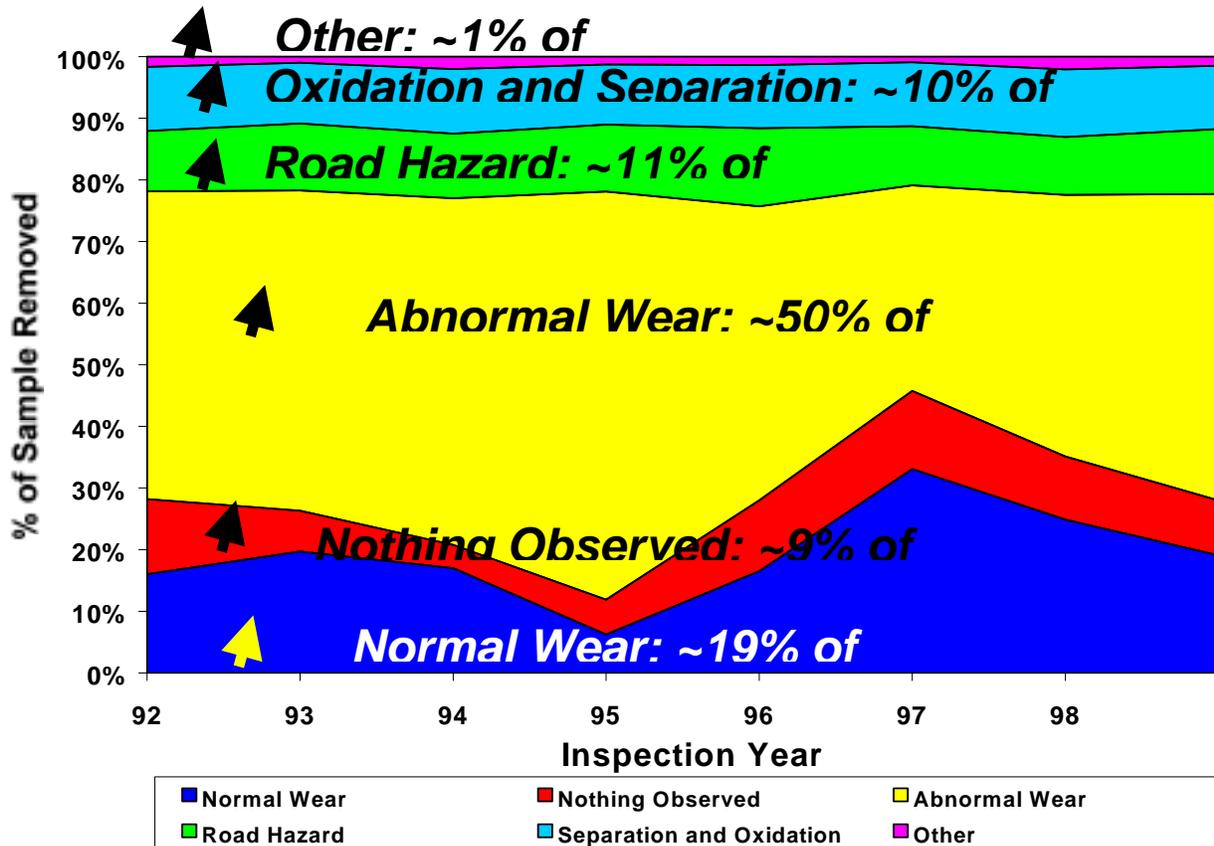


Figure 3.1: Causes for discarding tires (Source: Michelin).

Before proceeding to discuss the virtues of maintaining proper air pressure in tires, it is important to identify what a “properly inflated tire” means. Consumers seeking to inflate their tires are presented with two values. The first, embossed on the sidewall of each tire, is the maximum inflation pressure and associated maximum carrying load. The maximum pressure value is intended as the “cold” inflation pressure, which means that it is the pressure measured after the vehicle has been parked for a few hours.

<sup>4</sup> <http://www.goodyeartires.com/kyt/maintaningATire/#1>

<sup>5</sup> [http://www.michelinman.com/care/tire\\_saving\\_tips/index.html](http://www.michelinman.com/care/tire_saving_tips/index.html)

<sup>6</sup> [http://www.michelinman.com/care/tire\\_saving\\_tips/reg\\_care/air\\_pressure.html](http://www.michelinman.com/care/tire_saving_tips/reg_care/air_pressure.html)

<sup>7</sup> <http://www.rma.org.tiresafety.html>

The second option presented to the consumer is the placard value, which is found in the vehicle manual and is set by the automaker. It too is intended as the cold tire pressure. This value is lower than the maximum pressure embossed on the tire, and is intended to deliver, for a properly maintained vehicle, a safe ride with characteristics the automakers would like the vehicle to exhibit. Tire longevity is one of the considerations in setting the placard value. The placard value is the air pressure consumers should set their tires to.

As indicated both placard and maximum inflation pressure are prescribed as “cold” inflation pressures. A tire is considered to be cold when the temperature of the air in the internal cavity equals the ambient temperature. Thus, the meaning of “cold” is ambivalent. This fact is important because the optimal operating tire pressure and operating temperature are constant year round, yet they raise more in cold weather than in hot weather (NHTSA [2001b]). NHTSA [2001b] gives an illustration where the difference in air pressure increase is 2 psi (raising 2.5 psi in the summer, and 4.5 in the winter). This suggests that for this illustration placard should be 2 psi lower in the winter. Unfortunately, this temperature dependence of the optimal air pressure is not considered in a vehicle placard (a single value is prescribed for each tire).

The results of a recent survey conducted by NHTSA are provided in Table 3.2 (NHTSA [2002b]). 11,530 vehicles took part in this nationwide study including 6,442 passenger cars, 1,847 sport utility vehicles (SUVs), 1,376 vans, and 1,838 pickup trucks.

Table 3.2: Results of NHTSA air pressure study (Source: NHTSA [2002b]).

% Below placard	Passenger Cars	Light Trucks
20% or more	49%	55%
25% or more	43%	48%
30% or more	37%	42%

The data shown in Table 3.2 indicates a rather poor state of tire maintenance. However, the actual condition is probably far worse than that depicted in Table 3.2. Specifically, the vehicles taking part in the NHTSA study traveled an unknown distance immediately prior to the NHTSA measurements and consequently, the tires were hot. NHTSA, however, compared the measured pressure to placard, which is intended as the cold tire pressure. As is shown in Figure 3.2, tire pressure may increase by more than five psi for hot tires over cold tires. Therefore, the percentages below placard shown in Table 3.2 underestimate the true values. For example, if it is assumed that the average recommended cold inflation pressure is 30 psi and that the average pressure measured by NHTSA was 3 psi above the cold pressure, then the percentages shown in Table 3.2 actually represent 30, 35, and 40 percent below placard.

In its comments to NHTSA, Goodyear indicates a loss of 1.78% of tread life for each psi below placard (NHTSA [2002b]). Thus, combining the Goodyear and NHTSA inputs leads to the conclusion that 50% of light-duty tires are expected to lose more than 10.6% of their tread life, or more than 8,500 miles for a tire warranted for 80,000 miles.<sup>8</sup> If tire temperature is factored in,

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<sup>8</sup> Based on a placard of 30 psi.

then the estimated loss increases to 19.6% (or 15,600 miles for a tire warranted for 80,000 miles).<sup>9</sup>

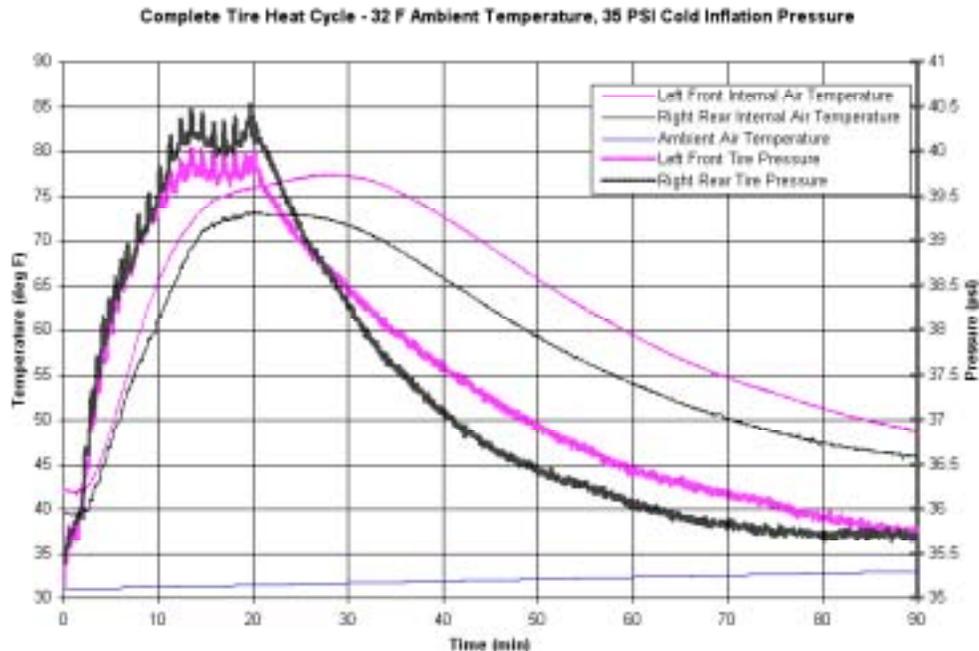


Figure 3.2: Temperature and pressure increase (Source: NHTSA [2001b]).

### 3.2.1.2 Tire rotation

To maximize tread life, tires should also be periodically rotated. A typical rotation interval is every six thousand miles.<sup>10</sup> Tire makers consider rotating tires essential in order to achieve even tire wear. For example, the Bridgestone/Firestone tire safety web site states:<sup>11</sup>

“Tire rotation is vital to achieving even tread wear and long tread life. Rotation is necessary because of the uneven wear characteristics of each wheel position on the vehicle. A good example is Front Wheel Drive vehicles which place braking, steering, and driving forces on the front axle tires. Rear axle tires only receive braking forces resulting in a much faster wear rate for the front axle tires. Tire rotation for these vehicles therefore becomes very important for optimum tire life.”

At least some tire vendors offer their customers free tire rotation (*e.g.*, Costco provides this service every 5,000 miles). However, taking advantage of this service requires a trip to the tire shop, and the service takes a couple of hours. Therefore, many consumers do not take advantage of these offers. Many consumers assume that their tires are rotated whenever they take their vehicles in for service. However, because of improved oils and engine designs new vehicles require less frequent maintenance. Therefore, consumers are taking their vehicles in for service at intervals that may exceed the recommended interval between tire rotations. For example, the

<sup>9</sup> Based on a pressure increase of five psi due to the tires being “hot.”

<sup>10</sup> <http://www.rma.org/tiresafety/tiresafety.html>

<sup>11</sup> [http://www.tiresafety.com/service/serv\\_nav.htm](http://www.tiresafety.com/service/serv_nav.htm)

recommended interval between oil changes for the 2003 Honda Accord is 10,000 miles.<sup>12</sup> As a result, tires are not rotated as often as they should be.

### 3.2.1.3 Alignment

Achieving optimal tire performance also requires that vehicles be properly aligned. Alignment consists of three different tire settings: toe, camber, and caster. “Toe angle” measures how tires are pointing towards the center of the vehicle when it is parked. The case where tires point towards the center is referred to as “toe-in,” while the case where tires point away from the center, common with front wheel drive vehicles, is referred to as “toe-out.” “Camber” indicates the relative tilt of the wheel. Finally, “caster” is the angle by which the vehicle’s steering angle diverts from the vertical (introduced to help wheels return to the straight-ahead position). The importance of alignment is described by the Ford web site as follows:<sup>13</sup>

“For safe handling, comfortable ride and maximum tire-tread life, all suspension components must be in precise geometric adjustment (alignment) as specified by the manufacturer. Any variation can affect the stability and tracking of the vehicle.”

The importance of proper alignment to the longevity of tires stems from the fact that if the car is not properly aligned then tires are required to perform in a mode for which they were not designed. For example, if the toe angle is greater than the specified one, then the tire is actually sliding sideways when the vehicle is moving straight-ahead. Clearly, if the tire is operated in this way, it will show excessive and uneven wear.

### 3.2.2 Pavement Design and Condition

The pavement system can contribute to tire wear in a number of ways, including: horizontal alignment, surface friction, surface texture, surface roughness, and structural section. Horizontal alignment refers to curves in the road. If a large number of relatively short radius curves exist, then tire wear will be increased because of lateral forces acting on the tires (Carpenter and Cenek, [1999]).

Pavement surfaces are required to provide a certain minimum coefficient of friction, termed  $f$ , between the tire and pavement in order to provide safe stopping distance. Normally the  $f$  value incorporated in pavements at the time of construction exceeds the minimum value established by the American Association of State Highway and Transportation Officials (AASHTO) (**missing ref**). This practice is intended to insure that the  $f$  value remains above the minimum value established by AASHTO throughout the service life of the pavement. As the friction coefficient increases, however, tire wear will increase. Therefore, it is important to ensure that the initial  $f$  value is such that expected traffic wear over the design life would reduce it to just above the

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[http://www.caranddriver.com/xp/Caranddriver/roadtests/2002/october/0210\\_roadtest\\_accord.xml?&page=3](http://www.caranddriver.com/xp/Caranddriver/roadtests/2002/october/0210_roadtest_accord.xml?&page=3)

<sup>13</sup> <http://www.fordvehicles.com/help/glossary/>

AASHTO minimum. Thus pavement designers must “tailor” the surface friction to the site. As the site requires more frictional resistance for safety reasons, tire wear will necessarily increase.

The influence of pavement roughness has been documented in a recent study by Papagiannakis, who studied dedicated trucking routes (Papagiannakis [1999]). Papagiannakis correlated tire wear with the International Roughness Index (IRI), and showed that tire wear increases as the IRI value increases (indicating rougher pavement surface). For example, Papagiannakis found a cost of \$0.00029 and \$0.00038 per mile for International Roughness Index (IRI) of 1.4 and 1.9, respectively (Papagiannakis [1999]). Thus, according to Papagiannakis, the cost can increase by about 31% for truck tires as the IRI increases from 1.4 to 1.9.

Traffic noise is greatly affected by the surface texture. For example, open-graded asphalt concrete mixes are known to reduce noise by five to eight db. Unfortunately, the effect of texture on tire wear is not well documented at this time. Anecdotal evidence, however, suggests that using large aggregate in both asphalt concrete and Portland cement concrete causes tires to wear faster.

Traffic on a poorly maintained road is more likely to be slowed down, either by motorists who do not like bouncing around or by repair work. In any case, the net effect may be stop-and-go traffic, which causes excessive tire heat due to repeated braking. Excessive heat damages tires (see *e.g.*, <http://www.tiresafety.com>), and increased friction causes tire wear and reduces the fuel efficiency of vehicles.

Finally, the actual physical maintenance of road pavements plays an important role in tire-wear. Specifically, if the road is in poor condition (*e.g.*, potholes, cracks, and ruts) then it could damage tires in two ways. First, it could cause direct fatigue and wear damage. Second, it may cause the vehicle to be thrown out of alignment, which could lead to a systemic problem as described in Section 3.2.1.3 above.

### **3.2.3 Road Congestion**

Road congestion leads to stop-and-go traffic typical of city driving, and now more and more the norm on California freeways. Consequently, motorists continuously apply their brakes, which cause heat buildup in tires, and, as is pointed out by every tire manufacturer, excessive heat buildup damages tires (see *e.g.*, <http://www.tiresafety.com/index.htm#>).

### **3.2.4 Driving Habits**

Certain driving habits can contribute considerably to tire wear. For example, frequent lane changing and excessive use of brakes causes tires to wear prematurely. However, it is very hard to quantify the extent to which driving habits contribute to tire wear, and it is even more difficult to conceive of ways to resolve this problem. Therefore, this issue will not be further addressed in this study.

### **3.3 Performance tires**

To achieve a higher level of performance (*e.g.*, road-grab, that is important to braking and maneuvering) and comfort, softer rubber compounds (*e.g.*, silica-based) are used in performance tires. Unfortunately, these rubber compounds wear faster.<sup>14</sup> Additionally, these tires are rated for higher speeds (*i.e.*, H and above speed ratings).<sup>15</sup> As a result, in many cases tire manufacturers do not provide any limited warranty whatsoever for these tires (*e.g.*, Michelin Energy MXV4 plus with a V speed rating). The performance tires market segment is important to note for two reasons. First, performance tires most likely contribute to a shortening of the average tire-life mileage. Second, the trend for passenger cars in the U.S. in recent years has been to increase the market share of performance tires. For example, performance tires constituted 13.7% of the tires sold to the passenger car market in 2000, and 15.5% in 2001 (Michelin [2002a]). Michelin is projecting this trend to continue over the next few years (Michelin [2002a]).

### **3.4 Budget tires**

Consider, for example, that you are the owner of a 1995 Ford Escort LX. You could go to Sears and buy a set of four Michelin WeatherWise P175/65R14 for \$371.96 plus tax, or you could purchase a set of four Guardsman III P175/65R14 for \$149.00 plus tax.<sup>16</sup> But, while the Michelin tires come with a 65,000-mile limited warranty, the Guardsman III comes with a 35,000-mile limited warranty.<sup>17</sup> It is important to note that some vendors offer a set of four tires for \$100 or less, but these tires often offer no limited warranty whatsoever. According to the Michelin Fact Book 2001, of the replacement light-duty tires sold in North America in 2001, major manufacturers (*e.g.*, Bridgestone, Goodyear, and Michelin) sold about 58% while private and associate brands accounted for 42% of the market.<sup>18</sup> In 1997, the split was 50-50, and the change is attributed to the 2000-2001 tire recalls (Michelin [2002a]). Thus, the contribution of low-end tires to reduce the average tire-life mileage has diminished in recent years. However, it may grow again as the effect of the highly publicized Firestone tire recall wears off.<sup>19</sup>

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<sup>14</sup> Note the rather poor tread-wear rating for the Bridgestone Potenza S-02 (140) compared to the other tires in Table 3.1. The Potenza S-02 is the only high performance tire included in Table 3.1.

<sup>15</sup> See <http://www.nhtsa.dot.gov/cars/rules/tiresafety/ridesonit/brochre.html> for a rating table.

<sup>16</sup> <http://www.sears.com>

<sup>17</sup> *Id.*

<sup>18</sup> Associate brands refer to brands owned by the flag brands, but sold under their own brand name. For example, Dunlop is an associate brand of Goodyear.

<sup>19</sup> On 9 August 2000, Firestone announced that it was recalling approximately 14.4 million tires due to a safety-related defect. The tires affected were all P235/75R15 Firestone ATX and all P235/75R15 Firestone Wilderness AT tires. Most of these tires were original equipment on Ford vehicles, primarily on the Ford Explorer SUV. A small number of these tires were used as original equipment in other manufacturer's vehicles. The increased public awareness resulting from the recall prompted the Congressional Transportation Recall Enhancement, Accountability, and Documentation Act of 2000.

### **3.5 Original equipment tires**

Some original equipment (OE) tires, because of their composition, have a shorter lifespan and therefore also contribute to reducing the overall average tire-life. OE tires are optimized specifically for a single vehicle to deliver a certain feel and performance that the automaker deems desirable (LaClair [2002]). For example, to meet Corporate Average Fuel Economy (CAFE) standards the automaker may require that the tire maker reduce the rolling resistance of a tire, which typically comes at the expense of tire wear (see Appendix A for a detailed discussion of this issue).<sup>20</sup> As a result of the optimization that goes into OE tires, a tire mounted on vehicle type A may be quite different in terms of rubber compounds, layering, and tread depth than a tire with the same marking (*i.e.*, manufacturer, type, size, and UTQG ratings) designed for vehicle type B. In contrast, replacement market tires are designed to deliver balanced performance across a broad array of vehicles and are optimized for the concerns of the after-market consumer, who typically places a higher priority on tire longevity than do carmakers. As a result, OE tires average only about 77% of the life mileage of replacement tires (CEC [2003b]). For some tire models, OE tires may achieve only 50% of the longevity of replacement tires.<sup>21</sup> OE tires constitute roughly twenty percent of the total tires shipped in the US (RMA [2002a]). Therefore, a loss of one percent of tire-life mileage for an OE tire constitutes a loss of 0.2% for the entire light-duty tire population. Thus, if for example the average OE tire achieves only 77% of the tire-life mileage of a replacement market tire, as reported by CEC [2003b], then the overall tire-life mileage is reduced by 4.6%. In California this reduced average life translates to about 1.1 million extra waste tires.

It should be emphasized that the consumer is not notified that OE tires are different from the replacement tires. Also, the limited warranty provided with OE tires may differ from one vehicle type to the next, and yet again differ from that provided with the replacement market tires. The tire makers maintain that the consumer can get the OE tires also as replacement tires. However, the consumer should first be alert to the difference between OE and replacement tires, and most consumers are not. Moreover, should the consumer specifically request that the same tires as the OE tires be installed on their vehicle, they will typically have to special order the tires.

### **3.6 Consumers' vehicle choice**

Sport utility vehicles (SUVs) are a fast-growing segment of the automobile fleet in North America in general, and in California in particular. According to the Michelin 2001 fact book, SUV tires accounted for 31% of the OE tire market, and 21% of the replacement tire market in 2001. These percentages are almost 50% higher than the corresponding 1997 market shares, which were 22% and 13%, respectively (Michelin [2002a]). Therefore, this market segment deserves special consideration.

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<sup>20</sup> Corporate Average Fuel Economy (CAFE) standard were created by the 1975 Congressional Energy Policy and Conservation Act. 2002 CAFE standard automakers must produce cars that collectively average 27.5 miles per gallon, and light trucks and SUVs must average 20.7 miles per gallon.

<sup>21</sup> Mr. William J. VanderWater, Consumer Products Manager, Bridgestone Firestone, in a presentation given at a California Energy Commission Workshop Fuel Efficient Tires (19 September 2002).

SUVs presently increase tire waste in two ways. First, and most obvious, is the fact that the tires mounted on SUVs are heavier than those mounted on sedans. A typical SUV tire weighs about 30 pounds, while a typical sedan tire weighs about 20 pounds. Thus, each SUV tire counts as 1.5 passenger tire equivalent (PTE).



Figure 3.3: The great outdoors, Ford Explorer's advertisement.

Second, many of the SUV manufacturers advertise their SUV's off-road capabilities, and deliver the suspension system and type of tires to match that image. Figure 3.3 indicates the image that Ford would like to convey of their Explorer SUV. Similarly, the Jeep web site states about the suspension system of the Jeep Grand Cherokee: "Jeep Grand Cherokee was built for performance on trails..."<sup>22</sup> Most owners of these SUVs, however, are city dwellers that will only rarely, if ever, use the off-road capabilities. Unfortunately, tires that are designed for off-road driving do not perform in highway driving as well as tires designed primarily for road travel. It should be noted, however, that some new SUVs have been designed primarily for road driving. For example, the Acura MDX comes equipped with a Michelin P235/65R17 cross-terrain tire that comes with a 65,000-mile limited warranty.

### **3.7 Maintenance of Heavy-duty Tires**

It is commonly believed that heavy-duty tires are better maintained than light-duty tires. This observation is supported by the fact that in 2000 52% of replacement heavy-duty tires were retreads (RMA [2002a]), whereas 85% of light-duty tires inspected were rejected for retreading.<sup>23</sup>

The heavy-duty tires category can be subdivided, by application, into two subcategories. The first group consists of tires mounted on tractors, and the second group is made of tires mounted on trailers. Truck drivers do indeed take good care of their trucks and, therefore, tires in the first group are indeed well maintained. However, because trailers are connected to a tractor for relative short periods (typically no more than a few days) drivers do not maintain them as well. For example, according to Mr. Carl Tapp Director of Maintenance at P.A.M. Transport Service Inc. employing automatic tire inflation (auto-inflate) systems on their trailers reduced their tire maintenance costs by about 40%. (Auto-inflate systems are discussed in detail in Section 9.) At the moment there are about 3 million trailers in service in the US, typically equipped with eight tires each. Thus, the potential for extending the lifespan of heavy-duty tires by better maintaining trailer tires is significant. This potential, however, is somewhat diminished by the fact that trailer

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<sup>22</sup> [http://www.jeep.com/grand\\_cheocee/suspension/index.html](http://www.jeep.com/grand_cheocee/suspension/index.html)

<sup>23</sup> <http://www.retread.org/packet/index.cfm/ID/20.htm>

tires can be retreaded as many as five or six time, depending on the type of application (*i.e.*, regional transport or cross country). For a detailed discussion of retreaded tires see Section 4.

## 4. Retread tires

Retread tires offer another way to reduce the number of tires entering the waste stream because they are not considered part of the waste tire stream. This logic is at least partially flawed because the waste generated during the buffing of the used tires (*i.e.*, shaving of the used tread) is ignored in considering the total tonnage of tire waste.<sup>24</sup> However, even if retreading tires is not a waste-free process, it may still offer a significant reduction in the amount of tire waste. The following subsections look separately at heavy-duty and light-duty retread tires because of the large difference in these markets.

### 4.1 Retread heavy-duty tire market

The potential of waste saving offered by retread heavy-duty tires is substantial. According to the Tire Retread Information Bureau (TRIB), producing a new heavy-duty tire requires on the average twenty-two gallons of oil, while a retread tire requires only seven gallons.<sup>25</sup> TRIB also contends that retread tires have roughly the same service life as new tires, and that a well maintained tire may be retreaded multiple times. This data suggests that even if the average heavy-duty tire could be retreaded only once, the total waste would still be reduced by about 33%, thus providing a significant reduction in waste.

With the cost of retread tires 30 to 50% less than the cost of a new tire, retread heavy-duty tires captured a large segment of the tire replacement market.<sup>26</sup> According to Michelin, out of a total of 33.8 million replacement heavy-duty tires sold in North America in 2001, 17.9 million were retread tires (Michelin [2002a]). According to TRIB, the use of retread tires saves about \$2 billion annually for truckers and trucking companies in North America.

The success of the retread heavy-duty tires is due to three main factors. First, new heavy-duty tires are expensive (*e.g.*, the Goodyear G397 LHS 11R22.5 G costs \$320.36). Thus, retread manufacturers have enough room to get a significant return on their investment, while remaining competitive (as evident by the big savings to the trucking companies).

Second, at least some heavy-duty retread tires come with a retreadability warranty (*e.g.*, Hercules-type of tires). This warranty implies that retreadability is part of the design of new tires, which makes the retread process more economical. This should not come as a total surprise since the large manufacturers of new tires (*e.g.*, Goodyear and Michelin) also produce retread tires.

Third, heavy-duty tires are used by commercial fleets, which typically have a high level of maintenance. As a result, it is easy to find good casings for retread. Even so, according to a report in the Ontario Business Report January/February 2000 issue, in North America \$340 million are wasted on the buffing of casings that passed initial inspection, but are disqualified as

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<sup>24</sup> Waste generated during the retread process is highly in demand and is 100% recycled. Nevertheless, it is recycled waste and therefore, it should be added to the total waste generated and then subtracted as being diverted.

<sup>25</sup> <http://www.retread.org/index.cfm/FuseAction/Facts.htm>

<sup>26</sup> Retread tire buyers guide (<http://www.retread.org/Guide>)

a result of defects that show up during buffing. An ultrasonic device discussed in that report is said to be able to detect these defects in advance. If this is indeed so, the retread industry could improve their bottom line while becoming even more competitive.

From the CIWMB standpoint, the main question is: what is the potential for further reduction of tire waste by increasing the market share of retreads? According to the Michelin Fact Book 2001, retread tires account for 44% of the total (new plus replacement) heavy-duty tire market. If each new tire could be retreaded twice (once for a driving wheel, and once for a trailing wheel), then the maximum potential for retread tires is 66% of the total market. This figure is somewhat optimistic in that it does not account for failures that would prevent tires from being retreaded before they have been retreaded for a second time. On the other hand, according to TRIB, heavy-duty tires used in short routes can be retreaded three or more times for trailing wheels, not just once as assumed above. Therefore, it is possible to assume that these contributions cancel each other and therefore, that the 66% limit is roughly correct. It is highly unlikely that this level will ever be achieved. However, it may be possible to increase the market share of retread tires by a few percentage points. According to CIWMB data from 1990, 28% of used heavy-duty tires end up in landfills.<sup>27</sup> Thus, an additional increase in the use of retreads could eliminate a significant percentage of the heavy-duty tires from going to landfills in California. For example, based on the 1990 data, increasing the number of retread heavy-duty tires by 10% would decrease the number of tires going to landfills by 25.7%.

## **4.2 Retread light-duty tire market**

The success of retread heavy-duty tires has not been replicated in the light-duty tire market. According to RMA data, in 2001 only 0.06% (1.67%) of the replacement tires for passenger cars (light trucks) were retread tires (RMA [2002a]). In other words, currently retread tires constitute an insignificant portion of the replacement market for light-duty tires. Apparently, the only category in which retread tires have a significant showing is the specialty tires market (*e.g.*, snow tires).

It is also important to note that the light-duty retread market was doing well in the 1970s, when it accounted for as much as 20% of the replacement market.<sup>28</sup> However, the market for light-duty retreads collapsed in the last ten years when cheap radial tires appeared at prices of about \$20 per unit, eroding the profit margin for manufacturers of light-duty retread tires. As a result, most manufacturers of retread light-duty tires got out of this business (*e.g.*, Lakin Tire, a producer of 1 million retread tires per year for passenger cars, got out of the market four years ago).<sup>29</sup> At the moment there seems to be only one producer of retread passenger car tires in California, Frank Fargo Tire & Rubber Co. of Los Angeles, and even this producer is primarily producing heavy-duty retread tires.

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<sup>27</sup> The 1990 data is used here because it appears to be the latest data that separates light- and heavy-duty tires.

<sup>28</sup> Harvey Brodsky, TRIB official 1-888-473-8732.

<sup>29</sup> Randy Roth, V.P., Lakin Tire 1-800-488-2752.

According to TRIB, seven gallons of oil go into the production of an average new light-duty tire, while only 2.5 gallons are required for the average light-duty retread tire.<sup>30</sup> This suggests the possibility for a significant potential for reduction of waste. Therefore, an important question that must be addressed before proceeding with the discussion of retread light-duty tires is their market-size potential. According to Michelin, the total passenger car market in North America in 2001 comprised 77 million original equipment (OE) market tires, and a 184-million replacement tire market. Excluding the OE market, retread tires can be candidates for 70% of the tires sold in the passenger car market. If fifty percent of the total replacement light-duty tires sold in California were retread tires (recall that retread tires account for 53% of the replacement heavy-duty tires market), and each tire could be retreaded only once, then the number of light-duty tires entering the waste stream would decline from 19.5 million to about 12.7 million.<sup>31</sup> This potential for a 35% reduction in the number of light-duty tires entering the waste stream justifies further investigation into the use of light-duty retread tires in California. Therefore, the question that arises is: is it possible to significantly increase the market share of light-duty retread tires?

To answer this question one has to begin by exploring new technologies that may alter the playing field for retread light-duty tires. For example, according to TRIB, in 2000, 85% of light-duty tires inspected were rejected for retreading.<sup>32</sup> TRIB attributes this relatively high percentage of rejects to inferior maintenance practices (relative to trucks).<sup>33</sup> Specifically, according to TRIB, the retreading potential of a tire is significantly reduced if the air pressure in it is 20% below placard for a significant amount of travel.<sup>34</sup> This is because the damage induced in the tire walls will prevent it from passing the rigorous inspections imposed by the retread tire industry.<sup>35</sup> This situation is about to be at least partially improved as a result of the NHTSA regulation on TPMS discussed in Section 8. Even more advanced systems are being developed that do not just warn of reduced air pressure but try to maintain proper pressure (see Section 9). The availability of such systems, together with better public education, would likely result in a significant increase in the percentage of tires accepted for retreading because of the dramatically improved level of maintenance achieved when these systems will be in place.

In discussing retread light-duty tires with current and past producers, they did not attribute much importance to a possible increase in the percentage of tires accepted. However, the following argument could change their outlook. First, the cost of selecting quality casings and the number of rejects after buffing will be reduced. This will represent a savings to the retread tire producers that will help their bottom line.

Second, with the notable exception of replacement exotic tires (*e.g.*, for the Chevrolet Corvette), which constitute an insignificant segment of the market, retread tire producers focus entirely on competing in the marketplace with budget tires. However, the availability of a large pool of tires can make it possible to produce retread lines that will be based on a single original casing

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<sup>30</sup> Harvey Brodsky, TRIB official, telephone discussion, 15 August 2002.

<sup>31</sup> The numbers are based on the 1992 CIWMB report to the legislature: Tires as a Fuel Supplement: Feasibility Study.

<sup>32</sup> <http://www.retread.org/packet/index.cfm/ID/20.htm>

<sup>33</sup> Id.

<sup>34</sup> <http://www.retread.org/packet/index.cfm/ID/138.htm>

<sup>35</sup> <http://www.retread.org/packet/index.cfm/ID/20.htm>

manufacturer, with the implication that a consumer will be able to get 4 tires that look the same. The vision here is that of a store where the consumer can purchase either a set of new tires, or an equivalent retread set. This would be especially attractive for the second and third replacement of higher end tires. For example, consider the owner of a 1992 Lexus LS400 who would like to replace a set of 4 Michelin Energy MXV4 plus tires. According to the Sears online catalog, the price for these tires would be \$651.96 plus tax. However, imagine that this may be the third time the customer is replacing their tires (or even that this is a second or third owner) she or he may be interested in a set of retread tires based on Michelin Energy MXV4 plus casings, that may cost only \$250 plus tax, thus offering a considerable advantage. The key here is that the retread tires will all have the Michelin Energy MXV4 plus label on them and thus, cater to the consumer's preference for "matching" tires.<sup>36</sup>

Another issue that might inhibit the increased use of retread tires in passenger cars is the perception of safety. For example, in 1997, 50.9% of the replacement passenger car market was taken by the big tire brand names (*e.g.*, Michelin, Goodyear, and Bridgestone). Aided by the Firestone scandal in 2000, the brand names' market share increased to 56.5%, and in the first nine months of 2001 the percentage further increased to 57.9% (Michelin [2002a]). Thus, the public will need to be educated as to the fact that retread tires are just as safe and provide roughly the same longevity as new tires. Here it is important to note that the even big brands such as Michelin are now producing heavy-duty retread tires, and that the retread industry has had to mount an aggressive campaign to educate heavy-duty vehicle fleet managers about the advantages of retread tires.

Finally, according to 2001 data, 1.5 million used tires are reused in California, and an additional 2.6 million tires are exported (CIWMB [2003b], Table 1). If the technologies noted above do increase the average tire-life mileage, the number of reused tires is expected to fall. Therefore, there will be a need to fill this void. Assuming that consumers resort to buying used tires primarily because of price, budget retread tires (*i.e.*, the traditional approach to retread tires) can fill some of that void.

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<sup>36</sup> With the exception of the addition of a code identifying the tire as a retread, the sidewalls of retread tires remain unaltered by the retread process. For example, a retread tire of an original Goodyear casing will continue to read "Goodyear" on the sidewall. This will be true regardless of who produces the retread—the original tire manufacturer or an independent one. The only difference will be in the tread pattern. The original tire maker can continue to use the original pattern. However, the independent producer will have to resort to a tread pattern that provides a similar performance, but will not be same as the original one, so as not to infringe on the intellectual property rights of the original tire maker.

## 5. Is there a need for government to mandate longer limited warranties?

The question raised in the title of this section is pivotal to the determination of which approach is best to achieve longer average tire-life mileage. To sharpen the question, there are tires available today that come with 100,000 mile limited warranty; would tires with a longer warranty advance the cause of extending tire-life mileage? The assumption underlying this question is that the extended warranty comes about because of government mandate, not because of technology breakthroughs. An extended warranty due to technology improvements would be welcomed.

Currently, tires with longer warranties tend to be heavier because they typically have thicker treads. Thus, when they come into the waste stream the total waste by tonnage would be increased, which would at least partially offset the gains achieved by longer tire lifespan. Also, these tires tend to have longer braking distance (wet and dry). As a result, introducing longer life tires would result in an increased number of accidents, injuries, and fatalities on the California roads. This in turn would result in a larger number of tires entering the waste stream from dismantled vehicles.

Presently the average vehicle in California is driven about 12,000 miles per year. This means that a properly maintained tire that comes with a limited warranty of 100,000 miles would last about eight years and four months. This period exceeds the period that a typical consumer owns a given vehicle. As a result, consumers are not likely to take advantage of tires with such a long lifespan. These longer-lifespan tires are also not likely to be used as OE tires because they would be detrimental to meeting CAFE standards.<sup>37</sup> Also, these tires would most likely increase the vehicle fuel consumption, which would hurt the consumer checkbook, and the environment because of increased pollution.

The average life mileage of passenger vehicles in the United States is 130,800 miles (CEC [2003b], Table 2).<sup>38</sup> OE tires average 38,100 miles (CEC [2003b], Table 2), and thus replacement tires are required for the next 92,700 miles. Presently there are tires that offer a 100,000 miles limited warranty, and therefore there is no need for tires with a longer life.

Finally, and most importantly, the benefit of an extended limited warranty is likely to be undercut by consumers replacing their tires before they reach the mileage promised in the limited warranty. These tires are replaced because of uneven wear (see Section 3.2 for a detailed discussion), and aging effects. As was noted above, tires currently available with 100,000 miles limited warranty are expected to last on the average for more than eight years (assuming proper tire maintenance). However, due to pollution, in urban environments tires develop significant aging damage after about 6 years.<sup>39</sup> Because of concerns over tire aging, which results in reduced tire performance and safety, many consumers would replace their tires before their treads were fully worn out.

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<sup>37</sup> See Appendix A for a detailed discussion of the tread-off between reduced rolling resistance and tire life mileage.

<sup>38</sup> NHTSA estimates the average life VMT at 126,678 miles (NHTSA [2002a]).

<sup>39</sup> Harvey Brodsky, TRIB official, telephone discussion, 15 August 2002.

To summarize, it is unlikely that, barring a technological breakthrough, consumers would voluntarily take advantage of tires with a limited warranty longer than 100,000 miles. Even if forced to use these tires, they would most likely not use them to their full tread potential. As a result, it is highly unlikely that a government mandate to introduce tires with longer than 100,000 miles limited warranty would reduce tire waste (by tonnage) in California. Therefore, other ways to achieve the goal of reducing tire waste should be adopted.

## 6. Tire Pressure Monitoring System Regulation

On 30 May 2002, in response to a mandate in the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000, NHTSA issued its final rule on Tire Pressure Monitoring Systems (TPMS) (NHTSA [2002b]). This final rule, which is actually the first part in a two-part ruling, governs passenger cars, trucks, multipurpose passenger vehicles, and buses with a gross vehicle weight rating of 10,000 pounds or less, except those vehicles with dual wheels on an axle.

NHTSA requires all vehicles that fit that standard to be equipped with a yellow telltale warning light that illuminates when tire pressure drops below a specified activation threshold. Two levels of compliance are allowed until November of 2006, when Part 2 of this standard, to be issued by 1 March 2005, will take effect. The first compliance option states:

“the vehicle’s TPMS will be required to warn the driver when the pressure in any single tire or in each tire in any combination of tires, up to a total of four tires, is 25 percent or more below the vehicle manufacturer’s recommended cold inflation pressure for the tires, or a minimum level of pressure specified in the standard, whichever pressure is higher.”

The second compliance option states:

“the vehicle’s TPMS will be required to warn the driver when the pressure in any single tire is 30 percent or more below the vehicle manufacturer’s recommended cold inflation pressure for the tires, or a minimum level of pressure specified in the standard, whichever pressure is higher.”

NHTSA is currently indicating that only the first compliance option will be allowed in Part 2 of the rule. However, a final decision has not been made, and NHTSA acknowledges that it is possible that both options may be allowed to continue, or yet a third, unspecified option, may be adopted.

The current phase-in schedule is as follows:

“10% of a vehicle manufacturer’s light vehicles will be required to comply with either compliance option during the first year (November 1, 2003 to October 31, 2004), 35 percent during the second year (November 1, 2004 to October 31, 2005), and 65 percent during the third year (November 1, 2005 to October 31, 2006).”

The motivation for the two levels of compliance is that current indirect TPMSs cannot meet the first compliance level (see Section 8 for a detailed discussion of direct and indirect TPMSs). The two levels of compliance have significantly different levels of costs and benefits. According to a NHTSA analysis, the total net annual cost of the first compliance level is \$862 million, and the

second compliance level is \$706 million.<sup>40</sup> The first compliance level would prevent 125 fatalities and reduce in severity 8,722 injuries per year, and the second compliance level would save 79 fatalities and reduce in severity 5,176 injuries per year.

The rule will also impact tire-life mileage. In its ruling, NHTSA estimates that if all vehicles subjected to the new TPMS rule would meet the 25-percent compliance option, average tread life would increase by 1,143 miles. NHTSA also estimates that if all vehicles met the 30 percent compliance option, the average tread life would increase by 15 miles. Based on an average tire-life mileage of 41,000 miles, the two compliance options translate to a 2.8% and 0.04% increase, respectively, in average tire-life mileage.

2001 data published by the CIWMB indicates that 24% of PTEs are being disposed of (CIWMB [2003b], Table 1). Accordingly, if all vehicles meet the 25% compliance option, the percentage of PTEs being disposed of will decrease by 11.67%, while the 30% compliance option will eliminate a mere 0.17% of the PTEs being disposed of.

