Smart Driving Resource Guide

This document provides a more comprehensive guide to smart driving strategies with links to resources to learn more about them.

Background

"Smart driving" refers to a set of strategies and techniques that maximize motor vehicle fuel efficiency by improving driving habits and vehicle maintenance. A variety of research studies suggest that drivers can reduce their fuel consumption through smart driving principles by 0 to 18%. More recent and rigorous studies have demonstrated average fuel economy savings of 2% to 4% for the average driver.

Smart driving techniques include:

- Using smooth starts to minimize rapid acceleration, and drive at constant speed when possible
- Anticipating traffic flows and coast when possible
- Observing speed limits, and minimize speeds over 65 mph
- Minimizing unnecessary idling
- Closing windows and sunroofs when driving over 40 miles per hour
- Minimizing use of air conditioning; open windows instead if driving under 40 mph
- Use cruise control when driving on the highway
- Using trip chaining to reduce miles traveled and vehicle trips

Smart driving also encompasses vehicle maintenance techniques such as:

- Maintaining proper tire pressure
- Eliminating unnecessary weight in the vehicle
- Removing roof-racks to improve vehicle aerodynamics
- Conducting regularly scheduled vehicle maintenance

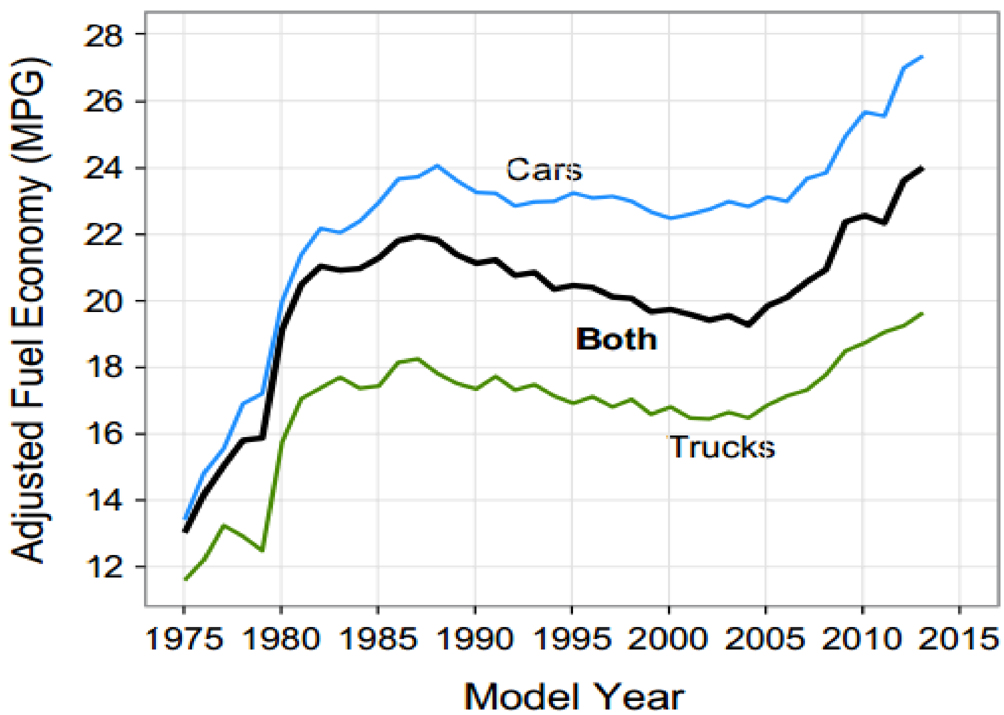
The concept of smart driving, also called "eco-driving", has been around for decades, receiving particular attention during periods of high fuel prices or fuel scarcity. The U.S. Department of Energy implemented a smart driving training program in late 1970s and early 1980s as part of nationwide fuel saving efforts. More recently, smart driving programs have been established in Europe, Japan, and Canada – often as part of GHG reduction commitments.

