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# Mitigation Techniques to Modify Driver Performance to Improve Fuel Economy, Reduce Emissions and Improve Safety

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16. Abstract

The goal of this project was to identify and test techniques to modify driver behavior to improve fuel economy, reduce emissions, and improve safety, in furtherance of MassDOT's mission and goals of the GreenDOT Implementation Plan. Two types of behavioral modifications were implemented and evaluated in the field test: in-vehicle feedback devices and classroom eco-driving training sessions. Devices from GreenRoad Inc. were installed in 133 MassDOT vehicles with designated drivers and provided real-time feedback on each driver's performances. A trainer from the University of Vermont conducted the 1.5-hour classroom eco-driving training session. Major conclusions were as follows. (1) Real-time feedback had a significant effect in reducing speeding and aggressive acceleration. The effect sustained for pickup trucks after the feedback was discontinued, while it disappeared for sedans and SUVs. (2) Training had a significant effect in reducing idling rate in the first month after training. The literature synthesis concluded that idling, speeding, and aggressive acceleration were major contributors to fuel inefficiency, greenhouse gas emissions, and unsafe driving. Therefore, it is expected that combined training and feedback can significantly improve fuel economy, reduce emissions, and improve safety.

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# Mitigation Techniques to Modify Driver Performance to Improve Fuel Economy, Reduce Emissions, and Improve Safety

**Final Report**


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# Disclaimer

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# Executive Summary

This study of Mitigation Techniques to Modify Driver Performance to Improve Fuel Economy, Reduce Emissions, and Improve Safety was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

Vehicular transportation has a major impact on our society and environment. Techniques for modifying driver behavior to operate motor vehicles in a more efficient, safe, and environmentally friendly manner, including the use of in-vehicle feedback devices and classroom eco-driving training, can be potentially cost-effective. These low-cost measures can be readily applied to any fleet of vehicles and drivers, in contrast to technological changes that usually require long phase-in periods and higher equipment costs. The goal of this research was to identify and test techniques to modify driver behavior to improve fuel economy, reduce emissions, and improve safety, in furtherance of MassDOT's mission and goals of the GreenDOT Implementation Plan.

Two types of behavioral modifications (or interventions) were implemented and evaluated in the field test: in-vehicle feedback devices and classroom eco-driving training sessions. Devices from GreenRoad Inc. were installed in 133 MassDOT vehicles with designated drivers and provided real-time feedback on each driver's performance. A trainer from the University of Vermont conducted the 1.5-hour classroom eco-driving training session.

The drivers were divided into four groups: (1) Received in-vehicle feedback and classroom training; (2) received in-vehicle feedback and no classroom training; (3) received classroom training and no in-vehicle feedback, and (4) no in-vehicle feedback device and no classroom training. All four groups participated in three chronological phases:

1. Baseline Period: June 1 to July 27, 2015; no real-time feedback, no eco-driving training.
2. Intervention Period: July 28 to Oct. 9, 2015; real-time feedback was provided to two groups and training was conducted for two groups, followed by bi-weekly eco-driving tip emails.
3. Off Period: Oct. 10, 2015 to Feb. 1, 2016; real-time feedback was turned off and emails providing eco-driving tips were discontinued.

Major conclusions from the data analysis were as follows:

1. Real-time feedback had a significant effect in reducing speeding and aggressive acceleration. The effect sustained for pickup trucks after the feedback was discontinued, while it disappeared for sedans and SUVs.
2. Training had a significant effect in reducing idling rate in the first month. The literature synthesis concluded that idling, speeding, and aggressive acceleration are major contributors to fuel inefficiency, greenhouse gas (GHG) emissions, and unsafe

driving. Therefore, it is expected that combined training and feedback can significantly improve fuel economy, reduce emissions, and improve safety.

Based on the conclusions, it is recommended that both real-time feedback and training be provided to maximize the effectiveness of the interventions. It is recommended that real-time feedback be combined with periodic self-evaluation and MassDOT monitoring, and that training be conducted by MassDOT trainers trained by external trainers, with customized MassDOT online training modules as follow-up refreshers.

# Table of Contents

# List of Figures

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# List of Tables

# 1.0 Introduction and Objective

This study of Mitigation Techniques to Modify Driver Performance to Improve Fuel Economy, Reduce Emissions, and Improve Safety was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

## 1.1 Background

Transportation has a major impact on our society and environment, contributing: 70% of U.S. petroleum use; 28% of U.S. greenhouse gas (GHG) emissions (Bureau of Transportation Statistics, 2013); and over 34,000 fatalities and 2.2 million injuries in 2011 (Environmental Protection Agency, 2016). In addition to the use of more fuel-efficient vehicles and alternative fuels, fuel consumption and $CO_2$ emissions can be lowered through a variety of techniques and strategies. Eco-driving is one such strategy, which typically consists of modifying a person's driving behavior by providing advice (both static and dynamic) to the driver. Techniques for modifying driver behavior to operate a motor vehicle in a more efficient, safe, and environmentally friendly manner, including the use of in-vehicle feedback devices and classroom eco-driving training, can be potentially cost-effective. These relatively low-cost measures can be readily applied to any fleet of vehicles and drivers, in contrast to technological changes that usually require long phase-in periods and higher equipment costs.

## 1.2 Objective

The objective of this research project was to identify and test techniques to modify driver behavior to improve fuel efficiency, reduce emissions, and improve safety, in furtherance of MassDOT's mission and goals of the GreenDOT Implementation Plan. To meet this objective, researchers completed the following activities:

1. Conducted literature synthesis of driver and vehicle characteristics that affect fuel efficiency, emissions, and safety.
2. Examined driver performance modification applications using in-vehicle devices from other states, private corporations, and abroad.
3. Evaluated commercially available in-vehicle devices that provide performance feedbacks to drivers and classroom training programs.
4. Conducted field tests using MassDOT vehicles to investigate (potential) changes of driving behavior before and after the installation of the devices and in-classroom training.
5. Performed statistical analysis to evaluate the effectiveness of the two types of behavioral interventions.

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# 2.0 Literature Synthesis

The goal of this chapter is to review and synthesize available literature regarding vehicle and driver factors that influence vehicle fuel efficiency, emissions, and safety. This synthesis, together with the next chapter of synthesizing driver behavior modification applications of other states, private corporations, and abroad, helped the Project Team understand the fundamental interactions between driver behavior and vehicle performance in the three major aspects: fuel efficiency, emissions, and safety, and guided the team in designing effective intervention techniques to modify driver behavior to improve performance in all three aspects.

The focus of this research was on short-term driver behavior at the operational level, that is, how a driver operates a vehicle, including speed selection, acceleration, deceleration, and reacting to traffic and other vehicles. This is in contrast to longer-term traveler behavior at the strategic and tactical levels, such as vehicle selection, mode choice, and route choice. As a result, this chapter focuses on factors at the operational level. It puts more emphasis on literature since 2000, and includes past articles of significant importance.

## 2.1 Factors Affecting Fuel Economy and Greenhouse Gas Emissions

The majority of the current U.S. vehicle fleet uses internal combustion engines that burn carbon-based fossil fuels. A direct product of complete combustion is carbon dioxide ($CO_2$), a major greenhouse gas. As $CO_2$ production is generally proportional to fuel consumption, factors that influence the two performance measures are discussed at the same time in this section.

In this report, fuel consumption (FC) factor is defined as the volume of fuel consumed by a vehicle to travel a unit distance (gallon per mile or liter per kilometer). Similarly, the $CO_2$ emission factor is defined as the mass of $CO_2$ emitted for a unit distance traveled (gram per mile or gram per km).

Two other commonly used measures of fuel efficiency are:

- *Fuel Economy*, the distance travelled per unit volume of fuel consumed (miles per gallon or km per liter). This is the measure that consumers are familiar with when purchasing a vehicle. It is the reciprocal of the fuel consumption factor.
- *Fuel Consumption Rate*, the volume of fuel consumed per unit of time traveled (gallon per second or liter per second). This measure is of less interest compared to the FC factor, as often the total distance to travel is fixed, and the FC factor can give a direct measurement of the total fuel consumption for a given trip.

For a given vehicle, engine, and fuel type, the speed profile of the vehicle is a major determinant of fuel consumption and emissions (Ericsson, 2001). A speed profile can be described by many parameters; in this report, the focus is on the cruise (or instantaneous) speed, acceleration, deceleration, and stops (idling). Note that average speed in general is not a good predictor of fuel consumption and emissions, since it fails to capture the underlying speed profile. Andre and Hammarstrom (2000) showed that fuel consumption estimation difference based on average speed and speed distribution can be as high as 14% on motorways, and carbon monoxide (CO) emission estimation difference as high as 30% on rural roads.

Often, the team found a particular study was conducted to examine multiple factors affecting fuel efficiency, and thus these studies are reviewed in different sections of this report, with more details about the background of each study the first time it is reviewed.

### 2.1.1 Cruise and Instantaneous Speed

Tong, Hung, and Cheung (2000) studied four different instrumented vehicles (petrol passenger car, petrol van, diesel van, and double-decker bus) and related FC and emissions with instantaneous speeds in a relatively congested urban driving environment (Hong Kong). The FC factor was monotonically decreasing until the maximum speed that was recorded for all vehicles except petrol van, which suggests that the optimum fuel efficiency range was at least 60–70 km/h for the petrol passenger car and diesel van, and at least 85–90 km/h for the double-decker bus. The sharp decrease in FC factors from 0–5 km/h to 5–10 km/h was evident. The FC factor of the petrol van decreased gradually until 65–70 km/h and then increased gradually.

Ericsson (2001) conducted a comprehensive study of factors that affect fuel consumption and emissions based on driving data in real traffic, although the fuel consumption and emissions were estimated using mechanistic instantaneous emission models rather than measured. Driving patterns were studied in an average-sized Swedish city, representing 2,550 journeys and 18,945 km of driving of five passenger cars. These included traditional driving pattern parameters of speed and acceleration and new parameters of engine speed and gear-changing behavior. By using factorial analysis, the initial 62 parameters were reduced to 16 independent driving pattern factors, among which 5 were related to cruise speed: factor for speed 15–30 km/h, factor for speed 50–70 km/h, factor for speed 70–90 km/h, factor for speed 90–110 km/h, and factor for speed > 110 km/h. In the end, only the factor for speed 50–70 km/h was found to have a significant negative effect on fuel use and $CO_2$ emissions, while the other four cruise speed factors were not statistically significant. The factor for speed 70–90 km/h had a negative effect but not significant. See Table 2.1 for details, where a factor with at least two +’s or -’s was viewed as significant; the larger the number of +’s or -’s, the more significant the effect was. This indicated that the most fuel-efficient cruise speed was in the range of 50–70 km/h, even though the effect on fuel use and $CO_2$ emission was not as significant as some other factors related to acceleration, stops, and power demand. The stop factor was highly significant, suggesting that idling was a very important contributor to FC and $CO_2$ emission, a conclusion consistent with that from Tong et al. (2000).

**Table 2.1: Driving pattern factors with significant effect on emissions and fuel-use**

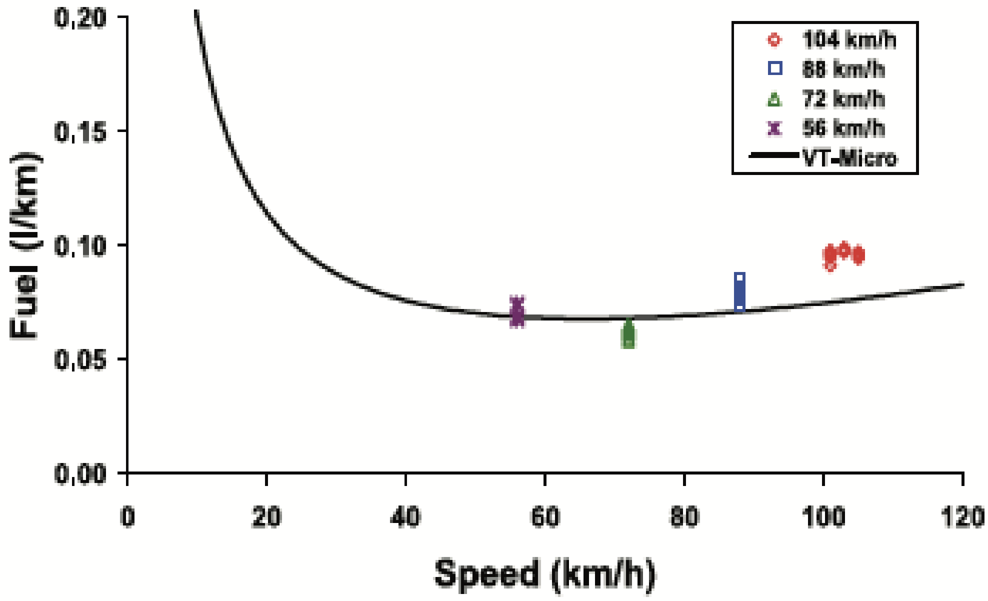
| Driving pattern factor | Fuel | $CO_2$ | HC | NOx |
|---|---|---|---|---|
| Deceleration factor | - | - | x | x |
| Factor for acceleration with strong power demand | ++++ | ++++ | +++ | ++++ |
| Stop factor | +++++ | +++++ | x | x |
| Speed oscillation factor | ++ | ++ | x | x |
| Factor for acceleration with moderate power demand | ++ | ++ | x | x |
| Extreme acceleration factor | ++ | ++ | +++++ | ++++ |
| Factor for speed 15–30 | x | x | x | - |
| Factor for speed 90–110 | x | x | x | x |
| Factor for speed 70–90 | - | - | x | x |
| Factor for speed 50–70 | -- | -- | x | x |
| Factor for late gear changing from gear 2 and 3 | + | + | (++) | +++ |
| Factor for engine speed > 3500 | x | x | (++) | ++ |
| Factor for speed > 110 | x | x | x | x |
| Factor for moderate engine speeds at gear 2 and 3 | -- | -- | x | - |
| Factor for low engine speed at gear 4 | - | - | x | (-) |
| Factor for low engine speed at gear 5 | - | - | x | (-) |

**Source:** Ericsson (2001)
**Note:** (x) values indicate data is not applicable

El-Shawarby, Ahn, and Rakha (2005) conducted field evaluation of the impacts of vehicle cruise speed and acceleration levels on fuel consumption and emissions, using one light-duty test vehicle on interstate highways. The vehicle emission and engine data were measured with a portable, on-road vehicle data-measurement device under real-world driving conditions. Figure 2.1 shows the bowl-shaped variation in the FC factor (liter/km) as a function of the vehicle cruise speed; the optimal FC factor appeared to occur at a cruise speed of approximately 72 km/h. The optimum range seemed to be 60–90 km/h, with considerable increase outside this range. The authors noted that this optimum range was consistent with findings from the literature. The $CO_2$ emission had the same relationship (see Figure 2.1).

Wang, Zhou and Li (2008) used a portable emissions measurement system on ten passenger cars and found that the FC factor was optimum at speeds of 50–70 km/h.

**Figure 2.1: Variation in vehicle fuel-consumption as function of cruise speed**

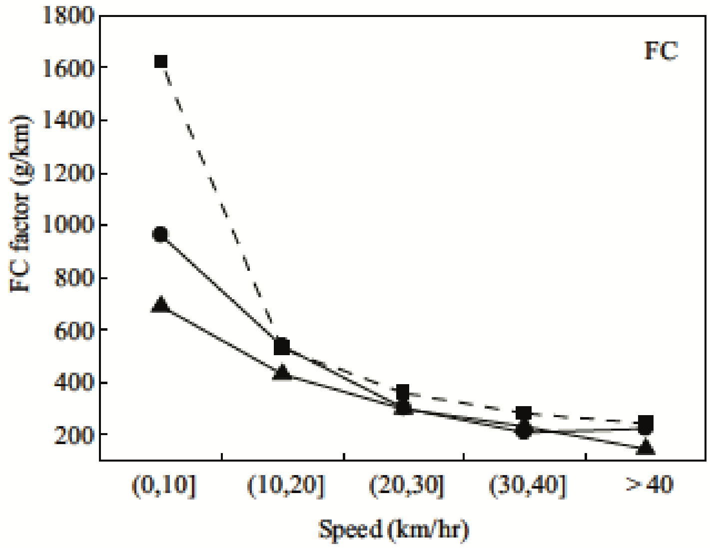



**Source:** EI-Shawarby, Ahn, and Rakha (2005)

Earlier studies (before 2000) have also shown similar fuel-efficient speed ranges of 60–80 km/h. See Samaras and Ntziachristos (1998) and Joumard et al. (1999) as cited in Andre and Hammarstrom (2000).

Wang et al. (2011) analyzed the effects of cruising speed on fuel consumption and emissions for six tested buses, which were fueled on diesel and compressed natural gas (CNG), rather than gasoline as in light-duty vehicles (LDVs). Figure 2.2 demonstrates that the FC factor decreased rapidly at first and then slowly as speed increased ($CO_2$ curves followed the same trend). The three curves represented different buses. The monotonic decreasing trend was different from the bowl-shaped one for LDVs in the previously reviewed studies, probably due to the fact that the maximum speed the buses drove was 40 km/h. The sharp decrease of FC factors from 0–10 km/h to 10–20 km/h suggested that bus drivers should avoid driving at extremely low speed.