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<sup>40</sup> It does not appear that the net costs include the cost of disposing of the tires, which are all going to go into storage or landfill because not all waste tires find a secondary use.

## 7. Tire Technology

New tires technologies and recent trends that will affect the average tire-life mileage are considered in this section. First, run-flat tires are discussed in Section 7.1. Second, smart tires are discussed in Section 7.2. Finally, new manufacturing processes are discussed in Section 7.3.

### 7.1 Run-flat tires

Run-flat capability is achieved by reinforcing the sidewalls so that the sidewalls can carry the entire load applied to the tire. Run-flat tires enable the safe operation of a vehicle for a few dozen miles, and at normal highway speed, even when the air pressure in the tire drops to zero. The inherent safety advantage offered by run-flat tires will make them the standard tire in the not too distant future. Goodyear indicated that it expects that 30% of all new vehicles will be equipped with run-flat tires by 2010, and Bridgestone indicated that it expects this percentage to grow to 100% by 2020 (Show [2002]).

Run-flat technology is safety-oriented, and it is not clear that it will extend the lifespan of tires. At the moment, most of these tires are installed on high performance vehicles such as the BMW 745iL, and typically come with a V, W, or Y speed rating.<sup>41</sup> As a result, they have rather poor wear performance. Anecdotal evidence suggests that current run-flat tires wear faster than high performance tires of comparable speed rating. For example, the Michelin Pilot HX MXM4 run-flat tires have a UTQG tread wear rating of 300 whereas Michelin's high performance Energy MXV4 plus tire have a UTQG tread wear rating of 400 (both these tires have a V speed rating, and come with no limited warranty).<sup>42</sup>

The added material strengthening the sidewalls adds to the tire weight and therefore, run-flat tires may increase the total tire waste by tonnage. On the other hand, reliable run-flat tires may eliminate spare tires, which in turn would contribute to a reduction in tire waste (Michelin [2002a]).

A different run-flat technology, termed the "PAX system," is being co-developed by Michelin, Pirelli, Goodyear, and Sumitomo (Michelin [2002a]). The PAX system combines a new anchoring design to attach the tire to the wheel, an insert, and a tire with a low sidewall-size to tread-width ratio (Michelin [2002a]). The PAX system also includes a pressure monitor (Michelin [2002a]). The role of the insert is to provide support in case the air pressure drops. The PAX system extends the safe driving range to 125 miles (Michelin [2002a]).

### 7.2 Smart tires

A recent development, still in research and development phase, aims to achieve "smart" tires that work together with the vehicle suspension and braking systems. The first to introduce such a system was Continental A.G. Combining the smart tire with the antilock brake system (ABS) led to a 5% reduction in braking distance (Show [2002]). Additionally, Dr. Horst Glaser, who is

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<sup>41</sup> See <http://www.nhtsa.dot.gov/cars/rules/tiresafety/ridesonit/brochre.html> for a rating table.

<sup>42</sup> [http://www.nhtsa.dot.gov/cars/testing/utqg/table\\_8.htm#Brand:MICHELIN](http://www.nhtsa.dot.gov/cars/testing/utqg/table_8.htm#Brand:MICHELIN)

responsible for suspension development at Audi, said that connecting the Continental smart tires to the vehicle's electronic stability program (ESP) led to "the most stable car he had ever driven" (Show [2002]). Thus, smart tires have the potential to provide important advantages to consumers. It is therefore no surprise that these improvements caught the industry's attention, and other manufacturers, among them Bridgestone, Goodyear, and Michelin, have announced interest in pursuing this type of technology (Show [2002]).

Integrating smart tires into the suspension system offers a significant advantage also from the standpoint of extending the lifespan of tires (ERJ [2002]). Specifically, by identifying forces and moments acting on it, a tire could detect if it wears evenly. In case it does not, it would convey this information to the suspension system, which would then redistribute the load between the tires so as to achieve a more even tire-wear. However, for this type of smart system to work, the tires must be properly inflated, because it will be difficult for the suspension system to correct the situation when the load is carried primarily by the sidewalls.

### ***7.3 Developments in manufacturing***

Tire price-to-performance ratio has come down in the past few years. New production technologies will most likely extend this trend. For example, Michelin is now introducing a new production process (termed "C3M") that combines seven fully separated production steps into one (Michelin [2002a]). The new process simplifies production, brings manufacturing costs down, and can lead to improvement of the product (Michelin [2002a]).

Normal market forces will pass some of the savings to the consumer, who may use this opportunity to obtain better tires. However, the availability of tires at lower prices may strengthen the current trend, noted in Section 3.3, to move towards high performance tires that contribute to the reduction of average tire-life mileage. Also, lowering the price-performance ratio may turn tires into a commodity and result in increased consumer consumption. For example, consumers would be less likely to wait for the tread to wear before they replace their tires.

## 8. Technology to monitor and control tire pressure

The poor state of tire maintenance depicted in Table 3.2 can be improved by employing technologies that monitor and maintain tire pressure. Two types of monitoring systems are commercially available. The first type, based on direct measurement of the air pressure in each tire, is reviewed in Section 8.1. The second type, presented in Section 8.2, deduces the air pressure based on the angular velocities of the tires. Hybrid systems are also possible, and are discussed in Section 8.3.

The discussion focuses on under-inflated tires. Over-inflated tires also lead to excessive wear, but will not be addressed for the following reasons. First, over-inflation is not known to be a significant safety issue (NHTSA [2001b]). Second, tires lose pressure under normal operating conditions, so that an over-inflated tire will become a properly inflated tire after a short period. Third, a NHTSA survey conducted in 2001 found that most tires are significantly under-inflated, not over-inflated (see Table 3.2).

### 8.1 Direct tire pressure measuring systems

A direct tire pressure monitoring system (TPMS) employs pressure gauges mounted in each tire to directly measure the air pressure in each of the tires. The measured pressure is transmitted via a wireless system to a main unit located in the vehicle, which processes and displays the information to the driver. Figure 10.1 provides an illustration of the Siemens A.G. VDO direct TPMS called “Tire Guard.” A direct TPMS is installed in the Chevrolet Corvette, and is expected to be widespread soon. For example, a Siemens A.G. press release on 19 December 2001 announced orders totaling 400 million Euros for their Tire Guard TPMS to be installed with original equipment.

The accuracy of direct TPMSs is about  $\pm 1.5$  psi (*e.g.*, Tire Guard by Siemens A.G. and TireWatch by TRW). Some devices also measure the temperature and “correct” the measured pressure (*e.g.*, model 2019 by smarTire). This feature is important because as a tire rolls on a pavement its temperature increases and the tire pressure builds up (see Figure 3.2). As a result, without temperature correction a situation may arise where the TPMS issues a warning, and then cancels the warning. This is not a desirable feature because the specification is for a cold tire, with the understanding that air pressure builds up in the tire as the temperature increases. Additionally, the effect of a flickering warning may be to cause consumers to distrust the system.

The example display to the driver illustrated in Figure 8.1 shows an important capability of direct TPMSs, namely the ability to display to the driver the air pressure in each tire, and identify the tire(s) requiring attention. Displaying the tire pressure for each tire is pivotal to improving tire maintenance. Specifically, each time the driver starts the car it will display the air pressure in the tires. The driver will then be able to determine, in advance, the need to inflate the tires the next time she or he refuels.



Figure 8.1: Schematic of the Tire Guard direct TPMS by Siemens A.G.<sup>43</sup>

Direct TPMSs suffer from two major drawbacks. First, the sensor, which is mounted on the wheel (see Figure 8.1), may be susceptible to damage when the tire is taken off the rim. However, the sensors are both very small (a typical sensor weighs 1.5 oz or less) and are built to withstand large g-forces (*e.g.*, at 156 MPH the transmitter endures 1,000 g). Therefore, it is not likely that the transmitter will be easily damaged.

Second, current direct TPMSs include a battery with each pressure sensor (*i.e.*, one battery per tire). These batteries are said to last seven to ten years (*e.g.*, the TireWatch by TRW claims a ten-year battery life). Thus, given that there are 200 million vehicles in the U.S., and assuming four wheels per vehicle and a ten-year battery life, there will be a need to dispose of 80 million batteries on an annual basis. However, IQ-mobile, a German company, is already claiming to have produced a battery-less sensor, and that it is cheaper than the battery-operated sensor it replaced. Therefore, since the technology is available and apparently competitively priced it appears that battery-powered sensors may be phased out. It should be noted that the availability of battery-less sensors should be of no surprise since battery-less technology has been available in other applications for quite some time (*e.g.*, self-winding watches).

As part of its study of TPMSs, NHTSA evaluated six direct systems (NHTSA [2001b]). For all six systems, the rotational motion of the tire activates the in-tire sensor and consequently, the vehicle is required to move for these systems to warn the driver of under-inflated tires. Thus, because of communication cycles between the sensors and the central unit, the driver may not be

<sup>43</sup> This image is reproduced from Siemens A.G. website.

warned for a few minutes.<sup>44</sup> This may be too long a delay from a safety standpoint. From a maintenance standpoint this may also represent a problem because the consumer may not be tuned anymore to the tire pressure display. Moreover, as illustrated in Figure 3.2, air pressure in tires builds up during this period and thus the delayed display may be misleading. Consequently, waiting for the low-pressure warning will not achieve the full potential of the tire-life mileage because it will not be kept at optimal conditions.

Some new systems continue to monitor tire pressure even when the vehicle is parked (*e.g.*, TireWatch 2019 by smarTire) thereby potentially eliminating the delay time discussed above. However, even this newer generation goes into sleep mode while the vehicle is parked, and checks the pressure only every fifteen minutes. Therefore, the system may still require a few minutes to warn the driver of low pressure in one or more of the tires. This new development indicates that low-pressure warning could be issued even faster in the not too distant future.

It is important to note that there is yet another low-tech direct tire pressure gauge that can be used. This gauge replaces the standard tire valve cap. It measures the air pressure in the tire, and its external color changes from green when the pressure is proper, to yellow when the tire experiences moderate loss of air pressure, to red when the pressure drops below a specified threshold. These gauges are relatively cheap, easily installed, and are pressure-specific (*i.e.*, if your placard pressure is 30 psi, you'll get a 30 psi gauge).<sup>45</sup> However, there is no central unit in front of the driver displaying a warning. Rather, the consumer has to go around the car and look at the color on each gauge. Therein lies the weakness of this system. After checking a few times, and finding that the tires are fine, as they are likely to be since in normal circumstances pressure loss is slow and gradual, the consumer will stop looking at the devices, assuming that the tires will always be properly pressurized. Also, it is very easy to lose this gauge, and so most consumers will not replace them. Finally, the sensing device does not correct for temperature and therefore, if the tire is hot the consumer may erroneously think that the pressure is fine, when in reality it is not (see Figure 3.2).

Finally, it is important to recognize that at least part of the reason that consumers do not maintain the proper air pressure in their tires is that for many consumers the current process is too difficult. Therefore, a simpler mechanism may be called for. One approach that can assist is if the consumer would not have to actually check and recheck the pressure while filling air. To this end a new valve may be developed that combines pressure and thermal sensors that are already there for the TPMS, with a one-way valve that is also already there, and a control unit that lets air in until the internal pressure is set to the temperature-corrected placard value.<sup>46</sup> The advantage of such a valve is the ease of filling tires with air. It has, however, two disadvantages. First, this valve would be more expensive than the current one. The difference, however, is probably no more than a couple of dollars per rim, and the extended tire-life mileage would most likely return more than the value of the valve. Second, consumers will still need to remember to fill the tire with air.

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<sup>44</sup> At least one of the systems tested by NHTSA had a feature that caused it to increase the transmission rate when a problem is detected and thus, the delay time is reduced considerably.

<sup>45</sup> A web search found that a set of four gages could be obtained for \$15 to \$17.

<sup>46</sup> The Cycloid system, which is discussed in detail in Section 9.2, contains two such valves.

## **8.2 Indirect tire pressure measurement devices**

Indirect TPMSs are based on the observation that for a vehicle moving at a given velocity, the angular velocity of its wheels depend on their rolling radius. As a tire's pressure decreases, its rolling radius also decreases, and its angular velocity increases. By comparing the angular velocity at the different wheels, indirect TPMSs identify tire pressure. In 2001, indirect TPMSs were installed in 1.6 million vehicles in the U.S. (NHTSA [2001b]). Vehicles equipped with indirect TPMS include Toyota Sienna, Ford Windstar, and Oldsmobile Alero.<sup>47</sup> Finally, it should be noted that all currently available indirect TPMS require the vehicle to be equipped with ABS.

Because indirect TPMS rely on comparison among the tires, currently such systems cannot detect lower tire pressure if all four tires are under-inflated; if two tires on the same side are under-inflated; or if two tires on the same axle are under-inflated (NHTSA [2001b]). Moreover, practical aspects of current systems limit them to indicate that a tire is under-inflated, but they cannot identify which one it is or if more than one tire is under-inflated. Also, current indirect TPMS require a differential of 30% in the air pressure before a warning is displayed and consequently, the warning can be displayed only when the air pressure is 30% or more below placard.<sup>48</sup>

NHTSA evaluated four indirect TPMSs, all preinstalled by the original equipment manufacturer (NHTSA [2001b]). This study found that “it was discovered that vehicles with WSB systems might not warn during straight-line driving (but will on roads with turns).”<sup>49</sup> This raises the question of the value of indirect systems for freeway travel, which is characterized by many long stretches of straight-line driving. Also, all four indirect systems studied failed to warn the driver when two tires on the same side of the vehicle were significantly under-inflated (50% below placard).

All four systems evaluated by NHTSA in 2001 required a considerable amount of time to calibrate. One system required eight hours of driving and another required driving at speeds of up to 155 MPH. For example, NHTSA quotes the calibration procedure recommended by BMW for their RDW system:

“Drive the vehicle for an hour in the speed range of 9 to 62 mph. Then, drive for 15 minutes each in the following speed ranges: 62 to 80 mph, 80 to 100 mph, 100 to 120 mph, and finally 120 to 155 mph. The system is then deemed ready to detect loss of tire pressure at any speed.”

System calibration is required after tire rotation, repair, or replacement. NHTSA estimated that system calibration would be required about 100 times during the life of the average vehicle. Therefore, an important question is whether these systems will ever really be properly calibrated. Is every new car going to be driven for eight hours, or at speeds of up to 155 MPH during the

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<sup>47</sup> <http://www.nhtsa.dot.gov/cars/rules/rulings/TirePresFinal/Index.html>

<sup>48</sup> Toyota indicated in its comments to NHTSA that its next-generation indirect TPMS will be able to detect a differential of 20% of placard between the tires, but it did not indicate when such a system would be available.

<sup>49</sup> “WSB” stands for “Wheel-Speed Based.”

quality control testing? Or is the consumer expected to do this each time they replace their tires? This elaborate calibration system casts doubt over the use of such systems. It should also be noted that none of the four systems tested by NHTSA informed the driver if the system was calibrated.

From the above discussion it is evident that indirect TPMSs are inadequate from a tire maintenance standpoint. Indeed, both NHTSA and automakers state that these systems are intended for safety and should not for tire maintenance. However, a NHTSA study found that a majority of the people asked stated that if their car were equipped with a TPMS, they would rely on the system to tell them when the tires need to be inflated. Therefore, in view of the fact that tires deflate slowly under normal operation, it would appear reasonable to assume that indirect TPMSs will either fail to warn the driver of low air pressure entirely, or will do so only when the air pressure has dropped more than 30% below placard.

### ***8.3 Hybrid tire pressure monitoring systems***

TRW, a maker of both direct and indirect TPMSs, suggests that the limitation of indirect TPMSs could be removed by using a hybrid system that will employ direct pressure measurements of two wheels and use indirect measurements for the other two wheels (NHTSA [2002b]). Such a system could in theory be used to determine the air pressure in all four tires. However, it would require a considerable lead-time (possibly as much as 8 minutes) to identify the pressure in the two tires for which only indirect measurements are available. By that time the vehicle would have traveled a considerable distance, and its temperature would have probably risen (see Figure 3.2), in which case even hybrid TPMSs cannot detect the “cold” pressure (note that no temperature compensation is available for the two tires where pressure is measured indirectly).

## 9. Tire pressure auto-inflate systems

Direct and indirect TPMSs alert drivers, with varying degrees of reliability, of the need to inflate their tires. However, there is nothing to ensure that the driver will follow up on this warning. Therefore, it would be preferable if an automatic system could take on this task. Here it is important to recall that when a tire is under-inflated, even at 20% below placard, the change in the tire may not be visually significant (see Figure 9.1) and as a result, consumers may choose to ignore the TPMS warning. Moreover, indirect TPMSs warn only after a considerable air pressure loss (30% of placard) and as a result, they are not a good indicator for maintenance purposes.

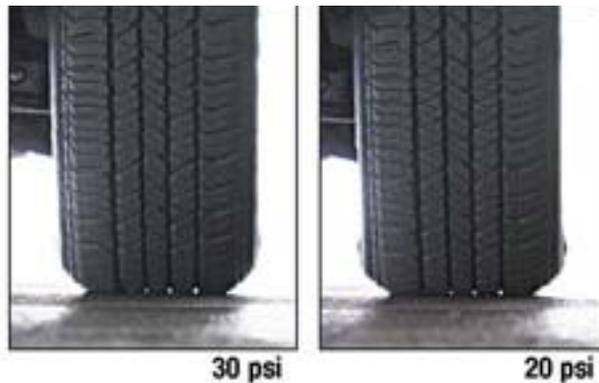


Figure 9.1: Visual appearances of severely under-inflated (right) and properly inflated tires.<sup>50</sup>

Air-pressure loss in tires is mostly attributed to slow loss through air permeation and/or small punctures to the tire. For these types of problems it would be desirable to have a system that detects when the air pressure dropped by a relatively small percentage of the placard air pressure and then proceeds to automatically inflate the tire back to the specified level. In the following discussion such systems are referred to as “auto-inflate systems.” Because of different levels of product availability and market penetration, in the following, auto-inflate systems are discussed separately for heavy-duty tires (Section 9.1) and light-duty tires (Section 9.2).

### 9.1 Heavy-duty tires

Auto-inflate systems for heavy-duty tires are available from a number of vendors. Common to all systems is the availability of a pressure sensor in each tire and a system to deliver air to the tires. The delivery system varies considerably between manufacturers. For example, Pressure Systems International (P.S.I.), marketed by ArvinMeritor, provides an auto-inflate system named “ATIS” for truck trailers. This system connects to the air tanks already mounted in the undercarriage to deliver air to under-inflated tires. A control box mounted in the undercarriage determines when additional air is required. Thus, extending the use of this system beyond truck trailers is limited (because of cost) to systems that use air tanks to operate the brakes.

A very different system is produced by Cycloid, where a centrifugal pump is connected to each tire and delivers air just to that tire. The main advantage of the Cycloid system is that it requires

<sup>50</sup> This image is reproduced from Bridgestone’s web site.

almost no changes to the trucks or trailers, and does not depend on the availability of air tanks, as does the PSI ATIS system. Both systems require some modification to the rim.

The tale that these companies tell is compelling. For example, according to ArvinMeritor's return-on-investment calculator (provided on their web site), the cost of the PSI ATIS system is \$725, and they expect a 10% increase in tire life mileage.<sup>51</sup> A video available on the ArvinMeritor web site states that for heavy-duty tires, 20% under-inflation reduces life mileage of tires by 25%, and 30% under-inflation results in 55% reduced life mileage.<sup>52</sup> An additional advantage noted in the video is that tires wear more evenly, thus making them more suitable for retreading. Consumer comments, such as those below, support these claims.<sup>53</sup>

*Lynden Transportation, Inc.* "We have in excess of 250,000 miles on our trailers with PSI ATIS. We run from Houston, Texas to Prudhoe Bay, Alaska. PSI has eliminated early cupping, increased tire life 50% and has proven to be durable."

*Landstar Companies, Inc.* "With an increase in miles per 1/32<sup>nd</sup> of over 30% and no maintenance problems or failures, PSI ATIS proves to be a good safety and maintenance device. All new trailers are to be equipped OEM."

By 2002 Union Pacific Rail Roads (UPRR) installed 16,000 PSI ATIS units, apparently all mounted on trailers equipped with retread tires.<sup>54</sup> A study by UPRR showed that they achieve a payback on the investment in less than two years.<sup>55</sup> Also, UPRR's average replacement of tires is 2.98 per chassis per year with the ATIS system, and 3.80 per chassis per year without the ATIS system.<sup>56</sup> Thus, auto-inflate systems can be quite effective in reducing tire-wear.

## **9.2 Light-duty tires**

Unlike the multiplicity of devices available for heavy-duty tires, only Cycloid appears to provide a system for the light-duty tire market, termed "AutoPump." According to a June 18, 2002 press release by Cycloid, DaimlerChrysler has featured the AutoPump on its new concept vehicle, the Jeep Grand Cherokee Concierge, which was unveiled in Stuttgart, Germany in early June 2002.

The Cycloid devices combine a direct TPMS with an inertia compressor to continuously top-off tire pressure as needed, so that the specified air pressure is always maintained. The compressor provides air to the tire when the pressure in it drops by 2 psi below placard. Thus, assuming a placard of 30 psi, the air pressure level should not drop by more than about 6.6% for a tire equipped with the Cycloid system.

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<sup>51</sup> [www.arvinmeritor.com/products/truckandtrailer/tireinflationsystemspaybackcalculator.asp](http://www.arvinmeritor.com/products/truckandtrailer/tireinflationsystemspaybackcalculator.asp)

<sup>52</sup> <http://www.arvinmeritor.com/products/truckandtrailer/tireinflationsystems.asp>

<sup>53</sup> <http://psi-atis.com/testimony.htm>

<sup>54</sup> ArvinMeritor, [2002], presentation at the *International Operations & Maintenance Seminar*, Oak Brooks, Ill.

<sup>55</sup> Id.

<sup>56</sup> Id.

In a letter to NHTSA, Goodyear indicated that a loss of 1 psi of air pressure results in a loss of 1.78% of tread life (NHTSA [2002b]).<sup>57</sup> Combining this information with the current maintenance practice in the U.S. as reflected in Table 3.2 suggests that an auto-inflate system with the characteristics of the Cycloid device can extend tread life by about 7.7 percent.<sup>58</sup> If the fact that the NHTSA study did not account for the fact the tires were hot is factored in then the Cycloid device extend tread life by about 12 percent. Also, the difference between the lower bound on the air pressure level maintained by the Cycloid system and the level at which direct TPMS will issue a warning leads to a saving of about 9.8% in the tread life.<sup>59</sup>

According to the 2001 CIWMB annual report, about 24% of passenger tire equivalents (PTEs) end up being disposed of (CIWMB [2003b]). Thus, extending tire-life mileage by 9.8% will eliminate 40% of the PTEs disposed of in California. This value most likely overestimates the actual reduction because light-duty tires probably constitute a higher percentage of the tires that end up being disposed of. 1990 appears to be the last year for which data is available separately for light- and heavy-duty tires (CIWMB [1992]). In 1990 19% of heavy-duty tires and 62% of light-duty tires were disposed of (CIWMB [1992]).

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<sup>57</sup> Goodyear holds a minority ownership in Cycloid.

<sup>58</sup> The 7.7% value is calculated as follows:  $1.78 * (0.4*[0.3*30-2]+0.05*[0.25*30-2]+0.07*[0.2*30-2]+0.48*[2])=7.68$ . The first number in each pair represents the percentage of the total fleet (see Table 3.2), and the expression within the square brackets represents the difference between the measured air pressure, which is converted from the percentage out of placard in Table 2 by assuming 30 psi placard, and 2 psi below placard. The last expression within square brackets, the number 2, represents an estimation of the average difference for tires that are inflated 20% or more below placard.

<sup>59</sup> This assessment may underestimate the life-mileage loss because when the tire is under-inflated its rolling friction increases, resulting in excess heat that further damages the tire (*i.e.*, beyond direct wear). Thus, the tire-life mileage is further reduced.

## 10. Framework for Economics Analysis

This section provides the necessary background and establishes the framework for the economics analysis. Two different strategies are available to conduct the analysis. First, benefit-cost analysis is discussed in Section 10.1. Second, cost effectiveness is addressed in Section 10.2.

### 10.1 Benefit-Cost Analysis

Benefit-Cost analysis [BCA] is used to assess the relative gains of undertaking one course of action rather than another. This could involve a new set of rules, an investment or a new process. BCA requires a baseline, or counter-factual, that defines the alternative in the absence of change. This base line provides a standard against which the different alternatives are compared.

The first step in benefit-cost analysis is the establishment of the merits of a proposed plan or project on an efficiency basis. This is an important point to recognize in choosing among evaluation methods. BCA evaluates strictly on the basis of economic efficiency. There are three components to the measure of economic efficiency: static allocative efficiency, dynamic [allocative] efficiency and productive efficiency. Productive efficiency addresses the question of whether an organization produces its output at a given level of quality at the least cost possible. Productive efficiency will be achieved if the best available process technology is utilized and the mix of inputs used is consistent with the set of relative input prices in the market. In other words, a firm or agency that achieves productive efficiency is operating on the lowest cost function available. This is the measure that most people identify with the meaning of efficiency and this is the best representation of what the new tire saving process is aimed at.

BCA undertakes to compare in commensurate terms the sum total of the benefits and costs resulting from a plan or project. This is normally accomplished by deriving monetary estimates of both benefits and costs at a common point in time. Benefits are estimated as the beneficiary's willingness to pay for the publicly provided good or service, and costs are valued at the inputs opportunity cost, that is, at values adequate to compensate the suppliers of the resource for foregoing its use in their best alternative allocation. One of the major tasks of BCA is the determination of willingness to pay and the opportunity cost, for often no market values exist and even where available, they need not be consistent with social value. If on this basis benefits exceed costs, the project is considered socially justified, as the beneficiaries of the project could compensate those who lose as a result of the project.

#### 10.1.1 Benefit Cost Analysis: Selection Criteria

The typical problem to which BCA is applied is to evaluate on a comparable basis the stream of social costs arising from the undertaking of a project or program. An essential and often difficult task is to determine the pattern of benefits and costs over the project's life, but once accomplished, the analyst has a time stream of benefits

$$B_0, B_1, B_2, \dots, B_{t-1}, B_t$$

and a time stream of costs

$$C_0, C_1, C_2, \dots, C_{t-1}, C_t$$

from the present, 0, to the termination date  $t$  or some future point such as the lifetime of the project.  $B_0$  is the benefits in the current year,  $B_1$  the benefits next year and so on until  $B_t$  are the benefits in year  $t$ . Similarly for costs,  $C$ . The monetary value of the respective time stream cannot simply be summed and compared to determine the project's viability since the time patterns of benefits and costs are likely to differ significantly. Usually the bulk of the costs occur in the early years when the project is under construction, being made or put in place while benefits are generated in later years once the activity becomes operational. The difference in the timing of benefits and costs would not matter if people valued a dollar today and a dollar in the future equally.<sup>60</sup>

Because a dollar is valued differently at different periods of time, it is necessary to relate the value of benefits and costs in different years to a common period. This is achieved by discounting future benefits and costs to their present value. The present value of one dollar available in period  $t$  and discounted at the rate  $i$  is

$$PV = \frac{\$1_t}{(1+i)^t}$$

Hence the present value of the benefit stream can be established as

$$PV_B = \frac{B_0}{(1+i)^0} + \frac{B_1}{(1+i)^1} + \frac{B_2}{(1+i)^2} + \dots + \frac{B_t}{(1+i)^t} = \sum_{n=0}^t \frac{B_n}{(1+i)^n}$$

and the present value of the cost stream as

$$PV_C = \sum_{n=0}^t \frac{C_n}{(1+i)^n}$$

Once discounted to the present, benefits and costs can be compared. In BCA this comparison is most commonly expressed either as a benefit-cost ratio

$$\frac{B}{C} = \frac{\sum_{n=0}^t \frac{B_n}{(1+i)^n}}{\sum_{n=0}^t \frac{C_n}{(1+i)^n}}$$

or as net present value

$$NPV = \sum_{n=0}^t \frac{B_n}{(1+i)^n} - \sum_{n=0}^t \frac{C_n}{(1+i)^n} = \sum_{n=0}^t \frac{B_n - C_n}{(1+i)^n}$$

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<sup>60</sup> The fact that borrowers are willing to pay interest, a premium, for the use of money today rather than waiting for the future, and that lenders require the interest as compensation for foregoing their use of money today and postponing its use until the future, is a testament to the unequal value of money over time. This is the reason that we find, for example, that a \$1,000 bond payable one year hence has a market value of \$925.93 when the rate of interest is 8 percent.

The project or investment is viable on efficiency grounds if the B/C is greater than one or if its net present value is positive. The former value provides a measure of the rate of return (*i.e.*, the benefits per dollar of expenditure). The latter gauge gives a measure of the magnitude of the return (*i.e.*, how big it is in dollars).

The major advantage of the net present value (NPV) criterion is that it shows the absolute magnitude of the returns from a project, investment, decision or change. This is in contrast to the benefit-cost ratio (B/C) that only reflects relative returns. Absolute magnitudes, while an essential consideration, are not the whole story because projects with the same dollar benefit may have much different relative returns. For example, \$10M net benefit might accrue from a project with benefit-cost ratio of  $\$20M/\$10M = 2$  or a project with a B/C ratio of  $\$200M/\$190M = 1.05$ . As a result, one cannot usually select projects on the basis of a single criterion, and both absolute and relative measures deserve consideration.

## **10.2 Cost Effectiveness Analysis: A brief Description**

Cost effective analysis [CEA] is sometimes used as an alternative to BCA. CEA seeks to maximize the extent of achievement of a given beneficial goal within a predetermined budget or, equivalently, to minimize the expenditure required to achieve a pre-specified goal. Often, the goal will have been set under a separate process in which benefits and costs may have not been considered. In marked contrast to BCA, no attempt is made to place a monetary value on the beneficial goal. CEA is potentially useful when analysts seek efficient policies but face constraints in undertaking a BCA. Three common constraints are: (i) the inability or unwillingness to monetize some impacts of the project<sup>61</sup>; (ii) when the effectiveness measure will not capture all of the social benefits of each alternative, and some of these other social benefits are difficult to monetize. When BCA is used all impacts must be monetized. If the CEA measures capture “most” of the benefits, it may be reasonable for analysts to use CEA to avoid the effort of undertaking a BCA; (iii) when the project is linked to intermediate goods where the linkages to preferences are not clear. The latter constraint would seem appropriate for some automatic vehicle location projects in which their contribution to the overall public transportation network is not clear but CEA may give useful information concerning the relative efficiency of alternatives.

CEA measures involve computing for each alternative the ratio of input to output. Thus, they are a measure of *technical efficiency* and might be interpreted in some cases as measures of productivity. As described in Appendix B below<sup>62</sup>, differences in policy alternatives in the scale of projects, as well as the fact that CEA often omits important social costs and benefits, make them poor measures of *allocative efficiency*.

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<sup>61</sup> CEA is used quite commonly when values must be placed on life in the evaluation of a project.

<sup>62</sup> Appendix B contains a more detailed discussion of cost efficiency analysis.

## **11. Framework for Benefit-Cost Analysis**

The categories of benefits and costs and what data are required in order to evaluate the returns from the different strategies are identified in this section. The analysis herein draws data largely on the final economic analysis report prepared by the National Highway Transportation Safety Administration (NHTSA) for their tire pressure monitoring system (TMPS) (NHTSA [2002a]).

The benefit-cost analysis performed in the NHTSA [2002a] report, however, appears to have not carried out a full social benefit cost analysis. For example, although the benefits associated with improved safety are computed, they are not included in the present value calculations of the net benefits. The NHTSA [2002a] report presents private and social net benefits (or costs) separately.

The principal reason for undertaking the present study is to identify strategies that will extend the lifespan of tires and thus, lead to fewer tires being discarded. However, implementing some of the proposed strategies results in additional benefits that cannot be ignored. For example, some of the strategies result in reduced fuel consumption. Indeed, the “side benefits” may have larger monetary values than the monetary value of reducing the number of waste tiers. Therefore, the analysis presented in this report attempts to address all major economical contributors.

### ***11.1 Developing the Base Case***

As was noted above, a base case must be selected in order to gage the influence of the different strategies studied on the number of waste tires generated. The base case provides a point of reference and information on the rate of tires discarded if nothing else were done than currently. However, the base case must reflect current legislation, particularly as it relates to tire pressure monitoring systems, and the resulting changes that these rules bring. The base case would also take as given: current accident rates, fuel use and purchase/registration trends in the automotive and truck sectors. Additional aspects to be considered include the proportion of tires that are currently used for retreading for both light and heavy tire categories as well as the distribution between passenger car, light truck and commercial truck tires in the total number of tires discarded.

The current NHTSA regulation on TPMS provides for two levels of compliance (see Section 8). For the purpose of this benefit-cost analysis the 30% compliance level is accepted as the base case (*i.e.*, indirect TPMS is assumed as the default case), and it is noted that according to NHTSA’s own analysis, if all vehicles met this level of compliance, then the average tire life mileage would increase by 15 miles. Since the current average tire life is 41,000 miles, adopting this level of compliance would have no impact on the number of waste tires.

#### **11.1.1 Forecast of Tires Discarded**

This study employs two alternative tire disposal rate forecasts. The first is that provided by the California Integrated Waste Management Board (CIWMB) and the second was developed based on information provided by the Rubber Manufacturers Association (RMA) and integrated with information obtained from firms in the recycling industry, the change in the rate of growth of

sport utility vehicles (SUVs) in the vehicle stock and information from reports provided by the Environmental Protection Agency (EPA). This second database is referred to hereafter as the RMA database. The two forecasts are illustrated in Figure 11.1. It is clear the two forecasts differ in both level as well as rate of change over time. The CIWMB’s forecast is more optimistic and has discard rates growing at a slow rate over time. From 1989 through 2001 the CIWMB data show tire discard growth at 1.9% while the growth rate based on RMA and other data shows a growth rate of 2.9%, a significant difference. From 2001 to 2013 the forecast growth rate in discarded tires is approximately 2.3% for both databases.

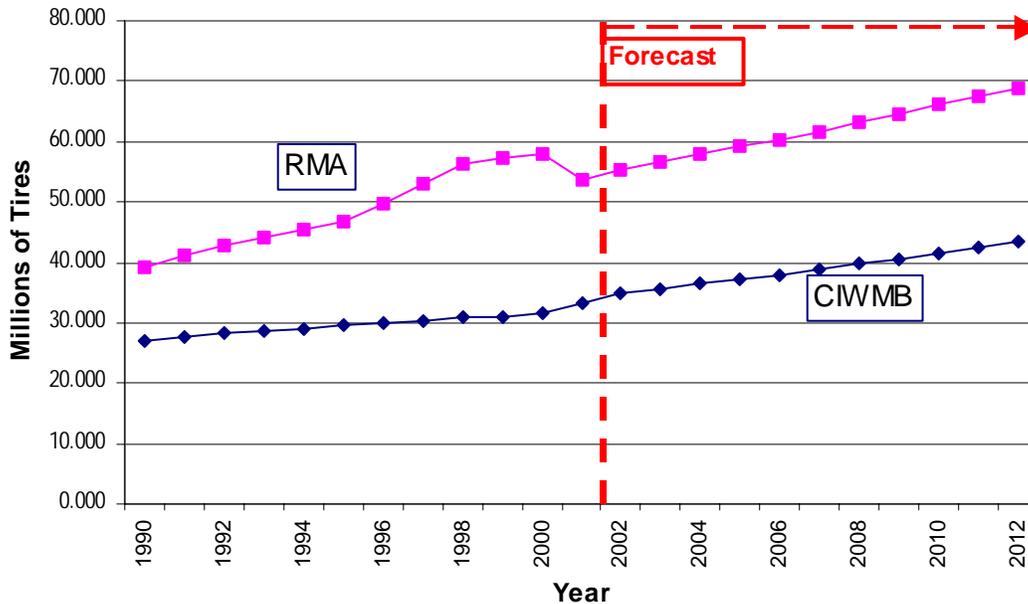


Figure 11.1: Comparison of CIWMB and RMA forecasts.

For purposes of the current analysis the two data sets represent a lower and upper bound on the discard rate of tires. It is important to understand that changes in the discard rate will not necessarily affect the number of tires going to landfill on a one to one basis. Tires are discarded when they become unsafe or are deemed not useable by vehicle owners. Since light- and heavy-duty tires weigh different amounts, they are indexed in terms of passenger tire equivalents (PTEs). Discarded tires can be exported if they still have some useable life; they can be ground up and recycled in different ways; they can be treated and re-treaded. Under the current CIWMB forecast, 30 percent of tires were diverted from landfill in 1990 and this has grown to 74.8 percent in 2001.

Tables 11.1 and 11.2 provide the base data for undertaking the calculations of the effect of each strategy on the number of tires discarded. These tables form the basis of measuring the social benefits, reduced emission, reduced accidents, and reduced numbers of tires going to landfill, with tire inflation strategies. NHTSA, in its benefit cost analysis, argued that to these must be added private benefits such as increases in fuel economy and reduced tread wear that lowers tire life. However, as we will argue subsequently, some of these costs are in effect transfers.

Table 11.1: CIWMB Base Case Data with Forecast to 2012

Year	California population (Millions)	Estimated tires generated RMA Data (millions)	Tires Imported (millions)	Total PTEs (RMA Data)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfill
1990	29.5	27.000	0.00	27.000	0.60	2.3	1.3	4.00	8.20	18.80
1991	30.1	27.500	0.40	27.900	0.80	2.2	1.3	5.80	10.10	17.80
1992	30.7	28.200	0.60	28.800	1.10	2.1	1.3	6.80	11.30	17.50
1993	31.1	28.500	0.30	28.800	1.50	2.1	1.3	7.70	12.60	16.20
1994	31.7	29.000	0.20	29.200	1.70	2.4	1.3	11.70	17.10	12.10
1995	32.3	29.500	0.60	30.100	1.80	2.4	1.7	10.80	16.70	13.40
1996	32.6	30.000	1.50	31.500	2.30	2.4	1.7	8.90	15.30	16.20
1997	33.2	30.400	3.20	33.600	5.40	2.8	1.7	9.00	18.90	14.70
1998	33.8	30.900	2.20	33.100	9.10	2.8	3.1	7.50	22.50	10.60
1999	34.0	31.100	2.00	33.100	10.10	2.5	1.5	7.90	22.00	11.10
2000	34.5	31.600	3.20	34.800	11.00	2.4	1.9	5.20	20.50	14.30
2001	34.8	33.300	1.70	35.000	14.90	2.4	2.6	5.30	25.20	9.80
2002	35.8	34.835	2.00	36.835	15.65	2.5	2.5	5.50	26.15	10.69
2003	36.4	35.668	2.00	37.668	16.43	2.5	2.5	5.50	26.93	10.74
2004	36.9	36.425	2.00	38.425	17.25	2.5	2.5	5.50	27.75	10.68
2005	37.4	37.203	2.00	39.203	18.11	2.5	2.5	5.50	28.61	10.59
2006	37.8	37.904	2.00	39.904	19.02	2.5	2.5	5.50	29.52	10.39
2007	38.4	38.830	2.00	40.830	19.97	2.5	2.5	5.50	30.47	10.36
2008	38.9	39.681	2.00	41.681	20.97	2.5	2.5	5.50	31.47	10.22
2009	39.4	40.559	2.00	42.559	22.01	2.5	2.5	5.50	32.51	10.05
2010	40.0	41.570	2.00	43.570	23.11	2.5	2.5	5.50	33.61	9.96
2011	40.4	42.403	2.00	44.403	24.27	2.5	2.5	5.50	34.77	9.63
2012	40.9	43.372	2.00	45.372	25.48	2.5	2.5	5.50	35.98	9.39

Table 11.2: RMA Base Case Data with Forecast to 2012

Year	California population (Millions)	Estimated tires generated RMA Data (millions)	Tires Imported (millions)	Total PTEs (RMA Data)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfill
1990	29.5	39.17	0.00	39.17	0.60	2.30	1.30	4.00	8.20	30.97
1991	30.1	41.00	0.40	41.40	0.80	2.20	1.30	5.80	10.10	31.30
1992	30.7	42.74	0.60	43.34	1.10	2.10	1.30	6.80	11.30	32.04
1993	31.1	44.10	0.30	44.40	1.50	2.10	1.30	7.70	12.60	31.80
1994	31.7	45.47	0.20	45.67	1.70	2.40	1.30	11.70	17.10	28.57
1995	32.3	46.87	0.60	47.47	1.80	2.40	1.70	10.80	16.70	30.77
1996	32.6	49.64	1.50	51.14	2.30	2.40	1.70	8.90	15.30	35.84
1997	33.2	52.94	3.20	56.14	5.40	2.80	1.70	9.00	18.90	37.24
1998	33.8	56.16	2.20	58.36	9.10	2.80	3.10	7.50	22.50	35.86
1999	34.0	57.16	2.00	59.16	10.10	2.50	1.50	7.90	22.00	37.16
2000	34.5	58.05	3.20	61.25	11.00	2.40	1.90	5.20	20.50	40.75
2001	34.8	53.58	1.70	55.28	14.90	2.40	2.60	5.30	25.20	30.08
2002	35.8	55.35	2.00	57.35	15.65	2.50	2.50	5.50	26.15	31.21
2003	36.4	56.68	2.00	58.68	16.43	2.50	2.50	5.50	26.93	31.75
2004	36.9	57.88	2.00	59.88	17.25	2.50	2.50	5.50	27.75	32.13
2005	37.4	59.11	2.00	61.11	18.11	2.50	2.50	5.50	28.61	32.50
2006	37.8	60.23	2.00	62.23	19.02	2.50	2.50	5.50	29.52	32.71
2007	38.4	61.70	2.00	63.70	19.97	2.50	2.50	5.50	30.47	33.23
2008	38.9	63.05	2.00	65.05	20.97	2.50	2.50	5.50	31.47	33.59
2009	39.4	64.45	2.00	66.45	22.01	2.50	2.50	5.50	32.51	33.93
2010	40.0	66.05	2.00	68.05	23.11	2.50	2.50	5.50	33.61	34.44
2011	40.4	67.38	2.00	69.38	24.27	2.50	2.50	5.50	34.77	34.61
2012	40.9	68.92	2.00	70.92	25.48	2.50	2.50	5.50	35.98	34.93

## 12. Benefit and Cost Measures

The influence of the strategies studied on each category of benefit and cost must be measured. For example, a direct TPMS can provide information on different degrees of tire under-inflation. The likelihood of blowouts or skidding *etc.* is related to under-inflation.<sup>63</sup> Different taxes or subsidy schemes can induce people to purchase longer life mileage tires or to maintain their tires for longer life. Education programs may induce people to monitor their tires pressure on a more frequent basis. A tax placed on tires of low warranted mileage, will induce some consumers to shift to longer life tires. Higher costs will reduce the demand for vehicle miles traveled (VMT), thus tires will last longer and will be replaced less often over time (assuming a given level of care). On the other hand, longer life tires may reduce the tire contribution to the cost of operating vehicles per mile and thus, lead to an increase in the demand for VMT. These are complex relationships and it may be the case that requisite data or elasticity measures are not available to complete the calculations.