Key Smart Driving Recommendations

Physical Basis for Fuel Saving Potential

Vehicles have become increasingly efficient over the last 100 years. These improvements have been spurred by technological breakthroughs in response to air pollution, high gas prices and/or fuel rationing, increases in government fuel efficiency standards, and the environmental movement's demand for reducing the use of limited resources. In particular, there were large fuel efficiency gains in the late 1970s and early 1980s following the oil crisis, and then improvements that began around 2005 and continue to this day. See Figure 1 for a graph of fuel economy improvements over time.

Figure 1: Average U.S. Fuel Economy for MY 1975-2013



Source: EPA, "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 – 2013", http://www.epa.gov/otaq/fetrends-complete.htm

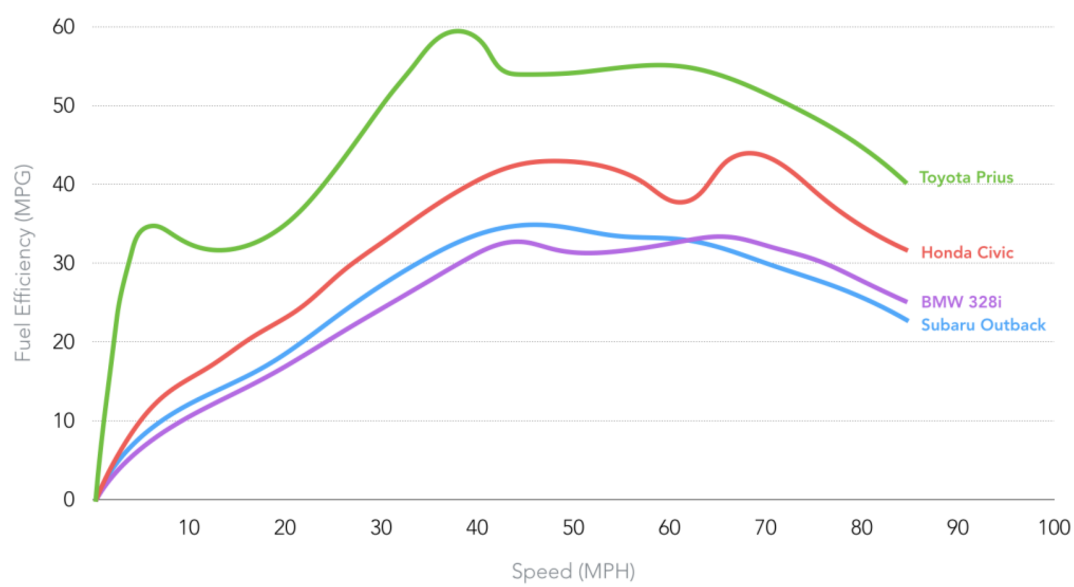
Improvements in fuel economy have been accomplished through tactics such as downsizing the weight of vehicles, a shift from rear-drive to front-drive vehicles, more efficient transmissions, more gears, the incorporation of computers in fuel injection and engine control, and decreased aerodynamic drag. More recently, the technology advancements with the introduction of hybrids and electric vehicles have significantly improved the fuel efficiency of those vehicles.

However, technology is only part of the story in vehicle fuel economy – the other critical piece is driver performance.

Avoid Overspeeding

The EPA's fuel efficiency ratings for various vehicles are commonly taken as absolute numbers when, in reality, "actual results may vary." Those ratings are arrived at through a series of lab-based tests which may not mirror real world driving conditions or more importantly, driving styles. While overall fuel economy has increased tremendously, fuel efficiency varies over a range of speeds and rates of acceleration. Figure 2 illustrates that **all vehicles (hybrids, sports cars, and utility vehicles) have lower fuel efficiency at lower speeds and, reach their most efficient speed around 40 to 60 miles per hour, with substantial decreases in fuel efficiency at higher speeds**. If armed with this information, drivers could consciously try to not exceed their vehicles peak operating speed and thus increase their overall fuel economy.