**Figure 2.2: Effect of speed on FC for Euro III diesel, Euro IV diesel and CNG buses**




**Source:** Wang et al. (2011)

Idling a vehicle for any amount of time significantly reduced efficient fuel economy for a trip, as Saboohi and Farzaneh (2009) implied. In an experiment that lasted 276 seconds, an additional fuel consumption of 0.33 liters (0.08 gallons) was detected. Thus, for every hour of idle running for an average passenger car, 4.3 liters (1.14 gallons) of gasoline was used. Another experiment mentioned in Sivak and Schoettle (2011) monitored vehicles on a 16 km course. By turning off the engine during each of the ten idle periods, lasting two minutes each, there was a 19% fuel economy improvement.

**Summary of Speed Effects on FC and $CO_2$ Emissions**

In general, the FC and $CO_2$ emission factors have a bowl-shaped relationship with cruise or instantaneous speed. The curve first decreases sharply in the low-speed range (idling 10–20 km/h) and then decreases gradually until it reaches its minimum (optimum) in the range of 50–90 km/h (31–56 mph). This is the range where the trade-off between overcoming rolling road resistance and increasing wind resistance is optimized (Young, Birrell, and Stanton, 2011). This suggests that if the surrounding conditions allow for it, one should cruise at a speed of 50–90 km/h. Idling or driving at a very low speed should be avoided as much as possible. These are consistent with Edmunds' fuel economy tips (Edmunds, 2005):

- Lowering speed can save up to 14% of gas, with average savings of 12%. It is recommended to drive the speed limit.
- Cruise control can save up to 14% of gas, with average savings of 7%. It is recommended to use cruise control to maintain a constant speed.
- Avoiding excessive idling can save up to 19% of gas. It is recommended to shut down the engine if the vehicle will be stopping for more than one minute.

### 2.1.2 Acceleration and Deceleration

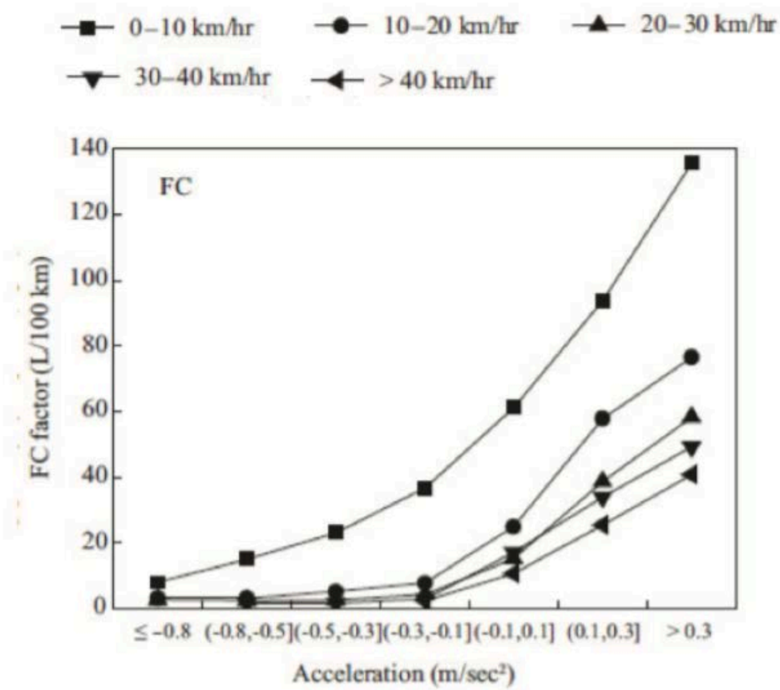
In the acceleration process, the engine needs more fuel to generate enough power to accelerate. Tong et al. (2000) analyzed four standard driving modes: acceleration, cruising, deceleration, and idling. They found that the fuel consumption during the acceleration mode was comparatively higher than for other driving modes. For the passenger car, the FC factor during acceleration was more than 80% higher than that during cruising. The FC factor of cruising was slightly higher than for that of deceleration for the petrol passenger car and van, and almost the same as that of deceleration for the diesel van.

Among the nine significant independent factors that affect FC and $CO_2$ emissions reported in Ericsson (2001), four are related to acceleration: factor for acceleration with strong power demand; speed oscillation factor; factor for acceleration with moderate power demand; and extreme acceleration factor. The author concluded that speed in itself did not cause large environmental problems in urban traffic, and one needed to focus on changing environments, drivers, and vehicles in a way that did not promote heavy acceleration, power demand, and high engine speeds.

In the study conducted by El-Shawarby et al. (2005), a sequence of ten trips at three levels of acceleration, namely, mild, normal, and aggressive, was executed over a fixed 1.4-km section of the Smart Road test facility in Southwest Virginia. The authors found that if vehicle fuel consumption and emission rates (g/sec) were only considered while the vehicle was accelerating, then as the aggressiveness of the acceleration maneuver increased, the FC per maneuver decreased. The reduction in vehicle FC was caused by the reduction in the distance and time that were required to execute the acceleration maneuver as the acceleration aggressiveness increased. However, if the FC and emissions were gathered over a sufficiently long fixed distance, then the conclusions were reversed (i.e., as the level of acceleration increased, the FC and $CO_2$ emission factors increased). Exploiting the vehicle's maximum acceleration capabilities could use up to 60% more fuel than mild or normal acceleration levels.

Similar conclusions have been drawn for buses. Wang et al. (2011) found that the FC factors were the highest at acceleration, modest at cruise speeds, and the lowest at deceleration for non-idling buses. Figure 2.3 shows FC factors as functions of acceleration at five different speeds. The FC factor was the highest in the low-speed and high-acceleration range (speed 0–10 km/h; acceleration > 0.3 $m/sec^2$).

**Figure 2.3: Effect of speed on FC for Euro III diesel, Euro IV diesel and CNG buses**




**Source**: Wang et al. (2011)

Kim and Choi (2013) estimated critical values of aggressive acceleration from a viewpoint of FC and emissions, recognizing that the literature had a consensus that acceleration was a major contributor to FC and emissions. The aggressive acceleration was defined where FC and emission rates increased rapidly while driving. One test vehicle was used whose speeds ranged from 10 km/h to 80 km/h considering driving patterns in urban areas. 1.4705 $m/s^2$ and 2.2770 $m/s^2$ were determined as estimates of aggressive acceleration and extreme aggressive acceleration. From the other angle, Waters and Laker (1980) demonstrated that the optimal acceleration rate was 0.07g, with fuel consumption increasing by 20% as acceleration increased up to 1.8g.

**Summary of Acceleration Effects on FC and $CO_2$ Emissions**

There is a consensus in the literature that acceleration significantly increases fuel consumption and $CO_2$ emissions. In fact, all eco-driving rules focus heavily on maintaining a steady speed (see, e.g., Johansson, Farnlund, and Engstrom (1999); Austrian Energy Agency (n.d); Sivak and Schoettle (2011); and Rakotonirainy et al. (2011)). Edmunds (2005) cited aggressive driving as the number-one factor of fuel consumption and concluded that moderate driving saved up to 37% of fuel, with an average saving of 31%.

### 2.1.3 Other Factors

For a manual transmission vehicle, Minett et al. (2011) found that it was helpful to transition the gear upward as early as possible, and that the optimal revolutions per minute (RPM) was between 2,000 and 2,500, depending on specific powertrains. Ideally, drivers should stay in fourth gear at 50 km/h (31 mph) and fifth gear at 80 km/h (50 mph). Celli (2011) agreed with this conclusion and claimed that it was fundamentally important to maximize the torque usage provided by the engine. Therefore, within the powertrain, gear ratios were an important factor in improving overall fuel consumption. Similar results were reported in Saboohi and Farzaneh (2009).

As discussed in Haworth and Symmons (2001), 5% to 25% of fuel could be consumed by a vehicle's air conditioner. However, simply opening windows brought increased aerodynamic air resistance, which in turn produced additional fuel efficiency loss. Edmunds (2005) found no measurable difference between air conditioning on with windows up versus air conditioning off with windows down, and suggested that individuals make themselves comfortable.

Lastly, underinflated tires could produce an additional 1.5% drop in fuel economy (Sivak and Schoettle, 2011; El-Shawarby et al., 2005).

## 2.2 Air Pollutant Emissions

### 2.2.1 Background

Motor vehicles are major contributors to air pollution, responsible for nearly one half of smog-forming volatile organic compounds (VOCs), more than half of the nitrogen oxide (NOx) emissions, and approximately half of the toxic air pollutant emissions in the United States (Environmental Protection Agency, 2007).

There are six common air pollutants: particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. Of these six pollutants, particulate matter and ground-level ozone impose the most widespread health threats. Motor vehicles are major contributors to the two pollutants (Environmental Protection Agency, 2007).

Particulate matter (PM) includes the very fine dust, soot, smoke, and droplets that are formed from chemical reactions. NOx gases from motor vehicles react with sunlight and water vapor to form particles. These fine particles can get deep into the lungs and aggravate asthma, cause acute respiratory symptoms, reduce lung function resulting in shortness of breath, and cause chronic bronchitis.

Ground-level ozone is a primary component of smog. Repeated exposure to ozone can make people more susceptible to respiratory infections and lung inflammation. VOCs and NOx are the main ingredients in forming ground-level ozone. Both are released by cars burning gasoline.

Carbon monoxide (CO) is a colorless, odorless gas emitted from combustion processes. The majority of CO emissions to ambient air come from mobile vehicles. CO can cause harmful effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues.

The following review will focus on NOx, VOCs (sometimes termed hydrocarbon, or HC), and CO emissions from vehicles.

### 2.2.2 Speed

Tong et al. (2000) found that for each of the four types of vehicles tested (petrol passenger, petrol van, diesel van, double-decker bus), the NOx, HC, and CO emission factors decreased as the instantaneous speed increased, and the decrease rate became more gradual as the speed increased, similar to the trends for FC. For an instantaneous speed increase from 5–10 to 10–15 km/h, the CO, HC, and NOx emission factors of the double-decker bus generally decreased more than 70%. Emission rates during idling were generally much lower than other modes (acceleration, cruise, and deceleration), as a small amount of fuel was needed to maintain engine operation. However, if idling periods were included in calculating average emission factors over a sufficiently long trip, the non-zero emissions over zero-distance would still worsen the emission factors.

In the independent driving factor analysis of Ericsson (2001), none of the speed factors (including the stops factor) had significant effects on the emissions of HC or NOx. As will be discussed in the next subsection, acceleration and power demand factors played a major role.

In El-Shawarby et al. (2005), the NOx, HC, and CO emissions were found to have similar bowl-shaped trends as those for FC and $CO_2$ with respect to cruise speed. 60–90 km/h appeared to be the optimum speed range for minimum emissions.

Wang et al. (2011) found monotonic decreasing relationships between buses' NOx, CO, and HC emission factors and cruise speeds up to 40 km/h. The decrease was more dramatic at lower speeds. The trends were similar to those of FC and $CO_2$ emissions.

**Summary of Speed Effects on Pollutant Emissions**
The effect of speed on NOx, HC, and CO emission factors is generally similar to the effect of speed on FC and $CO_2$ missions. It appears that idling (stops) has a smaller negative effect on pollutant emissions than on FC and $CO_2$ emissions (Ericsson, 2001).

### 2.2.3 Acceleration and Deceleration

Tong et al. (2000) found that NOx, HC, and CO emission factors were highest during acceleration and deceleration and lowest during cruising, except for the double-decker bus. This finding was slightly different from that for FC, for which deceleration generally had the lowest FC factors. The common trait was that acceleration mode had the highest pollutant emission factors. The double-decker bus had significantly larger cruising emission factors than those for the acceleration and deceleration, because the average speed during cruising model was very low at 11 km/h, which fell into the highly inefficient speed range.

Ericsson (2001) demonstrated that HC emissions were primarily affected by factors for acceleration with high power demand and extreme acceleration, and NOx emissions were mainly affected by the factors for acceleration with high power demand, extreme acceleration, engine speed > 3,500 rpm and late-gear changing from gears 2 and 3. None of the speed factors were significant for either NOx or HC emissions, while the factor for speed 50–70 km/h was significant for FC and $CO_2$ emission. This suggests that acceleration increased pollutant emissions more than it increased FC and $CO_2$ emissions.

El-Shawarby et al. (2005) showed that the HC and CO emissions per trip were highly sensitive to the level of acceleration, with much higher emissions resulting from more aggressive acceleration. This conclusion was caused by the fact that high levels of acceleration resulted in a rich fuel-to-air ratio operation, which is required to prevent engine knocking, thus bypassing the catalytic converter and increasing vehicle emissions. This bypassing of the catalytic converter continued even after the aggressive event was completed, causing increases in vehicle emissions. However, the NOx emissions had an opposite trend. The authors acknowledged that this decreasing trend for NOx emissions was consistent with what had been reported in the literature: namely, the NOx emissions were highest at stoichiometric engine conditions, as opposed to high engine loads.

Wang et al. (2011) found similar relationships between pollutant emissions and acceleration as those between FC and acceleration. From deceleration to cruise speed, and to acceleration, emission and FC factors increased rapidly as acceleration increased. The emissions were highest in the low-speed and high-acceleration range (speed 0–10 km/h; acceleration > 0.3 m/sec2).

**Summary of Acceleration Effects on Pollutant Emissions**

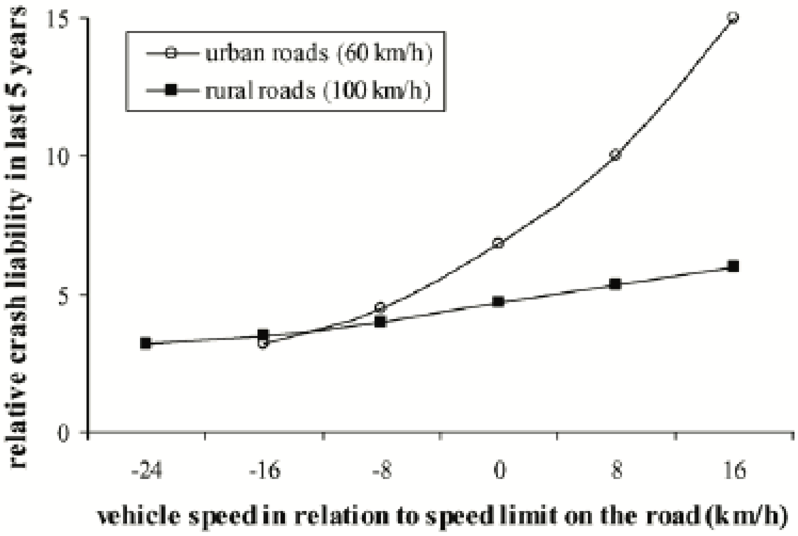
It is clear from the literature that acceleration is the most important factor affecting NOx, HC, and CO emissions. Its relative importance compared to speed factor appears even higher than that for FC and $CO_2$ emissions. At least one study (EI-Shawarby et al., 2005) indicated that NOx emissions decreased with the aggressive level of acceleration; however, the emission was still higher than that during cruising.

## 2.3 Safety

### 2.3.1 Speed

Speed is an important factor in road safety. At high speeds, the time to react to changes in the environment is shorter, the stopping distance is larger, and maneuverability is reduced. Aarts and van Schagen (2006) provided a literature review on the speed-crash risk relationship. The authors noted an Australian study by Fildes, Rumbold, and Leening (1991) that applied a self-report method. Drivers with different driving speeds were stopped and asked about their history of road crashes during the last five years. For both the urban and rural roads, the relationship had the shape of an exponential function, which was much steeper for urban roads than for rural roads (Figure 2.4). The exponential function was also reported in other studies (see, e.g., Kloeden, McLean, and Glonek, 2002).