### 12.1 Cost Categories

It is generally easier to measure costs associated with the different strategies. In developing the cost measures a key issue is to decide on the useful life of the investment. This will influence the length of time that costs and benefits are considered and over which they will be discounted. The cost of each strategy consists of initial costs (*e.g.*, hardware or development in the case of education programs), and ongoing costs (*e.g.*, maintenance). In the case of some technologies the costs may vary depending on the level of technology. For example, an indirect TPMS is less costly than an auto-inflate system. Costs will also vary according to what equipment the car comes with. For example, installing an indirect TPMS requires that the vehicle be equipped with an antilock brake system (ABS).

### 12.2 Benefit Categories

#### 12.2.1 Social Benefits

Social benefits arise indirectly as a result of the different strategies. They include reduced emissions with less fuel used, an improvement in safety and a reduction in incident congestion. Improvements in safety come from more vehicle control (less skidding and loss of control), and a reduction in flat tires and blowouts. Social benefits are measured in terms of the reduction in [social] costs resulting from accidents and pollution from emissions. Accident costs would include lost productivity, and direct hospitalization and health care costs associated with a change in the accident and injury rate.<sup>64</sup> Reductions in emissions can affect the social costs

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<sup>63</sup> NHTSA [2002a] provides a good illustration of this issue as well as useful data tables that are used in our analysis.

<sup>64</sup> NHTSA [2002a] report is an important source of information providing some of the models for measuring the impact of changes in inflation levels on improved stopping distance and hence on the probability of injury, or severity of injury. In each case the measure of aggregate benefit for this category will be a function of how many people or what amount of VMT is affected by the particular strategy.

associated with pollution emitted by vehicles including health care, lost productivity, and environmental degradation.<sup>65</sup>

Each strategy will have a different effect on the 'expected' wear rate of tires. The increase in mileage will be translated into the reduction in disposal rate and the number of tires reaching landfills. This reduction can be translated into the reduction in environmental degradation. Some issues that do arise with these calculations are first, as tires are used at a mileage closer to their useful life, there will be fewer tires that may be exported but there will be more that enter the re-tread stream. This may be a one-to-one shift.<sup>66</sup>

### **12.2.2 Private Benefits**

The benefit to individuals is the dollar value of not having to spend as much money on tires over the lifetime of the vehicle. This can be measured as the opportunity cost of funds. A second private benefit is the reduction in fuel use. This is a direct gain measured as the expected increase in fuel economy times the number of people or amount of VMT per person per year.

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<sup>65</sup> These costs have been calculated for California in a study by D. Gillen, D. Levinson and A. Kanafani, *The Full Social Costs of Air, Rail and Highway in California*, (UCB-ITS-RR-96-3) University of California at Berkeley, Institute of Transportation Studies, Berkeley CA.

<sup>66</sup> An issue not investigated in this study but which might be researched is the effect of increasing the number of retreaded tires entering the domestic market. These tires would sell at a lower price and affect the disposal rate. This would be akin to the rebound effect in energy use with higher gasoline prices.

### 13. Factors Affecting Tire Disposal

This section examines what factors influence the amount of tire disposal. These factors included different types of vehicle registrations, the average mileage obtained on tires, and trend effects such as population and economic growth. The results of the statistical analysis are contained in Table 13.1. The general form of the statistical relationship would be:

$$D = f(t, q, \Sigma R_i)$$

where D is the number of tires discarded, t is a time or trend index, q is some measure of tire quality such as long wear and  $R_i$  is the number of vehicles registered in category i. A number of different functional forms were investigated and the version reported in Table 13.1 was selected based on statistical fit and level of explanation ( $R^2$ ).

Table 13.1: Regression of Tire Disposal on Mileage and Registrations<sup>67</sup>

Dependent Variable: LOGTIRES				
Variable	Coefficient	Std. Error	t-Statistic	
Constant	4.2144	3.0685	1.37	
LOGMILEAGE	-0.3637	0.2215	-1.64	
LOGTIME	0.3789	0.0965	3.93	
LOGAUTO	2.2710	0.8361	2.72	
LOGTRUCK	-1.1565	0.7146	-1.62	
LOGTRAILER	-1.1255	0.7369	-1.53	
LOGMIS	-0.1432	0.2159	-0.66	
AR(1)	0.3565	0.1562	2.28	
R-squared	0.99			
Adjusted R-squared	0.98			
Log likelihood	45.39			
Durbin-Watson stat	2.18			
F-statistic	79.69			

The regression equation is expressed in log-log form so the coefficients can be interpreted as elasticities.<sup>68</sup> The equation is explaining how the number of tires disposed of is influenced by the supply of used tires and the improved quality of tires. First, as the average mileage of tires increases, a measure of the change in average quality or improved maintenance, it reduces the number of tires disposed. This is as expected since the VMT per unit of tire use increases, but what is somewhat surprising is the magnitude of the elasticity, -0.36. This indicates that a 10 percent increase in the tire mileage will result in a decrease in tires disposed by 3.6 percent. This clearly suggests that any strategy that improves average mileage will have a significant effect on the disposal rate.

<sup>67</sup> The AR(1) variable is a correction for serial correlation.

<sup>68</sup> Elasticity is a measure of responsiveness of one variable in relation to another.

Different types of vehicles contribute to the supply of waste tires. The largest generators of scrap tires are light-duty vehicles. Table 13.1 gives the elasticity for light-duty vehicles (LOGAUTO), generated from a log-log relationship, as 2.27 (*i.e.*, a 10 percent increase in light-duty vehicle registration results in a 22 percent increase in scrap tires).<sup>69</sup> This is a dramatic effect and emphasizes the importance of improving tire wear. The elasticities of tire disposal by truck and trailer registrations (LOGTRUCK) appear to provide counter-intuitive negative signs. This may be attributed to the high percentage of retread tires (over 50%, see Section 4.1), and to better maintenance including the recent introduction of auto-inflate systems in truck trailers (see Section 9.1). Interestingly, the elasticities for truck and trailers are half the elasticity value for light-duty vehicles. The interpretation is important. On the face of it, it implies that truck registrations reduce the number of tires disposed of. However, it is not the truck registrations *per se* but the fact that trucks and trailers are commonly fitted with retreaded tires and have better maintenance which significantly improve the life of tires.

The regression also provides a basis for focusing our strategy choice. The regression indicated that over time, holding other things constant, tire disposal would rise, as one would expect. However, increasing light-duty vehicles registrations has a dramatic effect of increasing the number of tires disposed of; the elasticity was measured as 2.27. This suggests that a strategy that increases tire life for light-duty vehicles will have a considerable effect on reducing tire disposal rates. Second, the use of better maintenance and retreads can reduce the rate of tire disposal, as illustrated by the truck and trailer registration elasticities. Therefore, using technology to increase tire life can have a high private and social return and using strategies to increase average tire life for light-duty vehicles can have a substantial effect on the numbers of disposed tires.

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<sup>69</sup> The size of the elasticity should not be surprising since each light-duty vehicle uses 4 tires for each set change.

## **14. Strategies to Extend the Average Life Mileage of Tires**

The previous sections provided the necessary background needed to identify strategies to extend the average life miles of tires. This sections presents four different strategies to achieve this goal. The focus of this section is to set up the basic concept underlying each strategy. Effectiveness in reducing the number of waste tires generated, the economic effect, and implementation aspect are deferred to subsequent sections.

The first strategy, presented in Section 14.1, employs auto-inflate systems to automate tire pressure maintenance. Educating the public to better maintain their tires is considered as a second strategy in Section 14.2. The third strategy, discussed in Section 14.3, is centered about a corporate average tire life standard. Finally, the fourth strategy, outlined in Section 14.4, is based on replacing the flat tire disposal tax with a tax and rebate policy that promotes tires that increase the average life mileage of tires.

The four approaches are presented as stand alone strategies. Better results could be achieved if they were integrated. For example, adopting auto-inflate systems would resolve the acute problem of under-inflated tires noted in section 3.2.1.1. However, these systems will most likely be installed only as OE. Therefore, educating owners of existing vehicles to better maintain their tires remains an important strategy that complements adopting auto-inflate systems.

### **14.1 Strategy 1: Automatic Tire Pressure Maintenance**

The review in Section 3 identified poor maintenance of air pressure in tires as the leading contributor to reducing the lifespan of tires. Auto-inflate systems, discussed in Section 9, offer a technological solution to this problem by automatically maintaining tire pressure. Therefore, one of the main advantages of using auto-inflate systems is the high reliability of the outcome because it does not depend on human intervention (see Section 20). Thus, the first strategy considered is to equip, after a phase-in period, all new vehicles with auto-inflate systems as original equipment.

This strategy would increase, with very high reliability, the average lifespan of tires because tire pressure is automatically controlled. Existing automobiles can also be retrofitted to take advantage of these systems. But, this possibility is ignored under the evaluation of this strategy. Therefore, a transition period will be required before the full potential of this strategy is realized.

Auto-inflate systems are equally applicable to both heavy- and light-duty vehicles. In fact, at present these systems are installed in about four percent of truck trailers nationwide.<sup>70</sup> Track record with truck trailer shows that auto-inflate systems can significantly extend the average life miles of tires (see Section 9.1). The proposed strategy is primarily focused on light-duty vehicles because this segment holds the promise of better payoff. However, the heavy-duty segment should not be overlooked. Nevertheless, the projection of expected benefits in subsequent sections pertain to the light-duty segment only.

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<sup>70</sup> Varun Rao, sales technical representative with ArvinMeritor distributor of the PSI ATIS system; telephone interview on April 7<sup>th</sup> 2003; telephone number 248-435-9371.

NHTSA's TPMS rule allows for two levels of compliance (see Section 8). The lower level of compliance, 30% below placard level, is adopted as the base case against which to compare (see Section 11.1). The reality is, however, that some vehicles would be equipped with direct TPMSs (*i.e.*, meeting the stricter 25% compliance option). Therefore, in order to provide a complete picture, the 25% compliance option is also analyzed in subsequent sections (*i.e.*, the case where all light-duty vehicles would be equipped with direct TPMSs). Pursuing direct TPMSs is not considered, however, as an integral part of this strategy.

For both auto-inflate and direct tire pressure monitoring systems the initial capital costs and the annual maintenance costs over the assumed lifetime of the hardware have to be considered. It may also be necessary to make some assumptions about how these costs might change over time including any one time administrative costs. The initial costs used are as follows: \$21.13 for indirect TPMS, \$65.84 for direct TPMS and \$175 for auto-inflate.<sup>71</sup> The indirect TPMS was assumed to have no maintenance costs, and the direct TPMS and auto-inflate system maintenance cost was assumed to be \$100 in year 10 (primarily for replacing the battery required to operate the sensors).<sup>72</sup>

## **14.2 Strategy 2: Educating Consumers to Properly Maintain Tires**

Like the first strategy presented above, this strategy also seeks to extend the lifespan of tires by improving their maintenance. Unlike the first strategy considered that resorted to technology, here the vehicle owner has to take an active roll to achieve the desired result. Therein lies the weakness of this approach. Specifically, as exposed by the survey of air pressure maintenance conducted by NHTSA in 2001, the public does not pay much attention to maintenance despite educational efforts and the high media exposure that this issue received in the aftermath of the Firestone recall of 14.4 million tires on August 9, 2000 (see Section 3.2.1.1 and footnote 19).

Despite its drawbacks this strategy offers a number of important advantages. First, it is applicable to the current fleet and therefore, benefits could be immediate. Second, education can cover also vehicle alignment and tire rotation, issues that are left uncovered by adopting auto-inflate systems. Third, it requires a relatively modest investment when compared to the technology option. Therefore, this strategy should not be viewed as competing with the first strategy but rather as complementing it.

Currently, a number of organization are actively engaged in educating the public to better maintain their tires including the NHTSA, the RMA, individual tire companies, and automakers (some quotes from various sources are provided in Section 3). Unfortunately, there is very little if any empirical evidence one way or another as to how effective recent education programs are with respect to tire care or tire recycling. A method of assessing this strategy is to make some assumptions regarding the response rate to education programs, and the influence on increased tire life mileage, based on indirect evidence from other education programs. One can then make

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<sup>71</sup> The estimated cost of direct and indirect TPMSs is taken from the NHTSA final economic analysis for the TPMSs. The \$175 figure for the auto-inflate was estimated as OE cost by Cycloid, which is the only current manufacturer of such systems.

<sup>72</sup> The \$100 estimated was provided by Cycloid, and is significantly higher than the NHTSA estimate, which is about \$40.

some comparisons with the efficacy of education programs and costs relative to the one strategy, the auto-inflate systems, that has hard numbers and levels of outcome as per increased tire mileage.

Education programs have been used in other circumstances to affect consumer behavior. Programs such as anti-drunk driving, seat belt use, and driving habits on slippery roads are a few that come to mind. In addition, antismoking education programs have been evaluated extensively. A survey of education campaigns is offered in Appendix C. The analysis of the present strategy can therefore benefit from the evaluation techniques employed in these other fields including the calculations of the costs of developing and implementing the education program.

### **14.3 Strategy 3: Adopting a Corporate Average Tire Life Standard**

The first two strategies discussed above focused on maximizing the lifespan of tires through improved *maintenance*. The third strategy shifts to mandating that tires be *designed* for longer average lifespan. Thus, the emphasis moves from what happens during the service life of tires (first two approaches) to what could be done at the introduction of the tire into service (third strategy).

At present, thousands of different light-duty tire models are available nationwide (see *e.g.*, <http://www.nhtsa.dot.gov/cars/testing/utqg/index.htm>), composed of many subcategories (*i.e.*, different sizes, and designs depending on whether they are intended as OE or aftermarket tires). Therefore it is impractical to address each and every tire model. Rather, the third strategy requires that tire producers meet a prescribed average tire life mileage across *all* light-duty tires sold in California.

This strategy would mimic the federal Corporate Average Fuel Economy (CAFE) standard, which led automakers to improve the fuel efficiency of new vehicles (see footnote 20). The introduction of the CAFE standard was effective in improving fuel economy for new vehicles. In fact despite warning from automakers at the time when the CAFE standard was introduced, new vehicles are safer, deliver more horsepower and torque than their pre CAFE counterparts, and even exceed the demands of the standard.

By law it is required that all light-duty tires have embossed on them the UTQG ratings, which includes a tread wear rating (see Section 3.1). Because of its universality, the tread wear rating component of the UTQG can provide the measure for prescribing the desired life. For example, it could be set to 550 (*i.e.*, it would be possible to set a specific level just like the CAFE standard sets a specific level – see footnote 20).

This CAFE-like strategy would allow tire makers the freedom of continuing sales of high-performance tires, where they get their highest profit margins, while improving the overall average tire life mileage for the entire tire population. Moreover, how the life is extended is left open. For example, it could be achieved by increasing the percentage of long life tires (*e.g.*, those tires that come with a UTQG tread wear rating of 600 or more). An alternative would be to give credits for tires mounted on vehicles equipped with auto-inflate systems, which would effectively extend the average life mileage of tires. For example, a tire with a UTQG tread wear

rating of 500 mounted on a vehicle equipped with an auto-inflate system might be considered equivalent to a tire with a 600 tread wear rating mounted on a car without an auto-inflate system.

This strategy presents a much more difficult circumstance in which to measure cost data. The costs include both legislative and enforcement components. Computing the cost of enforcement may be the easier of the two because it would be based on an estimate of how many added resources would be need to undertake some specified enforcement level, over what time and what geographic space, and of course by whom. Measuring legislative costs is more difficult as developing the ‘Bill’ that is passed can be likened to research and development expenses. Additionally, the costs of lost consumer surplus must also be counted in any detailed economic evaluation of introducing CAFE like requirements for tire mix. Consequently, the legislative strategy is treated as a state variable in much the same way as the minimum current TPMS requirement is taken as a benchmark, and no attempt is made to quantify the costs or benefits associated with this strategy.

#### **14.4 Strategy 4: Ad-Valorem Tire Disposal Tax/Rebate**

The fourth strategy considered is to employ a combination of taxes and rebates to replace the uniform \$1 tire disposal tax with an *ad-valorem* tax/rebate.<sup>73</sup> This strategy is patterned after the rebate program for energy efficient appliances. The approach proposed here is to use the ratio of the weight of the tire to its UTQG tread wear rating to determine the *ad-valorem* tax, so that pounds per mile would be the actual measure on which the *ad-valorem* tax is based.

Taxes, rebates and subsidies are all designed to affect consumer behavior. Placing a tax on low mileage tires would lead some consumers to shift to longer life mileage tires. Similarly, providing a rebate on longer life mileage tires would induce people to switch from low to high life mileage tires since the ‘effective’ price has been reduced. This does not necessarily imply that they would monitor their tire inflation any more or better than they would with low life mileage tires.<sup>74</sup> Nonetheless, when the average tire life mileage increases, the discard rate is reduced. The method of introducing the change is to use the current proportion of actual tire life (assuming a given or current attention to proper inflation) to warranted tire life for shifts from low quality to average or high quality tires.

When introducing either an incentive program such as a tire rebate or subsidy it is necessary to calculate the opportunity cost of the funds used for the rebate or subsidy based on where they come from. If they are funded by taxes, they are measured as opportunity cost of public funds. There may also have to be some added costs for administration of the program. It will be necessary to explore what costs have been used in the past with similar types of programs.

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<sup>73</sup> Throughout the discussion the tax and rebates portion of the strategy are treated in a symmetric way and, therefore, the tax/rebate is abbreviated to tax.

<sup>74</sup> One could make some assumptions in this area but there is no factual basis for choosing one direction over another.

## 15. Calculations

Measuring benefits and costs requires that the number of vehicles and hence tires affected are quantified. This information is available through the NHTSA [2002a] report.

### 15.1 Vehicles and Tires Affected

The NHTSA [2002a] report examines 4 alternatives in assessing TPMSs. The alternative, which is most reasonable as a basis for assessing the hardware strategy is the direct measurement system, as, discussed above. The study provides information that forms the basis for quantifying benefits.

Table 15.1: Distribution of the Number of Tires on Vehicles that have One or More Tires 20% < Placard (Source: NHTSA [2002a] study Table III-2 (Page III-7))

No. of Tires 20% or more < Placard	Passenger Cars (percent)	Light Trucks (percent)
1	46.5	36.7
2	25.7	28.1
3	12.9	14.3
4	14.9	20.9
Total	100.0	100.0

The values contained in Table 15.1 are based on a nationwide survey conducted by NHTSA (see Section 3.2 for further discussion of this survey including a different representation shown in Table 3.2). For the purposes of the current study, these results are accepted as representative of California. Averaging over all vehicles, 27 percent of passenger cars and 21 percent of light trucks would receive a warning from the TPMS (NHTSA [2002a], Table III-4). They provide the basis for the number of tires affected with the new technologies.

### 15.2 Tread Wear

The NHTSA [2002a] study, citing Goodyear, took the average life of tires as 45,000 miles.<sup>75</sup> The report, also citing Goodyear, states that for every psi decrease tread wear life is reduced by 1.78 percent. A tire, which remained under-inflated over its lifetime by one psi, would have about 800 miles less wear (1.78 % of 45,000). Surveys undertaken by the NHTSA indicate on average each of a vehicle's tires is under-inflated by 6.1 psi.<sup>76</sup> Thus, the increase in tire life would be measured as the improvement in psi times 800 times the proportion of people who respond to the information or the incentive offered by a strategy.

<sup>75</sup> Note that this value is different from the 41,000 miles average that is used in this review, which is taken from a Michelin study. Also, note that the 45,000 (41,000) are the actual average tire life mileage, to be distinguished from the limited warranty provided with many tires, which may be as high as 100,000 miles.

<sup>76</sup> Note that this is based on a study that compared "hot" pressure with placard pressure.

### 15.3 Safety benefits

Under-inflation affects skidding and control when braking or maneuvering, hydroplaning, increased stopping distance, and tire blowouts and flat tires, which results in more accidents and fatalities. The NHTSA [2002a] report provides information on each of these influences and translates them into the change in the number of accidents. To make these calculations there must be a benchmark or steady-state tire pressure from which impacts are measured and there must be some assumptions made regarding driver response to tire pressure warning information. First, based on Bureau of Transportation surveys as well as NHTSA agency information, the NHTSA [2002a] study assumes 33 percent of drivers would inflate their tires to placard values when they are 10 percent below recommended and 66% would do so when tire pressure fell below 20 percent of placarded value.<sup>77</sup> For example, if the placarded value were 30 psi, 33% of drivers would refill when pressure fell below 27 psi and 66% would fill when pressure fell below 24 psi.

*A key question is how many VMT would be driven on the under-inflated tires.* Tires lose air at an average of 1 psi per month. If we assume people drive **X** miles per year, we can assume on average they drive **X/12** miles per month. We need to combine the information on miles driven and the amount of under-inflation of the tires. If the average placard value were 30 psi, a loss of 1 psi per month would mean for drivers who check their tires regularly (33%), at 27 psi they would fill up. They would therefore have an average (or steady-state) tire pressure of 28.5 psi. The remaining 66% would have to fill up their tires at a level of 24 psi. Their average steady-state would be 27 psi and the under-inflation would follow the values indicated in Table 15.2.

Table 15.2: Basis for Calculating Miles on Under-Inflated Tires (direct TPMS)

Month	PSI
1	30
2	29
3	28
4	27
5	26
6	25
7	24
8	23
Warning	
9	30

Additional potential benefits come from reducing accidents, injuries and fatalities. There are a number of causes detailed in the NHTSA study and these form the basis of the benchmark measures used herein (see NHTSA [2002a], Chapter V). First, for instances of skidding and loss of control crashes the benchmark numbers are 247 fatalities, 23,100 injuries and 53,130 property-damage only accidents. The NHTSA [2002a] study assumed a [conservative] 20

<sup>77</sup> The NHTSA [2002a] report was based on the premise that direct TPMSs would be required to issue a warning when the air pressure in any tire dropped 20% below placard level. However, the final ruling requires that this warning be issued at 25% below placard level.

percent effectiveness to go with the steady-state condition. Values reported in Table 15.3 are used as the basis of subsequent calculations.

Table 15.3: Change in Accidents due to Skidding & Control Problems.

	Property Damage	Non-Fatal Injuries	Fatalities
Base	53130	23100	247
Change due to TPMS	10,095	4,389	47

A second key benefit will arise from reduced stopping distance due to properly inflated tires. The gains depend on a number of factors including: the change in the probability of a less severe (or no) accident; the distribution of accidents occurring over different speed ranges (distinguished by wet and dry conditions, the number of vehicle occupants, and type of vehicle). In addition the benefits will depend upon how low the tire pressure is, whether the TPMS system would provide a warning and, whether the driver would respond to the warning. The difficulty as NHTSA points out is they do not have data on stopping distances in crashes. It therefore assumes crashes are equally spread over the range of stopping distances. The average stopping distance for passenger cars with correctly inflated tires is 85.2 feet and for light trucks is 90.7 feet (NHTSA [2002a], Chapter V (page 23-24)). Thus, the change in the stopping distance between properly inflated and improperly inflated tires provides an estimate of the number of preventable accidents, fatalities and property damage accidents. NHTSA estimates these proportions as 1.38 percent for all crashes for passenger cars and 1.36 percent for light trucks; that is, these proportions of accidents for the respective vehicle classes could have been prevented. Benefits are then measured as:

$$B_j = \sum_i [\rho \cdot A_i \cdot \alpha_i \cdot \beta_i]$$

where  $\rho$  = proportion of preventable crashes

$A_i$  is the accidents of type  $i$

$\alpha$  is the proportion of vehicles with under-inflated tires and,

$\beta$  is the proportion of drivers responding to the TPMS warning

where  $i$  goes from property damage, to injury accident to fatal accident.

The information contained in the NHTSA report provided a basis of measuring benefits from reduced accidents due to proper tire inflation. NHTSA's calculations were based on nationwide data. The estimates used herein for California are obtained by simply taking, for the reduction in each type of accident, the proportion of the California population out of the total US population.

As an example, with TPMS there would be 2,101 fewer Property damage accidents, 2,569 fewer injury accidents and 22 fewer fatalities.<sup>78</sup>

While 1.38 and 1.36 percent of passenger and light truck accidents (respectively) could be prevented with proper tire inflation, the remaining accidents could not be prevented but would take place at a lower speed due to better braking. The NHTSA [2002a] report estimates changes in stopping distance and uses these to recalculate impact speeds and the injury profile for the crash population. Safety benefits are calculated as the difference between current and adjusted injury profiles.

The key measurement is the difference in stopping distances when the tires are properly inflated relative to when they are under-inflated; inflation affects the tire friction coefficient (see NHTSA [2002a], Chapter V). Issues to consider are the base case of vehicles with under-inflated tires, 75%, and the fact that some strategies would not affect this value until a certain low pressure was established; with direct TPMS this would occur at 25% lower than placarded value. Additional issues include the distribution of vehicles with and without anti-lock brakes, the distribution between passenger cars and light trucks and the distribution of driving between wet and dry pavements as well as speed categories (see *e.g.*, NHTSA [2002a], Tables V-14 and V-15). Once these factors are incorporated and adjustments are made for response rate, current compliance and changes in braking speed, Table 15.4 lists the benefits in terms of the reduction in the number of property, injury and fatal accidents that would occur with better tire inflation achieved by TPMS with pressure display on the dashboard.

Table 15.4: Reduction in Property Damage, Injury Accidents and Fatalities due to Improved Braking, All Passenger Vehicles Assuming a 95% response rate under direct TPMS with Dashboard Tire Pressure Readout.

	Property Damage	Injury Accident	Fatality
Skidding	9994	4345	46
Braking	0	5299	60
Blowout/Flats	0	967	39
<b>Total</b>	<b>9994</b>	<b>10611</b>	<b>145</b>

Source: NHTSA [2002a] Table V-28

Total quantifiable benefits would be the sum of those from reductions in property damage accidents, injuries and fatalities resulting from skidding/loss of control, flat tires, blowouts and less efficient braking (see Table 15.5). These values are quantities that have not yet been monetized.

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<sup>78</sup> This analysis is based on a warning at 20% below placard, which was the original NHTSA proposal. However, the final rule calls for a warning at 25% below pressure and the number of preventable collisions is lower.

Table 15.5: Quantifiable Safety Benefits Impacts (Source: NHTSA [2002a], Table V-29).

	Property Damage	Injury Accident	Fatality
Wet			
0-35 mph	841	868	6
35-50 mph	891	1024	8
51+ mph	335	364	4
Dry			
0-35 mph	1129	1177	12
35-50 mph	1239	1346	16
51+ mph	430	529	13
Total	4865	5308	59

### 15.4 Fuel Economy Benefits

Vehicle fuel economy improves with correct tire pressure. The improvement in fuel economy has both private and social benefits. Privately it reduces the expenditure on fuel for a given driving distance. Socially it reduces the amount of pollutants emitted since less fuel is burned. A 1978 report claimed fuel efficiency was reduced by 1% for each 3.3 psi tires were under-inflated. This however was using older vehicle technology and bias ply tires. More recent information based on newer vehicle technology and predominately radial tires indicates fuel efficiency is reduced by 1% for each 2.96 psi below placard.

In order to measure the fuel and emission reduction benefits of using less fuel a number of measures are needed. These include: the proportion of vehicles with under-inflation; the proportion of vehicles that receive a warning (< 25% below placard); the real resource cost of gasoline; the discount rate for drivers; and the [average] distance driven by vehicles of different ages (and hence different levels of fuel economy).

Table 15.6: VMT for Cars and Light Trucks by Age of Vehicle

Cars		Light Trucks	
Vehicle Age	VMT	Vehicle Age	VMT
1	13,533	1	12,885
2	12,989	2	12,469
3	12,466	3	12,067
4	11,964	4	11,678
5	11,482	5	11,302
6	11,020	6	10,938
7	10,577	7	10,585
8	10,151	8	10,244
9	9,742	9	9,914
10	9,350	10	9,594
11	8,974	11	9,285
12	8,613	12	8,985

Source: NHTSA [2002a] Tables V-30 and V-31

The assumption is that 36% of passenger cars are an average of 6.1 psi below placard values and 40 % of light trucks are 7.7 psi below. Table 15.6 provides the mileage information by vehicle

type. One can assume a baseline mpg fuel economy for each vehicle type; following NHTSA [2002a], the following values are used: 28.5 mpg for passenger cars and 20.7 mpg for light trucks. In order to measure the fuel economy benefits, the following steps are needed:

1. 1% fuel efficiency = 2.96 psi lower
2. Change in air pressure = steady-state pressure – placard pressure
3. Change in fuel economy = change in air pressure / 2.96
4. New MPG = optimal MPG (*i.e.*, at placard pressure) \* (1 - change in fuel economy/100)<sup>79</sup>
5. Fuel expenditure = (VMT/MPG)\*price fuel\*average vehicle age\*discount rate
6. difference = fuel expenditure (new MPG) – fuel expenditure (MPG @ placard)
7. average benefit = difference\*% of fleet warned \* driver response to strategy
8. total benefit = average benefit \* fleet size

### 15.5 Emissions Benefits

Lowering fuel consumption leads to reduced amounts of CO<sub>2</sub>, particulate matter and other emissions. These would include carbon monoxide (CO), chlorofluorocarbons (CFCs), Methane (CH<sub>4</sub>), Nitrogen Oxide (NO<sub>x</sub>), Nitrous Oxide (N<sub>2</sub>O), Ozone (O<sub>3</sub>), Sulfur Oxides (SO<sub>x</sub>) and Volatile Organic Compounds (VOX). The reduction will be equivalent to the reduction in fuel use times the amount of emissions per unit of fuel. Multiplying this by the fleet size would quantify the total emission reduction. One rule of thumb is that each reduction of 1 billion gallons of fuel reduces emissions by 2.4 million metric tons of carbon equivalent. The other alternative is to take the reduction in fuel use times the amount of emission of each type per gallon times the social cost of each emission type. Multiplying this by the fleet size would provide a measure of the reduction in social costs due to improved fuel efficiency.

In a study on the full social costs of auto, air and rail, Gillen *et al.* [1996] found the emissions and costs associated with fuel consumption detailed in Table 15.7. The cost included health care, loss of productivity, damage to crops and agriculture, damage to buildings and environmental degradation.<sup>80</sup> The values contained in Table 15.7 provide a measure of the cost per gallon of fuel used for cars and light trucks. The reduction in fuel use with proper inflation times the fleet size times the values in Table 15.7 provide the social benefits from the strategy.

Table 15.7: Cost per Gallon expressed in 2002 \$ (Source: Gillen *et al.*, [1996]).

Pollutant	Passenger Car	light Truck
CO	0.0127	0.0012
VOC	0.0367	0.0027
Nox	0.0287	0.0256
Sox	0.0007	0.0018
PM10	0.0003	0.0085

<sup>79</sup> The average MPG @ placard for the entire 2002 model passenger vehicle fleet is 28.5 psi (Source: NHTSA).

<sup>80</sup> See Gillen *et al.* [1996] Chapter 3.

## **15.6 Other Private Benefits**

Is reduced tread wear and longer tire life considered a benefit? Not entirely, while it may be considered a private benefit to consumers it is a private loss to the tire industry. Chapter V in NHTSA [2002a] provides measures of the savings to drivers of properly inflated tires. For example, they note the average passenger car travels 126,678 miles on average over its life. There is also some evidence that for every psi drop in inflation pressure, tread wear increases by 1.78 percent; this would mean about 800 fewer miles for each tire over the lifetime of the car. Data collected by NHTSA found 36 percent of cars had at least one tire under-inflation by 20 percent; the average under-inflation of the 4 tires for these vehicles was 6.1 psi. With a TPMS with pressure indicated on the instrument panel, the average psi improves by 3.6 psi (NHTSA [2002a] Chapter V, page 69). Thus average passenger cars lose about 2,880 miles of tread life for each tire due to under-inflation. With direct TPMS warning of under-inflation and assuming 95 percent of drivers act on the information, an average of 2,736 miles of tread life could be saved per tire. The study goes on to note that if the average passenger car travels 126,678 miles over its lifetime, it would use 3 sets of tires but if average tire wear increased, it could purchase the 2<sup>nd</sup> and 3<sup>rd</sup> sets later than otherwise. This, it is claimed is a benefit to consumers. However, there is an offsetting benefit to producers who now do not have the resources (money) they would have otherwise. The differences are not necessarily offsetting since there is some consumer surplus available to consumers. The more inelastic (elastic) is the demand for tires the lower (higher) is the value of the consumer surplus. We are not able to find any studies reporting a value of such an elasticity but expect it would be relatively low for tires but high for substitution among types of tires.<sup>81</sup> Therefore, it might be argued that any benefits to consumers are offset by losses to producers.

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<sup>81</sup> For example, the retreaded tire business was severely hurt financially by the import of low price tires.

## 16. Measuring the Environmental Gains from Reduced Tire Disposal

The Environmental Protection Agency (EPA) estimates that in 1996, 266 million tires were scrapped of which 76% were recovered (202 million) with removal of tires from the municipal waste stream through recycling, use as fuel, and net exports (EPA [1999]). About 75.5% of those recovered were burned as tire-derived fuel. This has resulted in a stockpile of approximately 800 million used tires in the U.S.

There is a received opinion that disposal of used tires can pollute sewers, wastewater treatment plants, and ground water supplies, as well as takes up landfill capacity. Unfortunately, statistics are not available on the amount of ground water contamination, air pollution, or other environmental outcomes that are specifically attributable to disposal of tires from motor vehicles (EPA [1999]). Many landfills do not allow tire disposal because tires decompose extremely slowly; they collect gases released by decomposing garbage, and then gradually float up to the surface of the landfill (EPA [1999]). Unfortunately there is no quantification of what this means in terms of economic costs, it is simply assumed to be bad.

The Scrap Tire Management Council (STMC) reports that “since 1996, the use of scrap tires monofills (a landfill, or portion thereof, that is dedicated to one type of material) has become more prominent in some locations as a means to manage scrap tires... Monofills are portrayed as a management system that allows long-term storage of scrap tires without the problems associated with the above ground storage. In theory monofilled processed scrap tires can be harvested when markets for scrap tire material improve. Using monofills for scrap tires is preferable to above ground storage in piles, especially if a pile is not well managed. Available data indicates that there are no negative environmental impacts from monofilling tires.”

Surface scrap tire stockpiles represent both an esthetic and two potentially serious environmental problems: mosquitoes and fires. Because they absorb heat and trap rainwater, leaf litter, and microorganisms, scrap tire piles become an optimal breeding habitat for four of the most important disease-carrying mosquitoes in the United States. Epidemiological studies have concluded that epidemics in certain localities were the result of artificially enlarged populations of these disease-carrying mosquitoes facilitated by the optimum environment created by tire stockpiles (Eldin and Piekarski [1993]).

Thus scrap tire piles are often high-priority targets of efforts to prevent or slow outbreaks of mosquito-borne diseases. “Unfortunately, treating them with insecticides is problematic since it is difficult to penetrate tire piles to the depths where mosquitoes breed. Also, mosquitoes are developing resistance to many widely used insecticides. Finally, insecticides used to suppress adult mosquitoes are environmentally hazardous, and those used to suppress larvae are costly” (Blackman and Palma [2002]).

The most serious environmental problem is fire. At least partly because of their high energy content— 14,000 to 15,000 BTUs per pound versus 8,000 to 12,000 BTUs per pound for coal— tire piles burn intensely and are extremely difficult to extinguish. Additionally, applying water is

often a problem because of the attendant water pollution, and the recommended course of action is sometimes to simply let the pile burn itself out (U.S. Fire Administration [1998]).

In their report on the scrap tire problem in Ciudad Juarez and El Paso, Blackman and Palma [2002] note that:

Tire piles can burn for months. For example, a fire in Tracy, California involving some 7 million tires burned for more than two years between 1998 and 2000 before finally being extinguished (Carlson 2000). Tire fires generally have severe impacts on the air, water, and soil. When burned in the open, tires combust incompletely and emit both conventional air pollutants (including particulates, carbon monoxide, sulfur oxides, nitrogen oxides, and volatile organic compounds) and so-called hazardous air pollutants (including polynuclear aromatic hydrocarbons (PAHs), dioxins, furans, hydrogen chloride, benzene, polychlorinated biphenyles (PCBs) and heavy metals such as lead and arsenic).

Tire fire air pollutants can cause short-term and long-term human health problems, including irritation of the skin, eyes, and mucous membranes; respiratory effects; depression of the central nervous system; and cancer. Tire fire emissions are estimated to be 16 times more mutagenic (toxic) than emissions from residential wood-burning fireplaces, and 13,000 times more mutagenic than emissions from coal-fired utilities with good efficiencies and add-on pollution controls (U.S. EPA 1997).

Tire fires also generate water pollution. The tires melt into tarry oil that can seep into groundwater and run into surface water, especially if water is used to try to extinguish the fire.<sup>82</sup> Finally, oil, ash, and residue from tire pile fires contaminate soils with heavy metals and other toxic substances. Remediation is generally difficult, and the sites of many tire fires have been designated as hazardous waste cleanup sites. The costs of extinguishing tire fires and remediating the sites can be enormous.

There is some data on the costs of the Environmental Protection Agency's response for large scrap tire fires in EPA Region 6 (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas) in the second half of the 1990s (see Table 16.1). Note that these figures omit costs to the private sector and to municipal and state institutions. They also do not reflect the social cost in terms of environmental degradation. The figures are government expenditures or transfers from taxpayers to government. They are not true social costs.

In the United States, large tire pile fires are not uncommon. Although some are started by natural events (primarily lightning), most result from arson. Unfortunately, systematic national data on the frequency and magnitude of such fires are lacking (Zalosh 2001). However, EPA estimated that there were at least 176 large tire fires in the United States between 1971 and 1996 (Banipal and Mullins 2001).

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<sup>82</sup> A standard automobile tire generates about 2 gallons of oil (STMC 2000).

Table 16.1: Expenditures of Tire Fires in Different Locations (Source: EPA, Region 6).

Facility	Location	Cost of EPA Response	
SPE Tire Disposal	Midolithian, TX	\$	1,800,000
ERI	Stamford, TX	\$	380,000
Mid-South	El Dorado, AZ	\$	260,000
Gibson Recycling I	Atlanta, TX	\$	123,000
J.C. Elliott Landfill	Corpus Christi, TX	\$	554,000
Madisonville Drum	Madisonville, TX	\$	193,000
Los Ebanos	McAllen, TX	\$	16,000
S.W. Processor	Socorro, NM	\$	178,000
Gibson Recycling II	Atlanta, TX	\$	60,000
	Total	\$	3,564,000

While the types of hazards presented by waste tire disposal are clear, the final social and environmental costs are not. The price to fight fires, for example, represent only a fraction of the potential long-term environmental remediation costs. The Office of the Fire Marshal of Ontario Canada lists the following potential costs of any major environmental incident:<sup>83</sup>

- evacuation,
- community and business interruption,
- primary medical costs for the public and emergency response personnel,
- medium and long-term medical costs,
- cleanup and monitoring,
- any long term environmental disruption,
- any litigation, and
- social costs, such as unemployment, loss of tax base and reduced earnings.

These would not all align with costs seen by economists as true externalities. Litigation, for example, is a transfer as are many of the social costs included such as unemployment. This is not to argue that reducing resource use below equilibrium is not costly, just that one must distinguish between true economic losses and transfers.