Figure 2: Varied Fuel Efficiency with Speed

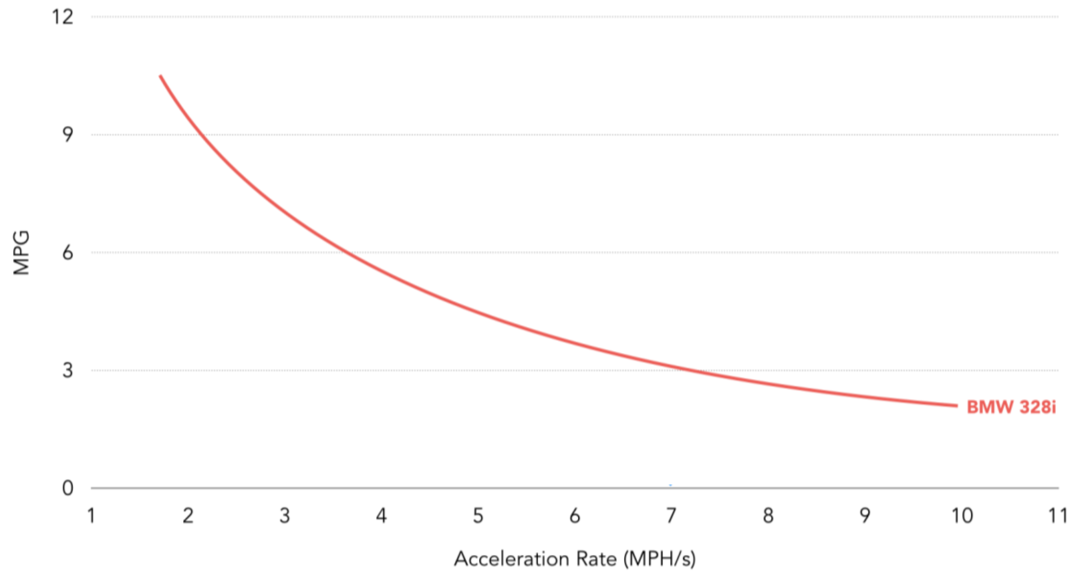


Source: Automatic, "The Cost of Speeding: Save a Little Time, Spend a Lot of Money", http://blog.automatic.com/cost-speeding-save-little-time-spend-lot-money/

Accelerate and Decelerate Gradually

Similar facts present themselves when assessing acceleration. Rapid acceleration results in significantly lower fuel efficiency (see Figure 3). **If drivers adopt slow and gentle acceleration and deceleration habits, their overall fuel efficiency can be improved.**

Figure 3: Fuel Efficiency Decrease with Vehicle Acceleration



Source: Automatic, "The Hidden Cost of Aggressive Driving", http://blog.automatic.com/aggressive-driving/

Avoid Idling

The argument against parking and going into a business, rather than using a drive-through window, has been that the emissions and fuel use associated with restarting your car are greater than those incurred by idling for that time. Argonne National Laboratory undertook a series of measurements to determine whether this was true, by comparing actual idling fuel use and emissions with those for restarting. This work seeks to answer the question: Considering both fuel use and emissions, how long can you idle in a queue before impacts from idling are greater than they are for restarting? **Fuel use is always greater when idling than restarting your engine when idling over 10 seconds.**

While idling in traffic is necessary for safety, vehicles can be turned off while waiting for passengers or for freight trains to pass. Drivers can choose to park and enter a fast-food restaurant, rather than idle in a drive-through line. If each car in the United States idles just 6 minutes per day, about 3 billion gallons of fuel are wasted annually, costing drivers $10 billion or more.

Keep Tires Properly Inflated

Experts estimate that a quarter of all vehicles run on underinflated tires. Even new tires loose pressure over time. Drivers should try to check their tire pressure once a month. Most vehicles list the proper tire pressure on the driver's side door jamb, inside the glove box or in the owner's manual.

Under-inflation increases the rolling resistance of a vehicle's tires and, correspondingly, decreases the vehicle's fuel economy. Additionally, when a tire is used while significantly under-inflated, its sidewalls flex more and the air temperature inside the tire increases, increasing stress and the risk of failure. A significantly under-inflated tire also loses lateral traction, making handling more difficult. Under-inflation plays a role in crashes due to flat tires and blowouts. Finally, significantly under-inflated tires can increase a vehicle's stopping distance.