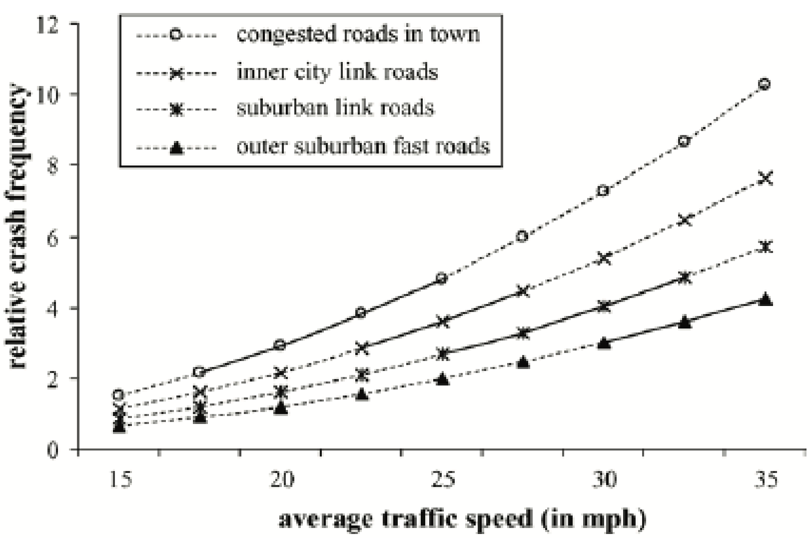
**Figure 2.4: Relation between individual speed and crash rate on urban 60 km/h and rural 100 km/h roads**




**Source:** Field, Rumbold and Leening (1991)

Aarts and van Schagen (2006) also reported studies on the relationship between average road section speed and crash rate. Taylor, Lynam, and Baruya (2000) distinguished four road types: congested roads in town, inner city link roads, suburban link roads, and outer suburban fast roads. The result showed that for each of these road types, the crash frequency increased with increasing average speed. Congested roads both had a higher absolute crash frequency and a larger increase in crash frequency with higher average speeds than fast roads (Figure 2.5). Later Taylor, Baruya, and Kennedy (2002) suggested that accident frequency increased with driving speed to the power of approximately 2.5.

**Figure 2.5: Relationship between average speed and crash frequency on four urban road types**




**Source:** Taylor, Lynam, and Baruya (2000)

Additionally, Robinson and Campbell (2006) identified exceeding the speed limit or driving too fast for the conditions as contributory factors in 15% of all accidents on U.K. roads in 2005. A recent study by the American Automotive Association (AAA Foundation for Traffic Safety, 2009) estimated that 56% of fatal crashes over a four-year span (2003 to 2007) could be attributed to aggressive driving maneuvers, with excessive speed being the number-one factor.

**Summary of Speed Effects on Crash Risk**
The literature is consistent in that excessive speed is the single biggest factor of both crash risk and severity.

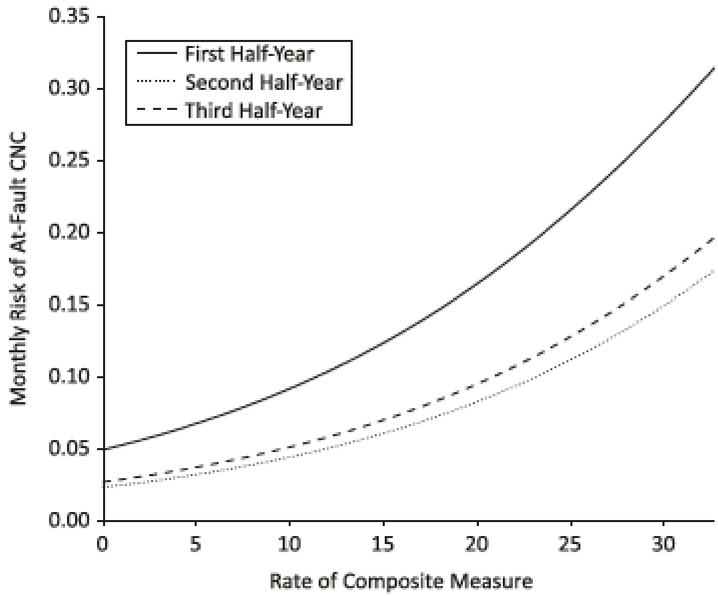
### 2.3.2 Acceleration

Quick acceleration and deceleration also lead to higher crash risk, because they increase the potential for loss of vehicle control and reduce the time available to the driver to respond to the actions of other drivers and to take evasive actions to avoid a crash should a conflict materialize (Elvik, 2006; Bagdadai and Varhelyi, 2011). Younger drivers also tended to drive more aggressively than experienced adult drivers. Research has shown that younger drivers do not fully understand the potential risks of aggressive driving (Borowsky, Shinar, and Oron-Gilad, 2010; Lee, Olsen, and Simons-Morton, 2006; Pradhan et al., 2009), thus possibly making them more willing to engage in aggressive or risky behavior. Other researchers have found a link between an individual's self-ranking of sensation-seeking behaviors/personality and aggressive driving habits (Constantinou et al., 2011; Romoser et al., 2012).

In-vehicle data recording (IVDR) devices have played an increasingly important role in safety studies. Devices can be placed within the vehicle to capture acceleration using gravitational-force (g-force) sensors and global positioning. Driver behavior can be recorded directly using cameras mounted strategically within the cockpit. Cameras can be aimed inward at the driver to record what a driver was doing leading up to and during a critical event, and they can also be aimed outward to record the environment in front of and around the vehicle. An IVDR system can include anything from a simple onboard diagnostics (OBD)-II data logger that records only summary information from the vehicle's computer to a fully integrated system that records OBD-II, GPS, g-force, and video, and stores high-fidelity data when undesirable events occur.

Using such devices, a research study conducted by Simons-Morton et al. (2012) found a strong relationship between high g-force events and crash rate. The system deployed included video, g-force data, and OBD-II information. Eight seconds of data leading up to an event and another ten seconds of data following an event were stored whenever an undesirable event, or "high g-force" event, was detected. High g-force events were recorded whenever the g-forces recorded by the three-axis accelerometer exceeded a predetermined threshold. Further high g-force event information was recorded, using a digital video recording system that recorded two video channels, a view within the cockpit of the vehicle and a second view of the roadway ahead. Data was recorded for a total of three years, with more than 68,000 individual trips captured and an average of 1,626 trips per participant. Results concluded that crash risk was statistically higher for drivers with a high rate of g-force events (Figure 2.6). High g-force events were some five times higher for teenagers when compared to experienced adults. These g-force events did not decrease significantly over the first 18 months of licensure.

**Figure 2.6: Estimated risk of having at least one at-fault crash and near-crash (CNC) event in a month**




**Note:** Figure shows function of the composite measure of elevated gravitational-force events (per 100 miles) in the previous month and time since licensure (in half-years).
**Source:** Naturalistic Teenage Driving Study, Blacksburg, Virginia, 2006–2009 (in Simons-Morton et al., 2012).

**Summary of Acceleration Effects on Crash Risk**
Excessive acceleration (high g-force) increases crash risk.

### 2.3.3 Driver Distraction

Driver distraction is another major contributor to traffic accidents. In a study conducted by Virginia Tech Transportation Institute (VTTI), sponsored by the National Highway Traffic Safety Administration (Dingus et al., 2006), 100 vehicles belonging to participants of ages varying from 18 to 55 and older were outfitted with cameras and sensors. Participants drove with the equipment in their vehicle for several months. The study collected over 2 million vehicle-miles of driving and almost 43,000 hours of data. The results of the study found that 80% of automobile crashes and 65% of all near crashes involved looking away from the forward roadway just prior to conflict. An operational definition of inattention included driver-engaged secondary tasks, not paying attention to the forward roadway, drowsiness, or other non-driving-related glances. When using this definition, 93% of crashes could be attributed to driver inattention. The use of hand-held wireless devices was associated with the highest frequency of secondary task inattention events.

Research in a driving simulator study suggested that teens were especially likely to glance away from the forward roadway for periods of time exceeding two seconds. Chan et al.

(2010) conducted a simulator study in which newly licensed teenage drivers were compared to a cohort of experienced drivers (20+ years of age). While driving the simulator, drivers were asked to engage in a series of in-vehicle tasks such as using a cellphone, looking for change, finding a CD, and searching a map. There were very large differences measured between the groups. Teens were much more willing to take their eyes off the forward roadway for longer periods of time than experienced drivers: 20.0% of experienced drivers compared with 56.7% of teen drivers looked away from the forward roadway for more than two seconds. At the higher threshold of three seconds, only 6.7% of experienced drivers looked away for longer, compared with 33.3% of teen drivers. Similar results were found in a study conducted in Finland (Wikman, Nieminen, and Summala, 1998).

**Summary of Driver Distraction Effects on Safety**

Driver distraction is another contributor to crash risk. Olson et al. (2009) reported that "text messaging while driving creates a crash risk 23 times higher than driving while not distracted."

## 2.4 Conclusion

The review of the literature on factors affecting fuel consumption, emissions, and safety reveals that the results are consistent to a large extent. Young et al. (2011) had the same conclusion. Haworth and Symmons (2001) reported a positive correlation between crash rates and fuel consumption in a large corporate fleet.

The three major characteristics of driver behaviors that improve fuel efficiency, reduce emissions, and improve safety are:

- *Smooth driving*. Acceleration significantly increases fuel consumption, $CO_2$, NOx, HC, and CO emissions and is a contributor to crash risk. Idling (stops) or driving at a very low speed (whether voluntary or involuntary) significantly worsens FC and emissions. One should avoid driving in a stop-and-go fashion if possible, e.g., avoid following the lead vehicle too closely in traffic jam.
- *Anticipating the traffic*. This is a characteristic related to the previous one, in that smooth driving requires deliberate efforts from the driver to anticipate the traffic and be vigilant to other vehicles' actions. A mindful driver is also less likely to be distracted and thus reduces crash risk.
- *Sensible speed for the driving conditions*. Abiding by speed limits on highways not only can significantly reduce crash risk, but also improves fuel economy and reduces emissions (50–90 km/h has emerged as the optimum FC and emission speed range from the literature).

Sometimes, there are conflicts among the recommended behaviors for the three aspects. CIECA (2007), cited in Rakotonirainy et al. (2011), identified the following potential conflicts:

- Drifting around junctions and pedestrian crossings in an attempt not to stop.
- Driving too closely to the vehicle in front in an effort to maximize evenness of speed.

- Coasting too early and disrupting the pattern of traffic to the rear, thereby increasing the risk of a rear-end collision.
- Rapid acceleration to cruising speed could cause shorter safety margins to vehicles in front.

It was suggested by the authors that driving safely and using eco-driving techniques wherever possible are perhaps more appropriate rules of conduct than the behaviors cited above.

In addition, in-vehicle devices that provide real-time feedback to drivers on their performance could potentially distract them and jeopardize safety. These potential conflicts should be considered in later tasks of the research in designing behavior interventions to improve driver performance.

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# 3.0 Equipment and Training Review

This chapter describes the review and synthesis of available literature pertaining to the use of in-vehicle devices to improve fuel economy, reduce emissions and improve safety. Both commercially available devices and those still in the research phase were reviewed based on technical reports, journal articles, conference presentations, and manufacturer websites. Emphasis was been given to the costs and benefits of the devices and lessons learned in conducting a successful field test. The two most suitable in-vehicle devices were identified and evaluated to select the in-vehicle device that was used for this research.

The chapter also includes an evaluation of the effectiveness and costs of three types of eco-driving training programs designed to help improve fuel economy, reduce emissions, and improve safety (e.g., web-based, classroom, and classroom with on-road instruction training). Based on the review of eco-driving training programs and vendor quotes, chapter 3 also includes recommendations for the selection of the driver training program used in this research.

## 3.1 Overview of In-Vehicle Devices

There were wide ranges of aftermarket in-vehicle devices designed to help drivers save fuel, reduce emissions, and improve safety by providing real-time feedback and/or advice on driving style. They were broadly divided into three categories, based on the types of monitoring technology and feedback.

The monitoring technology can be based on either GPS-enabled smartphone or on-board diagnostics (OBD). The feedback can be descriptive, advisory, or mandatory. Descriptive feedback refers to information on the current vehicle operating status, such as instantaneous fuel economy, throttle position, and engine speed. Advisory feedback refers to advice on how to drive under the current situation, e.g., reduce acceleration, turn off engine. The advice can be explicit or implicit. For example, a text or audible message "Release your gas pedal gradually" is explicit advice, while a red bar indicating excessive acceleration is implicit advice. Mandatory feedback refers to changes in the vehicle operation that the driver cannot override, such as a maximum speed.

The three types of devices are briefly summarized below, and examples of each type are presented in the next three subsections.

- *Smartphone apps with descriptive/advisory feedback.* This type of device is purely software-based in that no additional device is required other than the driver's smartphone with GPS capability. Vehicle operating characteristics (speed, acceleration) are calculated based on GPS coordinates sampled in a certain frequency, and fuel consumption and emissions are derived using mathematical models based on speed and acceleration. The major advantage is the low cost, ranging from free to around $10. The major disadvantage is the unreliability of the vehicle data, as GPS signals can be weak or lost, especially in an urban environment, and the performance metrics (e.g., fuel economy) are derived from mathematical models rather than directly measured.

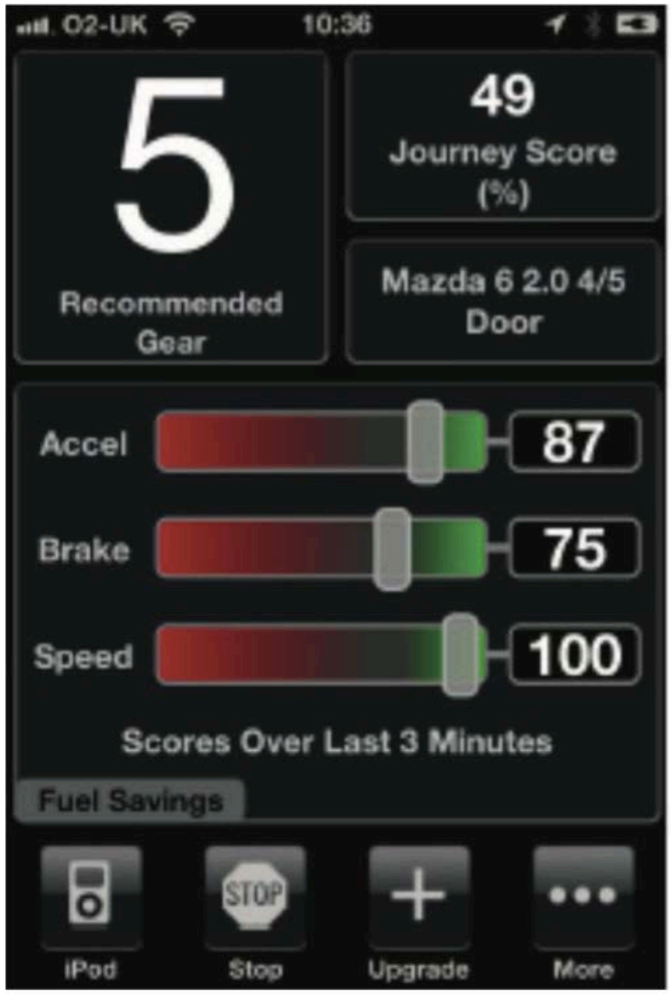
- *OBD devices with descriptive/advisory feedback*. Any vehicle model of 1996 and later has a OBD-II port from which instantaneous engine operating characteristics can be obtained, such as vehicle speed, throttle position, engine speed, engine load, engine fueling demand, and engine coolant temperature. These data are read and processed by a device connected to the OBD-II port, and feedback is generated and provided to the driver via a screen or dedicated indicator. Sometimes, a camera is also installed that monitors both the driver and the environment to detect safety-related driving behaviors such as distracted driving, and to provide more context-related feedback. This type of device usually has a good trade-off between cost and effectiveness, with a cost in the order of a few hundred dollars and reliable vehicle monitoring and feedback.
- *Driving style stimulators with mandatory feedback*. This type of device is connected to various electronic connections of the vehicle to regulate the operation, e.g., setting a maximum speed, and shutting off the engine while the vehicle is idling unnecessarily. This type of device usually requires the most complex technology and thus is the most expensive, with a cost usually in the order of a few thousand dollars. Since the feedback is mandatory, there is no driver noncompliance issue, and the effectiveness is potentially the most significant. However, the initial acceptance of such a device could be a problem.

## 3.2 Smartphone Apps with Descriptive/Advisory Feedback

As smartphones become increasingly available, eco-driving applications have been developed to use the phone's internal technologies such as GPS and accelerometer to deliver context-related feedback to drivers. Examples of these applications are: DriveGain, EcoDrive, greenMeter, Fuel Saver, Green Driver, BlissTrek, iEcoMeter, and Green Gas Saver. DriveGain is reviewed in detail as follows, since two relevant studies were conducted recently.

Figure 3.1 shows the DriveGain application interface (http://drivegain.com). The top third of the interface screen illustrates optimal gear change (not relevant for automatic transmission vehicles), journey score, and type of vehicle. Feedback meters are located in the central third of the screen, where feedback on acceleration, braking, and speed is displayed at a frequency of three-minute intervals. The feedback is based on a scale categorized red to green (green being most ecological), as well as a numerical score from 0 (being the least ecological) to 100 (representing most ecological). The journey score is a composite score, taking into account the three aspects (acceleration, braking, and speed) for the current journey. A higher score indicates greater efficiency, e.g., harsh braking and moderate average journey speed. A basic version of the application is free, and more advanced versions cost as much as US$6.99.