A recent article in the *Modesto Bee* describes the costs associated with the tire fire in Tracey, CA. The fire started on August 1998 and burned until December 2000. According to reports, the ravine, which contained the 7 million tires, contains approximately 60,000 cubic yards of ash, steel radials, liquefied rubber and other debris. The most important comment however, was

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<sup>83</sup> The tire fire in Hagersville, Ontario, for example, which took 200 firefighters 17 days to extinguish, cost approximately \$1,000,000 (U.S.) for only essential site cleanup and limited environmental testing (Eldin & Piekarski, [1993]). The cost to date, however, has climbed to \$12,200,000 (Canadian). See [www.gov.on.ca/OFM/recycle5.htm](http://www.gov.on.ca/OFM/recycle5.htm)

“environmental analysis will learn if the waste endangers the soil and water.”<sup>84</sup> In other words, there does not appear to be any firm numbers that provide some guidance as to what the value of the environmental degradation is for tire dumps or discarded tires. The CIWMB estimates that the cleanup of the Tracey fire will cost \$9 million (CIWMB [2003a]). Additionally, one of the largest tire fires occurred in Westley California in 1999. The cleanup took three years, and cost in excess of \$17 million (CIWMB [2003a]).

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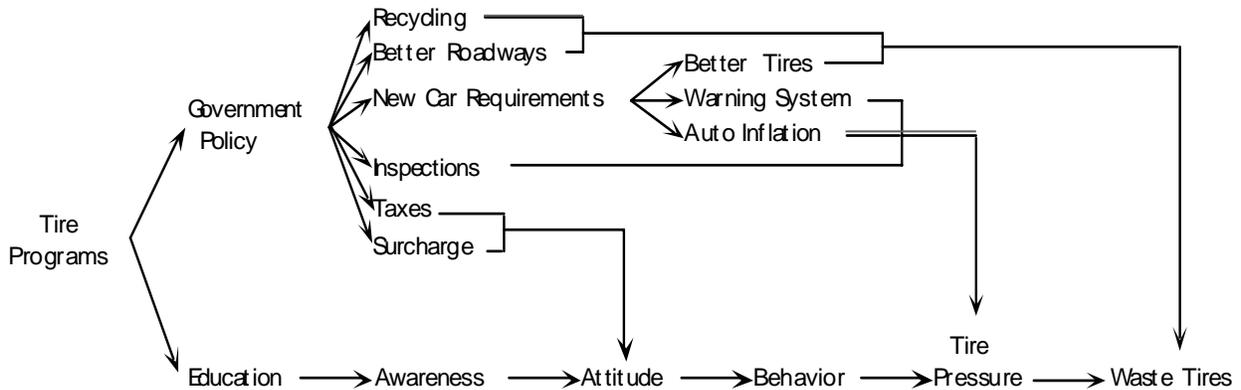
<sup>84</sup> Modesto Bee, January 4, 2003. The same article stated the waste management board had approved \$20 million for clean up of the Tracey and other sites.

## 17. Strategies: Levers, Benefits and Costs

Before undertaking the calculations for the benefits and costs of each strategy, it is useful to identify what key factor or factors a strategy focuses on. In other words what are the things that a manager of a strategic policy would consider in order to implement a strategy. Furthermore, what are the outcomes of such tactics; what benefits do they provide and what costs are incurred when choosing one strategy over another? Answering these questions provides not just an understanding of how each strategy is implemented and how it works but also what data are required to undertake the benefit/cost analysis.

Table 17.1 displays the alternative strategies and how they are implemented. Each strategy will have costs associated with it. For the technology strategy these costs consists of initial investment plus maintenance costs.<sup>85</sup> Figure 17.1 also helps to explain how the different strategies considered influence tire pressure.

Figure 17.1: The roll different strategies play in affecting tire pressure.



<sup>85</sup> The initial cost is the incremental cost from an indirect TPMS, which is assumed as the base case.

Table 17.1: Tire Strategies: Levers, Benefits (Private and Social) & Costs.

<b>Tire Technology</b>			
<u>Passive</u>	<ol style="list-style-type: none"> <li>1. Increase tire life with proper inflation but through operator maintenance</li> <li>2. Pressure less than optimal lower proportion of time</li> <li>3. Less than 100 percent response rate</li> </ol>	<ol style="list-style-type: none"> <li>1. Increased Safety</li> <li>2. Reduced Fuel use</li> <li>3. Lower Emission</li> <li>4. Longer tread Life-More VMT/tire unit</li> <li>5. Reduction in number of disposed tires</li> </ol>	<ol style="list-style-type: none"> <li>1. Hardware Costs</li> <li>2. Maintenance Costs</li> </ol>
<u>Auto-inflate</u>	<ol style="list-style-type: none"> <li>1. Increase tire life with proper inflation</li> <li>2. Pressure less than optimal lower proportion of time</li> </ol>	<ol style="list-style-type: none"> <li>1. Increased Safety</li> <li>2. Reduced Fuel use</li> <li>3. Lower Emission</li> <li>4. Longer tread Life-More VMT/tire unit</li> <li>5. Reduction in number of disposed tires</li> </ol>	<ol style="list-style-type: none"> <li>1. Hardware Costs</li> <li>2. Maintenance Costs</li> </ol>
<b>Taxes/Subsidies</b>			
Rebate on High Quality Tire	<ol style="list-style-type: none"> <li>1. Cross Elasticity of demand for quality tires</li> <li>2. More VMT per set of tires-fewer disposals</li> </ol>	<ol style="list-style-type: none"> <li>1. Longer tread life and more VMT per unit</li> </ol>	<ol style="list-style-type: none"> <li>1. Cost of subsidy with public funds</li> </ol>
Tax on Low Quality Tire	<ol style="list-style-type: none"> <li>1. Cross Elasticity of demand for quality tires</li> <li>2. More VMT per set of tires-fewer disposals</li> </ol>	<ol style="list-style-type: none"> <li>1. Longer tread life and more VMT per unit</li> </ol>	<ol style="list-style-type: none"> <li>1. Loss of consumer surplus with tax.</li> </ol>
<b>Education Programs</b>			
Tire Pressure Maintenance	<ol style="list-style-type: none"> <li>1. Changing proportion of operators maintaining tire pressure.</li> <li>2. Changing proportion of operators choosing new tire pressure information/inflation technologies</li> </ol>	<ol style="list-style-type: none"> <li>1. Increased Safety</li> <li>2. Reduced Fuel use</li> <li>3. Lower Emission</li> <li>4. Longer tread Life-More VMT/tire unit</li> <li>5. Reduction in number of disposed tires</li> </ol>	<ol style="list-style-type: none"> <li>Cost of education programs</li> </ol>

### **17.1 Strategy 1: Technology Based**

These strategies will include a direct TPMS and auto-inflate systems. For the former the key factors affecting the reduction in tire disposal are the degree to which operators respond to information that one or more of their tires is under-inflated and how long they will drive on the under-inflated tire. In the case of auto-inflate systems, the tire will automatically re-inflate once it reaches a particular level of under-inflation. Note two key differences between the TPMS and auto-inflate system; first, the auto-inflate system will always respond to lower tire pressure and second, the length of time (or VMT) on under-inflated tires will be minimized for the auto-inflate system.

For indirect TPMSs the costs will depend on whether there are ABS brakes installed, if so, the incremental cost of a TPMS is \$13.29. In year 2000 about 76 percent of the stock of passenger cars and trucks had ABS brake systems. With some differences in whether the ABS system is 3 or 4 channels and the incremental cost of moving from the former to the latter, NHTSA estimates the average capital cost for an indirect TPMS to be \$21.13, in 2000 dollars (NHTSA [2002a], Chapter VI). A direct TPMS ranges from \$69-\$106. Given that some cost economies and increasing competition in the parts supply sector are expected, using \$69 is a reasonable approach.

A direct measurement system with display for pressure per tire would be \$70.35 per vehicle (NHTSA [2002a], Chapter VI, page 6). If this system were improved to an auto-inflate system where a pump would inflate the tires when they dropped below a certain threshold, the incremental cost would be \$104.65, for a total of \$175. Maintenance costs are estimated to be \$40.91 over the life of the vehicle. Expenses occur in year ten when batteries must be replaced.

An auto-inflate system cost is approximately \$350 per unit, although this would be lower with original equipment and through scale economies. Following the logic and proportion of the cost for the TPMS, we would expect the cost to fall by about 50 percent to \$175. Maintenance costs would be similar to the passive system with batteries being changed after the second set of tires.

Past research and development expenses can be considered sunk and would not be included in any cost calculation.

### **17.2 Strategy 2: Education**

Education programs are designed to affect behavior. In the present context, education programs aim to affect two types of decisions. First, motivate consumers to better maintain their tires. Second, convey to consumers the value of monitoring and auto-inflate systems. A comprehensive search of literature on the impact and costs of education programs across a number of different issues is presented in Appendix C. A reading of this survey illustrates the problems of trying to measure effectiveness and to attach dollars to achieving a particular outcome. This means that given a particular dollar amount, it is difficult to measure what level of effect this budget would have. Similarly, looking at a particular outcome, it is difficult to measure the dollars that were used to achieve this outcome. Therefore, it is difficult to establish a measure of costs as well as have some credible measure of the proportion of people who might

change their tire pressure maintenance behavior. One could make some assumptions but these would not have any sound scientific basis.

One way of exploring this strategy is to ask the question, “what proportion of people would have to change their behavior in order to achieve the same reduction in tire disposal as that realized with another strategy such as auto-inflate systems where we do have good data?”

Note that both private as well as social benefits are realized under the education program like the more technology-based strategies and unlike the tax/subsidy strategy. This is because improved tire life due to better tire pressure maintenance has the same outcomes as having auto-inflate systems. It would therefore seem reasonable that education programs might be benchmarked against strategy 1.

The other perspective is that this strategy is unlikely to be a stand-alone strategy. Rather it would be used in conjunction with other strategies and provide positive reinforcement. However, as we said earlier, it may be hard to measure the incremental impact of such a combination. More research is needed.

### **17.3 Strategy 4: Taxes and Subsidies**

Other strategies sometime used in addressing public policy issues are to either tax a product which has negative consequences or subsidize a product that has positive consequences; for example, cigarettes are taxed whereas, fuel efficient appliances receive a rebate in some jurisdictions. This framework can be applied to tires as well. The attractiveness of this approach is that direct costs are relatively small, certainly to consumers. However, other costs are hidden. In the case of a rebate on high mileage tires, the money used to provide the rebate must come from public sources. These dollars have an opportunity cost both in terms of alternative public spending that would yield public returns to California but also in terms of money that has been gathered from taxpayers.<sup>86</sup> *Of course one could argue that disposal fees could be used to finance such a program but this would require more investigation.*

A tax on the other hand has no direct costs except perhaps some administrative expenses. There are economic costs in that economic welfare, defined as the sum of producers and consumers surplus, is reduced since consumers face higher real prices and there is a loss in consumer surplus. The amount of loss will depend on the magnitude of the elasticity of demand for low quality tires - relatively high, one would expect.

It should also be made clear that a rebate is different than a tax, although on the face of it they might appear to have the same effect. A rebate on a high price good is not [necessarily] equivalent to a tax on a low quality (hence low price) good. A rebate effectively shifts the demand curve whereas a tax shifts the supply or cost curve.

This strategy however is not particularly effective in reducing the level of tire disposal since it simply has the effect to move a proportion of people to higher quality tires which would have

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<sup>86</sup> The most recent work has shown that each \$1 of tax money cost \$1.43 in terms of the real resource costs.

lower wear for a given VMT. Therefore, the set of tires would not be changed as often over the life of the car. To measure the effect of this particular strategy requires some knowledge of the own-price elasticity of demand for tires and the cross-price elasticity between low and high quality tires. A search of the literature showed that this information is not available. We do however have information on the elasticity of demand for driving with respect to auto running costs. We also have information on the per mile cost of tires in operating costs. These are listed in Table 17.2.

Table 17.2: Vehicle operating and ownership costs by category (Source: Gillen *et al.*, 1996)

Operating Costs	cents per mile	Percent of Total		
		10,000 Miles	15,000 Miles	20,000 Miles
gas and oil	5.9	0.09	0.12	0.13
maintenance	4.1	0.07	0.08	0.09
<b>tires</b>	<b>1.8</b>	<b>0.03</b>	<b>0.04</b>	<b>0.04</b>
<b>Ownership Costs</b>				
	per year			
insurance	\$ 173			
collision insurance	\$ 357			
bodily harm insurance	\$ 484			
license, registration	\$ 201			
depreciation	\$ 3,721			
finance charge	\$ 828			
<b>Total Cost Per mile</b>				
20,000 miles per year	45.1 cents			
15,000 miles per year	50.2 cents			
10,000 miles per year	62.3 cents			

The elasticity of demand for VMT with respect to automobile running costs ranges from  $-0.2$  to  $-0.4$ , the latter being a long run elasticity and the former a short run elasticity. These elasticities measure the driver response to VMT so, for example, a 10 percent increase in running costs would reduce VMT by 2 percent in the short term and 4 percent in the long term. Given the values in Table 17.2, it is quite clear that tire costs would have to increase enormously to have an effect of reducing VMT. Some assumptions will be made and values estimated.

## 18. Effects of Different Strategies on Tire Disposal Rates

The first step in assessing the different strategies is to assess their contribution to reduce the number of waste tires generated in California. Three strategies are considered, first, a technology based one where we examine both the use of TPMS with instrument panel readouts for each tire and the use of auto inflate systems which maintain the tire at optimal values most of the time.<sup>87</sup> The other two strategies are taxes and subsidies, which are treated as being symmetric although they need not be. Not having enough information on the relevant elasticities led to this strategy. The final strategy is to look at education programs to have people better maintain the pressure in their tires. We treat this as equivalent to TPMS with a “once and for all” signal, meaning low sophistication. In developing these measures we have assumed that the distribution between passenger cars and trucks for ‘light vehicles’ does not change over the period of analysis. We also assume the response of passenger car versus light truck operators does not change (that is, there is no evolution in their behavior).

Tables 18.1 through 18.8 provide the first set of key results of the analysis.

The results are also presented for two data sets since, as was indicated earlier, they can be seen as representing the upper and lower boundary of the amount of discarded tires. One could clearly change some assumptions and undertake a sensitivity analysis on the basis of other criteria.

One reason for presenting the impact on the level of tire disposal prior to the benefit-cost analysis is because we do not have any good measure for the external cost of tire dumps or piles. We have some measures of how much it cost to clean up tire dumps or to clean up after a tire fire but we do not have a measure of the external damage such fires do in the same way we have reasonably good measures of the economic cost of emissions. Therefore in this section we present the “physical” evidence and then we place an expenditure value on tires that are disposed of and include them in the benefit-cost assessment.

The results have been organized by strategy and by database, and summaries are presented in Table 18.1. Tables 18.2 through 18.9 provide the forecast of waste tires generated for each strategy and for the two databases. The emphasis is on the forecast values from 2002 through 2012. Differences occur because of both the database as well as the effectiveness of the different strategies. The assumption is also made that no added recycling strategies are introduced, so all reduction are due to strategies to reduce tire wear or increase tire productivity.<sup>88</sup> Two points are evident, the base case has a dramatic affect on the measured impact and there are substantive differences among the strategies. The way in which taxes and subsidies work must be interpreted with caution since we used auto VMT elasticities to measure the response of drivers to a tax or subsidy. There would in effect be fewer VMT if a tax were imposed. Yet in the other strategies we have assumed VMT remains constant.

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<sup>87</sup> We assume that a tire stays within 2 psi of its placard value.

<sup>88</sup> An increase in tire productivity can be viewed as obtaining more VMT per unit of tires used. Thus, for example, better tire pressure maintenance leads to less wear per VMT, hence rising productivity.

The outcomes certainly agree with prior intuition but the value of the analytics is to see the marked differences between strategies. Among the technology based strategies which we have the most confidence in, in terms of measurement, the auto inflate systems are more than twice as effective as TPMS systems. The big difference is the former is entirely automated while the latter requires operator effort. The education program by itself is ineffective but may be valuable if introduced in conjunction with other programs to make them more effective. As we state, the impact of taxes and subsidies must be treated with caution. The impact appears more valuable than the education strategy, however, as we have argued earlier, both taxes/rebates and education are not adequate stand-alone strategies. They are valuable in conjunction with a technological strategy. More research is needed to see at what point in the process either or both of these ancillary strategies should be introduced.

Table 18.1: Summary of impact of Different Strategies on tire disposal.

<b>Strategy</b>	RMA	IWMB
TPMS	-0.026	-0.060
Auto Inflate	-0.073	-0.170
Taxes/Subsidies	-0.008	-0.018
Education	-0.006	-0.015

Table 18.2: Impact of direct TPMS on disposal of tires: Strategy 1 (RMA database).

Year	California population (Millions)	Estimated tires generated RMA Data (millions)	New Level of Tires Generate (millions)	Tires Imported (millions)	Total PTEs (RMA Data)	NEW Total PTEs (RMA Data)	Reduction in Total PTEs Generated (millions)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfill-Old	Landfill-NEW	Percent Change
1990	29.5	39.17	39.17	0.00	39.17	39.17	0.00	0.6	2.3	1.3	4	8.2	30.97	30.97	0
1991	30.1	41.00	41.00	0.40	41.40	41.40	0.00	0.8	2.2	1.3	5.8	10.1	31.30	31.30	0
1992	30.7	42.74	42.74	0.60	43.34	43.34	0.00	1.1	2.1	1.3	6.8	11.3	32.04	32.04	0
1993	31.1	44.10	44.10	0.30	44.40	44.40	0.00	1.5	2.1	1.3	7.7	12.6	31.80	31.80	0
1994	31.7	45.47	45.47	0.20	45.67	45.67	0.00	1.7	2.4	1.3	11.7	17.1	28.57	28.57	0
1995	32.3	46.87	46.87	0.60	47.47	47.47	0.00	1.8	2.4	1.7	10.8	16.7	30.77	30.77	0
1996	32.6	49.64	49.64	1.50	51.14	51.14	0.00	2.3	2.4	1.7	8.9	15.3	35.84	35.84	0
1997	33.2	52.94	52.94	3.20	56.14	56.14	0.00	5.4	2.8	1.7	9	18.9	37.24	37.24	0
1998	33.8	56.16	56.16	2.20	58.36	58.36	0.00	9.1	2.8	3.1	7.5	22.5	35.86	35.86	0
1999	34.0	57.16	57.16	2.00	59.16	59.16	0.00	10.1	2.5	1.5	7.9	22	37.16	37.16	0
2000	34.5	58.05	58.05	3.20	61.25	61.25	0.00	11	2.4	1.9	5.2	20.5	40.75	40.75	0
2001	34.8	53.58	53.58	1.70	55.28	55.28	0.00	14.9	2.4	2.6	5.3	25.2	30.08	30.08	0
2002	35.8	55.35	54.63	2.00	57.35	56.63	0.72	15.65	2.5	2.5	5.5	26.15	31.21	30.49	-0.023
2003	36.4	56.68	55.93	2.00	58.68	57.93	0.74	16.43	2.5	2.5	5.5	26.93	31.75	31.00	-0.023
2004	36.9	57.88	57.11	2.00	59.88	59.11	0.76	17.25	2.5	2.5	5.5	27.75	32.13	31.37	-0.024
2005	37.4	59.11	58.34	2.00	61.11	60.34	0.78	18.11	2.5	2.5	5.5	28.61	32.50	31.72	-0.024
2006	37.8	60.23	59.43	2.00	62.23	61.43	0.80	19.02	2.5	2.5	5.5	29.52	32.71	31.92	-0.024
2007	38.4	61.70	60.89	2.00	63.70	62.89	0.81	19.97	2.5	2.5	5.5	30.47	33.23	32.42	-0.024
2008	38.9	63.05	62.22	2.00	65.05	64.22	0.83	20.97	2.5	2.5	5.5	31.47	33.59	32.76	-0.025
2009	39.4	64.45	63.60	2.00	66.45	65.60	0.85	22.01	2.5	2.5	5.5	32.51	33.93	33.08	-0.025
2010	40.0	66.05	65.19	2.00	68.05	67.19	0.87	23.11	2.5	2.5	5.5	33.61	34.44	33.57	-0.025
2011	40.4	67.38	66.49	2.00	69.38	68.49	0.89	24.27	2.5	2.5	5.5	34.77	34.61	33.72	-0.026
2012	40.9	68.92	68.01	2.00	70.92	70.01	0.91	25.48	2.5	2.5	5.5	35.98	34.93	34.03	-0.026

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Table 18.3: Impact of direct TPMS on disposal of tires: Strategy 1 (CIWMB database).

Year	California population (Millions)	Estimated tires generated IWMB Data (millions)	New Level of Tires Generated	Tires Imported (millions)	Total PTEs (IWMB Data)	<b>NEW</b> Total PTEs (IWMB Data)	Reduction in Total PTEs Generated (millions)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfill-Old	Landfill-NEW	Percent Change
1990	29.5	27.000	27.00	0.00	27.00	27.00	0.00	0.6	2.3	1.3	4	8.2	18.80	18.80	0
1991	30.1	27.500	27.50	0.40	27.90	27.90	0.00	0.8	2.2	1.3	5.8	10.1	17.80	17.80	0
1992	30.7	28.200	28.20	0.60	28.80	28.80	0.00	1.1	2.1	1.3	6.8	11.3	17.50	17.50	0
1993	31.1	28.500	28.50	0.30	28.80	28.80	0.00	1.5	2.1	1.3	7.7	12.6	16.20	16.20	0
1994	31.7	29.000	29.00	0.20	29.20	29.20	0.00	1.7	2.4	1.3	11.7	17.1	12.10	12.10	0
1995	32.3	29.500	29.50	0.60	30.10	30.10	0.00	1.8	2.4	1.7	10.8	16.7	13.40	13.40	0
1996	32.6	30.000	30.00	1.50	31.50	31.50	0.00	2.3	2.4	1.7	8.9	15.3	16.20	16.20	0
1997	33.2	30.400	30.40	3.20	33.60	33.60	0.00	5.4	2.8	1.7	9	18.9	14.70	14.70	0
1998	33.8	30.900	30.90	2.20	33.10	33.10	0.00	9.1	2.8	3.1	7.5	22.5	10.60	10.60	0
1999	34.0	31.100	31.10	2.00	33.10	33.10	0.00	10.1	2.5	1.5	7.9	22	11.10	11.10	0
2000	34.5	31.600	31.60	3.20	34.80	34.80	0.00	11	2.4	1.9	5.2	20.5	14.30	14.30	0
2001	34.8	33.300	33.30	1.70	35.00	35.00	0.00	14.9	2.4	2.6	5.3	25.2	9.80	9.80	0
2002	35.8	34.835	34.39	2.00	36.84	36.39	0.45	15.65	2.5	2.5	5.5	26.15	10.69	10.24	-0.042
2003	36.4	35.668	35.20	2.00	37.67	37.20	0.47	16.43	2.5	2.5	5.5	26.93	10.74	10.27	-0.044
2004	36.9	36.425	35.95	2.00	38.42	37.95	0.48	17.25	2.5	2.5	5.5	27.75	10.68	10.20	-0.045
2005	37.4	37.203	36.71	2.00	39.20	38.71	0.49	18.11	2.5	2.5	5.5	28.61	10.59	10.10	-0.046
2006	37.8	37.904	37.40	2.00	39.90	39.40	0.50	19.02	2.5	2.5	5.5	29.52	10.39	9.89	-0.048
2007	38.4	38.830	38.32	2.00	40.83	40.32	0.51	19.97	2.5	2.5	5.5	30.47	10.36	9.85	-0.049
2008	38.9	39.681	39.16	2.00	41.68	41.16	0.52	20.97	2.5	2.5	5.5	31.47	10.22	9.69	-0.051
2009	39.4	40.559	40.03	2.00	42.56	42.03	0.53	22.01	2.5	2.5	5.5	32.51	10.05	9.51	-0.053
2010	40.0	41.570	41.02	2.00	43.57	43.02	0.55	23.11	2.5	2.5	5.5	33.61	9.96	9.41	-0.055
2011	40.4	42.403	41.84	2.00	44.40	43.84	0.56	24.27	2.5	2.5	5.5	34.77	9.63	9.07	-0.058
2012	40.9	43.372	42.80	2.00	45.37	44.80	0.57	25.48	2.5	2.5	5.5	35.98	9.39	8.82	-0.061

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Table 18.4: Impact of auto-inflate systems on disposal of tires: Strategy 1 (RMA database).

Year	California population (Millions)	Estimated tires generated RMA Data (millions)	New Level of Tires Generated	Tires Imported (millions)	Total PTEs (RMA Data)	NEW Total PTEs (RMA Data)	Reduction in Total PTEs Generated (millions)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfill- Old	Landfill- NEW	Percent Change
1990	29.5	39.17	39.17	0.00	39.17	39.17	0.00	0.6	2.3	1.3	4	8.2	30.97	30.97	0
1991	30.1	41.00	41.00	0.40	41.40	41.40	0.00	0.8	2.2	1.3	5.8	10.1	31.30	31.30	0
1992	30.7	42.74	42.74	0.60	43.34	43.34	0.00	1.1	2.1	1.3	6.8	11.3	32.04	32.04	0
1993	31.1	44.10	44.10	0.30	44.40	44.40	0.00	1.5	2.1	1.3	7.7	12.6	31.80	31.80	0
1994	31.7	45.47	45.47	0.20	45.67	45.67	0.00	1.7	2.4	1.3	11.7	17.1	28.57	28.57	0
1995	32.3	46.87	46.87	0.60	47.47	47.47	0.00	1.8	2.4	1.7	10.8	16.7	30.77	30.77	0
1996	32.6	49.64	49.64	1.50	51.14	51.14	0.00	2.3	2.4	1.7	8.9	15.3	35.84	35.84	0
1997	33.2	52.94	52.94	3.20	56.14	56.14	0.00	5.4	2.8	1.7	9	18.9	37.24	37.24	0
1998	33.8	56.16	56.16	2.20	58.36	58.36	0.00	9.1	2.8	3.1	7.5	22.5	35.86	35.86	0
1999	34.0	57.16	57.16	2.00	59.16	59.16	0.00	10.1	2.5	1.5	7.9	22	37.16	37.16	0
2000	34.5	58.05	58.05	3.20	61.25	61.25	0.00	11	2.4	1.9	5.2	20.5	40.75	40.75	0
2001	34.8	53.58	53.58	1.70	55.28	55.28	0.00	14.9	2.4	2.6	5.3	25.2	30.08	30.08	0
2002	35.8	55.35	53.33	2.00	57.35	55.33	2.02	15.65	2.5	2.5	5.5	26.15	31.21	29.19	-0.065
2003	36.4	56.68	54.59	2.00	58.68	56.59	2.08	16.43	2.5	2.5	5.5	26.93	31.75	29.66	-0.066
2004	36.9	57.88	55.74	2.00	59.88	57.74	2.13	17.25	2.5	2.5	5.5	27.75	32.13	29.99	-0.066
2005	37.4	59.11	56.93	2.00	61.11	58.93	2.18	18.11	2.5	2.5	5.5	28.61	32.50	30.32	-0.067
2006	37.8	60.23	58.00	2.00	62.23	60.00	2.23	19.02	2.5	2.5	5.5	29.52	32.71	30.48	-0.068
2007	38.4	61.70	59.43	2.00	63.70	61.43	2.27	19.97	2.5	2.5	5.5	30.47	33.23	30.96	-0.068
2008	38.9	63.05	60.73	2.00	65.05	62.73	2.32	20.97	2.5	2.5	5.5	31.47	33.59	31.26	-0.069
2009	39.4	64.45	62.07	2.00	66.45	64.07	2.37	22.01	2.5	2.5	5.5	32.51	33.93	31.56	-0.070
2010	40.0	66.05	63.63	2.00	68.05	65.63	2.43	23.11	2.5	2.5	5.5	33.61	34.44	32.01	-0.070
2011	40.4	67.38	64.89	2.00	69.38	66.89	2.49	24.27	2.5	2.5	5.5	34.77	34.61	32.12	-0.072
2012	40.9	68.92	66.38	2.00	70.92	68.38	2.54	25.48	2.5	2.5	5.5	35.98	34.93	32.39	-0.073

Table 18.5: Impact of auto-inflate systems on disposal of tires: Strategy 1 (CIWMB database).

Year	California population (Millions)	Estimated tires generated IWMB Data (millions)	New Level of Tires Generated	Tires Imported (millions)	Total PTEs (IWMB Data)	NEW Total PTEs (IWMB Data)	Reduction in Total PTEs Generated (millions)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfill-Old	Landfill-NEW	Percent Change
1990	29.5	27.000	27.00	0.00	27.00	27.00	0.00	0.6	2.3	1.3	4	8.2	18.80	18.80	0
1991	30.1	27.500	27.50	0.40	27.90	27.90	0.00	0.8	2.2	1.3	5.8	10.1	17.80	17.80	0
1992	30.7	28.200	28.20	0.60	28.80	28.80	0.00	1.1	2.1	1.3	6.8	11.3	17.50	17.50	0
1993	31.1	28.500	28.50	0.30	28.80	28.80	0.00	1.5	2.1	1.3	7.7	12.6	16.20	16.20	0
1994	31.7	29.000	29.00	0.20	29.20	29.20	0.00	1.7	2.4	1.3	11.7	17.1	12.10	12.10	0
1995	32.3	29.500	29.50	0.60	30.10	30.10	0.00	1.8	2.4	1.7	10.8	16.7	13.40	13.40	0
1996	32.6	30.000	30.00	1.50	31.50	31.50	0.00	2.3	2.4	1.7	8.9	15.3	16.20	16.20	0
1997	33.2	30.400	30.40	3.20	33.60	33.60	0.00	5.4	2.8	1.7	9	18.9	14.70	14.70	0
1998	33.8	30.900	30.90	2.20	33.10	33.10	0.00	9.1	2.8	3.1	7.5	22.5	10.60	10.60	0
1999	34.0	31.100	31.10	2.00	33.10	33.10	0.00	10.1	2.5	1.5	7.9	22	11.10	11.10	0
2000	34.5	31.600	31.60	3.20	34.80	34.80	0.00	11	2.4	1.9	5.2	20.5	14.30	14.30	0
2001	34.8	33.300	33.30	1.70	35.00	35.00	0.00	14.9	2.4	2.6	5.3	25.2	9.80	9.80	0
2002	35.8	34.835	33.58	2.00	36.84	35.58	1.25	15.65	2.5	2.5	5.5	26.15	10.69	9.44	-0.117
2003	36.4	35.668	34.36	2.00	37.67	36.36	1.31	16.43	2.5	2.5	5.5	26.93	10.74	9.43	-0.122
2004	36.9	36.425	35.08	2.00	38.42	37.08	1.34	17.25	2.5	2.5	5.5	27.75	10.68	9.33	-0.126
2005	37.4	37.203	35.83	2.00	39.20	37.83	1.37	18.11	2.5	2.5	5.5	28.61	10.59	9.22	-0.130
2006	37.8	37.904	36.50	2.00	39.90	38.50	1.40	19.02	2.5	2.5	5.5	29.52	10.39	8.99	-0.135
2007	38.4	38.830	37.40	2.00	40.83	39.40	1.43	19.97	2.5	2.5	5.5	30.47	10.36	8.93	-0.138
2008	38.9	39.681	38.22	2.00	41.68	40.22	1.46	20.97	2.5	2.5	5.5	31.47	10.22	8.75	-0.143
2009	39.4	40.559	39.06	2.00	42.56	41.06	1.49	22.01	2.5	2.5	5.5	32.51	10.05	8.55	-0.149
2010	40.0	41.570	40.04	2.00	43.57	42.04	1.53	23.11	2.5	2.5	5.5	33.61	9.96	8.43	-0.153
2011	40.4	42.403	40.84	2.00	44.40	42.84	1.57	24.27	2.5	2.5	5.5	34.77	9.63	8.07	-0.163
2012	40.9	43.372	41.77	2.00	45.37	43.77	1.60	25.48	2.5	2.5	5.5	35.98	9.39	7.79	-0.170

Table 18.6: Impact of taxes and subsidies on disposal of tires: Strategy 4 (RMA database).

Year	California population (Millions)	Estimated tires generated RMA Data (millions)	New Level of Tires Generated	Tires Imported (millions)	Total PTEs (RMA Data)	NEW Total PTEs (RMA Data)	Reduction in Total PTEs Generated (millions)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfi ll-Old	Landfill- NEW	Percent Change
1990	29.5	39.17	39.17	0.00	39.17	39.17	0.00	0.6	2.3	1.3	4	8.2	30.97	30.97	0
1991	30.1	41.00	41.00	0.40	41.40	41.40	0.00	0.8	2.2	1.3	5.8	10.1	31.30	31.30	0
1992	30.7	42.74	42.74	0.60	43.34	43.34	0.00	1.1	2.1	1.3	6.8	11.3	32.04	32.04	0
1993	31.1	44.10	44.10	0.30	44.40	44.40	0.00	1.5	2.1	1.3	7.7	12.6	31.80	31.80	0
1994	31.7	45.47	45.47	0.20	45.67	45.67	0.00	1.7	2.4	1.3	11.7	17.1	28.57	28.57	0
1995	32.3	46.87	46.87	0.60	47.47	47.47	0.00	1.8	2.4	1.7	10.8	16.7	30.77	30.77	0
1996	32.6	49.64	49.64	1.50	51.14	51.14	0.00	2.3	2.4	1.7	8.9	15.3	35.84	35.84	0
1997	33.2	52.94	52.94	3.20	56.14	56.14	0.00	5.4	2.8	1.7	9	18.9	37.24	37.24	0
1998	33.8	56.16	56.16	2.20	58.36	58.36	0.00	9.1	2.8	3.1	7.5	22.5	35.86	35.86	0
1999	34.0	57.16	57.16	2.00	59.16	59.16	0.00	10.1	2.5	1.5	7.9	22	37.16	37.16	0
2000	34.5	58.05	58.05	3.20	61.25	61.25	0.00	11	2.4	1.9	5.2	20.5	40.75	40.75	0
2001	34.8	53.58	53.58	1.70	55.28	55.28	0.00	14.9	2.4	2.6	5.3	25.2	30.08	30.08	0
2002	35.8	55.35	55.14	2.00	57.35	57.14	0.22	15.65	2.5	2.5	5.5	26.15	31.21	30.99	-0.007
2003	36.4	56.68	56.45	2.00	58.68	58.45	0.22	16.43	2.5	2.5	5.5	26.93	31.75	31.52	-0.007
2004	36.9	57.88	57.65	2.00	59.88	59.65	0.23	17.25	2.5	2.5	5.5	27.75	32.13	31.90	-0.007
2005	37.4	59.11	58.88	2.00	61.11	60.88	0.23	18.11	2.5	2.5	5.5	28.61	32.50	32.27	-0.007
2006	37.8	60.23	59.99	2.00	62.23	61.99	0.24	19.02	2.5	2.5	5.5	29.52	32.71	32.47	-0.007
2007	38.4	61.70	61.46	2.00	63.70	63.46	0.24	19.97	2.5	2.5	5.5	30.47	33.23	32.99	-0.007
2008	38.9	63.05	62.80	2.00	65.05	64.80	0.25	20.97	2.5	2.5	5.5	31.47	33.59	33.34	-0.007
2009	39.4	64.45	64.19	2.00	66.45	66.19	0.25	22.01	2.5	2.5	5.5	32.51	33.93	33.68	-0.007
2010	40.0	66.05	65.79	2.00	68.05	67.79	0.26	23.11	2.5	2.5	5.5	33.61	34.44	34.18	-0.008
2011	40.4	67.38	67.11	2.00	69.38	69.11	0.27	24.27	2.5	2.5	5.5	34.77	34.61	34.34	-0.008
2012	40.9	68.92	68.64	2.00	70.92	70.64	0.27	25.48	2.5	2.5	5.5	35.98	34.93	34.66	-0.008

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Table 18.7: Impact of taxes and subsidies on disposal of tires: Strategy 4 (CIWMB database).

Year	California population (Millions)	Estimated tires generated IWMB Data (millions)	New Level of Tires Generated	Tires Imported (millions)	Total PTEs (IWMB Data)	NEW Total PTEs (IWMB Data)	Reduction in Total PTEs Generated (millions)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfi Il-Old	Landfill- NEW	Percent Change
1990	29.5	27.000	39.17	0.00	27.00	39.17	27.00	0.6	2.3	1.3	4	8.2	18.80	30.97	0.64729
1991	30.1	27.500	41.00	0.40	27.90	41.40	27.50	0.8	2.2	1.3	5.8	10.1	17.80	31.30	0.75865
1992	30.7	28.200	42.74	0.60	28.80	43.34	28.20	1.1	2.1	1.3	6.8	11.3	17.50	32.04	0.83109
1993	31.1	28.500	44.10	0.30	28.80	44.40	28.50	1.5	2.1	1.3	7.7	12.6	16.20	31.80	0.96296
1994	31.7	29.000	45.47	0.20	29.20	45.67	29.00	1.7	2.4	1.3	11.7	17.1	12.10	28.57	1.36149
1995	32.3	29.500	46.87	0.60	30.10	47.47	29.50	1.8	2.4	1.7	10.8	16.7	13.40	30.77	1.29597
1996	32.6	30.000	49.64	1.50	31.50	51.14	30.00	2.3	2.4	1.7	8.9	15.3	16.20	35.84	1.21237
1997	33.2	30.400	52.94	3.20	33.60	56.14	30.40	5.4	2.8	1.7	9	18.9	14.70	37.24	1.53329
1998	33.8	30.900	56.16	2.20	33.10	58.36	30.90	9.1	2.8	3.1	7.5	22.5	10.60	35.86	2.38276
1999	34.0	31.100	57.16	2.00	33.10	59.16	31.10	10.1	2.5	1.5	7.9	22	11.10	37.16	2.34802
2000	34.5	31.600	58.05	3.20	34.80	61.25	31.60	11	2.4	1.9	5.2	20.5	14.30	40.75	1.84999
2001	34.8	33.300	53.58	1.70	35.00	55.28	33.30	14.9	2.4	2.6	5.3	25.2	9.80	30.08	2.06958
2002	35.8	34.835	34.70	2.00	36.84	36.70	0.13	15.65	2.5	2.5	5.5	26.15	10.69	10.56	-0.013
2003	36.4	35.668	35.53	2.00	37.67	37.53	0.14	16.43	2.5	2.5	5.5	26.93	10.74	10.60	-0.013
2004	36.9	36.425	36.28	2.00	38.42	38.28	0.14	17.25	2.5	2.5	5.5	27.75	10.68	10.53	-0.013
2005	37.4	37.203	37.06	2.00	39.20	39.06	0.15	18.11	2.5	2.5	5.5	28.61	10.59	10.45	-0.014
2006	37.8	37.904	37.75	2.00	39.90	39.75	0.15	19.02	2.5	2.5	5.5	29.52	10.39	10.24	-0.014
2007	38.4	38.830	38.68	2.00	40.83	40.68	0.15	19.97	2.5	2.5	5.5	30.47	10.36	10.21	-0.015
2008	38.9	39.681	39.52	2.00	41.68	41.52	0.16	20.97	2.5	2.5	5.5	31.47	10.22	10.06	-0.015
2009	39.4	40.559	40.40	2.00	42.56	42.40	0.16	22.01	2.5	2.5	5.5	32.51	10.05	9.88	-0.016
2010	40.0	41.570	41.41	2.00	43.57	43.41	0.16	23.11	2.5	2.5	5.5	33.61	9.96	9.79	-0.016
2011	40.4	42.403	42.24	2.00	44.40	44.24	0.17	24.27	2.5	2.5	5.5	34.77	9.63	9.46	-0.017
2012	40.9	43.372	43.20	2.00	45.37	45.20	0.17	25.48	2.5	2.5	5.5	35.98	9.39	9.22	-0.018

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Table 18.8: Impact of education programs on disposal of tires: Strategy 2 (RMA database).

Year	California population (Millions)	Estimated tires generated RMA Data (millions)	New Level of Tires Generate (millions)	Tires Imported (millions)	Total PTEs (RMA Data)	NEW Total PTEs (RMA Data)	Reduction in Total PTEs Generated (millions)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfill-Old	Landfill-I-NEW	Percent Change
1990	29.5	39.17	39.17	0.00	39.17	39.17	0.00	0.6	2.3	1.3	4	8.2	30.97	30.97	0
1991	30.1	41.00	41.00	0.40	41.40	41.40	0.00	0.8	2.2	1.3	5.8	10.1	31.30	31.30	0
1992	30.7	42.74	42.74	0.60	43.34	43.34	0.00	1.1	2.1	1.3	6.8	11.3	32.04	32.04	0
1993	31.1	44.10	44.10	0.30	44.40	44.40	0.00	1.5	2.1	1.3	7.7	12.6	31.80	31.80	0
1994	31.7	45.47	45.47	0.20	45.67	45.67	0.00	1.7	2.4	1.3	11.7	17.1	28.57	28.57	0
1995	32.3	46.87	46.87	0.60	47.47	47.47	0.00	1.8	2.4	1.7	10.8	16.7	30.77	30.77	0
1996	32.6	49.64	49.64	1.50	51.14	51.14	0.00	2.3	2.4	1.7	8.9	15.3	35.84	35.84	0
1997	33.2	52.94	52.94	3.20	56.14	56.14	0.00	5.4	2.8	1.7	9	18.9	37.24	37.24	0
1998	33.8	56.16	56.16	2.20	58.36	58.36	0.00	9.1	2.8	3.1	7.5	22.5	35.86	35.86	0
1999	34.0	57.16	57.16	2.00	59.16	59.16	0.00	10.1	2.5	1.5	7.9	22	37.16	37.16	0
2000	34.5	58.05	58.05	3.20	61.25	61.25	0.00	11	2.4	1.9	5.2	20.5	40.75	40.75	0
2001	34.8	53.58	53.58	1.70	55.28	55.28	0.00	14.9	2.4	2.6	5.3	25.2	30.08	30.08	0
2002	35.8	55.35	54.81	2.00	57.35	56.81	0.54	15.65	2.5	2.5	5.5	26.15	31.21	30.67	-0.017
2003	36.4	56.68	56.12	2.00	58.68	58.12	0.56	16.43	2.5	2.5	5.5	26.93	31.75	31.19	-0.018
2004	36.9	57.88	57.31	2.00	59.88	59.31	0.57	17.25	2.5	2.5	5.5	27.75	32.13	31.56	-0.018
2005	37.4	59.11	58.53	2.00	61.11	60.53	0.58	18.11	2.5	2.5	5.5	28.61	32.50	31.92	-0.018
2006	37.8	60.23	59.63	2.00	62.23	61.63	0.60	19.02	2.5	2.5	5.5	29.52	32.71	32.11	-0.018
2007	38.4	61.70	61.09	2.00	63.70	63.09	0.61	19.97	2.5	2.5	5.5	30.47	33.23	32.62	-0.018
2008	38.9	63.05	62.43	2.00	65.05	64.43	0.62	20.97	2.5	2.5	5.5	31.47	33.59	32.96	-0.019
2009	39.4	64.45	63.81	2.00	66.45	65.81	0.64	22.01	2.5	2.5	5.5	32.51	33.93	33.30	-0.019
2010	40.0	66.05	65.40	2.00	68.05	67.40	0.65	23.11	2.5	2.5	5.5	33.61	34.44	33.79	-0.019
2011	40.4	67.38	66.71	2.00	69.38	68.71	0.67	24.27	2.5	2.5	5.5	34.77	34.61	33.94	-0.019
2012	40.9	68.92	68.24	2.00	70.92	70.24	0.68	25.48	2.5	2.5	5.5	35.98	34.93	34.25	-0.019

Table 18.9: Impact of education programs on disposal of tires: Strategy 2 (CIWMB database).