Additional Smart Driving Tips

Engine Tuning

1. **Keep your car tuned up.** Keeping your car tuned up can improve gas mileage by an average of 4%, depending on the problem and repair. Fixing a serious maintenance problem, such as a faulty oxygen sensor, can improve your mileage by as much as 40%. (www.fueleconomy.gov/feg/maintain.jsp)

2. **Use the recommended grade of motor oil.** You can improve your gas mileage by 1%–2% by using the manufacturer's recommended grade of motor oil. For example, using 10W-30 motor oil in an engine designed to use 5W-30 can lower your gas mileage by 1%–2%. Also, look for motor oil that says "Energy Conserving" on the API performance symbol to be sure it contains friction-reducing additives." (www.fueleconomy.gov/feg/maintain.jsp)

Before you Leave the House

1. **Remove extra weight.** Unload unnecessary items from your vehicle, especially heavy ones. An extra 100 pounds in your vehicle could reduce your MPG by up to 1%. (www.fueleconomy.gov/feg/driveHabits.jsp)

2. **Remove roof racks**. Hauling cargo on your roof increases aerodynamic drag (wind resistance) and lowers fuel economy. A large, blunt roof-top cargo box, for example, can reduce fuel economy by around 2% to 8% in city driving, 6% to 17% on the highway, and 10% to 25% at Interstate speeds (65 mph to 75 mph). (www.fueleconomy.gov/feg/driveHabits.jsp)

3. **Plan your trips.** Combining errands into one trip saves you time and money. Trip planning ensures that traveling is done when the engine is warmed-up and efficient. Remember, the best way to warm up a car is to drive it, not to idle. (fhwa.dot.gov/environment/climate_change/mitigation/publications_and_tools/ten_steps/)

Driving Habits

1. **Use driver feedback devices.** Driver feedback devices can help you drive more efficiently by training you to avoid bad behaviors. Visit 511.org/DriveSmartBayArea for 50% off a high-tech driver feedback devise.

2. **Be cautious when filling up the tank.** In the summertime, fill your gas tank during cooler evening hours to cut down on gas evaporation. Avoid spilling gas and don't "top off" the tank. Replace gas tank cap tightly. Gasoline is a highly volatile (meaning it evaporates quickly) and

that will be your money evaporating into the air. (www3.epa.gov/airquality/peg_caa/reduce.html)

3. **Tighten your gas cap.** Tightening your fuel cap can prevent leakage of up to 30 gallons of gas a year. (www.ncdot.gov/travel/drivegreen/downloads/DriveGreenSaveGreen_10Ways_Poster.pdf)

4. **Use cruise control.** Using cruise control on 10,000 miles driven in a year could save you nearly $200 and save more than 60 gallons of fuel, according to the Department of Transportation (assuming $3 a gallon for fuel, 20 MPG, and 15,000 miles driven annually). Cruise control helps ensure you don't speed and that you accelerate smoothly. (www.ncdot.gov/travel/drivegreen/drive_more_efficiently.html)

5. **Reduce your air conditioner use**. Air conditioning can reduce fuel efficiency significantly. In fact, your air conditioner can consume up to one gallon of gas per tank to cool the vehicle. But driving with your windows open can produce aerodynamic drag, which reduces fuel economy. What's a driver to do? When driving at slower speeds (less than 40 mph), such as driving in urban areas, open windows are better. At higher speeds (over 40 mph), close the windows and turn on the air conditioner – the AC uses less fuel. (www.ncdot.gov/travel/drivegreen/drive_more_efficiently.html)

Carpool, Walk, and Bike

1. **Try out carpooling to work.** Cut weekly fuel costs in half, make friends, and save wear on your car by taking turns driving with other commuters or riding in a vanpool. Even if you can't share rides to work, consider carpooling with friends to events or on nights out. For information and incentives to setup a carpool or vanpool, visit rideshare.511.org/

2. **Walk or bike for short trips.** Get some exercise and some fresh air by walking or biking on short trips around the neighborhood.