**Figure 3.1: DriveGain application interface**




**Source:** DriveGain Ltd. (2013)

Tulusan, Staake, and Fleisch (2012) conducted a field test using DriveGain with 50 corporate car drivers who did not pay for fuel. A between-subject experiment design was adopted, with 25 drivers in the control group and 25 in the treatment group. Participants in the treatment group used DriveGain for a duration of eight weeks from Oct. 24 to Dec. 16, 2011. This type of design could eliminate the confounding effect of seasonal variations in fuel consumption, which usually makes the data difficult to interpret in many other studies. Drivers' monthly tank-refill details (mileage and gas volume) were provided by the company, which allowed the researchers to calculate and compare the fuel economy. Average fuel economies for the baseline period (Jan. 1–Oct. 24, 2011) and the experiment period (Oct. 24–Dec. 16, 2011) for both the control and treatment groups were calculated respectively, and the changes in fuel economy over the two time frames of the two groups were compared. It was found that the treatment group had a 3.23% improvement of fuel economy as compared to the control group.

In a follow-up study, Tulusan et al. (2012) further examined the issue of improving corporate drivers' intrinsic motivation to drive more sustainably, when financial motivation does not exist. Through the analysis of questionnaires following the field test, they concluded that it is imperative to raise drivers' awareness of their fuel consumption. Drivers' concerns regarding management monitoring leading to control and punishment must be addressed if their fuel efficiency has not improved. However, it is essential that an organizational rollout is not associated with punishments, but rather focused on motivating employees by providing extrinsic motivation through realistic goal setting, constructive and personalized feedback, and transparent comparison among peers.

## 3.3 OBD Devices with Descriptive/Advisory Feedback

### 3.3.1 OBD Devices with Simple Fuel Economy Feedback

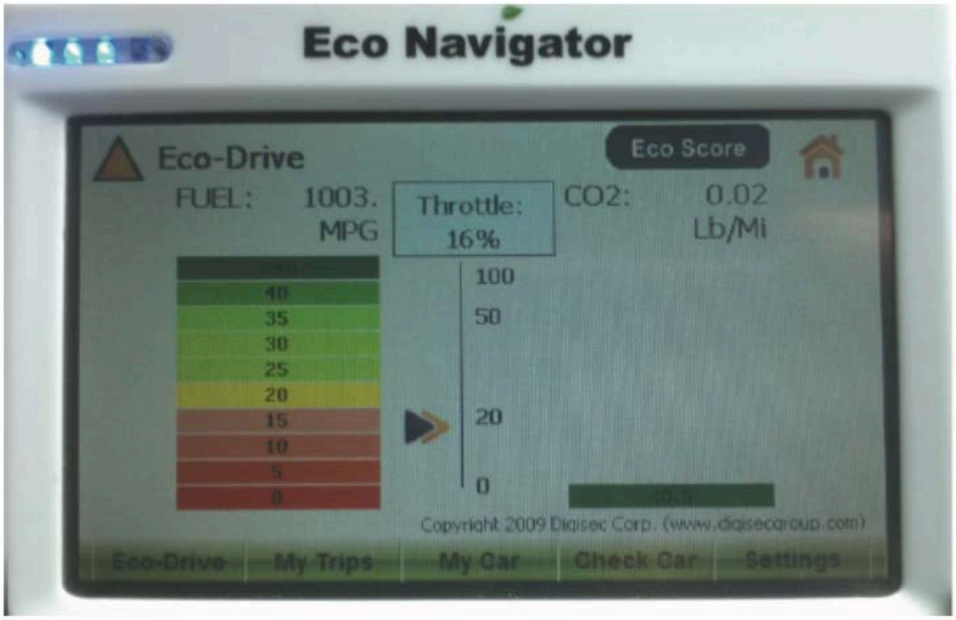
The simplest OBD-based in-vehicle device displays basic information such as fuel economy (instantaneous, average) and does not necessarily advise or suggest how to improve it. Examples of this type of device include Eco-Way and AutoMeter ($69.99 from Amazon.com).

Eco-Way by Earthrise Technology was used in two field tests in Southern and Northern California respectively, conducted by researchers from the University of California Riverside (Boriboonsomsin, Vu, and Barth, 2010; Martin et al., 2013). It consists of three components: (1) personal navigation device (PND); (2) OBD-II module; and (3) OBD-II cable. The OBD-II cable connects to the vehicles' OBD-II port, accessing messages from the controller area network (CAN) bus every two seconds. The cable also draws electrical power from the vehicle to supply the device. The OBD-II module is a firmware that decodes the received CAN messages. It also houses a GPS chip that is programmed to log the position (i.e., latitude and longitude) and speed of the vehicle. The data from the CAN bus and the GPS chip are synchronized before forwarding them to the PND. All the data are stored onboard in the flash memory of the PND, which can be downloaded onto a personal computer.

The PND of Eco-Way serves as the input/output interface to the driver. Figure 3.2 shows the feedback screen that displays real-time fuel economy (miles per gallon) and $CO_2$ (pounds per mile) emission in a color scheme from red (poor) to green (good). The My Trips screen (not shown) provides detained trip information, including start and end time, total travel time and distance, average and max speed, total fuel consumption and $CO_2$ emission, and maximum fuel rate and average fuel economy in miles per gallon (MPG).

Note that the manufacturer's website (http://dnagy.com/html/eco-way.html) states that the device also informs drivers if they are accelerating/braking too quickly or too slowly. It is possible that a more advanced version of the device has been developed since the studies were conducted. In this case, the device might be included in the discussion of "OBD Devices with Elaborate Screen Display" described in the following section.

**Figure 3.2: Eco-Way feedback screen**




**Source:** Martin et al. (2013)

Both field tests are "before-and-after" studies without a control group. In a two-week or four-week baseline period, no eco-driving feedback was provided. In the following two-week or four-week test period, Eco-Way feedback was provided.

The results from 20 samples of drivers in Southern California showed that, on average, the fuel economy on city streets improved by 6%, while the fuel economy on highways improved by 1%. According to responses to the questionnaire completed at the end of the study period, this group of drivers was willing to adopt eco-driving practices in the near future (mean score of 7.4 out of 10).

Results from 18 samples of drivers in Northern California showed less measurable improvements in fuel economy. The fuel consumption data recorded by the device found that 11 respondents (65%) exhibited an increase in fuel economy, while a remaining 6 (35%) exhibited a decline in fuel economy. The survey data in combination with the vehicle data suggested that the device was improving the fuel economy of some participants. However, measuring the exact extent of that influence was difficult in an uncontrolled, real-world environment. Other factors, such as variations in passengers across the two months of participation, the mix between city and highway driving, and the changes in the contents of the trunk, could cause measured fuel economy to change in either direction.

### 3.3.2 OBD Devices with Elaborate Screen Display

With a slightly higher price, some OBD devices provide more feedback than the basic fuel economy (and the derived $CO_2$ emission). Most importantly, the additional feedback gives the driver an indication of how to improve his or her driving style. Examples of this type of device include Garmin Mechanic with EcoRoute HD, Kiwi Drive Green, and CellAssist. Kiwi Drive Green is presented in more detail as follows (see Figure 3.3).

**Figure 3.3: Kiwi Drive Green screen**


**Source:** PLX Devices (2013)

The device has a number of features accessible through a menu system. Scores based on smoothness, drag, acceleration, and deceleration, as well as an overall score, are intended to motivate drivers to compete with themselves. Instant and average miles per gallon (MPG), as well as trip cost and money saved from thrifty driving, can also be displayed. One Drive Green option offers 20 training routines designed to help drivers learn to be more conscious of their driving techniques. One lesson, for example, has drivers maintaining a high acceleration rating for a timed period, while another has drivers keeping their deceleration score high through judicious use of the brakes. Some of the tests (particularly the braking tests), however, could be a bit distracting. The cost of a unit is $149.99.

### 3.3.3 OBD Devices with Color-Light Indicator

The most widely used types of devices by corporations usually have a more intuitive feedback design that is easy to understand and imposes minimum cognitive load. A color-light indicator with the usual red-amber-green design is generally adopted. Examples are GreenRoad and Lightfoot.

**Lightfoot by Ashwoods Ltd.**

Vagg et al. (2013) conducted a field test of Lightfoot with commercial vehicle drivers, even though the name of the device is not mentioned in the journal article. The device aims to reduce fuel consumption by encouraging two behaviors: reduced rates of acceleration, and early upshifting through gears.

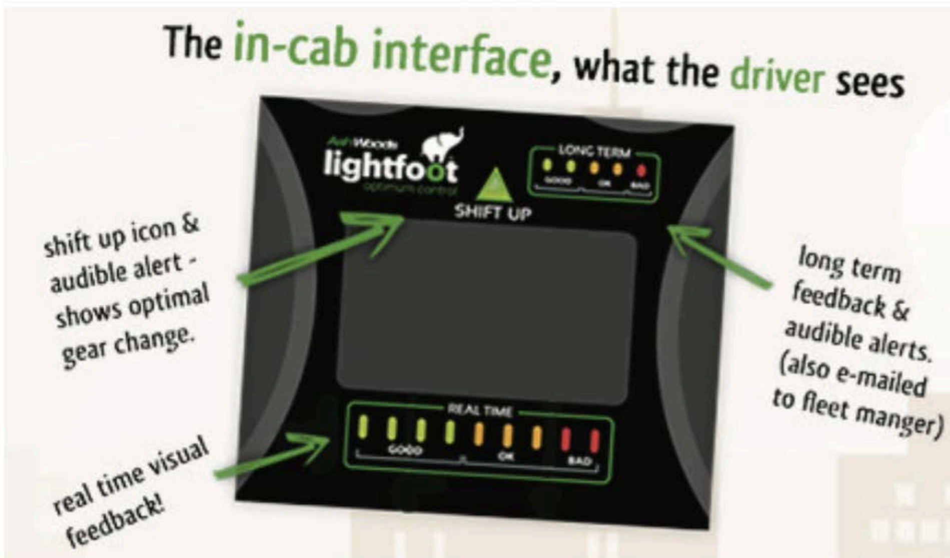
Figure 3.4 illustrates the feedback interface, and Figure 3.5 shows the device in a vehicle. The unit displays in real time a red/amber/green alert accompanied by an audible gearshift and verbal alerts to improve driver performance in the moment. The driver's performance is measured by a metric that combines speed and acceleration. Both short-term and long-term metrics are fed back to the driver; however, only the long-term metric will trigger warnings. This potentially eliminates warnings for isolated inefficient incidents such as pulling out into traffic, getting up to speed, or accelerating to overtake. If the driver is inefficient, he or she will receive the first audible warning; and if driving style is not revised, then a second audible is sounded. If both of these warnings are not adhered to, then an audible penalty is issued and recorded. Warnings received by the driver are not reported; it is only the third-strike penalties that are relayed to the fleet manager. The cost of a trial unit is £300 (approximately $465).

The device was fitted to 15 light commercial vehicles belonging to seven separate companies. In general, these companies were operators of large fleets of light commercial vehicles in urban environments, typically to provide delivery services or technical support services. Vehicles involved in the trial were all Ford Transit vans of Euro IV emissions stage specification. Devices were installed by a technician inside the instrument cluster of each vehicle, taking around 20 minutes per installation.

Trials were run for approximately four weeks: two weeks of baseline data collection followed by two weeks of testing with the system enabled. This period of time was considered to be long enough to negate the effects of short-term fluctuations in vehicle use such as those caused by weather conditions, drive cycle, loading, or traffic, while short enough to avoid issues arising from factors such as seasonal changes in weather conditions (ambient temperature).

The key finding was that the introduction of the system corresponded to a reduction in fuel use (liter/100km) of 7.22%. The savings of individual vehicles/drivers varied considerably, with the maximum savings being 12.03%. Average throttle position and engine speed were also considerably reduced. Changes in driver behavior and fuel consumption were achieved without any impact on average vehicle speeds.

**Figure 3.4: An illustration of Lightfoot feedback interface**




**Source:** Ashwoods Lightfoot Ltd. (2013)

**Figure 3.5: An illustration of Lightfoot feedback interface**


**Source:** Ashwoods Lightfoot Ltd. (2013)

**GreenRoad**

GreenRoad is a similar type of fleet management tool, as shown in Figure 3.6. It gives warnings to risky and inefficient driving maneuvers in five categories of maneuvers: acceleration, braking, cornering, lane changes, and speed. The usual green-amber-red light indicator is used. No published scientific work can be found using the device; however, the company website provides a large number of case studies, citing MPG improvement in the range of 5% to 15%. The pricing information is not readily available.

**Figure 3.6: In-vehicle GreenRoad device**

**Source:** GreenRoad (2013)

**Systems with Cameras**

Some devices also incorporate a camera that monitors both the driver and the environment, for example, DriveCam and SmartDrive. Such systems are suitable for commercial vehicle fleets, but would be more intrusive for other types of corporations.

## 3.4 Driving Style Stimulators with Mandatory Feedback

The feedback from the previously reviewed devices is either informational or advisory, yet another type of device actually makes changes to the vehicle operation directly (with or without driver override).

### 3.4.1 Acceleration Advisor

Larsson and Ericsson (2009) studied the effect of an acceleration advisor (AA) on fuel consumption and emissions. The AA is a driver support tool that increases resistance in the accelerator pedal when the driver tries to accelerate too hard. It is possible for the driver to override the resistance whenever necessary. The resistance of the accelerator may be set at different levels by modifying the speed of pedal depression and the initial resistance. There were no details in the article as to how the device is implemented. In a test carried out in Southern Sweden, the AA was installed in four postal delivery vehicles. On two of the three routes, the AA had a positive effect on emissions. In general, no significant reduction in fuel consumption was observed when driving with the AA activated, although the period of acceleration was significantly reduced. This indicates the complexity in how driving patterns affect fuel consumption, and the combination of several factors is more important than one single factor.

Nissan implemented a similar mechanism, Eco Pedal, in 2008 (Nissan, 2008) and its internal study showed fuel efficiency improvement of 5% to 10%. However, no commercial aftermarket device has this functionality.

### 3.4.2 Comprehensive Stimulator

EcoDriveIII is a more comprehensive stimulator with mandatory feedback in the Netherlands. The maximum speed, the gas pedal value, and the RPM can be adjusted for each gear. This allows for a number of applications: warming up the engine, less acceleration per gear, cruise control, variable speed limiter, increased idle RPM, reverse control, pulling a trailer, heavy loads and hilly areas, engine off control, and scheduled servicing. No effectiveness studies could be found in the literature or from the company’s website. The cost information was not listed on the website; however, Tulusan et al. (2012) mentioned a unit price of $1,350.

## 3.5 Devices in the Research Phase

There is a large body of research in designing the speed profile of a vehicle to minimize fuel consumption and emissions. Almost all of the studies assume inputs from the environment in addition to the vehicle’s operation status, for example:

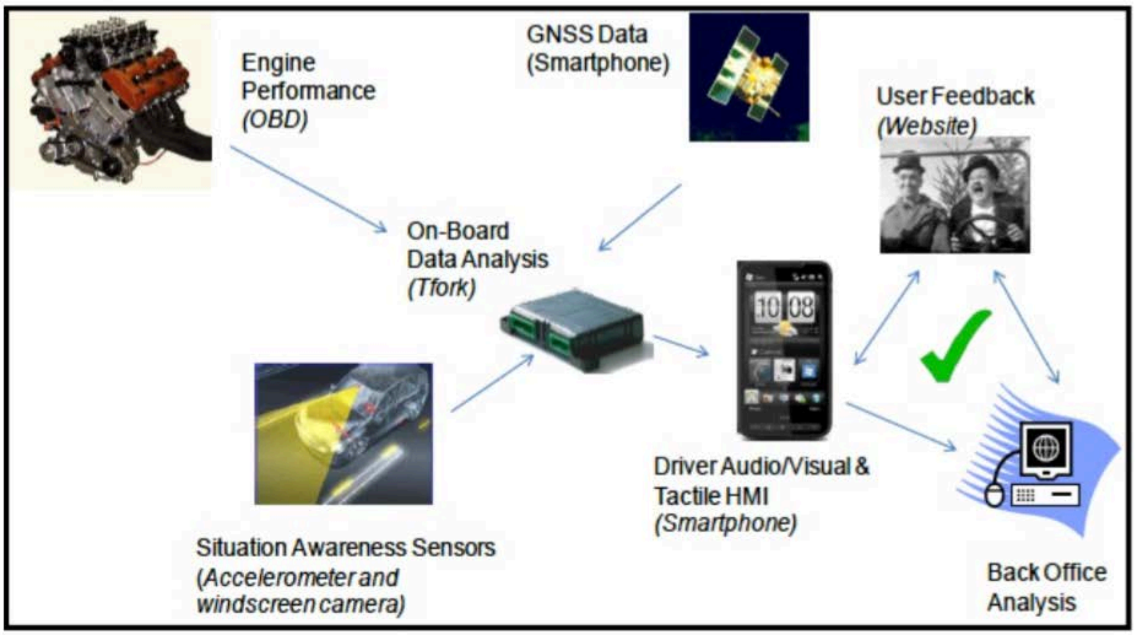
- Headway from the leading vehicle (van der Voort et al., 2001; Felstead et al., 2011; Wu et al., 2011).
- Upcoming traffic signal’s phase and timing (Wu et al., 2011; Xia et al., 2013; Muñoz-Organero and Corcoba Magaña, 2013).
- Upcoming stop/yield sign distance (Muñoz-Organero and Corcoba Magaña, 2013; Wu et al., 2011).
- Road geometry and grade (Bar et al., 2011).
- Traffic average speed in the vicinity of the vehicle (Barth and Boriboonsomsin, 2009).