Year	California population (Millions)	Estimated tires generated (millions)	New Level of Tires Generated	Tires Imported (millions)	Total PTEs (IWMB Data)	NEW Total PTEs (IWMB Data)	Reduction in Total PTEs Generated (millions)	Recycling and other uses	Retreaded	Exported	Diverted to fuel	Total diverted	Landfill-Old	Landfill-I-NEW	Percent Change
1990	29.5	27.000	27.000	0.00	27.00	27.00	0.00	0.6	2.3	1.3	4	8.2	18.80	18.80	0
1991	30.1	27.500	27.500	0.40	27.90	27.90	0.00	0.8	2.2	1.3	5.8	10.1	17.80	17.80	0
1992	30.7	28.200	28.200	0.60	28.80	28.80	0.00	1.1	2.1	1.3	6.8	11.3	17.50	17.50	0
1993	31.1	28.500	28.500	0.30	28.80	28.80	0.00	1.5	2.1	1.3	7.7	12.6	16.20	16.20	0
1994	31.7	29.000	29.000	0.20	29.20	29.20	0.00	1.7	2.4	1.3	11.7	17.1	12.10	12.10	0
1995	32.3	29.500	29.500	0.60	30.10	30.10	0.00	1.8	2.4	1.7	10.8	16.7	13.40	13.40	0
1996	32.6	30.000	30.000	1.50	31.50	31.50	0.00	2.3	2.4	1.7	8.9	15.3	16.20	16.20	0
1997	33.2	30.400	30.400	3.20	33.60	33.60	0.00	5.4	2.8	1.7	9	18.9	14.70	14.70	0
1998	33.8	30.900	30.900	2.20	33.10	33.10	0.00	9.1	2.8	3.1	7.5	22.5	10.60	10.60	0
1999	34.0	31.100	31.100	2.00	33.10	33.10	0.00	10.1	2.5	1.5	7.9	22	11.10	11.10	0
2000	34.5	31.600	31.600	3.20	34.80	34.80	0.00	11	2.4	1.9	5.2	20.5	14.30	14.30	0
2001	34.8	33.300	33.300	1.70	35.00	35.00	0.00	14.9	2.4	2.6	5.3	25.2	9.80	9.80	0
2002	35.8	34.835	34.50	2.00	36.84	36.50	0.34	15.65	2.5	2.5	5.5	26.15	10.69	10.35	-0.031
2003	36.4	35.668	35.32	2.00	37.67	37.32	0.35	16.43	2.5	2.5	5.5	26.93	10.74	10.39	-0.033
2004	36.9	36.425	36.06	2.00	38.42	38.06	0.36	17.25	2.5	2.5	5.5	27.75	10.68	10.32	-0.034
2005	37.4	37.203	36.84	2.00	39.20	38.84	0.37	18.11	2.5	2.5	5.5	28.61	10.59	10.22	-0.035
2006	37.8	37.904	37.53	2.00	39.90	39.53	0.38	19.02	2.5	2.5	5.5	29.52	10.39	10.01	-0.036
2007	38.4	38.830	38.45	2.00	40.83	40.45	0.38	19.97	2.5	2.5	5.5	30.47	10.36	9.98	-0.037
2008	38.9	39.681	39.29	2.00	41.68	41.29	0.39	20.97	2.5	2.5	5.5	31.47	10.22	9.82	-0.038
2009	39.4	40.559	40.16	2.00	42.56	42.16	0.40	22.01	2.5	2.5	5.5	32.51	10.05	9.64	-0.040
2010	40.0	41.570	41.16	2.00	43.57	43.16	0.41	23.11	2.5	2.5	5.5	33.61	9.96	9.55	-0.041
2011	40.4	42.403	41.98	2.00	44.40	43.98	0.42	24.27	2.5	2.5	5.5	34.77	9.63	9.21	-0.044
2012	40.9	43.372	42.94	2.00	45.37	44.94	0.43	25.48	2.5	2.5	5.5	35.98	9.39	8.96	-0.046

## 19. Benefit Cost Measures

Tables 19.1 and 19.2 provide the summary measures of the benefit cost analysis; the former for the RMA data and the latter based on the CIWMB data. The figures in the tables are very similar; primarily because the differences in the databases relate to tire disposal expectations and this will affect only the savings from tire disposal. It is therefore useful to focus on one table, the RMA table, and examine the relative values of the NPV (discounted net present value) and B/C ratio figures. The figures contained in this table are the discounted values that have been aggregated. In all cases we assumed a discount rate of 6 percent. The monetization of safety and emissions used values from Gillen, *et al.* [1996]. In the measure of the “costs” of tire disposal we have assumed each tire has a discounted cost over its lifetime of \$2. This is based on notions of a probability of a fire and long term breakdown and the values we have for environmental cleanup of some dump sites in California and elsewhere. We assumed a real gasoline price of \$1.64 per gallon from 2002 through 2013.<sup>89</sup> We have also expressed all values in 2002 \$. The passenger fleet average fuel economy is assumed at 28.6 mpg.<sup>90</sup>

In the BC analysis we have tried to convey *three key pieces of information*. First, we have segmented the benefits into different categories to better understand what the primary sources of benefit are. Second, we have provided two measures of benefit-cost, a net present value (NPV) which is the difference between the discounted values of benefits and costs and presents a measure of the magnitude of the return and a B/C ratio, measured as discounted benefits over discounted costs, which provides a measure of rate of return or benefit per \$ invested. Third, we have presented the results for each strategy so relative returns can be compared but also differences in the source of the benefits.<sup>91</sup>

One feature that is quite evident is that on the basis of tire disposal savings alone; none of the strategies could pass a benefit cost test. This of course assumes a \$2 value per tire over its lifetime. If one were going to justify the introduction of technology based systems, such as direct TPMS or auto-inflate systems, the social externality value of a tire would need to range between \$175-200. It may be that this is indeed the case but there does not appear to be any solid data to justify such a number. But one cannot ignore the additional social benefits that result from the introduction of the strategies; no more than one can ignore the additional social costs that result from under-inflation.

Upon inspection, it appears, from among the technology-based strategies, that the higher NPV and return results from adopting the auto-inflate system, with the indirect TPMS a distant

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<sup>89</sup> The \$1.64 is used by the California Energy Commission (Source: Jim Page Tel. [1-916-654-4886](tel:1-916-654-4886) e-mail: [jpage@energy.state.ca.us](mailto:jpage@energy.state.ca.us))

<sup>90</sup> Source: USDoT NHTSA report DOT HS 809 512 entitled Automotive Fuel Economy Program, Annual Update Calendar Year 2001, Table II-3.

<sup>91</sup> Recall that the cost of the two technology options (*i.e.*, auto-inflate and direct TPMS) is the incremental cost for upgrading from an indirect TPMS.

second.<sup>92</sup> This is in line with expectations. The results of the auto-inflate system are robust in that there are no key underlying assumptions that could change the outcomes. Based on the specification of the Cycloid system, vehicles equipped with auto-inflate systems achieve a steady-state pressure of 29 psi.

Results for the direct TPMS depend on assumptions regarding the response of consumers to under-inflated tire(s) warning signal. The assumption employed here is that 80% will respond, and will do so in sufficient time to have a steady-state pressure of 26.25 psi. The remaining 20% are assumed to have a steady-state pressure of 21 psi. Thus, the weighted steady-state pressure is 25.2 psi. If either of the assumptions changes, the outcome may be quite different.<sup>93</sup>

The taxes or subsidies strategy is, as was noted earlier, one to be interpreted with caution because there are no direct measures of how consumers would respond to such taxes or subsidies. Rather, cross-price elasticities are used to encourage consumers to switch to longer life mileage tires. We would place the tax/rebate strategy in the same camp as the education strategy; it is not a stand-alone strategy but one to be used in conjunction with a hardware strategy. The costs for the taxes and subsidies are calculated assuming a \$5 rebate per tire with a car having two sets of tires over its lifetime. The \$5 is assumed to come from tax revenue and thus the efficiency losses associated with each \$1 are factored into the cost calculation.<sup>94</sup> The high cost of public dollars explains the negative NPV and a  $B/C < 1$ ; this is clearly not a strategy to be undertaken. We also assumed that consumers might take better care of their tires because of this strategy, and placed the weighted steady-state pressure at 24.75 psi.<sup>95</sup>

Looking at each strategy, and the composition of benefits provides some interesting differences. For example, the direct TPMS strategy has a relatively smaller proportion of fuel savings compared to auto-inflate systems. Moreover, the auto-inflate system provides higher safety benefits both absolutely and relatively and substantial reductions in emissions. Tire disposal savings are three times higher than for direct TPMSs but the higher costs associated with auto-inflate systems brings the rate of return down.

The education strategy has no cost listed since we had no basis, despite an extensive literature survey (See Appendix C), for determining a value per unit or overall. We implemented the strategy by assuming that the education program would result in better tire pressure maintenance

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<sup>92</sup> Note that the direct TPMS has a negative NPV and B/C ratio less than one, which suggests that based on pure economic return indirect TPMS offers a better approach. However, direct TPMS reduces the number of waste tires generated.

<sup>93</sup> The weighted steady-state for indirect TPMS is assumed at 24.6 psi. Here it is important to note that the NHTSA survey discussed above detected a steady-state pressure of 23.9 psi (assuming a placard pressure of 30 psi). Moreover, as previously noted, the NHTSA study measured and reported hot. As a result, the current steady-state cold inflation pressure is about 20 psi.

<sup>94</sup> This means each \$1 of rebate has a social cost of \$1.43, the 43¢ increase results from the economic efficiency loss from collecting and transferring dollars from private to public sector.

<sup>95</sup> The tax and subsidies strategy is assumed to deliver 25% of the improvement achieved by direct TPMS over indirect TPMS.

and the weighted steady-state tire pressure would be 25.05.<sup>96</sup> The results would vary with the assumptions made.

One could ask, how robust the results are? As we have pointed out, the calculations for the auto-inflate system are robust. The values depend on common assumptions regarding the steady-state of tire pressure (psi) and the base from which we would be measuring the improvement. The key to the auto-inflate system is that it works to maintain tire pressure all the time; there is no period in which tire pressure falls significantly below the placard level. On the other hand, the results for TPMS, Tax/Rebate and Education strategies are subject to potentially significant variation. This would depend on the operators' response to information warning of under-inflated tires. It would depend also on the steady-state tire pressure. Our figures are neither conservative nor liberal and thus they could go up or down depending on the change in assumptions. However, the change would not be that large

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<sup>96</sup> The education strategy is assumed to deliver 75% of the improved air pressure achieved by the direct TPMS over indirect TPMS.

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Table 19.1:Benefit cost measures based on RMA data (2002 \$).

RMA Data	Aggregate Benefits	Percent of aggregate Benefits	Aggregate Costs	Net Present Value (Millions)	B/C Ratio	Normalized to Auto-Inflate
<b>Strategy 1-TPMS</b>						
Fuel	\$ 244,406,398	0.118	\$ 2,110,016,306			
Emissions	\$ 11,402,249	0.006				
Accidents & Safety	\$ 1,804,118,367	0.870				
Tire Disposal Savings	\$ 12,669,550	0.006				
Aggregate	\$ 2,072,596,564					
<b>Strategy 1-Auto Inflate</b>						
Fuel	\$ 1,769,226,158	0.322	\$ 4,432,948,012			
Emissions	\$ 82,558,757	0.015				
Accidents & Safety	\$ 3,608,236,734	0.657				
Tire Disposal Savings	\$ 35,474,740	0.006				
Aggregate	\$ 5,495,496,389					
<b>Strategy 2 -Taxes and Subsidies</b>						
Fuel	\$ 61,196,168	0.902	\$ 6,850,579,657			
Emissions	\$ 2,854,894	0.042				
Accidents & Safety	\$ -	0.000				
Tire Disposal Savings	\$ 3,800,865	0.056				
Aggregate	\$ 67,851,926					
<b>Strategy 3 Education Programs</b>						
Fuel	\$ 183,399,269	0.118				
Emissions	\$ 8,845,660	0.006				
Accidents & Safety	\$ 1,353,088,775	0.870				
Tire Disposal Savings	\$ 9,502,162	0.006				
Aggregate	\$ 1,554,835,867					

Table 19.2: Benefit cost measures based on CIWMB data (2002 \$).

CIWMB Data	Aggregate Benefits	Percent of aggregate Benefits	Aggregate Costs	Net Present Value (Millions)	B/C Ratio	Normalized to Auto-Inflate
<b>Strategy 1-TPMS</b>						
Fuel	\$ 244,406,398	0.118	\$ 2,110,016,306			
Emissions	\$ 11,402,249	0.006				
Accidents & Safety	\$ 1,804,118,367	0.872				
Tire Disposal Savings	\$ 7,962,838	0.004				
Aggregate	\$ 2,067,889,852				\$ (42)	0.98
<b>Strategy 1-Auto Inflate</b>						
Fuel	\$ 1,769,226,158	0.323	\$ 4,432,948,012			
Emissions	\$ 82,558,757	0.015				
Accidents & Safety	\$ 3,608,236,734	0.658				
Tire Disposal Savings	\$ 22,295,947	0.004				
Aggregate	\$ 5,482,317,596				\$ 1,049	1.24
<b>Strategy 2 -Taxes and Subsidies</b>						
Fuel	\$ 61,196,168	0.921	\$ 6,850,579,657			
Emissions	\$ 2,854,894	0.043				
Accidents & Safety	\$ -	0.000				
Tire Disposal Savings	\$ 2,388,851	0.036				
Aggregate	\$ 66,439,913				\$ (6,784)	0.01
<b>Strategy 3 Education Programs</b>						
Fuel	\$ 183,399,269	0.118				
Emissions	\$ 8,845,660	0.006				
Accidents & Safety	\$ 1,353,088,775	0.872				
Tire Disposal Savings	\$ 5,972,129	0.004				
Aggregate	\$ 1,551,305,833				\$ 1,551	NA

## 20. Risk Analysis

The calculations of net present value and benefit/cost ratios have, to this point, been based on point estimates for the key variables. This section provides sensitivity analyses on these values by performing Monte Carlo simulations based on probability distributions and ranges for the key variables.

While a single “expected value” can be used, it is often more helpful to look at the range of possible values and their accompanying probabilities, a process termed “risk analysis.” Risk derives from the fact that future outcomes can take a number of forms and there exists a non-zero chance that each can occur. It arises in some form or another in virtually all fields of endeavor and should be addressed rather than ignored. Reporting a single value such as a benefit/cost ratio or a net present value in effect states that such a value will occur with certainty (*i.e.*, with a probability value of 1). For a decision maker this information while providing some guidance is not helpful in identifying the risk associated with a decision to choose one strategy over another.

An important consideration for investors is the likelihood of realizing a specified level of return on their investment. A risk adverse investor would prefer an assured lower return than a less probable higher return. So too might decision-makers judging the economic efficiency of strategies to reduce the amount of waste tire material. These officials may prefer to know the likelihood that the 70, 80 or 90 percent of the predicted net present value, for example, would be realized. A choice of strategy may be based on the view that for Strategy 1 there is a 80% chance of achieving 90 percent of the net benefits, while Strategy 2 has only 60% chance of achieving a higher average value of net benefits.

Risk can be either objective or subjective. Flipping a coin is an objective risk because even though the outcome of a specific toss is uncertain, the odds are well known. An objective risk can be described precisely based on theory or experiment. Subjective risk, on the other hand, cannot be easily quantified. Whether it is the future state of the economy, interest rates, or actions of a competitor, probabilities and their distributions can only be based on historic trends, experience, and consensus.

A probability distribution describes a range of possible values and their likelihood of occurrence. One of the best known of these is the normal distribution (the “bell curve”) but there are a wide variety of distribution types to describe such diverse phenomena as traffic congestion or failure rates for electronic parts. Regardless of shape or purpose, all distribution types use a set of arguments to mathematically describe the possible outcomes. The normal distribution, for example, uses a mean and standard deviation as its arguments. The mean defines the value around which the bell curve will be centered and the standard deviation defines the range of values around the mean. The distribution used most often for tire pressure studies is the triangular distribution that requires an expected value and an upper and lower bound.

There are four steps in the technique for dealing with uncertainty and representing results in the form of probability distributions rather than point estimates:

1. Develop a model by defining the characteristics of the distribution of underlying input values. These characteristics are mean, variance, skewness and kurtosis. In the current case, the four strategies for keeping tires properly inflated will accrue benefits in the form of fuel savings, fewer emissions, increased safety, and fewer tires to be disposed of. These savings come at some cost, of course, including manufacturing, installation, and maintenance. For each of fuel savings, *etc.*, we specify the characteristics of the distributions based on the data used to generate the aggregate values.
2. Identify uncertainty in variables in the model and specify their possible values with probability distributions. The present study requires forecasting fuel prices, population growth, and interest rates. This information is developed based on historical trends.
3. Analyze the model with simulation to determine the range and probabilities of all possible outcomes for the results of the model. The @Risk software generates thousands of values for each of the variables “at random” from the specified distribution simulating possible final outcomes for the various strategies. Like the distributions used to describe the original variables, the outcomes have a range of values with a mean, a lower, and upper bound.
4. Compare the mean value of the variable of interest with the probability distribution around that mean.

The value of using such a risk management technique is that it provides information on the probability of all outcomes occurring. What this means is that the decision maker will have, if not perfect information, the most complete picture possible. He or she will be able to see what could happen, how likely it is to happen, and therefore be able to judge accordingly which risks to take and which to avoid.

## **20.1 Probability Distributions For Tire Pressure Strategies**

Tables 19.1 and 19.2 present point estimates for the net present value and benefit/cost ratio of the expected gains from three strategies to extend the lifespan of tires. This section shows the results of the Monte Carlo simulations based on probability distributions for the key variables fuel, emissions, safety, and tire disposal used in computing these values. In each of the diagrams below, the cumulative probability distributions are shown along with a vertical bar representing the point estimate value from Tables 19.1 and 19.2.

Of the two outputs from the simulation, net present value yields the most information in that it reflects the magnitude of the potential gain or loss. The benefit/cost ratio, on the other hand, could be high for no other reason than the fact that the costs are relatively low. The cost for direct TPMS, for example, is less than one half that of auto inflation which, in turn, is only two thirds that of the taxes and subsidies strategy.

### **20.1.1 Strategy 1: Technology**

First consider the case where all new vehicles are equipped with direct TPMS. This option is an improvement over the base case of indirect TPMS (see Section 8). Figures 20.1 and 20.2 show the benefit/cost ratio distribution for the CIWMB and RMA data, respectively. The point

estimate for both sets of data is .98. From these figures, it can be seen that there is a 30 and a 35 percent probability of doing at least as well as the point estimate. In other words the calculated benefit to cost ratio is 0.98, and there is a 35 percent chance that this value will be achieved or exceeded. The value of 0.65 is a relatively low value, which says that the chances of achieving the mean benefit cost of 0.98 are quite good. Furthermore the chances of exceeding this value are fairly good as well; there is a 35 percent chance that this value will be exceeded.

Figure 20.1

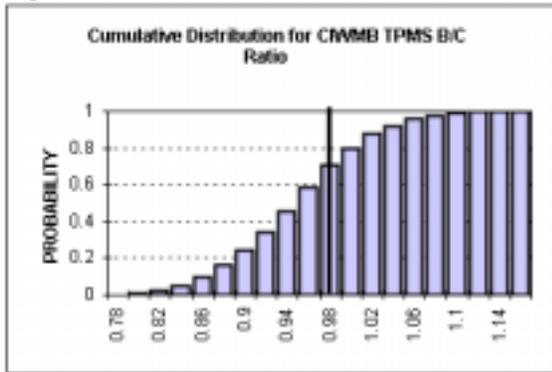
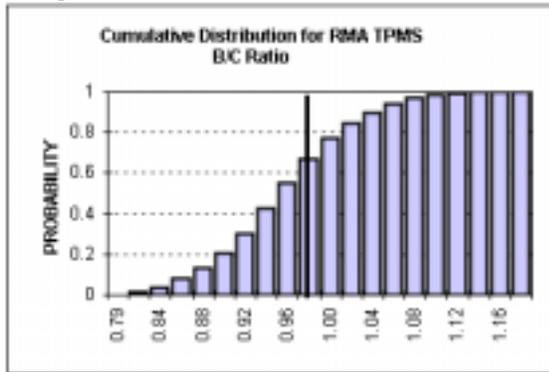


Figure 20.2



In Figures 20.3 and 20.4 the net present values for direct TPMS are given. The point estimate for the CIWMB data is a loss of \$42 million while that of the RMA data is a loss of \$37 million. For both sets of data, the probability of doing at least as well as the estimates is 30%. These cumulative probability distributions provide the same conclusions as the benefit cost ratio values.

Figure 20.3

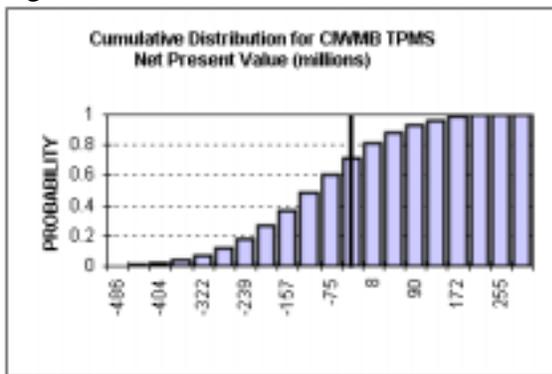
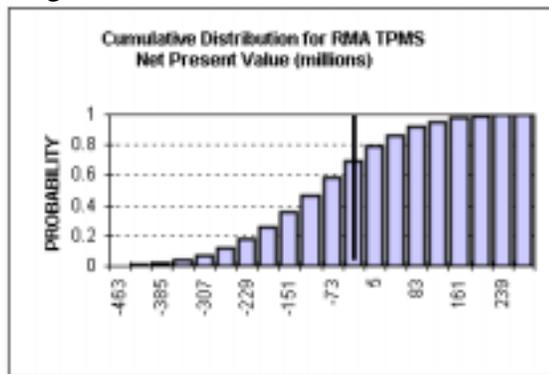


Figure 20.4



The next diagrams show the results for the auto inflate system. The key advantage to this strategy is that it requires no action on the part of the driver since a device in the wheel keeps the tires at the proper pressure. As a result, the expected returns are larger than the TPMS system. Figures 20.5 and 20.6 show that there is an approximately 55% chance of achieving at least the 1.24 benefit/cost ratio estimate for both CIWMB and RMA. As in the first strategy, this is a low value implying the chances of achieving the mean value are quite high and there is a relatively good chance of doing better than the mean value.

Figures 20.7 and 20.8 compare the CIWMB and RMA net present value for the auto inflate strategy. Here there is a 60% and 50% probability that the point estimates of \$1.05 billion and \$1.06 billion will be met or exceeded.

Figure 20.5

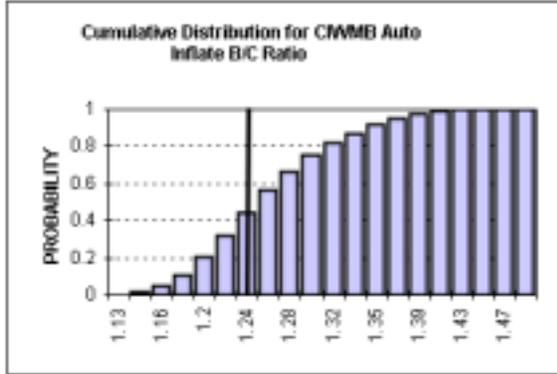


Figure 20.6

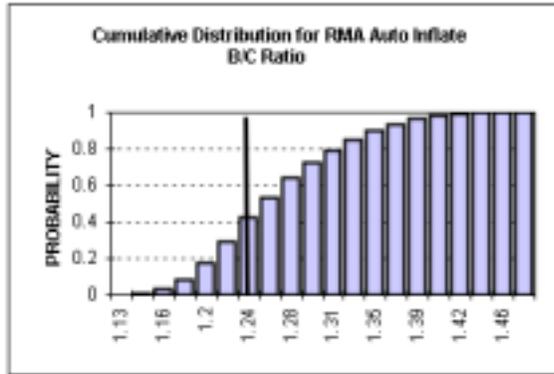


Figure 20.7

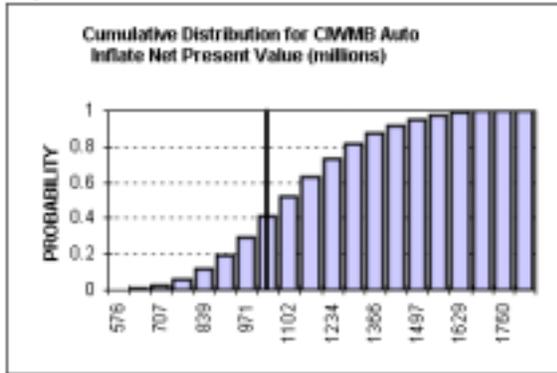
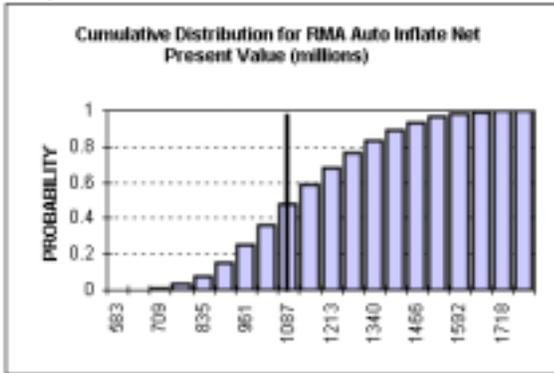


Figure 20.8



### 20.1.2 Strategy 2: Education

This strategy is perhaps the most difficult to assess in that there is little empirical evidence as to the potential effect such a strategy would have. Assumptions here can only be based on indirect data from other public information campaigns (see Appendix C). Costs are even more difficult to determine since there are no technology and few opportunity costs involved (most public service campaigns make extensive use of donated services).

Figures 20.9 and 20.10 show net present value targets of \$1.56 billion. In both cases, the lack of solid empirical data results in only a 5% chance that this target will be met or exceeded.

### 20.3 Strategy 4: Taxes and Rebates

The results for the tax and rebate strategy are shown in Figures 20.11 and 20.12. The focus of this strategy is to change consumer behavior by inducing them to buy longer life tires. Even if they buy these tires, however, there is no reason to believe that they will do a better job of maintaining the correct tire pressure. The aggregate benefit, therefore, is quite small when

compared to the other strategies while the opportunity cost of the funds used for the rebates and/or subsidies is relatively high. This results in the low target benefit/cost ratio for both data sets of only 0.01. Even this low target has only a 15% and 25% chance, respectively, of being met as shown in Figures 20.11 and 20.12.

The results for tax and rebates net present value are also poor. The expected return from both data sets is a loss of \$6.78 billion. There is, however, only a 35% chance that the results will be worse than this as shown in Figures 20.13 and 20.14.

Figure 20.9

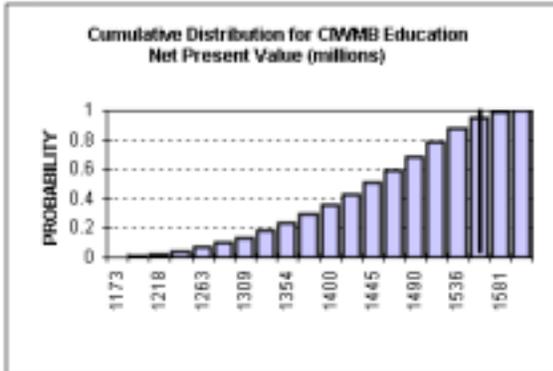


Figure 20.10

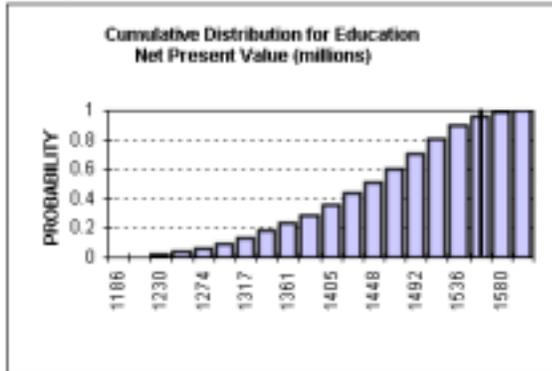


Figure 20.11

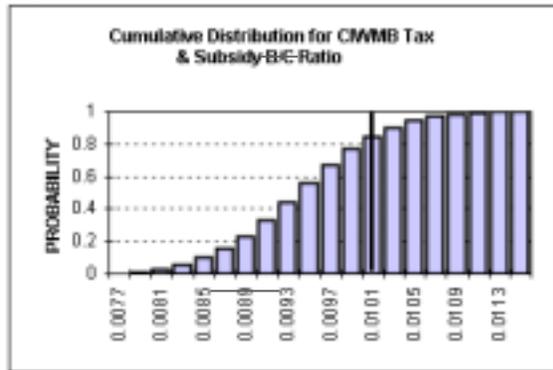


Figure 20.12

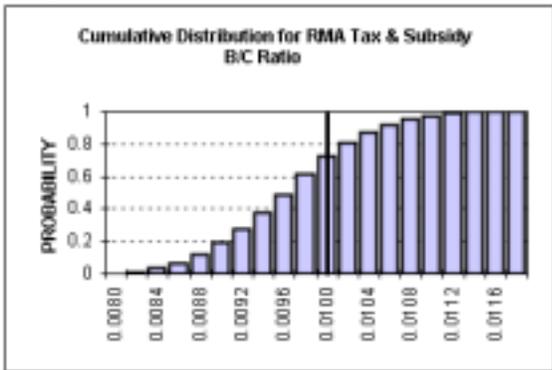


Figure 20.13

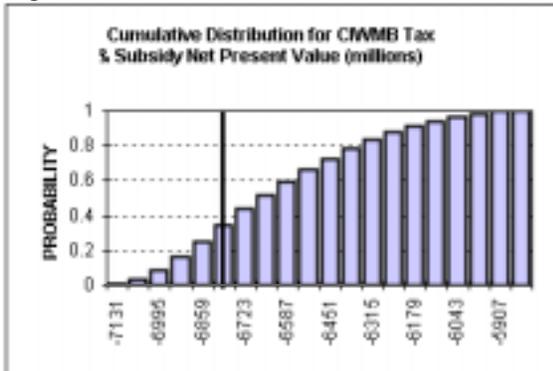
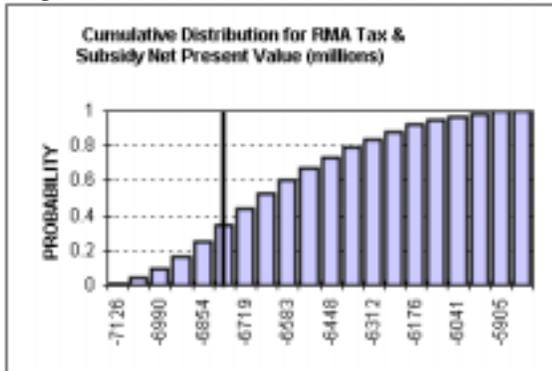


Figure 20.14



## 21. Which Benefit to Emphasize When Advancing a Strategy?

The objective of the CIWMB is to reduce the number of tires entering the waste pipeline as a means to decrease the number of tires requiring disposal. This report proposes a number of strategies that can contribute to the achievement of this goal. Each of these strategies requires some level of public and private investment, and brings benefits to both sectors. An important question is what argument should be used to advance a particular strategy: focusing *only* on reducing tire disposal, or showcasing *all* benefits.

The answer to this question is a two-tired approach. First, the CIWMB should adopt a strategy, or a combination of strategies, that deliver its objective. However, once the approach taken has been determined, the most effective arguments to advance this approach should be employed. For example, assume that a particular strategy is adopted because it delivers the largest reduction in the number of scrap tires. Further assume that the same strategy also contributes to improved fuel efficiency and vehicle safety. Should a public education campaign promote this strategy by proclaiming: “this strategy reduces the number of tires going into landfills,” and leave safety and financial benefits to the *small print*. Or, should the education effort proclaim: “this strategy improves your safety and saves you money, and it also reduces the number of tires being disposed.” It is much more likely that the public would respond to the second approach because they can see immediate benefit to themselves. Therefore, adopting the second advertisement approach is more likely to further the CIWMB goal.

Emphasizing benefits to the individual is a good public relation approach. But is it effective in soliciting support from public groups? For example, if improved vehicle fuel efficiency is a byproduct of a given strategy to extend the lifespan of tires then it also implies a reduction in emissions. This could help the CIWMB gain the support of groups such as the California Air Resources Board, the Sierra Club, the Natural Resources Defense Council, *etc.* to advance its initiative. Clearly the California Energy Commission will also be interested.

It was assumed above that the CIWMB would select the approach it intends to follow based on reducing the number of scrap tires alone. Should that be the case, or should the CIWMB also include in its deliberations side benefits? The answer to this question is that the CIWMB should include in its discussion the probability of a given approach yielding the maximum number of desired results. Thus, if for example, a given strategy appears to be more efficient in reducing the number of scrap tires, does it mean that it will actually deliver better results than a second approach that appears to be less efficient but is more likely to be adopted.

## **22. Implementation: Auto-Inflate Systems**

In this Section two approaches to introduce auto-inflate systems into the California vehicle fleet are considered. First, voluntary adoption is examined in Section 22.1. Legislation, or regulation, mandating auto-inflate systems in new vehicles in California is analyzed in Section 22.2. It would be advantageous to either of these approaches if the CIWMB could demonstrate the advantages of auto-inflate systems in a real-life application. To this end the CIWMB should undertake a pilot study of auto-inflate systems. This proposed study is further discussed in Section 22.3.

### ***22.1 Voluntary Adoption***

The basic idea is to allow market forces to act, and assume that auto-inflate systems will become prevalent because of their superior performance and the economic benefit that they bring (see Sections 9, 18, and 19). Indeed, successful voluntary adoption was the case with two technologies that become prevalent in cars in the 1990s. These are the antilock braking systems (ABS), and supplemental restraint systems (SRS). There is no law or regulation mandating either of these technologies. However, it is virtually impossible to buy a new passenger vehicle in California that does not feature ABS and at least front SRS for the driver and front passenger (many vehicles also offer side impact air bags).

There are other technologies whose voluntary adoption were less successful and required government regulations. Good examples are seatbelts and TPMSs, which, despite the clear safety advantage they offer and their relatively low cost, required government regulations.

Pursuing voluntary adoption of auto-inflate systems, however, does not mean that the CIWMB should play no role in getting auto-inflate systems to the market place. To the contrary, the CIWMB can play an important role by mounting an education campaign to advise consumers of the advantages of auto-inflate systems. Specifically, this effort should focus on potential buyers of new vehicles, aiming to persuade them to request that their new vehicle be equipped with an auto-inflate system.

Focusing the education campaign on potential buyers of new vehicles gives it a good chance to succeed. (Recall that this strategy calls for adoption of auto-inflate systems only through new vehicles (see Section 14).) This is because consumers are asked to take an active role only once, namely, at the time of purchase. This point is important because when asked to repeatedly perform a task the influence of education campaigns is short lived. A relevant example is the poor state of tire pressure maintenance detected by a NHTSA survey carried out in 2001 (NHTSA [2002a]).

The education campaign must convince consumers that they stand to directly benefit from auto-inflate technology. Advantages include: increased tire lifespan; improved safety due to reduced braking distance and lowering the risk of tire blowouts that may lead to rollover; reduced fuel consumption; and benefits to the environment (less pollution and less scrap tires). The contribution of auto-inflate systems to reduce the number of scrap tires is the focus of Section 18, and the results of a benefit cost analysis is presented in Section 19.

The CIWMB can use a combination of tools to proselytize auto-inflate systems at a relatively low cost. Specifically, the tools that can be used for this purpose include: public service announcements (PSAs); teaming up with local TV and radio stations to do specials on this technology as part of their consumer education activity (many TV stations include such a segment in their local news programs); direct mailings; promoting the technology on its web site; and sponsoring case studies and advertising the results (see Section 22.3).

The CIWMB should extend its effort beyond consumers to include auto-insurance companies and automakers. Specifically, the CIWMB should work to convince auto-insurance companies of the safety enhancements offered by auto-inflate systems. Auto insurance premiums depend to some extent on the safety rating for the vehicle. Therefore, auto-insurance companies may offer consumers discounts if they purchase vehicles equipped with auto-inflate systems in much the same way as they give discounts to vehicles equipped with ABS and SRS. Additionally, auto-insurance companies could participate in spreading the word of this technology by advising clients to request auto-inflate systems when buying new vehicles.

Asking automakers to offer auto-inflate systems with their vehicles should be approached based on market positioning. Specifically, automakers could not afford not to offer auto-inflate systems once some of their competitors offered them. Thus, one argument should be that rather than playing catch-up they should jump in and offer this technology, at least as an option, to give them a competitive edge.

Using the examples cited for success and failure of voluntary adoption, the pros and cons of this approach to introduce auto-inflate systems into the California vehicle market are considered in Sections 22.1.1 (advantages) and 22.1.2 (disadvantages). Barriers to the indirect approach are considered in Section 22.1.3.

### **22.1.1 Arguments for a voluntary adoption approach**

From the CIWMB perspective adopting this voluntary adoption approach offers some attractive advantages. First, it would require a relatively modest investment. The CIWMB could get its PSAs on the air at reduced cost or no cost at all. For example, it could team with local news organizations (TV, radio, and newspapers) to feature stories on the advantages of auto-inflate systems. It could also put up information on its web site.

Should the CIWMB be successful in educating auto-insurance companies to the safety benefit of auto-inflate systems then they may recommend these systems to their customers. This would be of great advantage to the CIWMB efforts for two reasons. First, a recommendation from the insurance company may carry some weight with consumers (especially if it is backed up by incentives). Second, many insurance companies have clients across the nation. Consequently, their endorsement of auto-inflate technology may spur demand nation-wide. This would make it more attractive for automakers to offer these systems.

The CIWMB can also use environmental groups to promote auto-inflate technology. For example, it may be able to persuade the Sierra Club that auto-inflate systems extend tire life mileage, and reduce fuel consumption and air pollution. Once convinced of the advantages of this technology, the Sierra Club may use its lobbying skills and nation-wide network to convince

automakers and the public to take advantage of this technology. As with insurance companies, this may increase demand in states beyond California, thus increasing the pressure on automakers to offer the technology.

Promoting auto-inflate systems through an education campaign would not require any legislation or regulations. Consequently, the CIWMB will not have to contend with restraint of its action by legislators, trade groups (*e.g.*, the Alliance of Automobile Manufacturers (Alliance)), or any other group that may take issue with this particular subject or object to government regulations in principle. Moreover, the CIWMB could finance this effort using money obtained from the tire disposal fee, which would avoid the need to go through the California legislature. Thus, this approach can be implemented relatively quickly.

Adopting an education campaign would reduce the likelihood that other government entities (state or federal) would take issue with this program. For example, recently the Federal Government sided with some automakers that are suing California over giving credits for hybrid cars, which is an interim advance on the path towards the full development of zero emission vehicles. In that case the Federal Government took the position that by giving credits California is, in effect, trying to regulate fuel efficiency, which is a prerogative reserved to the Federal Government (Seelye [2002]).

Finally, the education efforts should also target commercial fleets. The argument there would be that it saves fuel; decreases the risk of having to replace tires while on the road (an obvious productivity loss); and the improved ability to retread used tires (see Sections 3 and 4). (Note that the benefit cost analyses in Sections 18 and 19 did not consider the commercial vehicle segment.)