Other Tips

1. **Shift your trips.** Consider adopting a flexible work schedules where you leave for work and come home a little earlier or later than most people. By avoiding heavy traffic you can cut down on your weekly fuel costs. If you can't do this as part of your commute, keep traffic levels in mind when running errands. You can find real time traffic information at 511.org

2. **Buy a Fuel-Efficient Vehicle**. Go to www.fueleconomy.gov to find information on the most fuel-efficient vehicle that meets your needs. Driving a car that gets 30 MPG instead of one that gets 20 MPG would save $400 per year (assuming 12,000 miles of driving annually and a fuel cost of $2.00 per gallon) and almost 2 tons of CO_2 emissions.

3. **Telecommute**. Ask your employer if you can work at home sometimes. You'll save time and money, and reduce traffic congestion and CO_2 emissions. Americans spend more than 200 hours commuting each year – equal to 5 weeks of vacation! (The average daily round-trip commute takes about 50 minutes.)

Research on the Effectiveness of Smart Driving

Results of In-Vehicle Smart Driving Device Studies

Despite increasing interest in studying the impact of smart driving strategies on fuel efficiency, there is still no agreed upon estimate of the average fuel efficiency improvement that can be achieved by smart driving.

This section provides an overview of recent smart driving studies and offer insight on the range of results that have been produced.

Studies Based in the United States

In the United States, interest and study of smart driving first began in the late 1970s, when the Department of Energy (DOE) established the Driver Energy Conservation Awareness Training (DECAT) program[i]. It targeted large fleets and motor pools, but also intended to reach the general public. Officials from state governments and other large organizations could travel to the DOE Nevada Operations Office where, over a period of a few days, they were trained in fuel efficient driving techniques. By the mid-1980s over 8,000 people had been trained and returned to broadly disseminate their knowledge. The program, however, was terminated in the late 1980s due to low gas prices and shifting political interests.

In recent years there has been a resurgence of interest in smart driving strategies. This is partially due to improvements in technology that have allowed for the development of devices that can provide real-time feedback on fuel efficiency to drivers. Research on the results of implementing individual smart driving behaviors has diminished with the rise of these holistic feedback devices.

An interesting development in the auto market is the integration of pre-installed fuel efficiency feedback meters in vehicles. This practice was first introduced by Toyota with the launch of the Prius. Toyota may have included this feature because hybrid vehicles are particularly vulnerable to reductions in fuel efficiency with aggressive driving.[ii] Since then, Honda, Nissan, and Ford have all introduced various types of fuel efficiency meters into their hybrid (and some non-hybrid) models. The information displayed ranges from real-time fuel efficiency, 5 minute average fuel efficiency, overall trip fuel efficiency, simple color coded bars of fuel efficiency, a diagram of leaves that grow with improved fuel efficiency. The Ford SmartGauge, which displays real-time MPG and a leaf diagram, has won considerable praise for its innovative design (see Figure 4).

Figure 4: Ford 2013 C-MAX Hybrid SmartGauge with EcoGuide

Source: Clean MPG.com http://www.cleanmpg.com/forums/showthread.php?t=45323

Thus far, no studies have assessed the effectiveness of these factory installed fuel efficiency devices. Questions remain on how frequently the screen is viewed in vehicles where the screen can be turned off or changed to display other information. Additionally, it cannot be assumed that devices are available to many drivers because they are a relatively new feature and turnover of the vehicle fleet is a slow process. It may require multiple decades before these devices are in the majority of on-road U.S. vehicles. Recent studies have found a range in the potential fuel efficiency improvements due to smart driving techniques from zero to 18%. The substantial range in results is likely due to shortcomings in the studies including: insufficient sample sizes, short study periods, variations in the testing environment (simulations or tracks versus real-world driving conditions), and the lack of statistically significant findings. A summary of some recent studies is provided in Table 1.

Table 1: Smart Driving Study Findings (ordered by fuel use reduction results). Reproduced from Kurani et al.