With the advances in sensor and telecommunication technologies, such inputs from the environment are becoming increasingly available, e.g., signal phase and timing information could be obtained via vehicle-to-infrastructure communications. At the present time, field tests of such systems are rare. Most studies are in the prototyping stage, with the potential benefits calculated from computer simulation, driving simulator, or a small number of instrumented vehicles. The exception is the Foot-LITE project as described below.

Felstead et al. (2011) reported the field trial results of a major research project in the United Kingdom, Foot-LITE. The aim of the project was to create a revolutionary driver information system designed to educate and encourage safer and greener driving and provide longer-term behavioral changes. There were two trial systems, where the Hampshire system consisted of both an in-vehicle element and a web-based element. The in-vehicle Foot-LITE system provided feedback to the driver as he or she drove via a Human Machine Interface (HMI) running on a smartphone. The HMI was primarily supplied with data from the Tfork, an

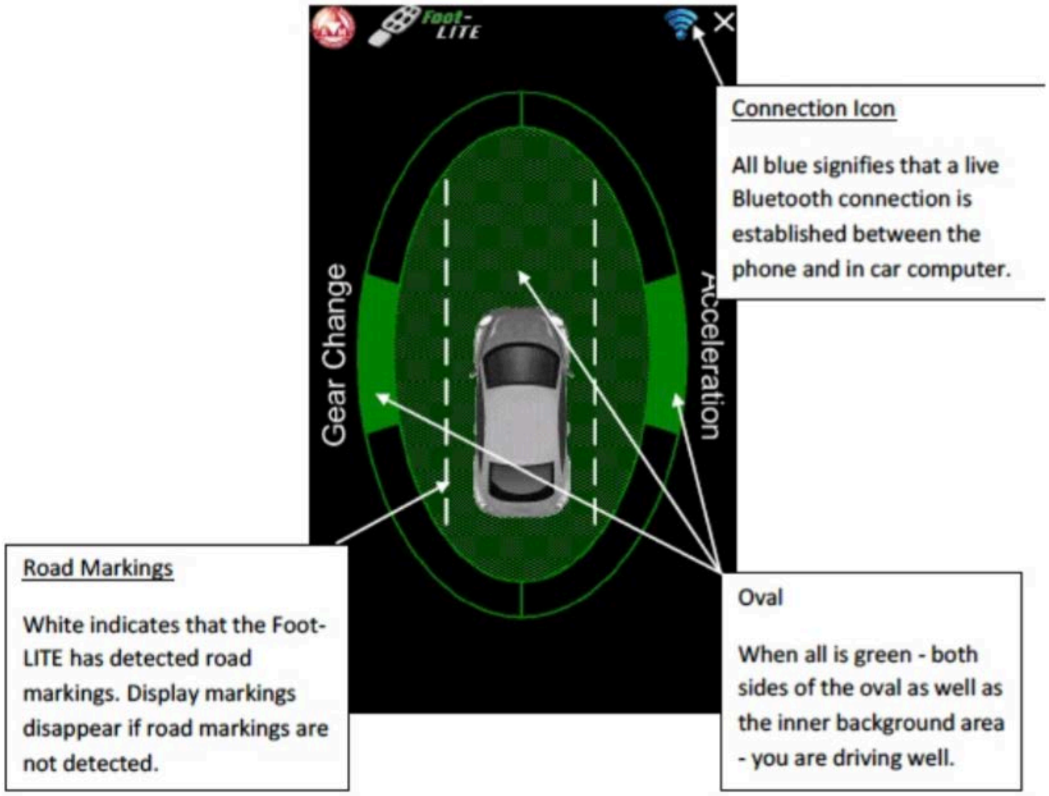
Electronic Control Unit (ECU) that fused data from the vehicle's OBD system, GPS data from the smartphone, lane position and headway data from the windscreen camera, and vehicle dynamics data from an internal accelerometer. Video data was also captured at the instant priority advice was delivered to the driver by the system. The system delivered instantaneous advice relating to gear position, acceleration/deceleration level, lane position, and headway (distance to vehicle in front). See Figure 3.7 for an illustration of the system architecture and Figure 3.8 for a basic in-vehicle display on smartphone.

**Figure 3.7: Overview of Hampshire Foot-LITE System**




**Source:** Felstead et al. (2011)

**Figure 3.8: Basic in-vehicle display on smartphone**




**Source:** Felstead et al. (2011)

Driving data from 12 of 30 driver participants in the trial test were found to be valid. For 7 out of 12 drivers, the number of heavy acceleration events (1.5 $m/s^2$) reduced by an average rate of 2.7%. A reduction in heavy deceleration was found for 4 drivers with an average rate of 5.4%. Fuel consumption was not evaluated, due to data unreliability and other confounding factors. The device reliability was identified as a major problem that caused the loss of more than half the original participants' data.

## 3.6 Summary of Commercially Available In-Vehicle Devices

Vagg et al. (2013) discussed three principles of designing a commercially relevant in-vehicle feedback device:

- Cheap, requiring the minimum of dedicate sensors (preferably none).
- Simple, such that the principles of its operation are transparent to the driver, and to reduce the need to calibrate it to different vehicle models.
- Safe, demanding minimal active concentration and adding minimum cognitive loading, so that the driver's attention is not diverted from the road conditions.

A study of fuel economy driver interface by the National Highway Traffic Safety Administration (Jenness, Walrath, and Lubar, 2009) also found that：

- symbolic forms of fuel economy information (e.g., bars or pictures) are preferred to text representation.
- presenting information relating directly to behavior (e.g., acceleration) may be as useful as presenting fuel economy information.

Rakotonirainy et al. (2011) argued that displaying the fuel use as an instantaneous variable could be difficult to interpret. Reaching a good level of fuel-efficient driving could be difficult, as many parameters could have an impact on that efficiency. They suggested that a global indicator, merging different driving parameters (e.g., acceleration, braking, speed, speed variation) could be more effective than fuel consumption.

Most of the previously reviewed devices do not give feedback to idling, while idling is a major factor in fuel consumption, especially for corporate drivers. Vagg et al. (2013) revealed that for some light commercial vehicles in their field test, a considerable proportion of operational time (up to 50%) was spent at idle. GreenRoad stated on their website that it provides idling management; however, it was not clear whether this was done in real time. It is desirable for the device to manage idling to some extent.

Although only real-time feedback devices were reviewed, almost all of them have some offline feedback components that provide periodic summary and suggestions on the drivers' performance. A FIAT report analyzed data from over 42,000 European drivers using the automaker's "eco:Drive" offline feedback program that tracked driving patterns, and revealed a 6% average reduction in fuel consumption and emissions (FIAT, 2010). The Foot-LITE New Castle system is also an offline system, and the field trial showed an improvement of 14% in fuel economy (Felstead et al., 2011). Given the effectiveness of offline feedback alone, it is a good idea to combine real-time feedback with offline feedback.

Table 3.1 summarizes the commercially available in-vehicle devices reviewed in this report in terms of technology, feedback content and representation, cost, and fuel economy (FE) improvement. Note that the FE improvement is not directly comparable, as the studies have very different settings. A/B/S stands for acceleration, braking, and speed.

It can be concluded from the review that in-vehicle real-time feedback can improve fuel economy, reduce emissions, and improve safety (as a good side effect and not explicitly included in the table) and is suitable to be included in the overall sustainability strategy of a corporation.

**Table 3.1: Summary of commercially available in-vehicle devices**

| Device | Technology | Feedback Content | Feedback Representation | Cost | FE Increase |
|---|---|---|---|---|---|
| DriveGain | Smartphone | Eco-score, A/B/S | Color Bars, Numbers | $6.99 | 3.23% |
| Eco-Way | OBD | FE | Color Numbers | N/A | 1%–6% |
| Kiwi Drive Green | OBD | Elaborate | Color Bars, Numbers | $149.99 | N/A |
| Lightfoot | OBD | Eco-score | Color Lights | $465.00 | 7.22% |
| GreenRoad | OBD | Eco-score | Color Lights | N/A | 5%–15% |
| EcoDriveIII | OBD, Electronic connections | Max. Speed, Gas Pedal Value, RPM | Mandatory Operation Changes | $1,350.00 | N/A |

Based on the principles of selecting an in-vehicle device discussed above, OBD devices with color-light indicator seemed to be the most suitable for the field test of this project due to their simple, safe, and effective designs. The next section focuses on the comparative evaluation of two OBD devices with color-light indicator.

## 3.7 GreenRoad by GreenRoad Technologies, Inc.

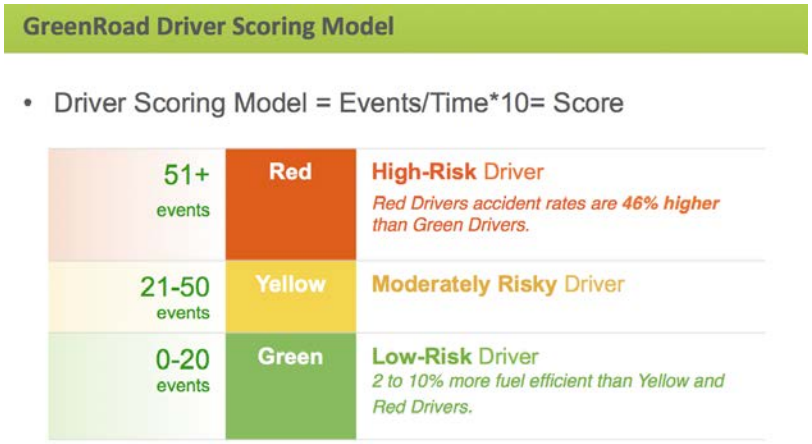
### 3.7.1 Overview

GreenRoad Technologies, Inc. is headquartered in San Jose, California. GreenRoad enables fleets to measure, improve, and sustain safe and fuel-efficient driving behavior. It combines in-vehicle technology with integrated web-based applications that continuously rate driving skills and behavior and provide real-time feedback to drivers. MPG improvement has been shown, ranging from 5% to 15%. GreenRoad offers an in-vehicle edition or smartphone edition (beta). Due to the nature of this project and the constraints of the beta version of the smartphone application, only the in-vehicle edition was examined in this study.

### 3.7.2 Features

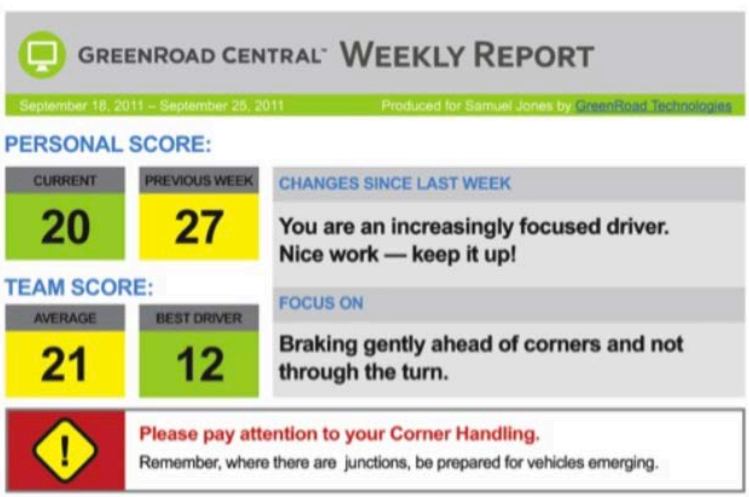
The GreenRoad system monitors 120 different driving maneuvers and distills them down to five basic categories: acceleration, braking, cornering, lane handling, and speed. Based on the driver scoring model, these events are assigned one of the three colors representing their safety level (red for high risk, yellow for moderate risk, and green for safe). Green maneuvers are ignored, and only the red and yellow are recorded. Figure 3.9 shows the driver scoring model and the corresponding safety levels. The color-light indicator issues warnings by flashing lights without distracting drivers.

**Figure 3.9: GreenRoad driver scoring model**




GreenRoad offers configurable dashboards and reports online to drivers and fleet managers. Weekly reports (Figure 3.10) show drivers their personal scores as well as team scores in the current and previous weeks, describe their change in driving behavior since the previous week, and provide driving suggestions.

**Figure 3.10: GreenRoad weekly report**




### 3.7.3 Hardware

**Display Unit**

As introduced above, the display unit gives feedback on safety level through the color-light indicator (see Figure 3.11). The indicator is easy to read while helping drivers maintain safe driving in real time. It is installed on the driver's side nearest to the left portion of the dashboard, within the driver's view.

**Figure 3.11: GreenRoad display unit**

**IMU, Modem, and Accelerator**

The inertial measurement unit (IMU) is the brain of the system and determines the type and risk level of a specific driving maneuver (See Figure 3.12). The modem allows communication, calibration, and information export to the device. The accelerometer is a sensor that enables GreenRoad to capture vehicle movement (see Figure 3.13). These components are installed under the vehicle dashboard and are not be seen by the driver.

**Figure 3.12: IMU unit and modem**


**Figure 3.13: Accelerometer**

**Source for both figures**: GreenRoad Technologies, Inc. (2013)

**GPS Antenna**

A GPS is used to measure speed at a resolution of two minutes. Higher resolution of 30 seconds (and thus more accurate speed measurement) is available at higher cost. The GPS antenna can be placed virtually anywhere on the dashboard.

**Dallas Keys**

Dallas keys are used to identify who is driving the vehicle if there are multiple drivers.

### 3.7.4 Costs

For a 10-unit pilot study, the total cost for a 4-month period is $2,980 (Table 3.2). This cost includes hardware, installation, and service fees. The total cost of 50 units for 12 months is $27,500 (Table 3.3). The installation is conducted by certified third-party technicians. GreenRoad can provide free online training to MassDOT technicians that will take a couple of hours. If installation is done in-house, the cost per vehicle per month for a 4-month period will be reduced to $42, and that for a 12-month will be reduced to $35.

The vehicle operating parameter data and GPS data at a resolution of two minutes are available to customers free of charge. Data at higher resolution (30 seconds) cost $10 per vehicle per month.

**Table 3.2: GreenRoad quote of 10 units for 4 months**

| | | | |
|---|---|---|---|
| Number of Vehicles | 10 | Number of Drivers | 12 (estimated) |
| Agreement Term in Months | 4 | - | - |
| Description | QTY | Price | Extended price |
| GreenRoad Hardware and Service Bundle | 10 | $42 | $1,680 |
| GreenRoad Installation | 10 | $130 | $1,300 |
| Total: | - | - | $2,980 |

**Note:** (-) values indicate data is not applicable.

**Table 3.3: GreenRoad quote of 50 units for 12 months**

| | | | |
|---|---|---|---|
| Number of Vehicles | 50 | Number of Drivers | 60 (estimated) |
| Agreement Term in Months | 12 | - | - |
| Description | QTY | Price | Extended price |
| GreenRoad Hardware and Service Bundle | 50 | $35 | $21,000 |
| GreenRoad Installation | 50 | $130 | $6,500 |
| Total | - | - | $27,500 |

**Note:** (-) values indicate data is not applicable.

## 3.8 Lightfoot by Ashwoods Ltd.

### 3.8.1 Overview

Developed by Ashwoods Ltd. in the United Kingdom, the Lightfoot system provides real-time feedback to improve driver efficiency, with fuel savings of over 10%. It develops personal relationships with drivers and fleet managers to help improve fuel savings.

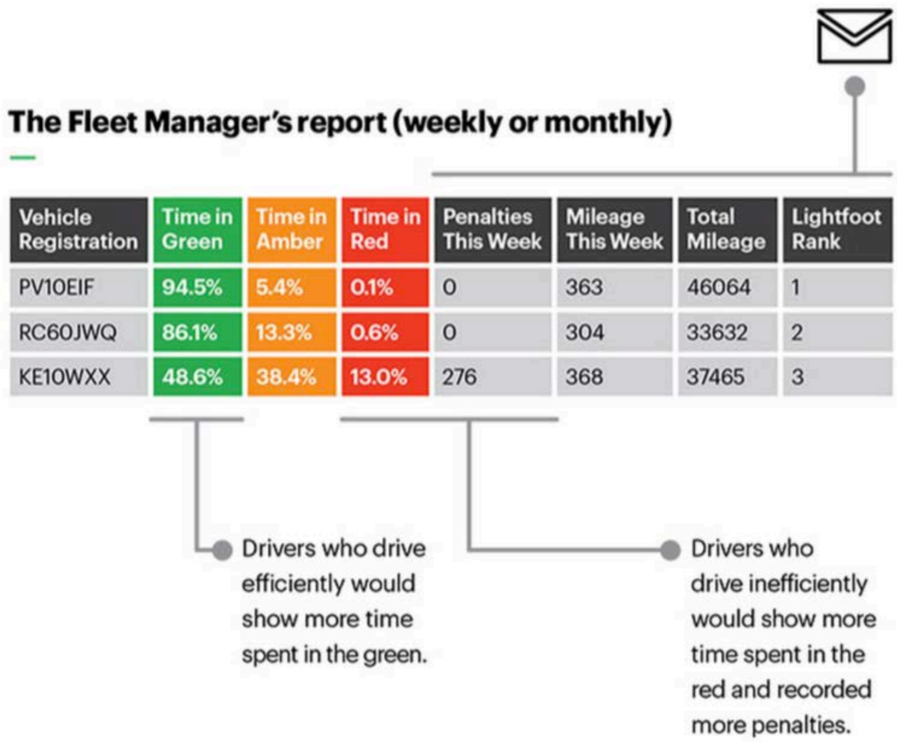
### 3.8.2 Features

The noninvasive in-vehicle unit displays in real time a red/amber/green alert, accompanied by a verbal alert to improve driver performance in the moment (see Figure 3.4 for an illustration of the feedback interface). If the driver is inefficient, he or she will receive the first audible warning; and if driving style is not revised, then a second audible is sounded; if both of these warnings are not adhered to, then an audible penalty is issued and recorded.