### **22.1.2 Arguments against a voluntary adoption approach**

The rate of fleet penetration via voluntary adoption of auto-inflate system is likely to be slow in comparison to that when a law or regulation mandates these systems. This is because it will take time for the education campaign to win people over. For example, both direct and indirect TPMSs have been available for a number of years. Yet TPMSs are installed in a small fraction of new vehicles; it took a NHTSA regulation to force automakers to add these systems to all vehicles. Even successful technologies such as SRS were available for a long period before suddenly becoming the *de facto* standard. (It took a well-publicized severe collision to demonstrate the life-saving potential of SRS technology to propel the adoption of these systems (Mannering and Winston [1995]).)

The counter argument to the relatively slow rate of penetration is that this may be true if one focuses entirely on the consumer side. However, the CIWMB can also work with automakers to advance this technology. There are a few things that could be done here. First, the CIWMB could undertake a pilot study in which auto-inflate systems are installed in a few hundred vehicles. Using its power as a large buyer, the state could condition buying new vehicles on the availability of auto-inflate systems as OE. (The pilot project is further discussed in Section 22.3.)

Second, the CIWMB can work with all sport utility vehicle (SUV) makers to convince them that employing auto-inflate systems gives them another tool to combat rollover. Recently, Volvo

introduced the XC90 SUV that is equipped with roll stability control. This demonstrates that the market is currently in search of tools to avoid rollover. Some rollovers are the result of tire blowouts. Therefore, because one cause for tire blowouts is under-inflated tires, SUV producers may be interested in auto-inflate systems. Once such a system is available on SUVs it will be much easier to also incorporate them into sedans because automakers will have the needed assembly lines, and consumers will be aware of these systems.

In making the case for auto-inflate systems the CIWMB will be in the awkward position of having to use arguments outside its scope to entice consumers to buy vehicles equipped with auto-inflate systems. Specifically, the arguments will have to depend primarily on fuel savings and improved safety, which directly benefits consumers. Environmental arguments will come only as secondary motivation. Even among environmental issues, improved air quality and reduced fuel consumption are likely to be far more effective arguments for auto-inflate systems than urgings based on increasing the average tire life mileage. This may result in various groups questioning the motivation of the California government in promoting auto-inflate technology. However, the fact that the CIWMB adopts an education approach should be the key to deflecting this criticism. Here, the CIWMB should take the approach that it is educating the public to the existence and advantages of the technology. But, ultimately consumers are free to make up their mind in accordance with their judgment.

This education campaign is probably not going to generate much objection from the tire or car industries. After all, it would be hard to argue against educating the public to the existence of this new technology that improves fuel efficiency; increases the life mileage of tires; and improves safety. Moreover, they themselves are trying to educate the public to the importance of proper tire maintenance (*e.g.*, the RMA's "be smart play your part" campaign).

During the NHTSA deliberations of the TPMS rule, the Alliance applied considerable pressure on NHTSA to allow indirect systems (NHTSA [2002b]). Therefore, it is possible that the Alliance would try to derail adoption of auto-inflate systems by putting out its own education campaigns attempting to promote an alternative technology. For example, it could argue that the NHTSA regulation mandating TPMSs provides ample safety, and introducing auto-inflate systems is wasteful. Such a parallel education campaign would confuse consumers and reduce the effectiveness of the CIWMB education campaign. As a result, the demand for auto-inflate systems may not become strong enough so as to mimic the success of ABS and SRS. One way to counter this criticism is to take the NHTSA stance that TPMSs are intended for safety not for maintenance. Thus, arguments pertaining to fuel savings, reduced pollution, and reduced number of scrap tires remain unaffected by arguments that the NHTSA TPMS regulation is sufficient. Moreover, even from a safety standpoint auto-inflate provides a more complete solution because it does not depend on a person reacting to the TPMS warning.

The Alliance might also use their lobbyists in California to intervene with the Governor and/or legislators to stop the education campaign. An argument that they may use is that it is a waste of public funds to advance technologies that are not yet in the marketplace. This criticism is addressed in Section 22.1.3.1.

### 22.1.3 Barriers to voluntary adoption of auto-inflate technology

The above discussion addressed the merits of a voluntary adoption approach. Direct barriers to introducing auto-inflate technology are addressed next. The first, and most critical, *availability*, is discussed in Section 22.1.3.1. Next, resistance from the automakers due to increased costs is addressed in Section 22.1.3.2. Finally, the current limited number of producers of auto-inflate systems is considered in Section 22.1.3.3

#### 22.1.3.1 Availability

The main barrier to the voluntary adoption approach is availability. Specifically, at the moment, no automaker offers auto-inflate systems as original equipment (OE) with their vehicles, not even as an option.<sup>97</sup> Thus, if a consumer is persuaded to require that his or her car be equipped with an auto-inflate system, the reality is that this consumer currently cannot buy such a vehicle.

This criticism is well placed. It is the classical chicken and egg dilemma. The solution here is multi-tiered. First, there is at least one vehicle that may be equipped with such a system in the near future. According to a June 18, 2002 press release by Cycloid, DaimlerChrysler has featured the AutoPump on its new concept vehicle, the Jeep Grand Cherokee Concierge, which was unveiled in Stuttgart, Germany in early June 2002 (Show [2002]).<sup>98</sup> Second, as is discussed in Section 22.3, the CIWMB should undertake a pilot study of this technology. As part of this study the government of California should wield its buying power to try to get some automakers to have auto-inflate systems as OE. Once an automaker meets this demand it could provide auto-inflate systems as OE to the general public, possibly as an option. Moreover, some vehicles will already be equipped with a direct TPMS to meet NHTSA regulation (NHTSA [2002b]) and consequently, both the cost of adding auto-inflate will be reduced, and the modifications to the vehicle will only include minor changes to the rims (at least for the Cycloid technology). Finally, one should consider that it might take a year or two before the CIWMB education campaign starts targeting consumers. Therefore, there should be ample time for automakers to provide some vehicles that feature auto-inflate systems.

Auto dealers cater to many consumer demands, and provide some added features that they use to justify their markup. Therefore, if automakers will not provide auto-inflate systems as OE with their vehicles, car dealers will step in to fill the void. Relative to this scenario it is important to note that installing auto-inflate systems is a relatively simple task. This is especially true for vehicles equipped with a direct TPMS as OE since only minor changes to the rims would be required.

An important safety downside for sport utility vehicles (SUVs) is their tendency to rollover. This problem gained notoriety in 2000 with the disclosure that Ford Explorer SUVs equipped with Firestone tires were especially susceptible to rollover, causing severe injuries and fatalities. The reason for at least a number of the Explorer rollovers was tire blowout. It is possible that the under-inflation started a chain of events that resulted in a catastrophic failure, an event that may

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<sup>97</sup> Recall that the discussion here is confined to passenger vehicles. Some truck trailers are equipped with auto-inflate systems as original equipment.

<sup>98</sup> AutoPump is the product name for the auto-inflate system produced by Cycloid.

have never occurred if the tire had been properly inflated. In other words auto-inflate system can reduce the risk of an SUV rolling over as a result of a tire blowout. Congress, in response to public attention, passed the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000, which in turn lead to NHTSA enacting the TPMS regulation in 2002. However, while TPMSs can warn drivers of low air pressure in their tires, it is up to the drivers to act on this information. Therefore, auto-inflate systems enhance vehicle safety beyond what is accomplished by TPMSs. Because SUVs are both one of the most profitable and fastest growing vehicle market segments, automakers are likely to adopt auto-inflate technology in SUVs in order to protect or increase their SUV market share. For example, recently Volvo introduced their XC90 SUV, which is equipped with a unique system that detects rollover initiation and tries to prevent it. Clearly an auto-inflate system is a relatively economical way to abate SUV rollover. Public education should build on this to create a domino effect of adopting auto-inflate technology. The fact that Jeep Grand Cherokee Concierge may be equipped with this system should help here. Also, intervention from the insurance industry could force automakers to adopt this technology.

#### **22.1.3.2 Cost**

Automakers are likely to argue that the cost of an auto-inflate system (\$175 when installed as OE) is too expensive. This will be consistent with the comments that the Alliance made to NHTSA regarding the TPMS regulation (NHTSA [2002b]).

The benefit cost analysis contained in Section 19 should prove effective in countering cost arguments. The analysis shows that California stands to gain a net present value of \$1 billion benefit over an eleven-year period. Thus, it is hard to argue against this technology on economic grounds. Nor does the analysis account for the benefit to commercial fleets from this technology (see Section 9 for a discussion of this aspect).

#### **22.1.3.3 Limited number of producers**

At the moment, there is only one producer of auto-inflate systems for passenger vehicles. Hence the CIWMB may be put in an awkward position of promoting a specific company, and may provide ammunition to those objecting to this technology (or just to the idea of government interfering with the free market). This fact may prove to be a difficult barrier to overcome, especially since the company in question is not based in California.

To diminish this barrier, it is important to note that auto-inflate systems consist of two components. A direct TPMS monitoring the pressure in each tire, and a system to supply the tires with pressurized air. There are several companies producing direct TPMSs (see *Section 8*). There are also a few producing pressurized air delivery systems for truck trailers (see *Section 9.1*). However, presently only one company provides that component for light duty vehicles. Thus, the criticism is limited to light duty vehicles, and only to the air delivery system component.

Before the TREAD Act of 2000 there were a few producers of indirect TPMSs, and just a handful of producers of direct TPMSs. However, in anticipation of the NHTSA rule on TPMSs, many companies started producing both direct and indirect TPMSs. This experience suggests

that it is reasonable to assume that once an auto-inflate system gains a foothold in the marketplace, additional companies will start offering such systems.

## **22.2 Regulated Adoption**

Under this approach the CIWMB will require all automakers to equip their vehicles with auto-inflate systems as OE. This regulation will be stricter than the NHTSA TPMS regulation and consequently will be subjected to much criticism. Mirroring the voluntary adoption Section above, this Section begins by presenting arguments for (Section 22.2.1) and against (Section 22.2.2) the regulatory approach. Barriers to implementing this approach are discussed in Section 22.2.3.

### **22.2.1 Arguments for mandating auto-inflate systems**

Mandating auto-inflate systems by law will accelerate their market penetration. For example, following the example set by NHTSA with its TPMS regulation, California could mandate that 33% of 2005 models be equipped with auto inflate. The percentage should increase to 66% with the 2006 models, and finally to 100% starting with the 2007 models. Such a fast rate of introduction is not likely to be met if a voluntary adoption approach is taken.

Auto-inflate systems provide a reliable way to reduce the number of scrap tires entering the waste pipeline (see Section 20). This is in contrast to educational programs, where it is up to the consumer to act on the given advice. Therefore, mandating auto-inflate systems provides a direct, and reliable, strategy to achieve the stated goal.

The benefit cost analysis (see Section 19) shows that California stands to gain a net present value benefit of \$1 billion over an eleven-year period (once all vehicles are equipped with auto-inflate). Thus, mandating these systems will benefit the California economy and adoption of the technology should be accelerated; regulation is the quickest way to achieve this goal.

Improved safety of vehicle occupants is another argument to get auto-inflate technology adopted as quickly as possible. Auto-inflate systems advance safety in two ways. First, as already noted above, the risk of a tire blowout is reduced. Thus, lowering the possibility for a vehicle to rollover, which is important to the ever-increasing population segment using SUVs. Second, braking distance is increased if tires are under-inflated (see Section 15.3). Therefore, vehicles equipped with auto-inflate systems may also be able to avoid more accidents than similar vehicles not equipped with these systems.

### **22.2.2 Arguments against mandating auto-inflate systems**

Congress passed the TREAD Act in November 2000, and the TPMS regulation issued by NHTSA took effect in August of 2002. Thus, even when NHTSA was focused on this one rule, and had the full support of the US Congress, it required almost two years to enact this rule. Accordingly, while it is true that once enacted a rule would accelerate adoption of the auto-inflate technology, the actual enactment of the rule may be considerably delayed. However, automakers and auto-inflate system producers are likely to take advantage of this period to advance the integration of these systems. For example, in the case of the TPMS rule, while

NHTSA was developing their rule TPMS producers developed more advanced systems, new producers appeared, and automakers integrated these systems into more vehicle models.

Automakers may argue that the TPMS rule adequately addresses all safety issues, and fuel efficiency is a prerogative of the federal government. Therefore, they may argue that the California demand makes no economic sense and amounts to unnecessary government interference with the free market. This argument was addressed above by noting that when considering a strategy to achieve a desired effect (increasing the lifespan of tires in this case) all benefit and cost categories must be considered. Additionally, mandating auto-inflate systems does not imply a stricter CAFE standard. Rather auto-inflate systems help vehicles deliver, under normal operating conditions, the performance promised by automakers.

### **22.2.3 Barriers to mandating auto-inflate systems in new vehicles**

The main expected barrier to a regulation mandating auto-inflate systems are legal challenges, and they are addressed in Section 22.2.3.1. The limited number of producers is addressed in Section 22.2.3.2.

#### **22.2.3.1 Legal challenges**

The main barrier to mandating auto-inflate systems is likely to be from legal challenges. Various organizations, ranging from automakers to citizen groups that oppose any government regulation, may note that the main advantages identified by the benefit cost analysis are due to safety and fuel efficiency. This, they may argue, is outside the scope of the CIWMB or even the California legislature. For example, they could argue that NHTSA is responsible for safety, and that setting fuel efficiency standards is a prerogative of the federal government. In fact, at present a federal court is considering a lawsuit brought by some automakers against the California Air Resources Board addressing the very issue of dominion over setting fuel efficiency standards (ARB [2003]).

California has enacted various environmental laws that are stricter than their federal counterparts. In doing so California opted to provide improved safety to its residents. These regulations provide legal precedents to the CIWMB action.

NHTSA is the federal agency responsible for setting minimum safety standards for transportation systems. The operative word here is minimum. NHTSA would welcome anyone who exceeds its standards. As noted above, auto-inflate systems combine a direct TPMS with a system to deliver pressurized air to the tires. Thus, auto-inflate systems can meet the stricter of the standard levels (25% below placard) set by NHTSA (see Section 6 for a discussion of the two levels of the TPMS standard). In this respect it is important to note that NHTSA itself evaluated a preliminary prototype of an auto-inflate system as one of the direct TPMSs (NHTSA [2002c]). Moreover, NHTSA expertise should be utilized in developing the auto-inflate regulations, and this should both put NHTSA in support of this regulation and assist in deflecting criticism.

Regarding the fuel efficiency regulation, demanding auto-inflate systems does not affect the results of the fuel efficiency tests conducted by the federal Environmental Protection Agency (EPA). This is because automakers, who have taken the pains to use OE tires that average 20%

lower rolling resistance than replacement tires, also make sure that the air pressure during the test is exactly at placard. Thus, all that the auto-inflate regulation can achieve is to reduce the gap between the EPA fuel efficiency ratings and the actual ones.

### **22.2.3.2 Limited number of producers**

Presently, a single company produces auto-inflate systems for private vehicles. This may put the CIWMB in the awkward position of promoting a single vendor and thus, open itself to criticism. However, once a law or a regulation is passed or enacted mandating such systems in new vehicles, additional producers would be expected to enter the market. This is not unlike what happened in the TPMS market where the number of producers increased in anticipation of NHTSA's rule. Here it is important to note that the rule or legislation will take time to be enacted, and the systems will be phased in over a number of years (similar to NHTSA's TPMS rule).

## **22.3 Pilot Study**

It will take some time to put in place either the voluntary adoption or regulation options discussed above. This time should be used to run pilot studies to investigate the performance of auto-inflate systems. Two pilot studies are outlined below (the development of a full study scope and plan is left for future work). The first study should be used to validate the potential to extend the lifespan of tires, as outlined in Section 22.3.1. The second study, discussed in Section 22.3.2, should be used to validate the reliability of auto-inflate systems.

The pilot studies should serve additional purposes. First, California should use its buying power to negotiate with automakers to offer auto-inflate systems on their vehicles as an option. This will assist in solving the availability dilemma. Second, the experience gained could greatly benefit the (auto-inflate) educational campaign discussed in Section 22.1.

As part of this pilot study it would be useful to do case study work on previous similar issues. For example: catalytic converters; what were the pitfalls, what were the successful strategies, and what were the arguments for and against their adoption.

### **22.3.1 Validate the potential to extend the lifespan of tires**

The motivation for the CIWMB to promote auto-inflate systems is to reduce the number of tires entering the waste stream in California. The analysis in Section 18 identifies promoting auto-inflate systems as the most effective strategy to achieve this goal. This conclusion is based primarily on two pieces of information: (1) a poor state of tire pressure maintenance, and (2) a Goodyear representation to NHTSA on tread loss due to inadequate air pressure. Therefore, it is important to validate these assumptions.

The proposed study should consist of two components. The first is a survey of tire pressure in California vehicles (the NHTSA study was a nationwide survey). Similar to the NHTSA study reported in NHTSA [2002b], the survey should measure tire pressure for vehicles stopped at gas stations around the state. However, unlike the NHTSA study, tire temperature should also be measured to enable converting the measured hot pressure to the cold inflation pressure, which

can than be compared with the placard pressure. Thus, the survey will require the following information for each tire: pressure, temperature, placard pressure, vehicle make, model, and year. The information collected will be used to identify the current level of tire pressure maintenance for California vehicles.

The second component of this study will investigate the influence of air pressure on tire wear. Specifically, this study aims to independently validate the Goodyear representation to NHTSA that tire life is shortened by 1.78% for each psi below placard. Thus, tires will be tested on a prescribed course. The air pressure in each tire will be maintained at a fixed (cold) air pressure at all times, and the wear of the tires at different prescribed air pressures will be compared. A number of replicas should be used in order to ensure reliability of the results. In addition, it would be instructive to test tires that are equipped with auto-inflate systems to see how they perform relative to the constant-pressure tires.

Information from the two components of this study will permit a more accurate prediction of the increase in life mileage of tires equipped with auto-inflate systems. This information could than be used to refine the predictions shown in Section 18 regarding the reduction in the number of tires entering the waste stream and the net present value benefit to the California economy.

### **22.3.2 Validate the reliability of auto-inflate systems**

The study should include two groups of identical vehicles that undergo similar usage. The first group should be equipped with auto-inflate systems, while the second, without auto-inflate systems, should function as a control group. This study serves two purposes. First, it should test the reliability of auto-inflate systems under extreme demands. Second, the results of this study should be used to educate the public, auto-insurance companies, and automakers about the inherent benefits of auto-inflate systems.

California Highway Patrol (CHP) vehicles experience extensive usage and are subjected to extreme demands. Because of these operating conditions CHP vehicles are likely to be very well maintained, so that the effect of auto-inflate systems can be isolated. Moreover, the CHP has a large fleet of vehicles that can allow testing both the test and control groups under similar conditions, and throughout the state. Therefore, the CHP seems an ideal setting to conduct this study. The only drawback of using the CHP fleet is that, because CHP vehicles are exceptionally well maintained, using CHP vehicles might not provide a good measure of expected benefits.

The CHP study will be able to provide information on expected tire longevity, fuel consumption, and safety benefits under real life conditions. Additionally, if the vehicles equipped with auto-inflate systems perform as well as the control group it means that, indeed, auto-inflate systems deliver close to optimum performance.

Another purpose of this study would be to spur the availability of auto-inflate systems. Specifically, the state should wield its buying power and demand that vehicles tested be equipped, as OE, with auto-inflate systems. It was noted above that unavailability is one of the drawbacks to the voluntary adoption of auto-inflate systems. However, if automakers are forced to equip state vehicles with auto-inflate systems it will make it easier for them to offer such systems to the public, at least as an option.

## **23. Consumer Education**

Increasing the average life mileage of tires can be achieved in two ways. First, consumers can better maintain their tires. Educating the public to maintain their tires is discussed in Section 23.1. Second, the public can choose tires that average higher life mileage. Educating the public to the benefits of purchasing long life tires is discussed in Section 23.2.

### ***23.1 Educating the Public to Better Maintain Their Tires***

Because of inadequate maintenance, the average life mileage of tires is significantly below their potential (see Section 3). Consequently, educating the California public to better maintain their tires can help reduce the number of scrap tires generated in this state. Fortunately, good tire maintenance is relatively easy to achieve and includes three simple steps:

1. Proper tire inflation
2. Rotating tires every few thousand miles (typically every 5,000 miles)
3. Proper alignment

The three aspects of tire maintenance are discussed at length in Section 3. Of the three maintenance items, consumers typically only perform the first item themselves, while the other two are delegated to maintenance shops. Thus, the education system should have two components. First, educate the public about the importance of properly inflating their tires, and what proper inflation means. Specifically, the public should be made aware of the difference between maximum tire pressure (the value embossed on tire walls) and placard, which is specified by the automaker. They should be educated to determine what the placard pressure is, and about the difference between hot and cold pressure.

Rotating tires and vehicle alignment are procedures typically done in a maintenance shop. Therefore, the public should be educated about the need to regularly maintain their vehicles. Second, they should be educated to ask for tire rotation and alignment on a scheduled basis. Such education, however, should also be directed to the maintenance shops. They should be advised to educate their clients about the importance of tire rotation and alignment.

Many tire shops offer free tire rotation every few thousand miles. Some put stickers on the windshield to remind the consumer when they need to come in for tire rotation. Therefore, given that the service is frequently free, and the public is reminded of the time of the next scheduled rotation, it should be relatively easy to convince the public to take advantage of this service.

The public is required to pay for vehicle alignment. This would create some resistance on its part to align its vehicles. Moreover, a review of the literature on this matter suggests that it is easy to throw a car out of alignment (see Section 3.2.1.3). This would further increase the resistance of the public to spend money on vehicle alignment. Thus, proper public education about the advantages that it stands to gain is critical.

In view of the above, what should public education focus on? The objective of the CIWMB is to reduce the number of tires entering landfills. However, this argument is not likely to carry much

weight with most of the public and with tire vendors (those offering free tire rotation). Therefore, even though the goal is to reduce the number of waste tires, the arguments should, while noting the lifespan advantage, emphasize direct benefit to individuals. These benefits include: increased life mileage of tires (therefore reducing tire cost per mile); reduced fuel expenditure (and associated improved air quality); and improved vehicle safety due to the reduction of effective braking distance and the propensity for rollover.

A number of entities are already trying to educate the public to better maintain their tires. Noteworthy among these efforts are the ongoing RMA public education campaign entitled “be smart play your part” and the web site launched by Bridgestone/Firestone [www.tiresafety.com](http://www.tiresafety.com).<sup>99</sup> Additionally, in 2002 Shell Oil Company ran TV advertisements promoting proper tire maintenance. The CIWMB could collaborate with these entities and utilize the educational materials they developed.

Avenues available to disseminate information range from launching a web site dedicated to tire maintenance (similar to the one launched by Bridgestone/Firestone), to public service announcements on radio and TV, to advertising in printed media. The CIWMB could also employ direct mailing. For example, it could send monthly email reminders to subscribers to check tire pressure (this service is currently offered by [www.tiresafety.com](http://www.tiresafety.com)). Additionally, the CIWMB could team up with local media to feature stories as part of their regular programming (e.g., during TV evening news segments), interest national TV news magazines such as “60 minutes” (CBS) and “Frontline” (PBS) to feature stories on the importance of tire maintenance. Teaming up with either local or national programs could be based on issues high on the public agenda. For example, gasoline prices are significantly up this year. Better tire maintenance leads to improved vehicle fuel efficiency. Similarly, the public is always interested in better safety, which is improved by better tire maintenance. Finally, motivated by improved safety, auto-insurance companies may be enticed to include educational materials on tire maintenance with the information they mail their customers.

As was already pointed out, it may be that the bait used to get people interested in better tire maintenance has nothing to do with extending tire life mileage. However, it may prove more efficient to get people to better maintain their tires for reasons other than tire lifespan, yet the benefit to tire lifespan will be delivered.

Enticing people to better maintain their tires may prove hard. In this respect it is important to recall that even at the height of public interest in the 2000 Firestone recall of tires mounted on Ford explorer SUVs, the public did not alter their behavior. While getting people interested in tire maintenance proves to be a difficult task, keeping them focused on this issue may prove even harder. One way to maintain public attention is to conduct short intensified education campaigns. For example, a biannual “tire safety week” could be instituted where people would be reminded of the need to maintain their tires.<sup>100</sup> Again, to get the attention of people, focus will have to be on something other than tire lifespan. Specifically, safety and economic benefits should be

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<sup>99</sup> The RMA 2003 education effort is focusing on California.

<sup>100</sup> Assembly Concurrent Resolution No. 87, introduced on April 8, 2003, proclaimed the week of April 27, 2003 to May 2, 2003 as California Tire Safety Week.

emphasized. Tire lifespan should be noted too. However, education will not be effective if the emphasis is reversed (*i.e.*, using tire lifespan as the big header and safety as a secondary benefit).

Another barrier to the effectiveness of public education is that consumers think that they properly maintain their tires, when in fact they do not. For example, a recent survey conducted by California State University, Chico for the CIWMB found that some consumer maintained tire pressure at the value embossed on the tire sidewalls (Chico [2003]). This means that these consumers, who think that they properly maintain their tires, actually inflate them to the *maximum* allowed pressure, not the service (placard) pressure (see Section 3.2.1.1 for a detailed discussion of the difference between the two pressure levels). The same study also found that some consumers use visual inspection and changes in handling to evaluate tire pressure (Chico [2003]). As is illustrated by Figure 9.1, these are poor methods of tire maintenance. Yet these consumers feel that they regularly check their tires (Chico [2003]). In the study conducted by California State University, Chico temperature was not considered and therefore, it remains unknown if people that try to inflate their tires to the placard level actually do so. Based on the findings of this survey, one can conclude that educating consumers to properly care for their tires is not going to be highly effective in extending the lifespan of tires. Yet, because this is the only avenue available to address tires mounted on existing vehicles, it should be pursued in parallel with adopting other strategies.

### **23.2 Educating the Public to Purchase Longer Lifespan Tires**

Tires that achieve high life mileage raise the average life mileage for the entire tire population. Consequently, if Californians switched to purchasing long life tires, the number of tires entering the waste pipeline would diminish. Long life means tires that achieve an average life mileage above the average for the entire tire population. The CIWMB could help promote long life mileage tires by educating Californians to the availability of such tires.

One way to educate the public is by providing a rating system that would indicate to the public which tires can deliver longer life. Fortunately, there are two such systems in place: the UTQG tread wear rating and the limited warranty provide with some tires. Section 3.1 provides a detailed discussion of these rating systems.

Educating the public to purchase long life tires may not generate much opposition. However, the CIWMB message may compete with the California Energy Commission (CEC) effort to convince the public to use reduced rolling resistance tires, which typically requires some compromise on other tire characteristics including tread wear. Additionally, it is highly unlikely that consumers that purchase high performance tires would be persuaded to switch to longer life tires (see Section 3.3 for a discussion of performance tires). Arguing that longer life tires reduce tire cost per mile is not going to carry much weight with these consumers because they are primarily interested in performance. Moreover, high performance tires are typically more expensive than tires that deliver longer life. For example, many mass-produced tires cost less than \$80 and offer a limited warranty of 80,000 miles, whereas many high performance tires cost well over \$100 and offer no limited warranty whatsoever.

Discount tires contribute to the reduction in the overall average tire life mileage (see discussion in Section 3.4). Yet, it will prove hard to convince some consumers to switch from inexpensive

tires to long life tires because these consumers may not be able to afford such tires. For example, consumers can get a set of four new tires for \$100 or less. They may prefer longer life tires, but those may be beyond their means.

From the above discussion it follows that consumers of high performance and budget tires are not likely to follow the CIWMB advice. Accordingly, it is likely that the CIWMB education effort would be preaching to the converted (*i.e.*, those who already use tire life as a main criterion in selecting tires). Here it is important to recall that tire producers claim that longevity is a main criterion used by the public in selecting replacement tires. Therefore, it is important to consider the return on investment, from the CIWMB perspective, before proceeding with this education effort.

Emphasizing one aspect of tire performance may come at the expense of other tire attributes. For example, improving tire wear may increase rolling resistance and reduce traction. Increasing rolling resistance of tires results in lower vehicle fuel efficiency (see Appendix A for a detailed discussion of this subject), while decreased traction may increase the number of accidents in California. Thus, the CIWMB should educate consumers about how to balance between the different tire characteristics. Indeed, the optimal choice may differ from one consumer to the next. For example, consider the case of an owner of an old vehicle that requires new tires, but the vehicle may be taken off the road in a year or two, during which it will be driven 14,000 miles. Should the CIWMB advise the owner of this vehicle to purchase a long life tire or a lighter tire? In this case the answer is easy. To minimize the total tonnage of tires entering the waste pipeline, such a consumer should be advised to purchase a “light” tire. Unfortunately, most cases are not as simple. Hence, providing consumers with guidelines on how to choose their tires in more complicated situations may achieve a very desirable result from both consumer and CIWMB standpoints. This is an important point because consumers are much more likely to follow such guidelines, since they will feel that they get the best return for themselves, rather than advancing some government agenda, lofty as it may be.

## 24. Corporate Average Tire Life Standard

OE tires average only about 77% of the life mileage achieved by first replacement tires (CEC [2003]), and they constitute roughly 20% of the tires sold in California (RMA [2002a]). Thus, OE tires reduce the average life miles for the entire light-duty tire population by about 4%. This suggests that one way to extend the average lifespan of tires is to disallow the sale of OE tires in California.

Unfortunately, such a regulation will be hard to enforce. Specifically, there is no easy way to distinguish between OE and aftermarket tires; they have the same name, markings, and the same UTQG ratings. Therefore, a different approach is required. One approach that would get the CIWMB out of having to address literally thousand of tire models is to use an approach similar to the Corporate Average Fuel Economy (CAFE) standard. Specifically, each producer of light-duty tires present in California would be required to sell a mix of light-duty tires that would average a given limited warranty, or a specified UTQG wear rating.

Tire producers may argue against such a regulation. Their arguments may focus on the government adding yet another layer of bureaucracy. Additional arguments will mirror that put forward by the automakers against the CAFE standard including objection to the level set by the California government, saying it is too high. They may argue that such a regulation would negatively affect two other objectives set by California agencies. Specifically, higher tread ratings come to some extent at the expense of rolling resistance and traction. Thus, they may argue that because of this proposed regulation the safety of Californians might suffer two negative consequences. First, because reduced traction implies longer braking distances, transportation safety would be reduced. Second, because increased rolling resistance results in less efficient fuel consumption, Californians would spend more on fuel. The benefit cost analysis contained in Section 19 shows significant benefits to the California economy resulting from improved safety, reduced fuel consumption, and reduced air pollution. Therefore, one can conclude that the opposite effect could potentially cause significant harm to the California economy.

The following arguments could be used to overcome the obstacles that may be raised by the tire makers. Starting with the last obstacle, California should consider basing the standard on the UTQG wear rating. This is a government mandated standard and therefore, it is a uniform criteria applied to all tire makers. As was explained in Section 3.1, UTQG tread wear rating is not as good an indication of expected tire life as the limited warranty. However, the CIWMB may choose to use UTQG tread wear rating as the basis. Unfortunately, the UTQG wear rating is not necessarily what the test revealed. Rather it may be lower than the test result, depending on how the tire maker wants to position the tire model in the market.

The safety and fuel consumption arguments depend largely on the specific level that tire producers are required to meet. Thus, the debate should be shifted from the existence of the standard, to the level imposed (which should be updated on a regular basis every few years). To address the specific arguments one must draw on the experience with the CAFE standard. Specifically, when the CAFE standard was introduced automakers claimed that it was too high

and vehicles would have to be less safe to meet the standard. This criticism proved to be incorrect (see Section 14.3).

The key to making this regulation work, therefore, would appear to be: avoiding being too overreaching at the outset. Specifically, the standard should be set in such a way that it continually raises the bar and forces tire makers to deliver tires that average ever-higher life mileage. At the same time tire makers should be allowed reasonable time to meet the standard. Moreover, it should be pointed out to them that the mechanism of this regulation allows them to keep profitable markets (*e.g.*, high performance tires), while delivering other tires that make up for the markets the tire producer wants to protect. In other words, this approach gives tire producers a lot of flexibility. As can be surmised, setting the “optimal” level requires a considerable amount of research and, therefore, this task is left for a subsequent study.

The CIWMB should not focus just on the rubber part of tires. Instead, credits should be given for smart tire systems. For example, tires mounted on rims equipped with auto-inflate systems will average higher actual life mileage than tires installed on conventional rims. By allowing this type of credit the CIWMB will both encourage innovative technologies, and be better positioned to address future tire developments, which seem to be focused to a large extent on “smart.”

The proposed regulation could have the effect of eliminating from the California marketplace producers of cheap low-end tires. Therefore, these producers, as well as some consumer groups, may object to this rule on the grounds that it will eliminate a choice for low-income consumers. They may also claim that eliminating the low-end producers from the market would enable the established tire makers to raise prices. In response to these claims the CIWMB could point out that these low-end tires primarily replaced light-duty retreaded tires, and did not take any meaningful market share from established tire producers. Thus, removing low-end tires from the marketplace could bring back light-duty retreaded tires, which may also benefit the local economy if tires are retreaded in California. Moreover, retreaded tires are diverted from landfills and thus this strategy could further benefit the CIWMB main objective.

Finally, other California agencies may object to such a standard. For example, the CEC is encouraging the use of reduced rolling resistance tires; this effort would be hindered by this standard. Arguments to avoid this internal impediment would depend on the specific source of the objections. At the moment the main difficulty would appear to be the opposing demands of the CEC, and this aspect is addressed in Appendix A.

## 25. Taxes and Rebates

The benefit cost analysis of using taxes and rebates to steer consumers to longer life tires yielded a negative return (*see* Section 19) and consequently, it is not considered a viable strategy. However, a change in the tire disposal tax should be considered. Currently a disposal tax of \$1 dollar is levied on all new tires sold in California. This tax is the same for tires that weigh 100 lbs and tires that weigh only 17 lbs. Similarly, this tax is the same for tires that are sold with a 100,000 miles limited warranty and tires that are sold with no limited warranty.<sup>101</sup>

An *ad-valorem* tax that would take into account the following criteria should be considered:

1. Weight
2. Limited Warranty or UTQG wear rating.
3. Retreadability.

**Remark:** An *ad-valorem* tax can be achieved either by changing the tax levied on tires, or equivalently by keeping the tax fixed and providing rebates. The rebate provided for energy efficient appliances is one example of the second approach. However, to keep notations short both approaches are referred to as tax. ♦

The motivation to screen by weight is quite simple. Scrap tires are typically shredded and thus, the important criteria is not how many tires are processed but how many tons of waste are generated. The limited warranty is preferred over the UTQG rating because it reflects the tire maker's realistic expectations for a tire (after all, they are willing to back their claim with money). A fleet equipped with tires that average 50,000 life miles would generate less scrap tires than a fleet equipped with tires averaging only 40,000 life miles. Finally, tires that are warranted to be retreadable (as are some of the heavy-duty tires) should be encouraged because retread tires reduce the number of scrap tires that end up in landfills.

The objectives for such a tax will be to reward consumers who purchase long life tires. Additionally, consumers who are faced with higher taxes on one product vs. another may pause to consider what the difference is between the two products and, thus, be diverted to longer life tires. Third, such a tax policy may benefit the heavy-duty retread tire market, and possibly help rekindle the market for light-duty retread tires.

Objections to an *ad-valorem* tax would come from a large range of sources. Tire vendors may object on the grounds that the new tax will be difficult to administer. Tire makers may object because performance tires, the most profitable market segment, will be faced with the highest taxes.<sup>102</sup> Car dealers and automakers may object because the average life mileage of OE tires is about seventy seven percent of that for first replacement tires (CEC [2003b]) and thus, consumers will have to pay higher taxes on OE tires. Finally, consumer groups may argue that this is just another way to raise taxes.

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<sup>101</sup> See Section 3.1 for a discussion of the relevance of limited warranty to the expected tire life mileage.

<sup>102</sup> Many performance tires do not offer any limited warranty (*see* Section 3.3).

A counter argument to the administrative difficulty is that computing the tax is very simple. It should be done only once a year for each tire model and thus, for even a large store handling a few hundred tire models the administrative overhead will amount to just a few hours per year. Moreover, the CIWMB can distribute to all dealers a simple calculator where the dealer selects the tire, and the tax is displayed. Thus, using technology can bypass this aspect of the criticism, or at least take the sting out of it. Alternatively, the CIWMB could distribute and publish on its web site tables with the required tax for each tire model and size.

Addressing the tire makers' concerns will have to be done on a political level because their argument would be economically based. The objections of car dealers and automakers may be harder to address. The administrative component of their argument is addressed above. Additionally, car dealers may object to such tax because it is likely to cut into their profits since they may argue that they, not the consumer, will end up having to pay a large portion of the tax. They may further argue that since the *ad-valorem* tax is intended to provide consumers with an incentive to switch to longer life tires, it will not achieve its goal. The response to this argument is that should new vehicles be equipped with long life tires, the tax on them could actually be reduced. It is also hard to see how car dealers, automakers, and tire makers would argue the point that the tax on OE tires would be higher than that for seemingly the same replacement tires.<sup>103</sup>

Environmental groups, such as the Natural Resources Defense Council (NRDC), may opt to point out that replacement tires result in higher fuel consumption. Therefore, the NRDC would argue that OE tires should not only be encouraged but in fact replacement tires should be made more like OE tires.<sup>104</sup> A counter argument here would be that the tax is for the cost of disposal. The NRDC could argue that the California legislature should provide a rebate to consumers who purchase tires with reduced rolling resistance. But, that should be treated as a separate issue.

The anti-tax critics as well as the tire industry, however, are likely to complain about the fact that by this legislation the state would know exactly how many tires, and of what type, each producer sells in California. The critics could argue that this may give the government important marketing information, which if placed in the wrong hands could cause significant harm to one or all tire producers. This criticism is legitimate and should be addressed by setting up safeguards on the information provided to the government. For example, vendors could inform the government only of weight, and UTQG wear rating. Additionally, the CIWMB should install a strict privacy policy that would prevent misuse of this information. These issues should be further addressed in a follow-up study.

Future advances in tire technology will increasingly depend on tire "intelligence." For example, auto-inflate systems can extend tire life or rather deliver in practice results closer to what the vendors promise. Therefore, the proposed *ad-valorem* tax should account for smart tires. However, how to do that is left to a follow-up study.

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<sup>103</sup> This point would be applicable only if the tax will be based on limited warranty. If the tax will be based on UTQG tread wear rating then there will be no difference between the taxes levied on OE and aftermarket tires.

<sup>104</sup> According to the NRDC web site, OE tires average 20% lower rolling resistance than replacement tires (<http://www.nrdc.org/air/energy/rep/app.asp>).

Finally, much of the criticism discussed above can be eliminated if the tax change is achieved through direct rebates to consumers. For example, tire vendors will not be subjected to any additional administrative demands. However, taking this approach will require significant funding as discussed in Section 17.3.

## **26. Proposed Future Research**

The CIWMB can act immediately on any of the four strategies detailed above. However, increasing the lifespan of tires can benefit from additional studies. Two of these areas of research are discussed next. First, this review identified smart tires as a main vehicle to extend the lifespan of tires. An in-depth look into smart tires technologies is proposed in Section 26.1. Second, it was pointed out in Section 3.2.2 that preliminary studies identified road roughness as an important contributor to tire longevity. Studies of the contribution of tire-pavement interaction to tire longevity are outlined in Section 26.2

### **26.1 Research Smart Tire Technologies**

The main outcome of the current review is that auto-inflate systems are pivotal to extending the lifespan of tires. However, auto-inflate systems are but one example of smart tire systems. Because of their importance, this section looks separately at studying auto-inflate systems (Section 26.1.1), and then proceeds to propose studies of additional smart tire systems (Section 26.1.2).

#### **26.1.1 In-depth look at Auto-Inflate Systems**

The current review accepted some important data as given. Examples of such key data include the state of tire pressure maintenance found by the 2001 NHTSA survey (see Section 3), and Goodyear's disclosure to NHTSA that for each psi below placard tires lose about 1.78% of their tread life. An important step, proposed in Section 22.3, is to validate these findings for California. The finding of these proposed studies would enable a more detail analysis of the effect that auto-inflate systems would have on the lifespan of tires (*i.e.*, improve the prediction of potential reduction of tire waste, and the benefit to the California economy). These studies would require two years to conduct, and the needed budget would probably be about \$1,250,000.

The auto-inflate system can have additional benefits. For example, according to Mr. Carl Tapp, Director of Maintenance at P.A.M. Transport Service Inc., trailers equipped with auto-inflate systems can continue to operate safely at highway speeds even when a tire suffers a small puncture. This enables the driver, who is notified that a tire is losing air, to proceed safely to a service location without risking tire blowout. This idea can be extended to consider auto-inflate systems as "soft" run-flat tires. Having this technology may enable lighter run-flat tires (because some of the burden is shifted to the compressor), and may finally eliminate the spare tire, which both adds to tire waste and takes up valuable space.

As was already noted current auto-inflate systems attempt to maintain tire pressure near placard. However, a fully computerized system could take into account temperature and replace the fixed placard level with a temperature corrected level, thus further optimizing vehicle performance.

The above improvements offer just a sample of advantages that next generation auto-inflate systems could offer. Therefore, in addition to the validation studies noted above, the CIWMB should consider sponsoring further conceptual development of the functionality offered by auto-inflate systems. Specifically, such studies should attempt to identify ways in which auto-inflate

systems can better optimize tire performance, and conduct cost-benefit analyses to predict the potential benefits to reduce tire waste and to the California economy. The development of actual systems, however, should be left to the private sector. Studying improved auto-inflate systems concepts could be carried out as a one-year \$250,000 project.