Source	Period of Measure (Days)	Fuel Use Reduction	Sample Size	Statistically Significant Findings?	Design	Real-World Driving?
Lee et al., 2010[iii]	1	0%	14	No	3 icon color display	No
Larsson and Ericsson, 2009[iv]	42	0%	20	No	Vibrational feedback	Yes
Driving Change: City of Denver Case Study, 2009[v]	Unkn.	0%	214	Unkn.	Web-only feedback	Yes
Greene, 1986[vi] citing a 1981 study	Unkn.	2.2%	1	Unkn.	Simple, Vacuum-based meter	No
Greene, 1986[vii] citing a 1977 study	1	3.0%	140	No	Simple, Vacuum-based meter	No
Boriboonsomsin, 2010[viii]	14	3.8%	20	No	Real time mpg and CO_2/mile, throttle feedback, trip summary	Yes

Wahlberg, 2007[ix]	365	4.0%	350	Yes	Real time and average mpg	Yes
Ando et al. 2010[x]	126	4.3%	50	Unkn.	Web and mobile phone feedback/scoring	Yes
Greene, 1986[xi] citing a 1976 study	1	5.4%	1	Unkn.	Simple, Vacuum-based meter	No
Van der Voort, 2001[xii]	2.5	6.0%	12	Unkn.	Not Described	No
Greene, 1986[xiii]	Unkn.	8.8%	1	Unkn.	Simple, Vacuum-based meter	No
Syed and Filev, 2008[xiv]	1	10%	1	No	Accelerator pedal position advisory	No
Van der Voort, 2001[xv]	2.5	11%	12	Unkn.	Driver advice based on vehicle operations	No
Satou et al., 2010[xvi]	180	18%	150	No	Complex. Onboard and web realtime feedback, fuel use	Yes

Table source: Kurani, K., Stillwater, T., and Jones, M., 2013. Ecodrive I-80: A Large Sample Fuel Economy Feedback Field Test: Final Report. Institute of Transportation Studies Report: ITS-RR-13-15. Available at http://www.fueleconomy.gov/feg/pdfs/EcoDrive%20I-80.pdf

A 2013 study by Kurani et al. managed to overcome some of the previous shortcomings by conducting a large study of 118 drivers that reside along Interstate 80 from San Francisco, CA to Reno, NV.[xvii] Kuani et al, collected one month of baseline information and one month of feedback from the three types of in-vehicle fuel efficiency devices. They achieved a statistically significant average reduction in fuel consumption of 2.7%. The most efficient of the three displays produced a 2.9% decrease in fuel consumption. Men, on average, reduced their fuel consumption by 1.9% while women reduced theirs by 5%. An interesting result of the study is the authors calculation that had the messaging of the devices been targeted to match the drivers goals (such as saving fuel, or helping the environment) the effectiveness of the devices could have increased to an average improvement of 9.2%.

Another recent study by Birrell et al.[xviii] conducted a 50 minute real world driving study test of fuel-efficiency and safety feedback devices. They found an average of 4.1% improvement in fuel economy with the devices. The most important part of this study is the conclusion that well-designed devices can lead to fuel efficiency improvements without significantly distracting drivers by pulling their attention away from the road.

International Examples

Europe, Japan, and Canada are farther ahead with implementing smart driving campaigns for a variety of reasons including higher gas prices. Additionally, counties that ratified the Kyoto Protocol can use smart driving campaigns GHG emissions reductions towards their requirements[xix].

The largest smart driving study to date was conducted in Europe by Fiat[xx]. Fiat launched eco:Drive in 2008 to 45,000 of their European drivers. Drivers could use a USB stick to record information on their driving habits and fuel efficiency. The driver could then load the information from the USB drive to their computer to obtain personalized "tips" on ways to improve their fuel efficiency, and information on their fuel efficiency over time. Drivers were rated in five key areas – acceleration, deceleration, shifting, speed, and overall performance. Fiat prepared a summary report of the effects of the eco:Drive program by analyzing 428,000 trips made by 5,697 drivers over 150 days in 5 countries. They found that the average improvement in fuel economy was 6% and the top 10% of participants improved their fuel efficiency by 16%. Importantly, they found that these changes were sustained over time. However, 31% of the improvements are attributed to earlier shifting habits. In the United States, manual vehicles only account for approximately 6.5% of new vehicle sales which brings into question the ability of U.S. drivers to achieve the same fuel efficiency improvements.