Because only long-term inefficient behavior can incur penalties, the driver is not penalized for isolated inefficient incidents such as pulling out into traffic, getting up to speed, or accelerating to overtake. Warnings issued to the driver are not reported; it is only the third-strike penalties that are relayed to the fleet manager. This provides positive support as the Lightfoot system works with drivers to improve driving behavior and gives them every chance to ensure their reports show them in the best possible light.

Unlike the GreenRoad system, which provides comprehensive online reports to drivers and mangers, the Lightfoot system sends weekly and monthly email reports to provide a snapshot of driver performance and key metrics. Figure 3.14 shows a sample report.

**Figure 3.14: Lightfoot email report**




| Vehicle Registration | Time in Green | Time in Amber | Time in Red | Penalties This Week | Mileage This Week | Total Mileage | Lightfoot Rank |
|---|---|---|---|---|---|---|---|
| PV10EIF | 94.5% | 5.4% | 0.1% | 0 | 363 | 46064 | 1 |
| RC60JWQ | 86.1% | 13.3% | 0.6% | 0 | 304 | 33632 | 2 |
| KE10WXX | 48.6% | 38.4% | 13.0% | 276 | 368 | 37465 | 3 |



### 3.8.3 Technology

Lightfoot reads vehicle parameters from a vehicle's OBD-II port and does not use GPS. Lightfoot stores journey and more comprehensive high-resolution (e.g., second-by-second) data on an SD card in-vehicle. The data are easily accessible to the user at the end of a journey, but not transmitted in real time.

Lightfoot states that the instantaneous fuel demand obtained from the OBD-II port is not accurate and cannot be directly used in calculating fuel economy (miles per gallon). The accurate fuel economy can only be obtained from direct measurement of fuel usage such as that from fuel gauge. However, the instantaneous fuel demand data can be used to measure relative fuel economy for the same vehicle over different time periods.

### 3.8.4 Costs

The costs of Lightfoot include hardware and subscription fee. See Table 3.4 for the Lightfoot quote of 50 units for 12 months, including hardware and subscription fees. There is an upfront charge at £250.00 ($345.18) per unit. The minimum contract length is 12 months.

**Table 3.4: Lightfoot quote of 50 units for 12 months**

| Quality | Details | Unit Price | Net Price |
|---|---|---|---|
| 50 | Lightfoot systems (hardware)<br>Lightfoot subscription (£10.00/month) | £250.00 ($345.18)<br>£10.00 ($13.81) | £12,500.00 ($17,258.76)<br>£6,000.00 ($8,284.20) |
| - | - | Total Net Amount | £18,500.00 ($25,542.96) |

**Note:** (-) values indicate data is not applicable

## 3.9 Selection of In-vehicle Device

Based on the principles and evaluation of those commercially available in-vehicle devices, GreenRoad was selected for this project with regards to the following aspects:

- Simple but intuitive descriptive feedback on driver performance, which reduces the distraction.
- Acceptable fuel economy improvement range (i.e., 5%–15%).
- Comprehensive reports and summaries readily available to be used for data analysis.
- Raw data recorded with GPS coordinates, accessible from data storage server for further analysis.
- The cost is within the project budget.

## 3.10 Evaluation and Selection of Training Program

One of the objectives of the project was to investigate the effectiveness of employing eco-driving training to improve fuel economy, reduce emissions, and improve safety. Three types of eco-driving training programs were identified as suitable for this project, in a project meeting on Jan. 31, 2014: (1) web-based training; (2) classroom training; and (3) classroom training with on-road instruction training. This section evaluates the effectiveness of the three types of eco-driving training, as well as commercially available eco-driving training programs in the United States. A selection was made based on this evaluation.

### 3.10.1 Effectiveness of Web-based, Classroom, and Classroom with On-Road Instruction Training Program

Table 3.5 shows a selection of studies on the effectiveness of classroom-only and classroom with on-road instruction training programs. No such studies that examine the effectiveness of web-based training programs were found. But most commercially available web-based training programs claimed fuel savings between 5% and 15% (BrightFleet, 2014; Drivefleet, 2012).

These key points should be considered when reviewing the table:

- These studies employed a wide range of methods and experiment conditions (in terms of, e.g., specific training content, driving environment, fuel consumption measurement, and data filtering) and are not scientifically comparable. However, the results in the table demonstrate the magnitude of what may be possible through eco-driving training.
- An on-road instruction session in addition to a classroom session could make the training more effective in the long run (Symmons and Rose, 2009).
- Training with stimuli (e.g., offering prizes) can bring significant fuel savings (Henning, 2008; Barkenbus, 2010).
- For both types of training, fuel economy was improved significantly immediately after the training and partially slipped back in the long term.
- For both classroom-only and classroom with on-road instruction training, long-term effect was hardly seen among bus drivers. This may be due to the low incentives of fuel saving for bus drivers and the required frequent stops.

**Table 3.5: Selected studies on effectiveness of eco-driving training**

| Types of Training | Study | Number of Drivers | Type of Vehicle | Length of Experiment | Fuel Economy Short-term (less than a month) | Fuel Economy Long-term (over a month) |
|---|---|---|---|---|---|---|
| Classroom-only | Johansson, Farnlund, and Engstrom (1999) | 16 | Light vehicle | - | 10.9% | - |
| Classroom-only | Henning (2008), cited in Barkenbus (2010) | 300 | Light vehicle | Up to 18 months | 25% | Up to 10% |
| Classroom-only | Taniguchi (2007), cited in Berry (2010) | - | Light vehicle | - | 20% | - |
| Classroom-only | Zarkadoula, Zoidis, and Tritopoulou (2007) | 3 | Bus | 2 months | 4.35% | Slipped back |
| Classroom-only | Symmons and Rose (2009) | 12 | Heavy Vehicle | 6 weeks | - | 0 |
| Classroom with on-road instruction | Bureau de l'efficacité et de l'innovation énergétiques (2011) | 69 | Light vehicle | Up to 6 months | Highway: 6.5%–15%; City: 9%–13% | Highway: 6.2 %; City: 7.2 % |
| Classroom with on-road instruction | Degraeuwe and Beusen (2013) | 8 | Light vehicle | 10 months | 2%–10.3% | Effect was gradually lower over time |
| Classroom with on-road instruction | Abuzo and Muromachi (2011) | 27 | Passenger Cars | 4 days | 16% | - |
| Classroom with on-road instruction | Wahlberg (2007) | 5 | Bus | 12 months | - | Light effect |
| Classroom with on-road instruction | Symmons and Rose (2009) | 12 | Heavy Vehicle | 12 weeks | - | Up to 27% |

**Note:** (-) values indicate data is not applicable

### 3.10.2 Evaluation of Commercially Available Eco-Driving Training Programs in the United States

While eco-driving training programs are widely available in Europe, only a small number of vendors or organizations offer such programs in the United States. Table 3.6 is a summary of the training programs based on their features, costs, and effectiveness. The total costs are calculated based on training 100 drivers.

**Table 3.6: Features and costs of eco-driving training programs**

| Types of Training | Fuel Economy Improvement | Company/ Organization | Features | Total Cost |
|---|---|---|---|---|
| Web-based | 5%–15% | BrightFleet | 3 modules to pass.<br>Drivers can choose how often they want to receive training session. | $2,399 |
| Web-based | 5%–15% | Drivefleet | 15–20 minutes session.<br>Certificates of completion upon passing final exam. | $1,200 |
| Web-based | 5%–15% | Eco-driving Solutions | 3 modules: introduction, concepts and practices, and final assessment;<br>90 minutes in total. | $4,000 |
| Web-based | 5%–15% | University of Vermont | 2 sessions: "idling free" and "Eco-driving."<br>Each session 40–50 minutes. | $2,000 |
| Classroom-only | 4%–25% | Eco-driving Solutions | 2 hours.<br>Short stories, discussion, video demonstrations, and interactive activities;<br>Program can be augmented with web-based training;<br>25 individuals per session. | $10,000<br>$12,500 (augmented version) |
| Classroom-only | 4%–25% | University of Vermont | 1 hour in total.<br>Up to 50 individual per session.<br>Provide train-the-trainer option. | $2,000 plus travel expenses from/to Burlington |
| Classroom-only | 4%–25% | Eco-Fleet Training Solutions | Up to 34 individual per session. | $4,250 plus travel ($700 max) |
| Classroom with on-road instruction | 6%–27% | University of Vermont | 3 hours in total: 1-hour classroom and 2-hour on-road training. Classroom: up to 50 individual per session; On-road: 5 drivers per session | $5,200 plus travel |

**Note:** Fuel economy improvement is based on training types as reviewed in 3.2.1, not on specific programs quoted.

Some companies and organizations offer the train-the-trainer option. Features and costs of such programs are summarized in Table 3.7.

**Table 3.7: Features and costs of eco-driving training programs with train-the-trainer option**

| Company/Organization | Features | Total Cost |
|---|---|---|
| University of Vermont | • 3 hours in total: 1 hour classroom and 2-hour on road training. | $260 plus travel expense. Price based on training 5 trainers. |
| EcoFleet Training Solutions | • 3–4 hours.<br>• Class materials include instructor kit, video, and Student Guides.<br>• Provides support to the customer before, during, and after implementation of the program, including an annual refresher online update at no extra cost.<br>• Assists the customer with the development of policies an implementation strategies to maximize effectiveness of fuel use reduction plans. | $3,975 plus travel expense ($500 max). Price based on training 6–10 trainers and providing 5 instructor kits ($395 each). |

### 3.10.3 Conclusion and Selection

The pros and cons of the three types of eco-driving training programs are as follows.

- The web-based programs have the lowest cost. However, the level of a driver's engagement is lowest, so is the effectiveness consequently.
- The classroom-only and classroom with on-road instruction programs offer in-person interactions with experienced trainers and are potentially more effective. There is a large cost variation among different eco-driving training vendors; eco-driving training provided by the University of Vermont is the most cost-effective.
- The train-the-trainer option can potentially save cost compared to training drivers directly, especially if the training program is to be rolled out to the whole agency. However, two risks should be considered: (1) longer training time (training the trainers plus training the drivers; and (2) the lack of experience and dedication of internal trainers. One of the companies, Eco-driving Solutions, strongly discouraged the research team from using this option and did not give a quote on it.

Based on evaluation in this section, the research team, in consultation with the Technical Working Group at MassDOT, chose the classroom (without on-road instruction) training program offered by University of Vermont, due to the effectiveness of classroom training and the relatively low cost.

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# 4.0 Field Test Methodology and Results

## 4.1 Experiment Design

All vehicles in the field test were owned by MassDOT, with a designated driver[1] so that potential driver behavioral changes could be properly attributed to interventions. Vehicle types were restricted to sedans, SUVs, vans, and pick-up trucks, while heavy trucks and State Police vehicles were explicitly excluded from the study.

Two types of behavioral interventions were tested: in-vehicle real-time feedback and classroom training with follow-up email tips. A two-factor, two-level factorial design resulted in four groups:

- Feedback/training
- Feedback/no-training
- No-feedback/training
- No-feedback/no-training

Vehicles were randomly assigned to groups, while five major and four minor factors that could potentially affect fuel economy and safety performance were counterbalanced. The major factors were:

- Vehicle type (sedan, SUV/van, and pick-up)
- Manufacture year (2000–2004, 2005–2009, and 2010–2015)
- Fuel type (gasoline and hybrid)
- Driving distance in Phase I (baseline phase)
- Potential in-vehicle device problems[2]

The four minor factors were:

- Driver gender (male and female)
- Age (21–30, 31–40, 41–50, 51–60, 61+)
- Vehicle carrying weight (<100 lb, 100–200 lb., 200–300 lb., and >300 lb.)
- Existing eco-driving feedback (yes and no).

[1] Some vehicles were reassigned during the test. These changes have been appropriately accounted for in data analysis.
[2] Some in-vehicles devices did not give proper data after installation and could be eliminated in final data analysis.

All groups went through three chronological phases:

- Phase I (baseline phase): June 1–July 7, 2015 (8 weeks), no real-time feedback, no training.
- Phase II (intervention phase): July 28–Oct. 9, 2015 (10 weeks), real-time feedback was provided to two groups throughout Phase II, and classroom training was conducted for two groups at the beginning of Phase II, followed by bi-weekly eco-driving tip emails from the trainer.
- Phase III (off phase): Oct. 10, 2015–Feb. 1, 2016 (16 weeks)[3], real-time feedback was turned off and eco-driving tip emails discontinued.

Table 4.1 summarizes the four groups and three phases.

**Table 4.1: Summary of study groups and phases**

| Phase | Phase I | 6/1–7/27/2015 | Phase II | 7/28–10/9/2015 | Phase III | 10/10/2015–2/1/2016 |
|---|---|---|---|---|---|---|
| Group | Training | Feedback | Training | Feedback | Training | Feedback |
| Training/ Feedback | No | No | Yes | Yes | No | No |
| Training/ No-Feedback | No | No | Yes | No | No | No |
| No-Training/ Feedback | No | No | No | Yes | No | No |
| No-Training/ No-Feedback | No | No | No | No | No | No |

## 4.2 In-vehicle Device Installation and Removal

An initial pool of 288 vehicles was selected by the Technical Working Group (TWG) in February 2015. It was later narrowed down to 200 vehicles based on email validity. In early April 2015, installation scheduling forms were sent to the driver participants, and responses were collected along with the entry survey to finalize the test vehicle pool. Additional vehicles were added to the pool during the process, due to the lower than expected response rate from potential driver participants. The installation took place April 13–29, 2015, in three MassDOT garages (West Springfield, Weston, and Bridgewater, Massachusetts). The research team worked closely with Orbital, the installation contractor, and the TWG on a continuous basis on (1) collecting participants, scheduling responses, and performing initial

[3] Speeding data for all vehicles were unusable for 7 weeks (Oct. 24 to Dec. 5) due to vendor's mistake.

scheduling; (2) rescheduling drivers who could not make the scheduled appointments; (3) recruiting new drivers; and (4) dealing with installation issues, such as missing cables and malfunctioning strobes. By April 29, 2015, 133 vehicles were installed with the in-vehicle tracking devices. Detailed summaries of the 133 device-installed vehicles can be found in Tables 4.11–4.14, in Appendix A.

An entry survey was sent out to the 133 drivers, and 115 responses were collected. Questions on the survey included drivers' demographics, such as gender and age, as well as carrying weight of the vehicle and existing in-vehicle eco-driving feedback. Those questions were later used as minor factors in counterbalancing test groups. Detailed summaries of the 115 entry survey responses can be found in Tables 4.15–4.19, in Appendix B.

The removal of the 126[4] devices was also scheduled to be conducted using the same three MassDOT garages (West Springfield, Weston, and Bridgewater). Removal for vehicles near the locations of West Springfield and Bridgewater were carried out as scheduled on Feb. 3–4 and Feb. 11–12. For the Weston location, the removal was postponed to Feb. 22–24 due to bad weather conditions. After the first-round service, 6 devices still needed to be removed and were removed on March 10.

## 4.3 Classroom Eco-Driving Training

Eco-driving training typically refers to offering drivers suggestions so as to modify their driving behaviors. Generally, it consists of two types, static eco-driving tactic and dynamic eco-driving strategy. In-class eco-driving training is one of those static eco-driving strategies, and what follows is a brief summary of the classroom eco-driving training for this project.

The research team scheduled a 1.5-hour classroom eco-driving training session for drivers assigned in receiving training groups. The 1.5-hour training session was given by a trainer from the University of Vermont. The training was held at three locations: July 28, 10:00–11:30 a.m. and 1:30–3:00 p.m. at MassDOT Headquarters in Boston; July 29, 10:00–11:30 a.m. at the District 2 Office in Northampton; and July 30, 10:00–11:30 a.m. at the District 5 Office in Taunton. Driver group assignments were adjusted according to attendance.

Also, an exit survey was conducted after each training session to evaluate the perceived effectiveness of the training. Summaries of survey responses can be found in Table 4.20, in Appendix C. Bi-weekly eco-driving tip emails were sent to the trainees throughout Phase II. The emails served as a reminder to reinforce eco-driving training effects.