### **26.1.2 Identify additional technologies**

Additional smart tire systems can also contribute to extend the lifespan of tires. For example, the optimal tire inflation pressure depends among other things on the load they support. Thus, the optimal pressure would be lower for a lightly loaded vehicle than for a vehicle loaded to capacity. The placard pressure, however, is based on the maximum load. Thus, a smart system could adjust the tire pressure in accordance with the load carried. Integrating the tires into the suspension system, which can reduce the braking distance and extend the life mileage of tires (see Section 7.2), offer a second example of the possibilities of smart tires.

Because of the potential of smart systems the CIWMB should consider investing in identifying smart systems that can contribute to extend the lifespan of tires. Specifically, a first step should be to review what are the different smart systems under consideration (excluding auto-inflate systems), and prioritize them in terms of their potential. This study should parallel the general format of the present work and consist of a review of technologies and a benefit cost analysis including a prediction of the reduction in tire waste. A one-year effort with a \$200,000 budget appears to be the general framework for such a study.

## ***26.2 Research the Effect of Pavement Design on Tire Longevity***

The review in Section 3.2.2 suggests that tire wear is greatly affected by the characteristics of pavement surfaces. At the same time little information exists in the published literature on this subject. Therefore, this section proposes a three-phase approach to define tire wear as a function of pavement surface characteristics.

### **26.2.1 Phase 1: Review Published and Unpublished Sources**

This phase would involve a review of existing published and unpublished information. The sources for this information would include: tire manufacturers, truck manufacturers, and trucking companies as well as organizations that maintain passenger car fleets. An example of the type of information that would be most useful is that developed at WesTrack, a test track conducted at the Nevada Automotive Test Center (NATC) for the Federal Highway Administration. The purpose of the test track was to evaluate the behavior of asphalt concrete mixes subjected to traffic loading. NATC monitored truck tire wear during the operation of four truck-trailer combinations in the period 1995-2000. During this period continuous measurements were made of both the pavement surface characteristics including road roughness and tire wear. Unfortunately, funds were not available to analyze the effect of pavements on tire wear.

In evaluating this information it will be imperative to attempt to separate, at least in a qualitative manner, the effect of road surface characteristics on tire wear from other factors, such as inflation pressure. This could be achieved by following the approach of Papagiannakis [1999] who studied fleets that operated on dedicated routes.

It is anticipated that this phase would cover a period of one year at an estimated expenditure of \$250,000. Activities would include not only the analyses of existing information as discussed above, but also plan the Phase 2 and Phase 3 programs.

### **26.2.2 Phase 2: Tire-Pavement Interaction Under Controlled Conditions**

This phase would involve the use of a device that could apply accelerated loading in tires at a fixed site. The site would involve pavements in which the friction characteristics and surface texture characteristics would be controlled. As an example, for the series, pavement surfaces would consist of asphalt concrete and Portland cement concrete with controlled coefficients of friction, *e.g.*, 0.9 and 0.3. Another series would consist of asphalt concrete, constructed with a specific aggregate (to control the friction characteristics), one surface would be a dense-graded asphalt concrete, the other an open-graded asphalt mix. For the concrete surfaces, there would be considered one with a broomed texture, a second with transverse grooves, and the third with longitudinal grooves. The smoothness of the sections would be carefully controlled so that all would have the same low IRI so that the effects of friction and texture could be evaluated. It is anticipated that this phase would require about one year to complete, including the development of the device to apply the accelerated tire loading. The estimated cost is \$1.5 million.

### **26.2.3 Phase 3: Full Scale Testing**

This phase would involve the use of the WesTrack facility previously noted. In this case the variables of friction and texture would be controlled and from a tire-wear standpoint would be used to investigate the influence of pavement smoothness. The track would include both asphalt and concrete sections. Tire wear would only be one research aspect of this phase since it would involve other considerations as well which are associated with vehicle pavement interaction. These would include pavement damage, truck damage and fuel costs as a function of pavement smoothness.

During the WesTrack project only heavy-duty trucks were used (since they are the ones damaging the pavements). During the next round it should be possible to add also a number of light-duty vehicles to the traffic mix. These vehicles would not contribute to damage the pavements, and will add important information regarding the interaction between light-duty tires and the surface of the pavement. Note that if light-duty tires are also tested then this study could be combined with the study proposed in Section 22.3.2 and further discussed in the beginning of Section 26.1.1.

To reconstruct and operate four trucks on the WesTrack facility for a four-year period the cost is estimated to be about \$10 million. Cost sharing for this phase would include the following agencies: Federal Highway Administration, Department of Energy, truck manufacturers, the American Trucking Association, tire manufacturers, fuel and lubricant producers and possibly the National Highway and Traffic Safety Administration.

## 27. Conclusions

This report presents four different strategies to extend the average life mileage of tires. These strategies are: (1) employing auto-inflate systems; (2) educating the public to better maintain their tires; (3) employing a corporate average tire life standard; and (4) *ad-valorem* tire tax/rebate. It is emphasized again that these strategies, while presented independently, are likely to be more effective if implemented in an integrated manner.

These strategies are analyzed from three different angles: (1) potential to achieve the stated goal; (2) economic benefit cost analysis; and (3) obstacles to implementation. (No benefit predictions are made for the third strategy, corporate average tire life standard.) Additionally, risk analysis is used to gage the reliability of achieving the benefits predicted. The proposed strategies are compared to a uniform adoption of indirect TPMSs (the lower level of compliance with NHTSA's TPMS rule). For completeness, however, predictions are also made for the case of uniform adoption of direct TPMSs.

First, consider the contribution of each strategy to reduce the number of waste tires being generated in California. It is evident from the forecasts shown in Section 18 that auto-inflate systems offer the largest reduction in waste tires. For example, in 2012 2.54 million waste PTEs will be saved (RMA data analysis) while the second best solution (direct TPMS) would reduce the number of waste tires by 0.91 million waste PTEs.

Second, consider the effect of each strategy on the California economy. Two measures are used. The first is the net present value, which is the difference between benefits and costs, discounted to present value.<sup>105</sup> The best result appears to be achieved by the education system, with about \$1.55 billion. However, note that the cost for this strategy was not computed. The second best return is achieved by auto-inflate systems with about \$1.06 billion return. The direct TPMS and tax strategies both appear to have a negative return. There are two important issues to be considered when reading these results. First, the cost associated with the education strategy was not computed and therefore, is not included in the analysis. This cost would reduce the economic benefit of the education strategy. Second, fuel and emission benefits computations depend on the base tire pressure, which is selected as 24.6 psi. This choice is influenced by a NHTSA study.<sup>106</sup> However, the NHTSA study surveyed hot tires, while the placard pressure is intended as cold inflation pressure. Because the hot pressure is typically four or five psi above the cold pressure, and the extra pressure builds up rapidly and declines slowly, it is possible to conclude that the fuel and emission savings may increase by as much as 50%. Also, the safety benefit may increase as well. As a result, it is most likely that the auto-inflate system should be considered as the best strategy based on a net present value analysis. Finally, factoring in the results of the risk analysis shows that the reliability of the auto-inflate strategy is considerably higher than that of

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<sup>105</sup> The results are presented in 2002 dollars.

<sup>106</sup> The assumptions build on a NHTSA survey of tire pressure that found an average of 23.9 psi, and the estimate by NHTSA that indirect TPMSs contribution to extending the lifespan of tires is marginal. Thus, our assumption of 24.6 psi can be viewed as conservative (*i.e.*, it minimizes the reduction in fuel consumption and extending the lifespan of tires).

the education strategy, thus, again suggesting that even on a pure economic basis the auto-inflate strategy is best among the strategies considered.

The second economic criterion is the B/C ratio. These ratios are computed for the two technology solutions, and for the tax and subsidies strategy. It is not considered for the education strategy because the costs were not computed. Of the alternatives for which B/C is computed auto-inflate systems achieve the highest ratio. Thus, auto-inflate systems appear to be the winner on the basis of all three criteria.

Finally, the reliability of the different strategies must be considered. Of all strategies evaluated only the auto-inflate solution does not depend on human intervention. All other strategies require a person to inflate the tires. Therefore, the degree of reliability of the different strategies varies considerably, with the highest degree of reliability associated with auto-inflate systems.

This report also presents some of the obstacles, and ways to overcome them, to the implementation of the proposed strategies. A major barrier to implementing the proposed strategies is the inability to make winning arguments based solely on extending the lifespan of tires. Rather, additional benefits such as improved fuel economy, safety, and reduced air pollution must be used to draw consumer interest.

Competing demands on tire characteristics are also a barrier to extended life. For example, reducing rolling resistance may sacrifice tire life (see Appendix A). A way to overcome this type of barrier is to identify strategies, if possible, that advance multiple demands. For example, automatic maintenance of tire pressure via auto-inflate systems both extends the effective life mileage of tires and improves fuel efficiency.

The goal of the CIWMB is to reduce total tire waste, not necessarily to promote longer life tires. Therefore, if the CIWMB undertakes an education campaign to promote longer life tires it should consider that in some cases following this recommendation would hinder its objective. Rather, the CIWMB should promote guidelines that would always reduce waste by weight. For example, the CIWMB could have different guidelines for each generation of replacement tires (*i.e.*, first replacement, second replacement, etc.).

Any strategy to extend tire life mileage has to look towards the future and be adaptive. For example, the third and fourth proposed strategies depend on the expected life of tires. However, a tire mounted on a vehicle with an auto-inflate system will achieve longer life than if the vehicle was not equipped with such a system. Therefore, as an incentive, these strategies should give “credits” for tires mounted on vehicles with installed auto-inflate systems. It may prove difficult to administrate these credits for used vehicles, but should be possible for new ones.

Finally, a number of proposed research projects that can advance the cause of extending the lifespan of tires are also presented. These projects range from taking an in-depth look at smart tire technologies, to validating some of the underlying assumptions accepted in the current report, to finding ways to consider tire wear when designing pavements (currently pavement engineers pay little or no attention to tire wear).

## Appendix A: Reduced Rolling Resistance Tires vs. Tire Wear

The California Energy Commission (CEC) recently issued a two-part report promoting reduced rolling resistance tires (RRRTs) in order to achieve a three percent reduction in auto-fuel consumption (CEC [2002a,b]). As noted in the body of this report, rolling resistance and tread wear are coupled tire design criteria. Specifically, improving one comes at the expense of the other. For this reason, and in view of California government agencies possibly issuing conflicting demands, RRRTs are discussed in this Appendix.

Before proceeding to address the relevant CEC comments it is important to state that improving vehicle fuel economy brings both direct and indirect economic benefits. Direct benefits include reduced cost of fuel. Indirect benefits include reduced air pollution. These are important advantages. Using RRRTs is one approach to improving vehicle fuel economy and therefore, this technology should be pursued. However, the implications for other aspects of vehicle operations (*e.g.*, safety and tire longevity) should be carefully considered.

OE tires average about 20% lower rolling resistance compared to first replacement tires (<http://www.nrdc.org/air/energy/rep/app.asp>). Therefore, examining the implications of RRRTs begins by comparing OE and first replacement tires in Section A1. Next, the CEC tested a few tires to determine their rolling resistance. These results are reviewed in Section A2. The CEC is advocating RRRTs, but how does the reduced fuel consumption fare with the age of the tire? This issue is considered in Section A3. Finally, some general comments pertaining to RRRTs and the future of tire evolution are presented in Section A4.

### **A1 OE vs. Replacement Tires**

According to the Natural Resources Defense Council (NRDC) “The average rolling resistance of replacement tires is about 20 percent higher than that of tires that automakers put on new vehicles” (<http://www.nrdc.org/air/energy/rep/app.asp>). According to the CEC report the relation between rolling resistance and fuel efficiency improves by about 1% for every 5% (10%) reduction in rolling resistance during highway (city) driving (CEC [2003b], Section 3.2). Combining this information leads to the conclusion that OE tires are expected to improve fuel efficiency by about 3% for combined city and highway driving.

According to the CEC report, the average life mileage for OE tires is 38,100 miles while the average life mileage for first replacement tires is 49,600 miles (CEC [2003b], Table 2). Thus, OE tires average only 76.81% of the life mileage delivered by the first replacement tires. This is a significant reduction in tire life mileage. The gap between the OE and first replacement tires becomes even more pronounced when vehicle age is factored in. Specifically, the condition of a suspension system of a vehicle that traveled 62,900 miles is considerably degraded compared to a vehicle that logged only 19,050 miles.<sup>107</sup> Therefore, it is reasonable to expect that should the first replacement tires be installed on new vehicles the gap in service life between the OE and first replacement tires would increase. On the other hand, typically purchasers of new vehicles

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<sup>107</sup> 62,900 and 19,050 are the medians for the vehicle miles traveled (VMT) for the vehicle equipped with the first replacement and OE tires, respectively.

are more affluent than purchasers of used cars. Consequently, OE tires being removed from vehicles may be in better condition than first replacement tires when they are taken out of service. This suggests that OE tires can actually average more than 38,100 life miles if used to their full capacity. Thus, two opposing conditions are in play, and until better data become available the CEC numbers are used.

The CEC acknowledges the need to balance between different tire design performance characteristics. However, it proceeds to quote the titles of four different research papers to reach the conclusion that “the State should be able to pursue both the goal of improving fuel economy from LRR tires and the goal of reducing tire waste” (CEC [2003b], page 17).<sup>108</sup> The CEC report goes on to note (CEC [2003b], page 22):

“While there is evidence that OEM tires can frequently have shorter lifespan than replacement tires, this is more likely due to the fact that tires are not covered by car manufacturer warranties (and therefore bring with them little incentives for longevity) than due to some unavoidable aspect of LRR design. If for example, one straightforward means of reducing rolling resistance is to produce a lighter weight, thinner tire, it is also the case that other means of doing so are available, and rely in large part on material *substitution* instead.”

The four research papers noted in the CEC report discuss rubber compound technologies that, generally speaking, are used extensively in OE tires (*e.g.*, replace carbon black fillers with synthetic silicas). In fact, rubber compound substitution is the main tool available to tire makers to engineer OE and other RRRTs (Hermann [2003]). This is because hysteretic losses account for 80 to 95% of the total energy lost (LaClair [2002]).<sup>109</sup>

Tires are the only vehicle component not covered under the warranty provided by the automaker. Rather, it may be covered by a limited warranty provided directly by the tire manufacturer. Tire producers typically provide a limited warranty also for the replacement market. Moreover, many high-end tires provide no limited warranty for either the OE or the replacement tires (see Section 3.3). Therefore, it is not clear what role the limited warranty plays in shortening the average OE tire life mileage relative to the average replacement tire, as claimed in the above quote taken from the CEC [2003b] report.

It was already pointed out above that automakers specifically require that tires be optimized for each vehicle individually. In this optimization process reducing rolling resistance is highly valued because it helps automakers meet the Corporate Average Fuel Economy (CAFE) standard. It is also widely acknowledged by the tire industry that they place much more emphasis on tire life mileage for after market tires. This would strongly suggest that the large longevity disparity between OE and first aftermarket tires is due indeed to engineering limitations.

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<sup>108</sup> LRR stands for lower rolling resistance.

<sup>109</sup> Hysteretic losses are a characteristic property of viscoelastic materials such as rubber.

There is a caveat to the above conclusion. It is common knowledge that producers of tires sell OE tires at a significant discount.<sup>110</sup> This may give some credence to the CEC claim noted above that tire makers have an incentive to reduce the life mileage of OE tires. According to CEC report (see quote above) tire producers may resort to lighter weight, thinner, tires. If by this the CEC implies that the tread thickness is reduced then it is also the case that OE tire makers are running the risk of consumer dissatisfaction. Specifically, a large percentage of first replacement tires are of the same tire brand and model as the OE tires they replace. In fact, it is the hope for brand loyalty that partially motivates discounting OE tires. However, while automakers emphasize rolling resistance and vehicle performance, the public wants long life tires. Therefore, tire makers seeking brand loyalty should be motivated not to sacrifice life mileage for OE tires. Moreover, generally speaking brand loyalty does not extend to the second replacement tires, because consumers are reluctant to buy expensive tires for older vehicles. This means that the advantage of deliberately reducing the lifespan of OE tires is marginal.

The tire market is highly competitive, with many manufacturers and no dominant player. Therefore, it seems reasonable to assume that each tire producer would leverage any marketing advantage they can utilize. Thus, marketing tires that deliver low rolling resistance, long lifespan, good traction (safety and performance), and are competitively priced would be a tremendous asset. The question therefore is why tire makers have not introduced such a product. One should therefore consider the possibility that technological limitations prevent the development of such tires.

Finally, as was noted above, OE tires are optimized for each individual vehicle. Yet OE tires average 3% improved fuel efficiency over the first replacement tires. This is the value that the CEC set as the improved fuel efficiency goal for all tires. However, replacement tires are required to deliver a certain performance level for a wide range of vehicles from a number of automakers. Therefore, it is less likely that aftermarket tires can achieve the same level of optimization as OE tires and consequently, the goal set by the CEC appears to be overly optimistic. Here it is important to note that a 2002 Transportation Research Board (TRB) report, quoted in the CEC report, sets a more modest target of only 1 to 1.5% improved fuel efficiency by reduced rolling resistance.<sup>111</sup> Not reflected in the CEC report is that the TRB report (TRB [2002], page 39) goes on to note “The impact on performance, comfort, durability, and safety must be evaluated, however.”

## **A2 CEC Tire Test Results**

The CEC studied the relationship between rolling resistance and various tire design parameters for a limited number of tires. The following discussion is primarily focused on the analysis of the link between rolling resistance and tire tread wear.

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<sup>110</sup> Tire makers justify this pricing strategy by noting that automakers buy tires in large volume. Additionally, installing OE tires gives the tire maker an advantage in influencing a vehicle owner’s selection of their first replacement tires.

<sup>111</sup> The CEC report identifies the TRB as the National Academy of Science (NAS), of which the TRB is indeed a part.

**Remarks:**

1. The CEC used a composite tread wear rating scheme, which appears to be an average of a scaled UTQG wear rating and consumer reports testing, and tire rack survey results. This rating will also be used here when compared to specific plots in the CEC report.
2. The CEC used a database of German tires in its study. It should be pointed out that Germans use summer and winter tires, not the all-season tires that are used in California. However, design criteria for all-season tires are different than those used for either summer or winter tires. Therefore, it is not clear that a direct comparison is possible. ♦

Figures A1 through A4 present the data shown in Figure 6 of CEC [2003b], broken down by tire size.<sup>112</sup> The first two figures correspond to passenger tires, while the last two show light truck tires. The CEC notes that there are a number of tires that have a similar rolling resistance, but very different tread wear ratings. For example, Figure A1 shows six tires whose rolling resistance range between 1.03 and 1.13, and whose wear rating ranges from 4.1 and 9.2. Thus, they conclude, it is possible to have tires that have both long tread life and low rolling resistance.

This analysis has merit as long as tires are distinguished only by their size. However, if this were the case then each tire maker would produce only one tire type for each tire size. A review of any large tire manufacturer reveals that they produce a large array of tires of the same size, each catering to a different market segment. Thus, the CEC conclusion is somewhat premature, unless they took care to compare tires that address the same consumers. However, this is not discussed in their report.

Tires are required to meet a wide range of simultaneous demands including: wear rating, reduced rolling resistance coefficient, comfort level, cost, and noise level. Therefore, it is customary to present tire performance in radar plots showing in a single plot how tires perform for different criteria. Figures A5 through A8 present the radar plots for the four tire sizes presented in Figures A1 through A4, respectively. The criteria shown are UTQG tread wear rating (normalized by 620, which is a rating that was correlated, Table 3.1, with tires that have a limited warranty of 80,000 miles), rolling resistance (denoted RR), cost (normalized by \$157, the most expensive tire considered by the CEC), and wet and dry tractions (the traction ratings reported by the CEC are scaled by dividing by 10). Only tires for which the CEC provided all data are shown in these figures.

The axes in Figures A5 through A8 are such that the better tires in terms of rolling resistance (RR) are those tires that lie closer to the origin. Better tires in terms of traction (wet and dry) and tire wear are those that appear further from the center. A tire is more expensive if it lies away from the origin.

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<sup>112</sup> Figure 6 of CEC [2003b] combines information for all tire sizes into one figure.

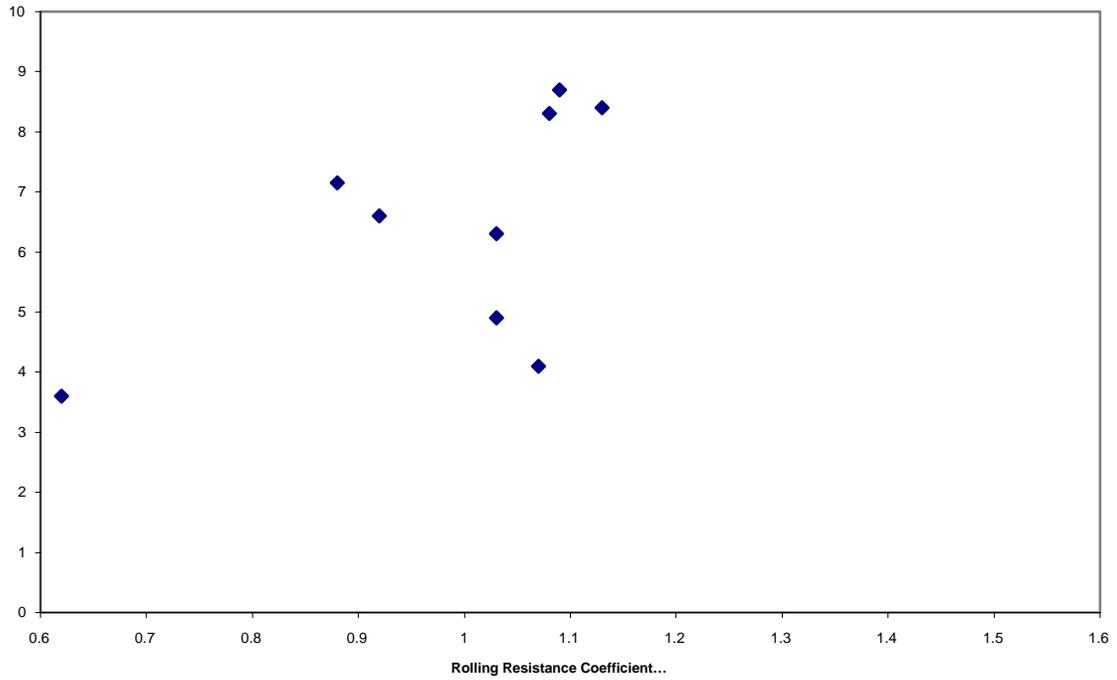


Figure A1: Composite tread wear vs. RR coefficient for 185/70R14 tires (Source: CEC [2003b]).

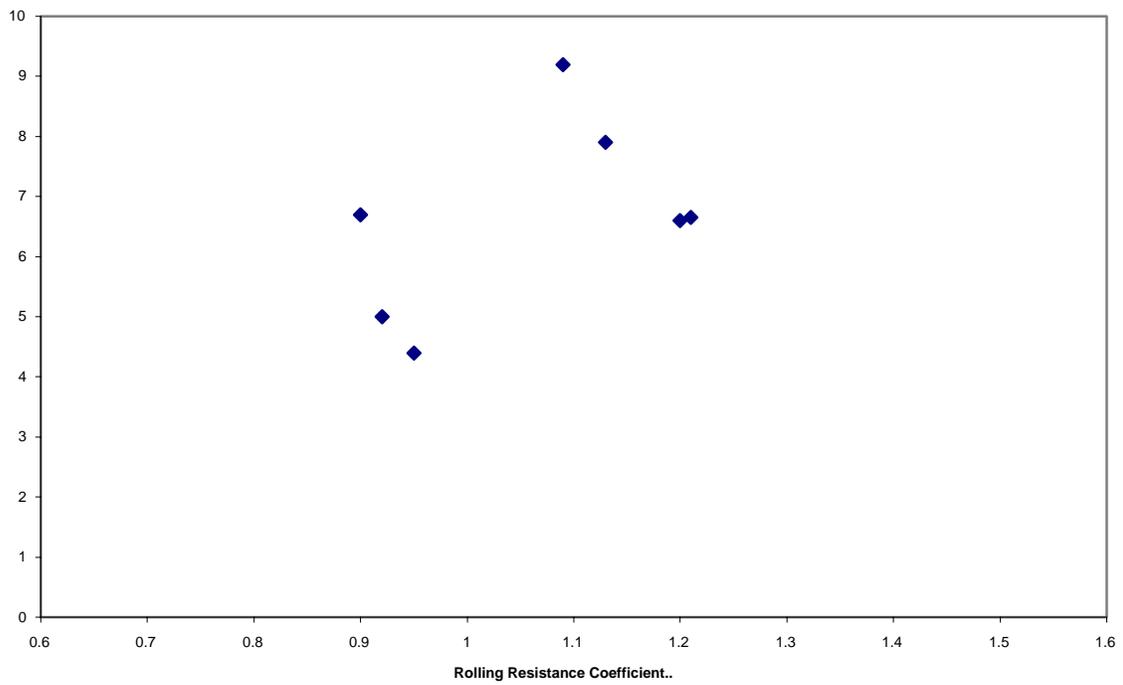


Figure A2: Composite tread wear vs. RR coefficient for 205/55R16 tires (Source: CEC [2003b]).

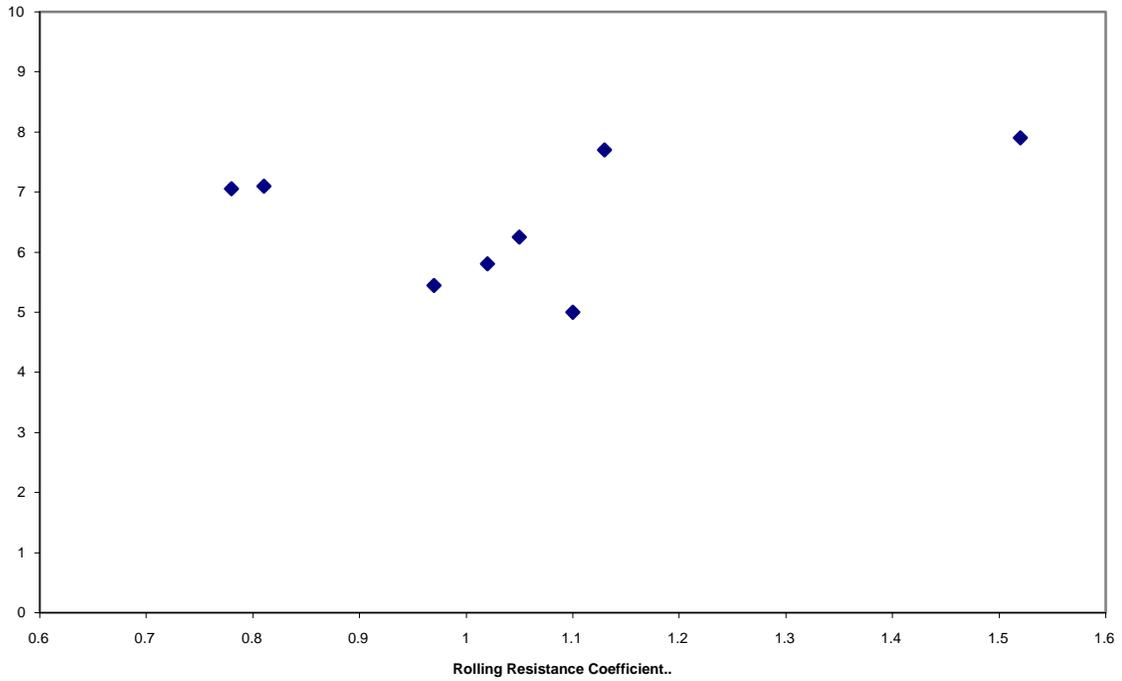


Figure A3: Composite tread wear vs. RR coefficient for 235/75R15 tires (Source: CEC [2003b]).

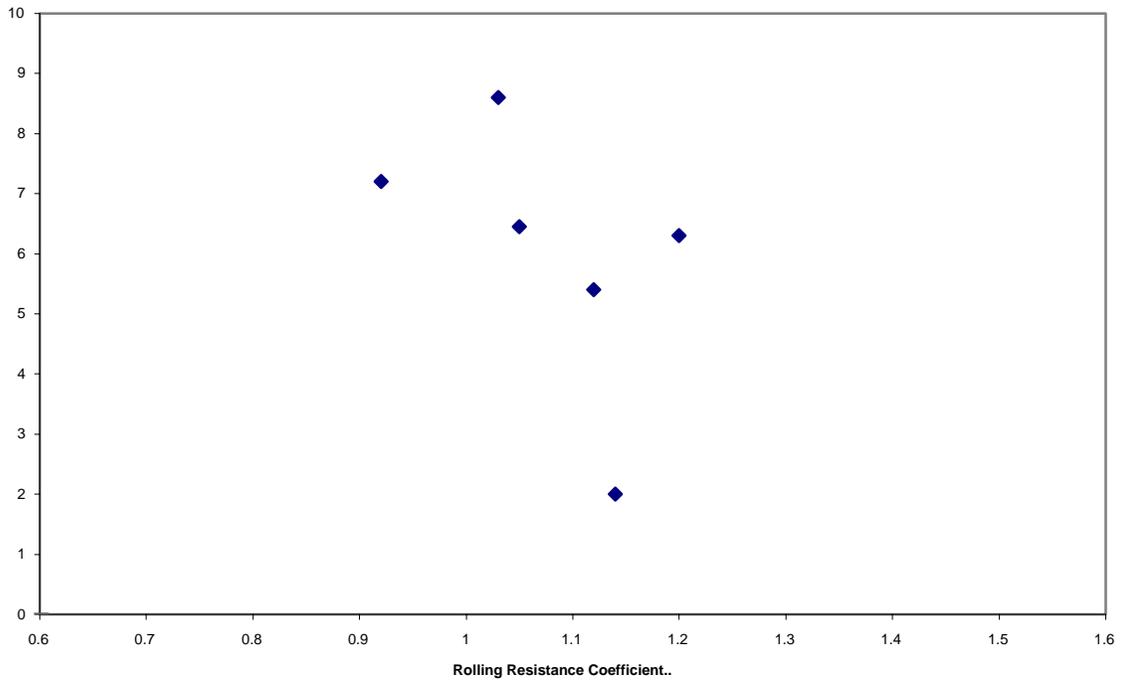


Figure A4: Composite tread wear vs. RR coefficient for 245/75R16 tires (Source: CEC [2003b]).

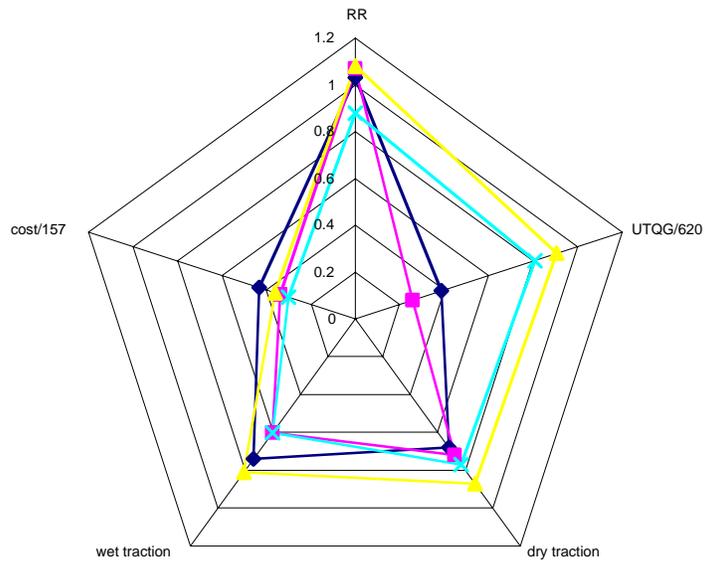


Figure A5: Performance tradeoffs for 185/70R14 tires (Source: CEC [2003b]).

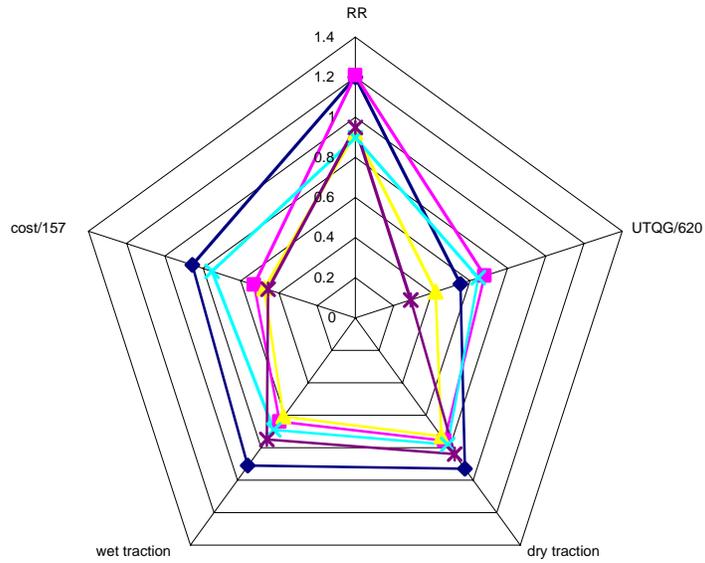


Figure A6: Performance tradeoffs for 205/55R16 tires (Source: CEC [2003b]).

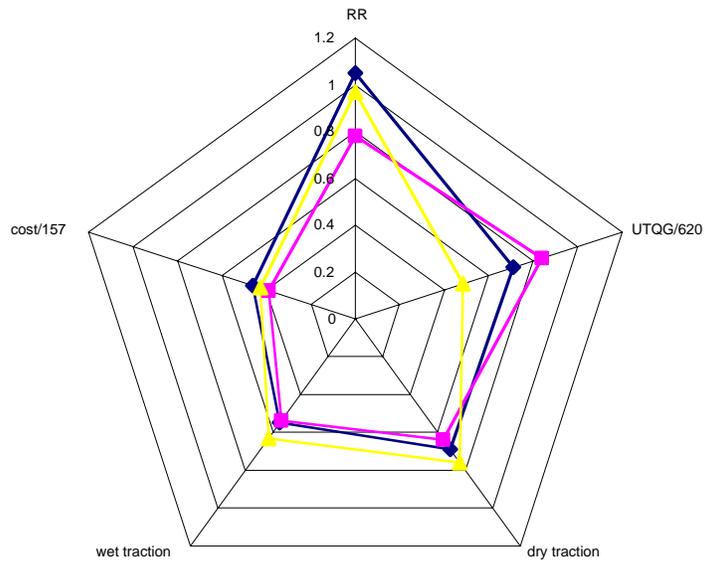


Figure A7: Performance tradeoffs for 235/75R15 tires (Source: CEC [2003b]).

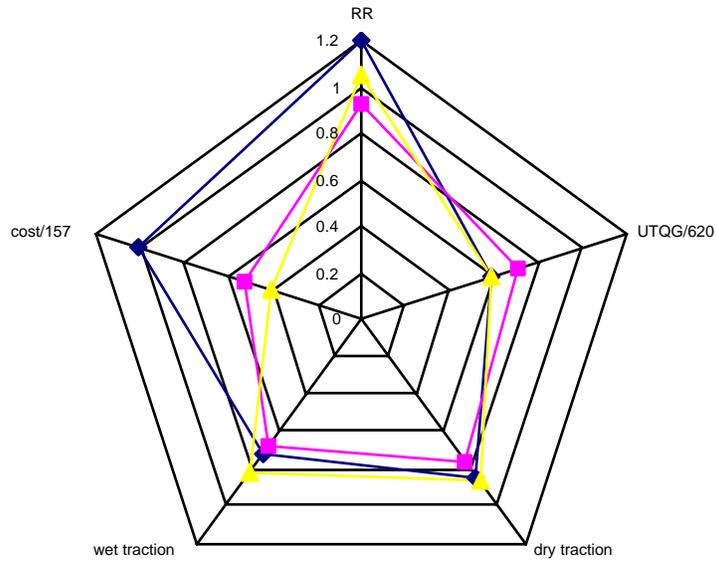


Figure A8: Performance tradeoffs for 245/75R16 tires s (Source: CEC [2003b]).

Consider Figure A5. The most expensive tire is also the best in terms of wet and dry tractions, it is average in terms of tread wear, and it is the worst in terms of rolling resistance. The tire with the lowest rolling resistance is also the second best in terms of tire wear, but it is also the worst in terms of wet traction. Similar results can be seen in Figures A6 and A7. Figure A8 presents data for the 245/75R16 tires. The tire that has the lowest rolling resistance also has the best tread wear rating. However, it also has the worst traction wet or dry. The price for this tire is about the average for this tire size.

### ***A3 How do Fuel Efficiency Gains of RRRTs Fare With Time?***

According to LaClair [2002], hysteretic energy dissipation, resulting from the viscoelastic nature of rubber compounds, accounts for 80 to 95% of the rolling resistance losses. Aging, repeated loading (mechanical and thermal), and exposure to the environment (*e.g.*, air pollution and radiation) change the properties of rubber. Consequently, it is reasonable to assume that rolling resistance would be affected by these factors.

As a tire wears, its mass is reduced. As a result there is less rubber to dissipate energy, and its rotational inertia is reduced. Thus, as the tire wear increases its rolling resistance decreases. Tire wear also reduces aerodynamic drag of tires, which also contributes to lower rolling resistance.

Therefore, an important question that should be addressed, but seems to attract no attention in the CEC reports or the studies they propose, is how will the energy gains obtained from RRRTs fare with time? Is the difference between a standard and a reduced rolling resistance tire going to remain the same, increase, or decrease? These are important questions because the objective is to improve the average fuel economy throughout the tire life, not only when it is new. It appears that currently data on this issue is unavailable or nonexistent. Thus, this issue should be thoroughly studied before advancing RRRTs. Unfortunately the CEC plan does not seem to address this important issue at all.

### ***A4 RRRTs and the Future of Tire Evolution***

It is important that any new mandates address future, not past, tires. Therefore, current tire evolution trends should be considered. Specifically, two important trends must be considered in any discussion of tires. The first is that the tire industry response to public demand for safety is to advance run flat tires. The most common run flat tire technology employs reinforced tire walls that can support the vehicle at highway speeds, and for a considerable distance, even when tire pressure drops to zero. Clearly such tires are heavier and therefore, are likely to possess higher rolling resistance than standard tires of comparable performance (*i.e.*, tires that don't have a run flat capability). Preliminary review of run flat tires in Section 7.1 found that these tires also deliver shorter tire life. However, this finding may be attributed to the fact that current run flat tires are aimed at the high performance vehicles (*e.g.*, the BMW 745Li) where tread wear and rolling resistance are not important factors. Therefore, this issue should be further studied before proceeding with RRRTs.

Another important technology is smart tire systems. For the purpose of discussion, smart tire systems are those that deliver something more than just the tire surface to roll on. For example,

this report discusses at some length auto-inflate systems. These can be thought of as smart tire systems because they also deliver information on air pressure and temperature in tires, and, if needed, act to correct the pressure. Thus, auto-inflate systems can allow tires to run at near optimal condition, which, among other benefits, also improves fuel efficiency.

A second type of smart tires, developed by Continental A.G. of Germany, employs magnetic strips in the tire wall to communicate information from the tire to the suspension system. Preliminary results show that such technology has considerable safety advantages. For example, Audi reported a five percent reduction in braking distance, which is a big improvement (Show [2002]). However, it is unclear how this technology would impact rolling resistance. Yet, it may contribute also to longer tire life and improved vehicle fuel efficiency. Determining the impact of such technologies on either the lifespan of tires or vehicle fuel efficiency remains to be determined. Yet it is clear that considering tires just as reinforced rubber is no longer indicative of the overall performance. Other technologies should be considered as integral parts of tires.

## **A5 Conclusions**

The CEC stated goal of achieving 3% improved fuel efficiency appears overly optimistic. This is because it asks that replacement tires achieve the same average fuel efficiency improvement as do OE tires. However, replacement tires are required to perform consistently across an array of vehicles, while OE tires are optimized for a specific vehicle and, therefore, replacement tires are unlikely to achieve the same level of optimization.

The CEC claims to achieve its goal without negatively impacting other tire characteristics including tread wear. However, the analysis above suggests that reducing rolling resistance will negatively impact some of the other tire characteristics such as tire longevity.

The studies proposed by the CEC are focused on identifying the rolling resistance of new tires. However, the *average* tire rolling resistance *throughout its life* should be determined to identify actual fuel savings. Therefore, even after the proposed studies, the actual fuel savings achieved will remain unknown.

## Appendix B: Cost Effectiveness Analysis (CEA)

CEA compares alternatives, usually mutual exclusive, on the basis of their costs and a single qualified but not monetized effectiveness measure, such as number of lives saved, or number of minutes of travel time saved. Though there is no conceptual reason why costs cannot be measured comprehensively, in practice analysts generally measure them narrowly as budgetary costs. Thus social costs are generally excluded yet many projects and decisions have an impact on externalities such as congestion or air quality.