Eco:Drive has been expanded to all countries where Fiats are sold (including the U.S.) and now has a community of 90,000 users. Users can engage with smart driving information via smart phone apps, in-vehicle displays, and an online community[xxi] of users that supports competition for improving fuel efficiency and the sharing of tips and suggestions for smart driving.

ECODRIVEN[xxii] was funded by the European Commission Energy Efficiency programme Intelligent Energy Europe (IEE). It included nine countries and was implemented from January 2006 through December 2008. ECODRIVEN collaborated with Ford of Europe, BP, FIA, ACEA, the German Road Safety Council DVR, EFA, Leaseplan and GE Capital Solutions. Although implementation of the program varied from country to country, a large emphasis of most of the campaigns was driver training and marketing. Overall, over 20 million licensed drivers were exposed to the smart driving campaign messages and it is estimated that the program eliminated 1million metric tons of CO_2 between 2006 and 2010.

A major component of the campaigns was to advise drivers to shift to a higher gear earlier than standard (between 2000-2500 RPM). This strategy is less relevant in the U.S. due to the lower number of manual vehicles. However, the other strategies are consistent with U.S. smart driving techniques, including maintaining a steady speed, anticipating traffic, avoiding high speeds and eliminating idling.

Immediate "before and after" tests of the effectiveness of smart driving training showed a range of results between 14% and 22.5%. The long term impacts were tracked by Ford (the specific data set is proprietary) and the Swiss General Office for Energy, both showed long term fuel savings of 10%. In the Netherlands (where there was a smart driving campaign between 1990 and 1998) they found that the long term fuel efficiency reductions were generally half of what they were immediately following driver training.

Interestingly, insurance companies in Europe tracked the number of insurance claims before and after the introduction of smart driving campaigns[xxiii]. They found between 14% and 35% reductions in claims. Smart driving improves safety by reducing speeding, emphasizing the need to anticipate what's happening on the road ahead and overall promotion of a calmer driving experience.

Results of Vehicle Maintenance Studies

Under-inflated tires can reduce vehicle fuel efficiency. The National Highway Traffic Safety Administration (NHTSA) conducted a study that found that 20% of light duty vehicles have at least one tire that is severely under inflated (more than 6 psi below the vehicle manufacturer's recommended pressure).[xxiv] Another 34% of vehicles have one or more tires that are moderately under inflated (1 to 6 psi below recommended pressure). ARB conducted a smaller survey that found similar results.[xxv] Every 3 psi drop in average tire pressure causes a 1% reduction in fuel economy, according to ARB. Thus, 20% of cars on the road are experiencing about 3% lower fuel economy due to tire under-inflation.

The NHTSA ruled that beginning in September 2007, all new light duty vehicles must be equipped with a monitoring system to alert drivers when one or more of their tires are inflated to 25% below the manufacturers' recommendations. Over time, with the turnover of the vehicle fleet, this monitoring system will hopefully reduce the number of vehicles driving with underinflated tires.

Roof racks and other exterior accessories decrease vehicle aerodynamics and increase drag. A large, blunt, roof-top cargo box can reduce fuel economy by 2% to 8% during city driving. This effect increases to 10% to 25% reduction in fuel efficiency when driving at freeway speeds. Rear mounted cargo boxes have less of an impact on drag and only reduce fuel efficiency by 1% to 2% during city driving and 1% to 5% at freeway speeds.[xxvi]

Carrying excessive weight in a vehicle can reduce fuel economy by requiring the vehicle to work harder to move the heavier vehicle. Every additional 100 pounds can reduce fuel economy by 2%. This effect will be larger for smaller, lower weight vehicles than it will be for larger, heavier vehicles.[xxvii]

Regular vehicle tune-ups can help identify and lead to the repair of engine problems that effect fuel economy. Some repairs, such as replacing a clogged air filter, will not affect vehicle fuel efficiency but repairing a critical component such as a faulty oxygen sensor can significantly improve vehicle fuel efficiency.

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