[4] 7 out of 133 devices had already been removed either due to malfunction of vehicle or device itself.

## 4.4 Data Collection and Quality Issues

GreenRoad data was provided through its web portal, GreenRoad Central. A variety of reports were available on a daily basis regarding fuel economy, idling, and safety performance. In addition, a customized Amazon cloud database was created by GreenRoad for this particular project, which provided the following information every 30 seconds: vehicle location coordinates with time stamps, cumulative fuel consumption, fuel economy, and cumulative traveling distance. This allowed for potential analysis based on geographic location.

There were a number of data quality issues. (1) 35 vehicles' fuel consumption data were completely missing, and 10 vehicles' fuel consumption data were partly missing. (2) Several vehicles were reassigned to different drivers or converted to pool vehicles, and several in-vehicle devices were removed during the test due to safety concerns. (3) From Oct. 17 to Dec. 4, 2015, the function to detect speeding events was mistakenly disabled by GreenRoad so that no speeding events were recorded for 7 weeks. The first two issues significantly reduced the sample size and potentially jeopardized the statistical significance of the interventions' effects. The third issue was less severe, as Phase III was extended to be 16 weeks, and the remaining weeks were of an adequate length compared with other phases.

## 4.5 Data Analysis Method

This section first describes the data cleaning process used to remove outlier fuel economy data entries. Next, linear regression models of fuel economy change, vehicle idling rate change, and safety score change rate between phases were developed to test the significance of the two behavioral interventions' effects. Each driver contributed one data point in each study phase for fuel economy, idling rate, overall safety score, and each safety score by category. The daily raw data were obtained from GreenRoad Central and averaged over all days for a given study phase.

### 4.5.1 Data Cleaning

Through manual inspection, the team found several potentially erroneous records in vehicle daily fuel economy, either extremely large or small. These outliers might significantly affect the accuracy of data analysis. In general, the vehicle fuel economy would tend to distribute uniformly for vehicles' travel on each specific type of roadway, e.g., local road or highway. However, it is worth noting that the difference in fuel efficiencies could be quite large between different roadway types.

The Project Team adopted a traditional method of boxplot to detect potential outliers with loosened criterion. Each driver had a sample of daily fuel economy records for a given phase. $Q_1$, $Q_3$, and IQR represented the first quantile value, third quantile value, and inter-quantile value respectively. Any records outside the range $[Q_1 - a * IQR, Q_3 + a * IQR]$ was viewed as outliers, where "a" was a scalar to be determined. Traditionally, "a" has been set at 1.5.

However, given the potential bi-modal distribution of fuel economy data, a much larger value of 6.35 was chosen after trial-and-error. This method was complemented by manual verification.

Speeding data from the abnormal seven weeks (Oct. 17–Dec. 4, 2015) in Phase III were excluded. Detailed reasons are presented in Section 4.4.

### 4.5.2 Regression Analysis

Multiple linear regression analysis was conducted to test whether the two interventions, eco-driving training and real-time feedback, were effective in improving fuel economy, reducing idling rate, and improving drivers' safety performance. The dependent (response) variables were fuel economy percentage change, vehicle idling rate percentage change, and safety score percentage change. The definitions of those dependent variables are given in Table 4.2.

**Table 4.2: Definitions of Dependent Variables**

| Dependent Variable | Definition |
|---|---|
| Fuel Economy | Fuel Economy Percentage Change =<br>(Fuel Economy of Phase II or III – Fuel Economy of Phase I) / Fuel Economy of Phase I |
| Idling Rate | Idling Rate Percentage Change =<br>(Idling Rate of Phase II or III – Idling Rate of Phase I) / Idling Rate of Phase I |
| Overall Safety Score | Overall Safety Score Percentage Change =<br>(Safety Score of Phase II or III – Safety Score of Phase I) / Safety Score of Phase I |
| Safety Score by Category | Safety Score by Category Percentage Change =<br>(Safety Score by Category of Phase II or III – Safety Score by Category of Phase I) / ((Safety Score by Category of Phase II or III + Safety Score by Category of Phase I) / 2)* |

***Note:** Since some drivers' safety scores by category were 0, the definition was revised to avoid dividing by zero.

Three dummy variables, corresponding to training, feedback, and training and feedback interaction effect, were used as explanatory (independent) variables. A dummy variable equaled 1 if a driver received the corresponding intervention, and 0 otherwise. The interaction variable equaled 1 if a driver received both interventions, and 0 otherwise. An intervention (or the combination of them) was statistically significant at level $\alpha$, if its coefficient was significantly different from zero at level $\alpha$, that is, its p-value was equal or less than $\alpha$. Usually $\alpha$ was set at 0.05 or 0.10. The regression function was of the form shown in Table 4.3.

**Table 4.3: Definition of Regression Functional Form**

| Performance Measure | Function |
|---|---|
| Fuel Economy | Fuel Economy Percentage Change = $\beta_0$ + $\beta_1$ Training + $\beta_2$ Feedback + $\beta_3$ Training&Feedback |
| Idling Rate | Idling Rate Percentage Change = $\beta_0$ + $\beta_1$ Training + $\beta_2$ Feedback + $\beta_3$ Training&Feedback |
| Overall Safety Score | Overall Safety Score Percentage Change = $\beta_0$ + $\beta_1$ Training + $\beta_2$ Feedback + $\beta_3$ Training&Feedback |
| Safety Score by Category | Safety Score by Category Percentage Change = = $\beta_0$ + $\beta_1$ Training + $\beta_2$ Feedback + $\beta_3$ Training&Feedback |

The linear regression for the change between Phases I and II tested the short-term effect of interventions, while that for the change between Phases I and III tested the long-term effect.

Phase II was further divided into two periods: first month (July 28–Sept. 9, 2015) and second month (Sept. 10–Oct. 9, 2015). Coincidentally, during the first month, drivers had no access to GreenRoad Central to see detailed personal records, while in the second month they had such access. Analysis was also done for hybrid/non-hybrid vehicles separately. Lastly, analysis was conducted based on vehicle types, namely, SUV, pick-up truck, and sedan.

## 4.6 Results

### 4.6.1 Descriptive Statistics

Tables 4.4 through 4.10 provide summary statistics by group and phase for each of the seven performance measures respectively: fuel economy, overall safety score, acceleration score, braking score, cornering score, lane handling score, and speeding score. The unit for safety score was the number of safety events per 10 hours, and a lower score indicated a safer driving record. A safety event happened when a maneuver exceeds a pre-set threshold. Specifically, the threshold for speeding was 7 miles per hour above posted speed limit. The unit of fuel economy was miles per gallon (MPG).

**Table 4.4: Summary statistics of fuel economy (MPG)**

| Phase | Phase I | 6/1–7/27/2015 | Phase II | 7/28–10/9/2015 | Phase III | 10/10/2015–2/1/2016 |
|---|---|---|---|---|---|---|
| Group | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Training/ Feedback | 23.37 | 7.57 | 24.72 | 9.46 | 23.69 | 8.47 |
| Training/ No-Feedback | 23.54 | 6.46 | 23.17 | 6.28 | 21.46 | 4.98 |
| No-Training/ Feedback | 21.47 | 9.34 | 21.14 | 9.05 | 19.29 | 7.94 |
| No-Training/ No-Feedback | 22.49 | 8.93 | 23.48 | 9.78 | 22.44 | 9.86 |

**Table 4.5: Summary statistics of overall safety score (# of events/10 hours)**

| Phase | Phase I | 6/1–7/27/2015 | Phase II | 7/28–10/9/2015 | Phase III | 10/10/2015–2/1/2016 |
|---|---|---|---|---|---|---|
| Group | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Training/ Feedback | 48 | 31.65 | 41.99 | 24.64 | 47.09 | 32.06 |
| Training/ No-Feedback | 49.35 | 22.41 | 49.21 | 20.84 | 48.98 | 33.67 |
| No-Training/ Feedback | 49.35 | 25.9 | 39.68 | 19.39 | 43.79 | 25.53 |
| No-Training/ No-Feedback | 43.91 | 28.05 | 44.32 | 27.88 | 50.34 | 43.26 |

**Table 4.6: Summary statistics of acceleration score (# of events/10 hours)**

| Phase | Phase I | 6/1–7/27/2015 | Phase II | 7/28–10/9/2015 | Phase III | 10/10/2015–2/1/2016 |
|---|---|---|---|---|---|---|
| Group | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Training/ Feedback | 6.26 | 7.84 | 4.13 | 5.47 | 6.89 | 9.84 |
| Training/ No-Feedback | 4.13 | 7.37 | 5.1 | 6.03 | 5.92 | 8.1 |
| No-Training/ Feedback | 4.13 | 4.00 | 3.47 | 3.26 | 4.39 | 3.72 |
| No-Training/ No-Feedback | 3.6 | 3.19 | 3.99 | 4.56 | 4.36 | 4.1 |

**Table 4.7: Summary statistics of braking score (# of events/10 hours)**

| Phase | Phase I | 6/1–7/27/2015 | Phase II | 7/28–10/9/2015 | Phase III | 10/10/2015–2/1/2016 |
|---|---|---|---|---|---|---|
| Group | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Training/ Feedback | 3.13 | 3.72 | 4.53 | 12.16 | 2.61 | 2.81 |
| Training/ No-Feedback | 3.08 | 2.67 | 3.37 | 2.88 | 3.27 | 2.33 |
| No-Training/ Feedback | 3.08 | 4.14 | 2.57 | 2.68 | 2.38 | 2.67 |
| No-Training/ No-Feedback | 2.66 | 2.08 | 2.92 | 2.47 | 5.9 | 15.06 |

**Table 4.8: Summary statistics of cornering score (# of events/10 hours)**

| Phase | Phase I | 6/1–7/27/2015 | Phase II | 7/28–10/9/2015 | Phase III | 10/10/2015–2/1/2016 |
|---|---|---|---|---|---|---|
| Group | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Training/ Feedback | 13.91 | 16.94 | 11.38 | 13.97 | 14.02 | 19.95 |
| Training/ No-Feedback | 9.49 | 10.30 | 12.53 | 11.6 | 12.99 | 14.03 |
| No-Training/ Feedback | 9.49 | 9.19 | 7.71 | 6.76 | 9.15 | 10.3 |
| No-Training/ No-Feedback | 7.96 | 8.27 | 8.33 | 8.47 | 9.36 | 10.7 |

**Table 4.9: Summary statistics of lane handling score (# of events/10 hours)**

| Phase | Phase I | 6/1–7/27/2015 | Phase II | 7/28–10/9/2015 | Phase III | 10/10/2015–2/1/2016 |
|---|---|---|---|---|---|---|
| Group | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Training/ Feedback | 2.78 | 2.45 | 2.93 | 2.07 | 2.49 | 1.8 |
| Training/ No-Feedback | 4.58 | 2.95 | 3.36 | 1.95 | 3.54 | 2.29 |
| No-Training/ Feedback | 4.58 | 2.36 | 4.17 | 2.53 | 4.47 | 3.22 |
| No-Training/ No-Feedback | 3.65 | 3.89 | 4.49 | 4.42 | 3.55 | 3.38 |

**Table 4.10: Summary statistics of speeding score (# of events/10 hours)**

| Phase | Phase I | 6/1–7/27/2015 | Phase II | 7/28–10/9/2015 | Phase III | 10/10/2015–2/1/2016 |
|---|---|---|---|---|---|---|
| Group | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Training/ Feedback | 21.93 | 13.53 | 18.99 | 12.60 | 21.9 | 11.82 |
| Training/ No-Feedback | 28.10 | 12.80 | 24.86 | 15.28 | 23.72 | 13.8 |
| No-Training/ Feedback | 28.10 | 13.81 | 21.76 | 12.60 | 23.03 | 13.48 |
| No-Training/ No-Feedback | 26.04 | 18.66 | 24.59 | 17.38 | 23.38 | 14.67 |

## 4.7 Regression Analysis Results and Interpretation

The results of the regression analysis are summarized in Appendix D, Tables 4.21 through 4.42 (pages 67–77).

### 4.7.1 Short-term Effect

***Safety.*** Table 4.31 shows that the overall safety score had been reduced in Phase II due to in-vehicle device at a 1% level of significance. Specifically, the positive effect of feedback in reducing speeding score was significant at the 0.01% level during Phase II (Table 4.41). Note that a lower safety score meant safer behavior.

Further analysis by vehicle type (sedan, SUV, pickup truck) showed that pickup trucks benefited the most from real-time feedback.

- In-vehicle feedback reduced overall safety scores for pickup trucks at the 5% significance level during Phase II, while the effect was not significant for sedans or SUVs.
- In-vehicle feedback reduced acceleration scores for pickup trucks at the 10% significance level during Phase II, and the effect sustained in Phase III.
- In-vehicle feedback reduced speeding scores for pickup trucks at the 0.01% significance level during Phase II, and the effect sustained in Phase III (at the 10% significance level).

***Idling.*** Table 4.28 shows that training had a positive effect in reducing idling rate in the first month of Phase II at a 10% level of significance. Idling rate is a major contributor to fuel inefficiency, so reducing idling rate could potentially lead to improvement of fuel economy. The in-vehicle feedback device did not provide feedback on idling and only monitored it; thus, it is not surprising that feedback did not have any effect in reducing idling rate. The classroom training session discussed idling as a major factor, and the first two follow-up tip emails were mostly about idling with clear guidelines. This suggests that targeted education on an implementable behavioral change could be effective.

***Fuel Economy.*** The effect of in-vehicle feedback or classroom training was not as significant as it was for safety scores or idling rates. The combination of feedback and training, however, had a positive effect in improving fuel economy for sedans in the first month of Phase II at a 10% significance level (Table 4.23), and for hybrid vehicles throughout Phase II at a 10% significance level (Table 4.25).

Classroom training provided drivers with a systematic treatment of eco-driving theories and practices, while real-time feedback provided immediate indication of driving performance. On the one hand, it takes conscious effort and practice to translate what is learned in a classroom training session to real-world behaviors. On the other hand, real-time feedback might be difficult to understand if drivers are not familiar with energy-efficient driving styles. It is thus hypothesized that a combination of the two interventions could overcome the shortcomings of each intervention; that is, drivers do not need to make conscious effort but are rather reminded to change behaviors and can understand what to change based on the real-time feedback. The result above provides some preliminary support for this hypothesis.

***Remarks.*** As suggested by the results for idling rate and safety scores, training has a positive effect on reducing idling, while feedback has a positive effect in reducing speeding and aggressive acceleration. According to the literature synthesis, idling, speeding, and aggressive acceleration are major contributors to fuel inefficiency, GHG emissions, and unsafe driving. It is plausible that the goal of improving fuel efficiency and safety and reducing emissions is more likely to be achieved when all three factors are accounted for, and thus combined training and feedback is needed.

### 4.7.2 Long-term Effect

Drivers no longer received any feedback or eco-driving tip emails in Phase III. The regression analysis of the change from Phase I provided evidence as to whether the intervention would have long-term effects. As shown in Tables 4.22, 4.25, 4.27, and 4.30, there was no significant positive improvement in fuel economy or idling rate. While some safety improvements sustained for pickup trucks, in general the effects diminished in Phase III. This suggests that drivers tended to slip back to old driving habits after feedback devices were turned off, and effect of training diminished in a couple of months after in-classroom training.

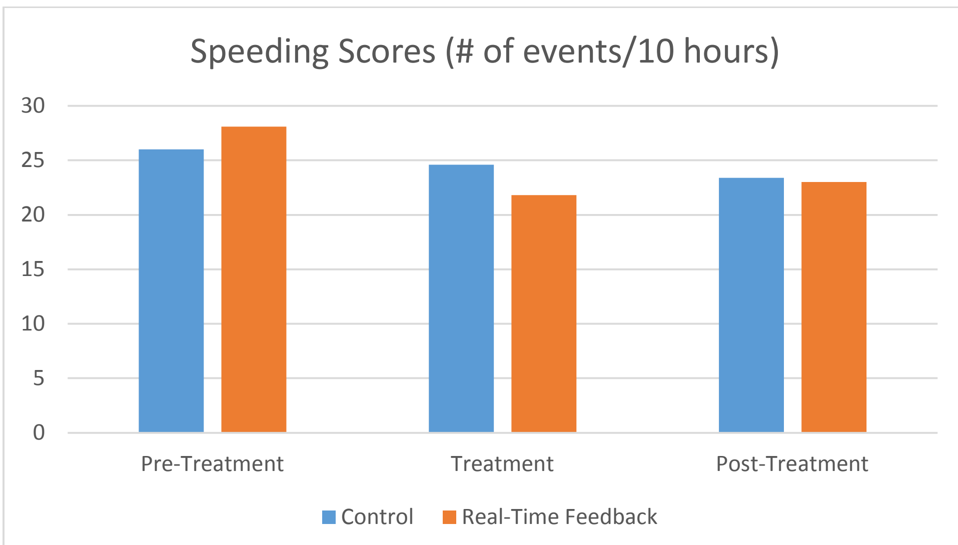
# 5.0 Conclusions and Recommendations

## 5.1 Conclusions

Based on the analysis in the previous section, several conclusions could be drawn.