If budgetary costs happen to equal opportunity costs *and* the effectiveness measure is the only impact for which people are willing to pay, *and* the scale of the alternatives being compared is the same, then the rankings of the alternatives by CEA and BCA will be identical. However, unlike CEA, BCA not only produces a ranking of alternatives but also reveals whether the highest ranked alternative actually increases efficiency. In effect CEA makes the assumption that the project should be undertaken and what is being sought is the most cost-effective way of accomplishing this. It does not provide information as to whether there are positive net social benefits associated with any of the alternatives. BCA addresses both questions of whether to undertake the project and how.<sup>113</sup>

In many situations, the effectiveness measure selected by analysts or decision-makers for use in CEA does not correspond to social benefits as measured under BCA, which are based on, estimated of willingness-to-pay [WTP] of individuals. One can reasonably infer, in most cases, that individuals would demonstrate WTP for incremental units of 'effectiveness' such as lives saved or increased productivity or enjoyment. For example, the number of minutes saved on a given trip may not be an approximate measure of such benefits as increased productivity, lower costs or improved life style. While decision-makers or analysts cannot avoid making estimates of WTP in doing BCA, even when they must rely on shadow prices, they often do not make an explicit connection between WTP and the effectiveness measure used in CEA. To highlight this problem some have distinguished between intermediate outputs, greater number of passengers processed on a given route, where the value may not be clear, and final outputs, such as greater mobility or accessibility for which people are willing to pay more. Clearly, the effectiveness measure should be as close to the final output or product as possible.

Among the applications of CEA the majority do not include all social costs. CEA studies focus on budgetary costs not other social costs. In some cases it is not clear whether budgetary costs are related to marginal costs (the appropriate measure) or average or unit costs (which may differ markedly from marginal costs). When there are non-insignificant social costs and when alternatives have different opportunity costs CEA will differ from BCA and yield different rankings.

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<sup>113</sup> If all alternatives are mutually exclusive and the status quo is among the alternatives, sharing similar scale and patterns of costs and benefits, then CEA does select the most efficient policy.

## ***B1 Cost-Effectiveness Ratios***

There are two basic ways to create cost-effectiveness ratios. For decision-making purposes there are two ways to impose constraints to facilitate comparison of policy alternatives involving projects of different scales. There are also adjustments that can be undertaken to make CEA closer to BCA.

Since CEA does not monetize benefits, it inevitably involves two different metrics: cost in dollars and an effectiveness measure - for example, reduced travel time, increased safety, lower transactions costs. Because non-commensurable metrics cannot be added or subtracted, it is not possible to obtain a single measure of net social benefits from the two metrics. It is only possible to compute the ratio of the two measures as a basis for ranking alternative policies. This can be accomplished in two ways.

First, cost-effectiveness can be measured in terms of cost per unit of outcome effectiveness, for example, cost per minute of travel time saved. To compute this, one takes the ratio of the budgetary cost of each alternative  $i$ , denoted by  $C_i$  to the effectiveness (or benefit) of that alternative,  $E_i$ .

$$CE_i = C_i / E_i$$

This CE ratio can be thought of as the average cost per unit of effectiveness. The most cost-effective project has the lowest average cost per unit of effectiveness. Therefore, projects should be rank ordered from the most cost-effective, those with the smallest CE ratio, to the least cost-effective.

Second, cost effectiveness can be calculated as the ratio of the outcome effectiveness units per unit of budgetary cost, or:

$$EC_i = E_i / C_i$$

This EC ratio can be thought of as the average effectiveness per unit of cost. The most cost-effective project has the highest average effectiveness per unit of cost. Thus, projects should be rank ordered from the most cost-effective (those with the largest EC values), to the least cost-effective.

Both of these CEA measures involve computing for each alternative the ratio of input to output. Thus, they are a measure of *technical efficiency* and might be interpreted in some cases as measures of productivity. As described below, differences in policy alternatives in the scale of projects, as well as the fact CEA often omits important social costs and benefits, make them poor measures of *allocative efficiency*.

## **Appendix C- Consumer Education: A Survey of Experience**

### ***C1 Introduction***

Whether the ultimate goal of a social campaign is safety, better health, or a cleaner environment, the final result depends on modifying the behavior of the target audience. Research on drug education by Goodstadt (1986), indicates that “knowledge about...” can be influenced easily by various programmatic approaches, but while necessary, knowledge is not a sufficient condition for most behavior change. Attitudes, he continues, are difficult to influence in a predictable fashion and attitude change does not lead, automatically, to a corresponding change in behavior. Finally, behaviors are notoriously difficult to change and are associated with the most problematic outcomes for educators including some that are the opposite to those intended by the educator. McGuire (2001) puts this in another way: “correlations between how a given communication affects knowledge about a topic, feelings regarding it, and behavior toward it tend to be modest.”

In 1986 McGuire reviewed the evidence “for massive television effects in six areas in which there is a deliberate attempt to influence the viewers - for example, the effects of commercial advertising on purchasing, the effects of political campaigning on voting, and the impact of public service health ads on changing audience lifestyles. The studies rarely show massive effects, as can be illustrated in what is probably the best studied of the intended mass media effect, namely, the effect of commercial advertising on purchasing behavior (or even weaker criteria such as brand recognition or preference). Effects tend to be surprisingly small, even when the evaluations are done by the advertising agencies' own study groups, which would be highly motivated to find large effects of ads (McGuire 2001).” McGuire points out, however, that he is not arguing that no media effects have been demonstrated, but only that the attained effect sizes suggest that the media account for no more than a few percent of the variance in the behaviors they are purported to be greatly influencing.

In a study involving the promotion of gun trigger-locks, Roberto et al. (2002) note that “the research literature indicates that public service announcements (and most commercial advertising) typically achieve only a modest degree of affective and behavioral impact, due primarily to restricted message quantity, moderate rather than high levels of credibility and attractiveness of the content, apathetic or resistant audiences, and competing influences in the media and interpersonal environment. At each stage of message dissemination and audience response, the proportion of people that are potentially influenced decreases to a narrow subset of the population; the “funnel effect” successively narrows until relatively few people adopt the intended behavior.”

Atkins (2001) lists several reasons why campaigns do not have a strong impact, including audience resistance barriers that arise at each stage of response, from exposure to behavioral implementation with the most elemental problem being to reach the audience and attaining attention to the messages. Other key barriers include misperception of susceptibility to negative outcomes, deflection of persuasive appeals, denial of applicability to self, rejection of unappealing recommendations, and inertia or lethargy. “It is often considered a quirk of human nature that we are unrealistically optimistic about our likelihood of experiencing negative

events...We believe that others might experience harmful effects of their behaviors, but not us (Stephenson, 2001).”

Small size effects do not necessarily denote failure, however. According to a formula credited to psychologist William James, "success can be thought of as the ratio of achievements divided by expectations. Thus an outcome is deemed a success or a failure only relative to what is desired or expected. "When the denominator (the expectation) is high, the numerator (the outcome) will have to be of proportionally greater magnitude for it to be judged “a success.” Conversely, when the expectation is low, even a much lesser outcome or achievement will be interpreted as successful.”(Salmon & Murray-Johnson, 2001). Murry, Stam, and Lastovicka (1996) note that “due to the very high costs of some antisocial behaviors, campaigns need change only a small portion of behaviors in order to be cost-effective.” They cite the example of a single traffic fatality costing 2.6 million dollars in medical, property, and legal costs. (Roberto et al., 2002))

There is another side to the efficacy debate. Snyder et al. (2000), using meta-analysis techniques, analyzed the average behavior change in 48 health communication campaigns in the United States that used at least one form of mass media and were community based (rather than school or workplace based). Behavior was chosen since it is often the *bottom-line* outcome for organizations that sponsor health campaigns. Additionally, since behavior change is more difficult to achieve than awareness, knowledge change, or attitude change, it is a more conservative measure of campaign success.

The conclusions drawn from the analysis are based on the correlation ( $\bar{r}$ ) between being in an intervention community and the amount of short-term behavior change, controlling for moderator variable of interest. The results can also be expressed as the average percentage behavior change in the intervention communities versus that in control communities. (The relationship between percentages changed and  $\bar{r}$  depends on the variance in levels of the target behavior. When the percentage of people doing the target behavior is very high or very low, variance is low and  $\bar{r}$  does not correspond exactly to the average percentage changed. Otherwise,  $\bar{r}$  and the average percentage changed are quite similar) (Snyder, 2001).

It is easier to promote new behavior than to persuade people to stop a behavior; campaigns that promoted the commencement of a new behavior had an average effect size of  $\bar{r} = 0.12$ , and approximately 12% of the target population adopted the new behavior. The commencement campaigns promoted seat belt use, exercise, mammography, dental care, condom use, health status screening, hypertension control, supportive interpersonal behaviors, fruit and vegetable consumption, and crime prevention behaviors. Topics for cessation campaigns included smoking, binge drinking, infants sleeping with a milk bottle, and sex with risky partners. The average effect size for cessation campaigns was  $\bar{r} = 0.05$ , and approximately 5% of the target population changed their behavior. The only prevention (also more difficult than commencement) campaign, youth smoking, had an average effect size of  $\bar{r} = 0.06$ , preventing 6% of the targeted youth from smoking (Snyder, 2001).

A very important point brought up by Snyder (2001) and often overlooked in media campaign studies is the role of enforcement. “Campaigns that used enforcement messages notified people that the authorities would soon be checking people for non-compliance. For example, some seat belt campaigns advertised random road check by the police (Lund, Stuster, & Fleming, 1989;

Roberts & Geller, 1994; Willaims, et al., 1987). These campaigns had a much higher success rate than earlier seat belt campaigns that did not use enforcement messages (Foss, 1989; Robertson et al., 1974). The average effect size among campaigns that use at least some enforcement messages was  $\bar{r} = 0.17$  or a 17 % change.”

One final qualitative observation: while there is still a great deal of debate regarding the efficacy of public health media campaigns, it is interesting to note that the tobacco industry understands the power of antismoking campaigns and has worked hard to limit their effectiveness. "An RJ Reynolds document, which discusses the industry's reaction to California's aggressive campaign, states that “the California campaign, and those like it, represents a very real threat to the intermediate term... Impact on self-esteem, social acceptance and smoking utility will ultimately influence business.” This same document summarized research on various California advertising strategies. Industry manipulation advertisements were generally seen as “believable, even among many smokers” and such an advertisement “presents risk of demotivating smokers.” The industry also developed a sophisticated strategy, including working through other organizations, in an effort to eliminate funding for the media campaign or reduce its aggressive tone (Goldman & Glantz, 1998).”

The following sections go into greater detail on the Ad Council, which has a 60 year history of public service announcement (PSA) campaigns, a more recent approach to public service campaigns called social marketing, and finally, reports on campaigns on child safety seats, alcohol, gun trigger-locks, and smoking.

## ***C2 Public Service Announcements by the Ad Council***

The Ad Council is a private, non-profit organization that uses volunteer talent from the advertising and communications industries, the facilities of the media, and the resources of the business and non-profit communities to produce, distribute and promote thousands of public service campaigns in issue areas such as improving the quality of life for children, preventive health, education, community well being, environmental preservation and strengthening families.

According to their website (<http://www.adcouncil.org>) the Ad Council has, for some time, relied on the tabulation of 800-number calls and anecdotal information to gauge the effectiveness of their PSAs. However, increased research funding and assistance has allowed them to obtain more accurate information about the effect of their messages. They feel that the results of their studies “conclusively show that public service announcements are an effective means of communication and education. Even if the message is used alone or is unwelcome and intrusive, the PSAs increase awareness, reinforce positive beliefs, intensify personal concern and move people to action.

Two studies are listed on the website, one evaluating a campaign to raise awareness of colon cancer and the other evaluating the National Crime Prevention Council's PSA campaign featuring McGruff the Crime Dog. For the first the Advertising Research Foundation (ARF) conducted a study in three waves, from July 1989 through July 1990, for the Ad Council in four major American cities. It found that:

- Awareness of the threat of colon cancer increased from 11% to 29% after 6 months of advertising, and then to 40% after a year.

- Men showed the most dramatic increase: from 6% before the campaign to 35% at the end.
- Over the one year period, the number of people who spoke to their doctors about colon cancer increased by 43%.
- The number of men who took action increased by a remarkable 114%.

In 1991, researchers at the University of Wisconsin gauged the impact of the National Crime Prevention Council's PSA campaign, which has been on the Ad Council docket for more than 15 years. They found that Awareness of McGruff reached 95% among media managers, 88% among crime prevention practitioners, and 80% among the general public. Additionally, nearly one-third of the respondents said they had learned from the ads and about one-fifth said they had taken specific actions as a result of what they had learned.

Unfortunately, the Ad Council site contains additional claims that cast doubt on the rigor of the research that has gone into measuring the efficacy of their campaigns. They take credit for the fact that "Safety belt usage is up from 21% to 73% since our Safety Belt campaign launched in 1985 -- saving an estimated 85,000 lives" and that "Destruction of our forests by wildfires has been reduced from 22 million acres to less than 4 million acres per year, since the Ad Council's Forest Fire Prevention campaign began." No mention is made of other exogenous factors (e.g., enforcement laws for seat belts) that may have played a role in the listed gains.

### ***C3 Social Marketing***

There have been a number of approaches to addressing social problems including education, persuasion, behavioral modification, and social influence techniques. The social marketing approach has features in common with each of these approaches. It often attempts to educate. It seeks to motivate individuals to act. It introduces group pressure when appropriate and it often employs modeling and rewards to ensure the long-term success of its programs (Andreasen, 1995).

Social marketing is essentially the application of marketing technologies developed in the commercial sector to the solution of social problems where the bottom line is behavior change. Just as marketing can persuade consumers to try new products, switch brands, take up a sport or travel to exotic locales, it can also be used as a powerful tool to improve consumers' physical and mental health and the general quality of our society and its environment (Andreasen, 1995).

Andreasen enumerates three key points that set social marketing apart from other similar technologies. First, the ultimate objective of social marketing is to benefit target individuals or society and not the marketer. While this is similar to nonprofit marketing, it differs in that it is focused on directly improving welfare rather than such activities as fundraising or lobbying.

Second, the basic means of achieving improved welfare is through influencing behavior, in most cases bringing about a change in behavior. While often very long in coming, behavioral change is central: all other measures of success are only interim measures that offer encouragement on the path toward the ultimate bottom line.

Third, the target audience has the primary role in the social marketing process. Since there is no behavioral influence until the person to be influenced takes an action. It is the customer who must ultimately undertake the action the marketer is promoting.

To be successful, a social marketing campaign must incorporate the following features (Andreasen, 1995):

- Consumer behavior is the bottom line - changes in knowledge do not constitute success.
- Programs must be cost effective - resources are always limited and must be used wisely
- Interventions involve:
  - Product - the reason for modifying behavior must be as attractive as possible
  - Price - benefits must outweigh costs to the consumer
  - Place - the desired behavior must be convenient and easy to carry out
  - Promotion - mass media, one-to-one, and rewards for behavior
- Market research is essential to designing, pre-testing, and evaluating intervention programs
- Markets must be carefully segmented - the market is not homogeneous and must be segmented for distinctive programs.
- Competition is always recognized - campaigns must keep in mind not only what the marketer is trying to get across but also what the customer sees as the major alternative.

#### ***C4 Child Safety Seats***

In a review of the literature on booster seats prepared by the Center for Applied Behavioral and Evaluation Research of Washington, DC, information needs identified by the parents included as an important first step is to make parents aware of the risks associated with the improper fit of seat belts and other alternatives, such as seat belt attachments or cushions and pillows. The participants suggested that following guidelines might be easier if they know and understand the rationale behind these guidelines.

When asked to consider message strategies, some parents suggested that campaigns would have the greatest effect if they showed the consequences of premature graduation or included research, such as crash tests and other findings. Parents indicated that using real-life stories and pictures of injured children could capture their attention. Possible spokespersons include celebrities known as being caring parents, children (who could target both parents and other children), and medical professionals.

Experts from a number of fields, particularly child immunization and vaccination, were asked to identify possible interventions. These included the following recommendations:

- make buying and using the product as easy as possible;
- make sure people understand the risks of not using the product;
- involve community-based organizations in delivering the message;

- develop a reminder system;
- create a profile of a high-risk child or family (e.g., understand those who are least likely to use booster seats or most likely to be at risk for injury)

Also discussed in the literature review was a study by Block (2000) reporting the results of the Motor Vehicle Occupant Safety Survey, which is a national telephone survey conducted every two years. As part of the survey respondents were read a list of six potential sources and were asked whether or not they received, heard, or read any information or advice about the need to use child safety seats from these sources. Respondents could also offer additional sources of information that they had used. The most common sources of information about child safety seats were television/radio (65 percent) and childcare books and articles (61 percent). Other commonly mentioned sources of information were doctors and nurses (56 percent), family members or friends (52 percent), and other kinds of books or articles (52 percent). Only 2 percent of respondents said they had received information from a safety hotline.

## **C5 Alcohol**

Each year, drinking and driving behavior is responsible for at least 24,000 traffic fatalities and more than one-half million injuries, with a disproportionate number of victims between the ages of 15 and 24 (Koop 1988). In many ways, current problems in formulating an effective drinking and driving policy parallel public health officials' early concerns about tobacco smoking behavior. Reduction in smoking behavior over the past 25 years can be attributed in part to several decades of a continuous public education program concerning both the health risks and social desirability of smoking. The 1988 Surgeon General's Workshop on Drunk Driving concluded that a similar educational effort should be undertaken for drinking and driving. A health education program is undoubtedly one of the cornerstones on which an effective drinking and driving policy should be constructed (Murry *et al.*, 1993).

While programs aimed at preventing or reducing adolescent drug use have proliferated over the last ten years, credible evaluations of their effectiveness have been much less plentiful. As noted by Krishnamurthi, Narayan, and Raj (1986), advertising studies combining the analytic rigor of time series analysis with the careful controls provided by a field experiment involving test and control sites are rare in the published literature (Murry *et al.* 1993). Among the often-cited weaknesses are limitations in scope (including both numbers and diversity), lack of random assignment, faulty implementation, questions about the accuracy of reported drug use, and inadequate statistical controls (Ellickson and Bell, 1992). Vega and Klitzner (1988) go so far as to state that by far the majority of these programs have no theoretical basis and that most of them appear to have been created simply out of a need to be doing something. Often, it seems, the will to believe on the part of implementers and program sponsors alike seems stronger than the evidence supports (Gerstein and Green, 1993).

The high cost of drinking drivers, in terms of both lives and money, has led to a variety of countermeasures over the years that can be broken down into three modes of intervention: primary, which refers to the education of potential drinking drivers with the purpose of preventing them from undertaking such behavior; secondary, which relates to the detection of drinking drivers and their removal from the roads; and tertiary, which is concerned with reducing recidivism, whether through punishment or rehabilitation (Mann *et al.*, 1983). In spite of the

massive body of evidence in the public health field attesting to the fact that both physical and mental health problems are relatively difficult to control through treatment after they have appeared and become established, treatment efforts have a long and expensive history compared to attempts to prevent development of these problems (Braucht and Braucht, 1984; Hansen, Malotte, and Fielding, 1988). It would seem logical, then, that if any real progress is to be made in the fight against alcohol abuse, the battle must be started before habits and lifestyles are established, *i.e.*, primary intervention. The natural place for this to occur is in our schools.

One of the major factors that work against the success of many school programs is the failure to recognize that the target audience is not homogeneous. In a typical school, subgroups of students represent a range of motivation and experience with respect to drug and alcohol use, yet vast education resources are spent on programs that send a “typical” message to the “typical” student, usually assumed to be a non-user. (Lamarine, 1993; Goodstadt, 1986).

While there is a wide variety of school based programs, Moskowitz (1989) groups them into three behavioral models; knowledge/attitude, values/decision, and social competency. The first of these, knowledge/attitude, is the most and assumes that increased knowledge about the consequences of alcohol misuse produces more negative attitudes toward misuse, which, in turn, reduces the likelihood of misuse. Unfortunately, with regard to alcohol or other drug use, there is little empirical support for the causal link implied by this model (Goodstadt, 1981; Hanson, 1980; Kinder et al, 1980; Wallack, 1981).

Both the informational and affect-based models typically emphasize changes in knowledge and attitudes as indicators of success. While these measures have several benefits including ease of design and administration, readily determined reliability and validity, and high levels of sensitivity to the desired changes, increased knowledge and changes in attitude cannot be assumed to be accurate indices of eventual effects on behavior or traffic safety (Mann *et al.*, 1983). In fact, in related areas of research, positive program impacts on knowledge/attitude measures and negative impacts on behavior/traffic safety measures have occasionally been observed (Mann *et al.*, 1986). Thus, while knowledge and attitude measures may be sensitive indicators of impact, these measures cannot be assumed to be accurate indices of eventual effects on traffic safety (Mann et al 1986).

Instead of a school-based program, Murry *et al.*, 1993, report on the effectiveness of a paid advertising campaign targeted at reducing youthful male drinking-driving behavior. The program was examined using pretest and posttest sample surveys taken at both a campaign site (Wichita, Kansas) and a control site (Omaha, Nebraska) and time series intervention modeling of monthly traffic accident data from both sites. These compatible analyses provide collaborative evidence that the advertising campaign reduced youthful male drinking and driving behavior and, consequently, traffic accidents. The remainder of this section on alcohol is adapted from the study by Murry *et al.*, 1993.

Market research and pretesting of advertising ideas under laboratory conditions were used to create a campaign that ran in a 6-month paid media schedule using television, radio, newspapers, and billboards. If this paid media schedule at the experimental site were scaled up to a national level, it would be equivalent to a \$25 million national campaign.

In the experimental site, an anti-drinking and driving advertising campaign was aired March through August 1986. The control site received no advertising campaign treatment during the same period. Pre-intervention and post-intervention surveys of independent samples of 18- to 24-year-old males in each site measured self-reports of drinking and driving behavior. Monthly drinking and driving-related highway accidents were reported by the Kansas and Nebraska Traffic Safety Departments for young males subpopulations at the two sites for the period January 1983 through September 1987.

A time series design was used for the crash data because it allowed the experimental effect to be compared to its pre-intervention and post-intervention time series as well as to the time series from the control group (Campbell and Stanley 1963). The use of time series analysis (instead of regression modeling) of the highway accident data allowed a rigorous analysis of model error structure, facilitating a clearer understanding of the impact of the intervention. The experimental control helps ensure correct inferences about attributing any detected intervention effect to the media campaign.

The pre-intervention and post-intervention telephone surveys with 18- to 24-year-old males conducted at each site indicated that the percentage of respondents reporting to have driven during the previous month after consuming four drinks decreased from 34.6% to 27.6% at the intervention site. In contrast, respondents' propensity to drink and drive after four drinks at the control site increased from 37.9% to 43.9% between the pre-intervention and post-intervention periods. This difference was significant at the  $p < 0.05$  level. Although the decrease in reported drinking and driving after six drinks was comparable to the decrease in drinking and driving after four drinks, it was not statistically different across the sites.

Since these differences are based on self-reports of drinking and driving behaviors and are thus subject to the well-known limitations of response effects in sample survey data (Sudman and Bradburn 1974), they were supplemented by non-self-reported data, namely the official counts of incapacitating and fatal highway accidents at the experimental and control sites.

Monthly accident data were reported from each site for a 5-year period that included 38 months before the intervention, the 6-month campaign intervention period, and 13 months following the campaign. The data were reported in six categories; total, single vehicle, and nighttime crashes for 18-24 year-old males and 15-24 year-old males and females combined.

These data were chosen for two reasons. First, blood alcohol content (BAC) data are considered unreliable indicants of aggregate drinking and driving behavior since police enforcement and reporting of drivers' BAC levels is inconsistent and frequently incomplete (Maxwell 1981). Because a major proportion of fatal and incapacitating single-vehicle and nighttime accidents are alcohol-related, these data are frequently used as proxies for alcohol-related accidents (Arnold 1985; Williams 1986). Second, these variables reflect the campaign's primary and secondary targeted populations: 18- to 24-year-old males and 15- to 24-year-old males and females.

Murry *et al.*, 1993, report that their "study produced five types of evidence for the positive effect of a paid advertising campaign on youthful drinking and driving. First, the sample survey data's pre-intervention and post-intervention differences in the proportion of 18- to 24-year olds claiming to drink and drive after four drinks decreased at the campaign site and increased at the

control site. Second, the number of monthly fatal and incapacitating accidents decreased in both the primary (total 18-24 year-old male) and secondary (total 15-24 year-old male and female) targeted populations for the campaign period in comparison to the same months in the previous year. Third, the intervention component for four of the six accident time series models from the primary and secondary targeted populations demonstrated a decreased proportion of fatal and incapacitating accidents at the campaign site during the campaign period. Fourth, the temporary effect models indicate that the proportion of fatal and incapacitating accidents in the targeted populations returned to their original baseline levels at the campaign's conclusion. Finally, there was a significantly greater decrease in fatalities at the campaign site than at the control site for five of the six fatality series.”

## **C6 Gun Locks**

A 2002 study in the *Journal of Applied Communication Research* by Anthony J. Roberto *et al.* on a radio based campaign to promote trigger-lock use in one Michigan county provides a detailed look at the planning, theoretical underpinnings, and execution of a social marketing campaign. The following is an adaptation of that journal article.

Injuries and deaths from guns represent a pervasive problem in the United States with the availability of a gun in a home cited as a major contributing factor (Michigan Task Force on Interpersonal Violence Prevention and Reduction, 1994; McDowall, 1991; Brent, Perper, Allman, Moritz, Wartella, & Zelenak, 1991; Kellermann, Lee, Mercy, & Banton, 1991; Cotton, 1992)

Communication research has often been utilized in interventions to persuade individuals to engage in healthier behaviors. Communication campaigns often have two goals: (1) to educate the public about the problem; and (2) to persuade individuals to take positive steps to protect their health. This approach has been taken with topics such as AIDS (Witte, 1992a), skin cancer (Parrott, Glassman, & Burgoon, 1989), and bicycle safety (Witte, Stokols, Ituarte, & Schneider, 1993).

The choice of channel for a message has always been an area of concern when creating a health intervention (Du Pre, 2000; Schooler, Chaffee, Flora, & Roser, 1998). Bauman, Laprelle, Brown, Koch, and Padgett (1991) state that television is the medium that receives the most attention from those who design health interventions. However, Hornik (1989) claims that practical matters must be taken into account when choosing a channel, including relative effects, costs, feasibility, and sustainability. Radio provides greater exposure to the message at a more economical price and is widely available across all socioeconomic groups (Fouk & Young, 1982; Hale & Hollander, 1988). Repetition of exposure is often perceived as necessary for desired effects (Epstein, Magrowski, & McPhail, 1975), and radio provides a feasible option for disseminating the message multiple times to allow repeated exposure.

Another advantage of radio is that it allows targeting of specific sub-populations within the larger population (Thompson, 1973) and has been cited as especially useful for accessing hard-to-reach audiences (Hammond *et al.*, 1990). One of the five key concepts of social marketing is audience segmentation, where a heterogeneous population is divided into more homogeneous subgroups (Dearing, Rogers, Meyer, Casey, Rao, Campo, & Henderson, 1996). Audience

segmentation is perceived as essential in health campaigns and provides the rationale for selecting certain message channels (Slater, 1996). Factors related to the specific topic studied need to be taken into consideration when determining how to segment certain populations (Borzekowski & Poussaint, 1999). Radio in general, and the radio stations selected for this intervention in particular, were believed to be ideal for targeting gun owners as the demographics of their target audiences closely matched the demographics of Michigan gun owners.

A series of focus groups conducted during the formative evaluation stage of the intervention revealed that surprisingly few gun owners perceived the potential for injury and death to members of their household or those outside their immediate family as a cost associated with gun ownership (Roberto, Johnson, Meyer, Robbins, & Smith, 1998) which suggests that “the cognitive link between guns and injury or death for gun owners and those who handle guns is weak at best, and nonexistent at worst” (Roberto et al., 1998). As a result, these authors note “that individuals must be moved from unawareness to awareness.” To do so, Andreasen (1995) and Maibach and Cotton (1995) suggest it is important to (1) increase awareness and knowledge of the risk through education; (2) personalize the risk by increasing perceived susceptibility and severity; (3) increase the perceived benefits of the recommended behaviors; and (4) decrease the perceived costs of the recommended behaviors. Mass media interventions are a common and often effective way of providing the information necessary to move individuals between these early stages (Andreasen, 1995; Maibach & Cotton, 1995).

The health belief model (Janz & Becker, 1984) and the extended parallel process model (EPPM) (Witte, 1992b; Witte, Meyer, & Martell, 2001) were selected to guide the development of the message used in this intervention. Generally speaking, both of these models are concerned with four variables. Perceived susceptibility refers to feelings of personal vulnerability to a particular threat (*e.g.*, “How likely is it that *my* gun will be involved in an accidental shooting?”). Perceived severity refers to the seriousness of the negative consequences should the threat occur (*e.g.*, “How serious are the short- or long-term physical or psychological effects of a firearm injury?”). The EPPM suggests these two variables together make up one's overall level of perceived threat.

Perceived benefit refers to beliefs concerning the advantages or effectiveness of various actions available to reduce a threat (*e.g.*, “Do trigger-locks prevent unintentional firearm injuries?”). Finally, perceived barriers refers to the disadvantages or costs associated with adopting a particular health behavior to avert the threat (*e.g.*, “Trigger-locks are too expensive or difficult to use.”). These two variables are closely related to what the EPPM refers to as response efficacy and self-efficacy. For example, if individuals believe an advantage of using a gun trigger-lock is that it will prevent unintentional firearm injuries, they are likely to exhibit a higher level of response-efficacy. If individuals believe a gun trigger-lock is difficult to use, they are likely to exhibit a lower level of self-efficacy. The EPPM suggests these two variables make up one's overall level of perceived efficacy.

A PSA was developed that focused on the danger to children from an unlocked and loaded guns. At the end of the message, individuals were given a toll-free phone number to call to receive a free gun trigger-lock. It was disseminated on three radio stations in one mid-Michigan county: a classic rock music station and a country music station, selected because their audiences closely represented the characteristics of Michigan gun owners, and an urban-contemporary music station, selected as the third station to explore whether this audience would also be interested in

the free gun trigger-lock offer (*i.e.*, even though their target audience was younger and contained a greater percentage of females and minority listeners). While the PSAs followed the same script, each was independently produced using a disk jockey and voices with which the radio station's specific target audience could identify.

The intervention lasted exactly three weeks, during which time the PSAs ran on each station approximately six times a day Monday through Friday, and at least two times each weekend day. Approximately 75 percent of the airtime was purchased to insure the PSA would play during all important listening times, including peak morning and afternoon drive times. The PSA ran a total of 340 times during the three-week intervention.

Two comparable counties in Michigan were used as treatment and control counties. There were two primary criteria for selection of the control county. First, it had to be similar to the treatment county along a number of important and relevant demographic and geographic dimensions. Second, it had to be far enough away from the treatment county so that their media markets would not overlap (this was necessary to avoid diffusion of treatment).

Three surveys were conducted to assess the reach and effects of this intervention. First, a general population telephone survey was conducted in both the treatment and control counties at two points in time (*i.e.*, pretest-posttest control-group design). Second, an automated telephone survey was used to collect information from the individuals who called the toll-free number to receive a free gun trigger-lock. Finally, a follow-up mail survey was sent to the individuals who received the free trigger-lock.

Respondents in the general population survey demonstrated a significant increase in knowledge regarding the lock-related gun-safety practices; knowledge of the unloaded-related practices remained unchanged. Further, respondents demonstrated very low perceived susceptibility to unintentional firearm injuries, but moderate perceived severity with respect to such injuries. Finally, respondents demonstrated markedly high response efficacy and self-efficacy (a finding that was also observed in the follow-up survey). Although the vast majority of the findings from the general population survey were in the desired direction, only one of the differences was large enough to be statistically significant.

In interpreting the small outcome effects obtained in the general population survey, it is important to recognize the limited potency of mass media interventions in general, and this radio PSA in particular. The research literature indicates that PSAs (and most commercial advertising) typically achieve only a modest degree of affective and behavioral impact, due primarily to restricted message quantity, moderate rather than high levels of credibility and attractiveness of the content, apathetic or resistant audiences, and competing influences in the media and interpersonal environment. At each stage of message dissemination and audience response, the proportion of people that are potentially influenced decreases to a narrow subset of the population; the "funnel effect" successively narrows until relatively few people adopt the intended behavior.

In spite of this "funnel effect," there was a substantial and statistically significant increase in knowledge of the locking-related gun-safety practices. Further, this intervention also had a sizable practical effect (*i.e.*, trigger-locks were distributed to 799 households; or approximately

one out of six gun-owning households exposed to the message). Price and Allensworth (1979) note that “commercial advertisers, with all of their money to buy 'slick' persuasive advertisements promoting their products, are pleased with one to two percent gain in sales” (p. 19). Further, Snyder (2001) looked at 48 health communication campaigns and found that approximately 12 percent of the target population adopted the recommended behavior. Finally, Murry, Stam, and Lastovicka (1996) note that “due to the very high costs of some antisocial behaviors, campaigns need change only a small portion of behaviors in order to be cost-effective” (p. 5). They cite the example of a single traffic fatality costing 2.6 million dollars in medical, property, and legal costs. National estimates indicate that annual cost of firearm-related injuries and deaths exceed 20 billion dollars, not including expenditures by the criminal justice system (Max & Rice, 1993). Additionally, the life lost is often a young one (particularly in the case of unintentional gunshot injuries), losing the potential for many years as a productive citizen (Anderson, Kochanek, & Murphy, 1997). Clearly, preventing even one gunshot injury or death will considerably reduce physical, emotional, and financial costs.

Findings from the three surveys suggest that future firearm safety interventions would be well advised to focus on the following two variables. First, knowledge of gun-safety practices needs to be increased. An individual cannot be expected to move from the pre-contemplation to the contemplation stage (and ultimately the action stage) without such knowledge. Second, perceived threat needs to be increased considerably; especially the perceived susceptibility dimension which was particularly low. An individual will not be sufficiently motivated to engage in the recommended response if perceived threat remains low.

Finally, experiences from the current intervention provide some insights regarding the use of radio in general. For example, we strongly believe inclusion of the following three common radio station practices would have further increased recall of the campaign, number of trigger-locks distributed, and perhaps even knowledge of exposed listeners. First, “live liners” can be read throughout the intervention. In this instance, live liners might have included disk jockeys reading the recommended gun-safety practices, informing listeners that they will be given an opportunity to receive a free gun trigger-lock before the PSA was aired (*i.e.*, so interested listeners could prepare accordingly), or reminding the listener of the toll-free number again after the PSA is played (*i.e.*, so interested listeners would have another opportunity to write down the toll-free number). Second, on-air registrations could have been utilized. In this instance, on-air registrations may have taken the form of inviting interested listeners to call the radio station directly to receive a free gun trigger-lock. Third, one or more live remote broadcasts could have been used. In this instance, a good example would be broadcasting from a local sporting goods store that sold guns, ammunition, and other hunting supplies (especially around one or more opening days for hunting season). Listeners would be invited to visit the live remote location, where additional free gun trigger-locks could be distributed on site. We found out after the intervention that radio stations often offer these services for free or at significantly reduced prices because their audience benefit directly from the items being promoted, and their other sponsors (including the live remote location) benefit from the additional incentive to listen to the station.

## **C7 Smoking**

The objective of the study by Goldman and Glantz (1998) was to review research on the effectiveness of different antismoking messages and published evidence of the effectiveness of paid antismoking advertising. To do so, the results of 186 focus group studies involving more than 1500 children and adults conducted by professional advertising agencies that contract with California, Massachusetts, and Michigan to run their antismoking advertising campaigns were reviewed. Additionally, published literature was located using MEDLINE and standard bibliographic sources on the effectiveness of large, paid anti-tobacco media campaigns. The authors also reviewed reports and studies conducted by, or for, the California and Massachusetts health departments on program effectiveness, and conducted their own comparison of California vs. Massachusetts using cigarette consumption data from the Tobacco Institute. This section on smoking is adapted from the Goldman and Glantz study.

Since 1989, California, Massachusetts, and Arizona have implemented large-scale, paid, tobacco-control campaigns to discourage people from starting to smoke and to encourage smokers to stop. The campaign in California is the widest in scope, utilizing a general market approach with strong, anti-tobacco industry and secondhand smoke components. Massachusetts' approach is more youth-oriented and, although it has sought to discredit the industry, its spots are less confrontational with the industry than California's. The Arizona program is the most narrowly focused, limiting itself to youth and pregnant women, with no messages attacking the tobacco industry.

This article reviews the qualitative marketing research used to develop anti-tobacco media campaigns and compares the overall cost-effectiveness of the California and Massachusetts campaigns using the difference in per capita consumption of cigarettes between California and Massachusetts and the rest of the United States (excluding California and Massachusetts) as the outcome variable. We found that more aggressive campaigns are more effective.

For California, examination of tobacco consumption data shows a relationship between the presence of the media campaign and declines in consumption in California. The 25 cent per pack increase in the state excise tax mandated by Proposition 99 went into effect on January 1, 1989 and was accompanied by a 13.7% decline in tobacco consumption from September 1988 to May 1989 (Pierce *et al.*, 1993 & 1994). Between April 1990 and March 1991, roughly the same period as the first wave of the media campaign, consumption again decreased, this time by 12.2%. Because the effects of the tax seemed to dissipate after May 1989 and no other Proposition 99-related tobacco control interventions were in effect during the first wave of advertising, the second drop in consumption can be attributed to the media campaign. Cigarette consumption declined again by 12% between February 1992 and April 1993. Because the second phase of the media campaign did not begin until October 1992 and the other Proposition 99 programs went into effect in 1992, this decline could reflect both the media campaign and the other interventions.

In addition to reducing consumption by individual smokers, media campaigns can also be effective in influencing smokers' decisions to quit smoking altogether. In a survey of adult Californians who had quit smoking during the first wave of the California media campaign in 1990 to 1991, Popham *et al.*, (1993) found that in response to un-cued questions, 6.7% of

smokers cited an advertisement that they had seen or heard as a factor in their decision to quit. When asked direct questions about the media campaign, an additional 34.3% in the survey replied that a tobacco-control advertisement had been influential in their decision to quit.

Changes in cigarette consumption in California have closely followed changes in the anti-smoking media campaign. Glantz (1993) estimated that prior to the passage of Proposition 99, total cigarette consumption was falling by 45.9 million packs per year. After enactment, the rate tripled to 164.3 million packs per year. In 1992, the rate of reduction slowed to 19 million packs per year at approximately the same time the media campaign was suspended. The American Lung Association sued and the media campaign was restored in 1992 and cigarette consumption began to decline again. From 1995 to 1997, when there had been little tobacco-control advertising in California (Balbach 1997) and no new advertising produced, tobacco consumption was essentially flat.

Goldman *et al.*, (1998) also discuss another study supporting of the efficacy of the California campaign. Hu *et al.*, (1995) “conducted an econometric analysis of cigarette consumption in California between 1980 and 1992 using quarterly data and controlling for time, price excluding taxes, state tax, federal tax, and the media campaign. They estimated that cigarette sales were reduced by 1.33 billion packs from the third quarter of 1990 through the fourth quarter of 1992. They attributed 232 million packs of this decline (7.7 packs per capita) to the media campaign. Hu *et al.*, (1995) probably underestimated the impact of the media campaign because it does not take into account the tobacco industry's increased use of promotional activities to counter the media campaign” (Johnson *et al.*, 1994).

In 1993, Massachusetts increased the tobacco tax by \$0.25 per pack with the funds devoted to anti-tobacco activities (Bal *et al.*, 1990). When the tax went into effect, the tobacco companies reduced their wholesale prices to the 1992 pretax level (Harris *et al.*, 1996) essentially eliminating the price increase associated with the tax. The state's tobacco control media campaign began in October 1993, after the price cut. In spite of the cut, per capita consumption in Massachusetts continued to decline from 1992 to 1996 (Houston) suggesting that the media campaign in Massachusetts played a role in reducing cigarette smoking.

An evaluation of the media campaign compared Massachusetts youth to their counterparts in states without antismoking media campaigns and found that Massachusetts youth had significantly more knowledge about tobacco use, were more likely to cite additional reasons (other than health) not to smoke, and held stronger antismoking attitudes than youth in other states (Houston).

In order to compare the cost effectiveness of the California and Massachusetts campaigns, the annual reduction in packs consumed per capita per year in excess of the national rate for each per capita dollar spent on the media was computed for both states. From 1989 through 1996, California per capita consumption of cigarettes fell 1.93 (t.21) (SE) packs per year faster than the rest of the United States, excluding Massachusetts. Dividing the rate of decline in consumption by the average annual per capita media expenditure of \$0.50 (in 1996 dollars) yields an estimate of a fall of 3.9 packs per capita per year for each per capita dollar spent on the media campaign.

In Massachusetts, between 1993 and 1996 per capita consumption of cigarettes fell 1.28 (0.90) (SE) packs per year faster than the rest of the United States, excluding California. Dividing this decline in consumption by the average annual per capita media expenditure of \$2.42 yields an estimate of a fall of a half a pack per capita per year for each per capita dollar spent on the media. Thus, the California media campaign appears to be about a factor of 7.8 more cost-effective than the Massachusetts campaign. These results are consistent whether one uses media campaign or total program spending. Similar results were obtained using several other analytical models.

The difference in cost-effectiveness of the California and Massachusetts campaigns suggests that California's more aggressive approach is about an order of magnitude more cost-effective than Massachusetts' approach. It is important to remember, however, that the statistical model used was relatively simple and does not model price changes, income distributions, age distributions, underlying economic conditions, or the precise patterns of airtime purchased in the two states. The fact that the differences hold up under a variety of different modeling approaches, combined with the large differences we find, suggests that there is a real difference in the cost-effectiveness of the two campaigns.

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<sup>116</sup> Id.