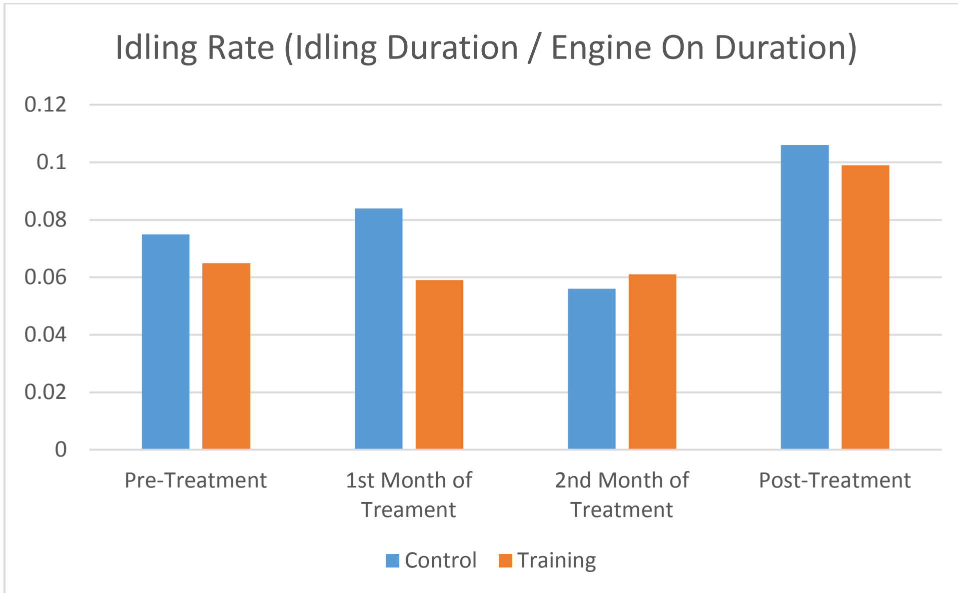
1. Real-time in-vehicle driver feedback had a highly significant effect (at a statistical significance level of 0.01%) in reducing speeding. The effect, however, diminished after the feedback was discontinued (Figure 5.1). According to the conclusion from the literature synthesis, abiding by speed limits on highways not only can reduce crash risk, but also improves fuel economy and reduces emissions (50–90 km/h has emerged as optimum fuel consumption and emission speed ranges from the literature).

**Figure 5.1: Effect of real-time feedback on speeding scores**



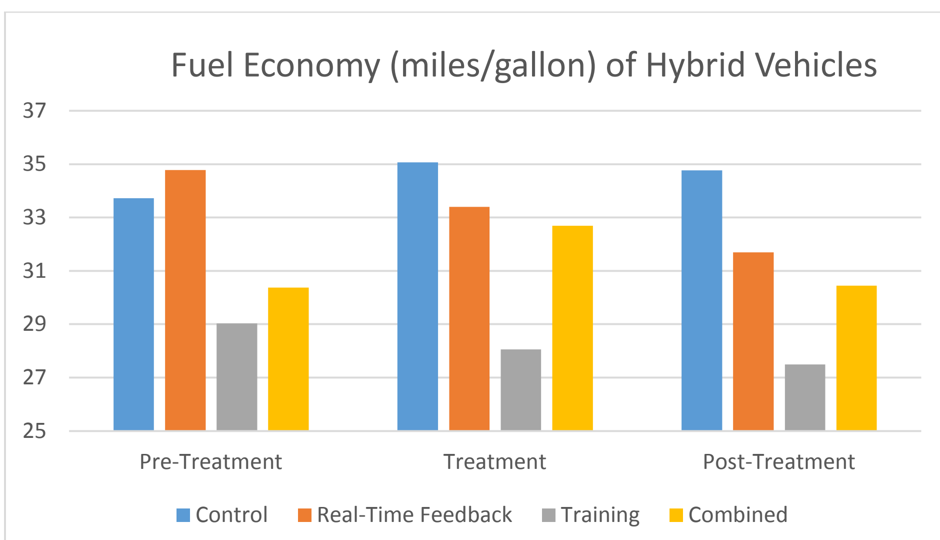

2. Real-time in-vehicle driver feedback had a moderately significant effect (at a statistical significance level of 10%) in reducing aggressive acceleration and lane handling. The effect, however, disappeared after the feedback was discontinued. According to the literature synthesis, aggressive acceleration increases fuel consumption, $CO_2$, NOx, HC, and CO emissions, and is a contributor to crash risk.
3. Classroom training had a moderately significant effect (at a statistical significance level of 10%) in reducing idling rate in the first month after training (Figure 5.2). The effect disappeared after the first month. According to the conclusion from the literature synthesis, idling (stops) or driving at a very low speed worsens fuel consumption and emissions.

**Figure 5.2: Effect of classroom training on idling rate**




4. Combined classroom training and real-time in-vehicle driver feedback had a moderately significant effect (at a statistical significance level of 10%) in improving fuel economy for hybrid vehicles. The effect disappeared after the feedback was discontinued (see Figure 5.3). Note: Real-time feedback or classroom training individually resulted in a slight reduction on fuel economy; these effects were not statistically significant (see Table 4.25 in Appendix D).

**Figure 5.3: Effect of combined real-time feedback and training on fuel economy**



5. In the long run, eco-driving not only helps reduce fuel consumption and emissions but also contributes to reduced accidents because of smoother and less-aggressive driving behavior. Savings due to reduced accident costs and insurance premiums should also add to the long-term benefits of implementing eco-driving.

## 5.2 Recommendations

Based on conclusions in Section 5.1, the Project Team offers the following recommendations regarding the widespread deployment of real-time feedback devices and training to improve fuel economy, reduce emissions, and improve safety.

**Combined Real-Time Feedback and Training**
Both real-time feedback and training could be provided to achieve maximum effectiveness. The specific recommendations regarding real-time feedback and training are discussed next.

**Real-Time Feedback and Periodic Self-Evaluation with MassDOT Monitoring**
MassDOT could install GreenRoad or similar real-time feedback devices in MassDOT-owned vehicles to provide drivers with real-time feedback on how they are driving. MassDOT could subscribe to the vendor's service for its value-added web portal on driver performance summaries and direction of improvement. Therefore, drivers not only would receive real-time feedback while driving but also would have access to their respective driving histories and receive recommendations for modifying driver behavior.

There are two cases regarding how driver behavior data could be transmitted to a central server.

- Data could be transmitted wirelessly in real-time to a central server, in which case the cost would be presumably higher; or
- Data could be stored on the in-vehicle device and downloaded only when the driver is logged in to a computer, in which case the cost would be presumably lower.

The data can be logged, but MassDOT would not monitor driving behavior, thus preserving the driver's privacy. This scenario relies on self-motivation to respond to in-vehicle feedback and data collected via the web portal to be effective.

MassDOT would have access to all drivers' data on the web portal, and thus would be able to monitor driver behavior and performance. Drivers would relinquish some privacy of their driving behavior for the greater good of achieving system-wide safety and fuel efficiency. With MassDOT monitoring, it would also be possible to incentivize drivers with the use of public recognition, awards, and/or prizes. This scenario could potentially achieve the most effectiveness but also would be the most costly, as it involves equipment installation and service, driver performance monitoring, and driver incentives.

If driver privacy is a major concern, then MassDOT could choose not to monitor driving behavior. This scenario relies on self-motivation to respond to in-vehicle feedback and data presented at the web portal and is presumably less effective.

**Classroom Training by MassDOT Trainers and Online MassDOT Training**
Rather than contracting with a vendor for an eco-driving trainer to visit MassDOT sites to train drivers in a classroom setting, in which case the cost is likely the highest, and the scheduling can be challenging, it is recommended that MassDOT send its trainers to the training program vendor to receive eco-driving training. The trained MassDOT trainers in turn would train MassDOT employees in a classroom setting. The MassDOT trainers and classroom training are existing resources, so this scenario would not only maximize the value of existing resources but also make it easy to implement the training logistically. Also, once trained, MassDOT trainers could provide such eco-driving training on a regular basis. Lastly, classroom training is more effective than online training, since the former allows face-to-face communication and onsite question answering. MassDOT trainers could be either in-house or from Baystate Roads, the Local Technical Assistance Program housed at the One Center at UMass Amherst.

Online training could be used to provide MassDOT drivers who received classroom training by MassDOT trainers with online "follow-up" eco-driving training sessions, similar to the University of Vermont's driver training course. The cost for online training courses would be lower than that of classroom training, as no travel costs (and energy consumption) for the trainer or trainees are incurred. Drivers would have the time flexibility and could take the course at their own pace. Online training could be as effective as classroom training if properly designed, e.g., customized for MassDOT.

## 5.3 Deployment Scale Options

MassDOT could choose to scale up the deployment one step at a time. For example, the deployment could start at a small scale at one location, e.g., MassDOT headquarters, or one of the districts could test-run the deployment and learn from the experience. If the deployment went well over a certain period of time, MassDOT could move on and scale it up by implementing the deployment in other locations. Eventually, a system-wide full implementation could be achieved.

## 5.4 Further Issues

Potentially, the deployment of the driver modifications described here may require agency review to ensure compliance with MassDOT policies, regulations, and other legal issues that are outside of the scope of this document.

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# 7.0 Appendices

## 7.1 Appendix A: Summary of Installed Devices

**Table 4.11: Device installation location distribution**

| District | D0 | D1 | D2 | D3 | D4 | D5 |
|---|---|---|---|---|---|---|
| W. Springfield | 9 | 9 | 10 | 0 | 0 | 0 |
| Weston | 27 | 1 | 0 | 15 | 22 | 0 |
| Bridgewater | 8 | 1 | 0 | 0 | 1 | 30 |
| Subtotal | 44 | 11 | 10 | 15 | 23 | 30 |

**Table 4.12: Vehicle type distribution**

| Vehicle Type | SUV | Sedan | Pickup | Van |
|---|---|---|---|---|
| W. Springfield | 12 | 4 | 10 | 2 |
| Weston | 12 | 28 | 23 | 2 |
| Bridgewater | 6 | 6 | 22 | 6 |
| Subtotal | 30 | 38 | 55 | 10 |

**Table 4.13: Vehicle manufacture year distribution**

| Manufacture Year | 2010–2015 | 2005–2009 | 2000–2004 |
|---|---|---|---|
| W. Springfield | 16 | 12 | 0 |
| Weston | 34 | 28 | 3 |
| Bridgewater | 21 | 18 | 1 |
| Subtotal | 71 | 58 | 4 |

**Table 4.14: Vehicles fuel type distribution**

| Fuel Type | Hybrid | Conventional |
|---|---|---|
| W. Springfield | 8 | 20 |
| Weston | 24 | 41 |
| Bridgewater | 8 | 32 |
| Subtotal | 40 | 93 |

## 7.2 Appendix B: Summary of Entry Questionnaire Answers

**Table 4.15: Driver gender distribution**

| Gender | Male | Female |
|---|---|---|
| W. Springfield | 26 | 2 |
| Weston | 47 | 10 |
| Bridgewater | 28 | 2 |
| Subtotal | 101 | 14 |

**Table 4.16: Driver age distribution**

| Age | 20 and under | 21–30 | 31–40 | 41–50 | 51–60 | 60 and above |
|---|---|---|---|---|---|---|
| W. Springfield | 0 | 3 | 3 | 10 | 9 | 3 |
| Weston | 0 | 2 | 8 | 19 | 18 | 12 |
| Bridgewater | 0 | 2 | 2 | 12 | 9 | 3 |
| Subtotal | 0 | 7 | 13 | 41 | 36 | 18 |

**Table 4.17: Vehicle carrying weight on a typical workday**

| Weight Carried | Under 100 lbs | 100–200 lbs | 200–300 lbs | Over 300 lbs |
|---|---|---|---|---|
| W. Springfield | 20 | 4 | 1 | 3 |
| Weston | 43 | 8 | 6 | 2 |
| Bridgewater | 17 | 7 | 3 | 1 |
| Subtotal | 80 | 19 | 10 | 6 |

**Table 4.18: Likelihood to change driving style due to fuel pricing change**

| | Not likely at all | Somewhat likely | Very likely |
|---|---|---|---|
| W. Springfield | 20 | 5 | 3 |
| Weston | 36 | 17 | 6 |
| Bridgewater | 21 | 5 | 2 |
| Subtotal | 77 | 27 | 11 |

**Table 4.19: Driver experience on feedback device prior to the project**

| Location | No feedback | Yes, but ignore it generally | Yes, and sometimes change drive behavior because of it | Yes, and almost always react to it | Yes, but don't understand it at all |
|---|---|---|---|---|---|
| W. Springfield | 16 | 7 | 3 | 2 | 0 |
| Weston | 31 | 7 | 9 | 8 | 4 |
| Bridgewater | 22 | 0 | 3 | 2 | 1 |
| Subtotal | 69 | 14 | 15 | 12 | 5 |

## 7.3 Appendix C: Summary of Eco-Driving Training Exit Survey Responses

**Table 4.20: Summary of eco-driving training exit survey responses**

| | | | | | |
|---|---|---|---|---|---|
| 1. Was achieving high fuel economy a goal of your driving prior to the training? | Yes/40 | Yes/40 | Yes/40 | No/21 | No/21 |
| 2. How much did you know about eco-driving techniques prior to the project? | Almost nothing/2 | A little/11 | Something/ 23 | Quite a bit/17 | A great deal/8 |
| 3. How often did you practice eco-driving techniques prior to this training? | Almost never/3 | Rarely/10 | From time to time/26 | Frequently/17 | Almost always/5 |
| 4. How much did you agree on the following statement? "This training course improves my eco-driving knowledge." | Strongly disagree/1 | Disagree/1 | Neutral/5 | Agree/42 | Strongly agree/12 |
| 5. How often would you practice eco-driving techniques learned in this training? | Almost never/0 | Rarely/0 | From time to time/14 | Frequently/ 36 | Almost always/11 |

## 7.4 Appendix D: Statistical Regression Results

**Table 4.21: Results of fuel economy analysis of Phase I/II data**

| Vehicle/Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | -0.01742 | 0.35 | 0.135 | 0.163 | -0.048 | 0.048 | -0.027 | 0.256 |
| Training | 0.001812 | 0.944 | -0.186 | 0.222 | 0.021 | 0.543 | 0.018 | 0.571 |
| Feedback | 0.002514 | 0.921 | -0.178 | 0.213 | 0.047 | 0.114 | 0.009 | 0.789 |
| Training & Feedback | 0.045374 | 0.209 | 0.31 | 0.130 | 0.016 | 0.726 | -0.004 | 0.935 |
| Sample Size | 86 | 86 | 23 | 23 | 18 | 18 | 45 | 45 |

**Table 4.22: Results of fuel economy analysis of Phase I/III data**

| Vehicle/ Phase | Overall | (Phase I/III) | Sedan | (Phase I/III) | SUV | (Phase I/III) | Pickup Truck | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | -0.015 | 0.654 | 0.13 | 0.203 | -0.04 | 0.377 | -0.099 | 0.0068 |
| Training | -0.026 | 0.597 | -0.11 | 0.524 | -0.02 | 0.786 | 0.047 | 0.31 |
| Feedback | -0.049 | 0.285 | -0.2 | 0.251 | -0.008 | 0.896 | 0.03 | 0.503 |
| Training & Feedback | 0.062 | 0.345 | 0.19 | 0.418 | 0.024 | 0.813 | -0.025 | 0.699 |
| Sample Size | 82 | 82 | 19 | 19 | 17 | 17 | 46 | 46 |

**Table 4.23: Results of fuel economy analysis of Phase I and first month of Phase II data**

| Vehicle/ Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | -0.020 | 0.296 | -0.015 | 0.765 | -0.04 | 0.052 | -0.015 | 0.554 |
| Training | 0.0011 | 0.965 | -0.095 | 0.252 | 0.008 | 0.778 | 0.024 | 0.465 |
| Feedback | 0.009 | 0.74 | -0.023 | 0.777 | 0.046 | 0.0705* | 0.0009 | 0.978 |
| Training & Feedback | 0.025 | 0.505 | 0.196 | 0.091* | 0.011 | 0.781 | -0.035 | 0.438 |
| Sample Size | 85 | 85 | 22 | 22 | 18 | 18 | 45 | 45 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.24: Results of fuel economy analysis of Phase I and second month of Phase II data**

| Vehicle/ Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | -0.019 | 0.4 | 0.014 | 0.806 | -0.023 | 0.461 | -0.038 | 0.235 |
| Training | 0.019 | 0.552 | -0.020 | 0.823 | 0.007 | 0.894 | 0.038 | 0.368 |
| Feedback | -0.018 | 0.563 | -0.153 | 0.133 | 0.011 | 0.79 | 0.014 | 0.746 |
| Training & Feedback | 0.044 | 0.336 | 0.217 | 0.114 | 0.067 | 0.326 | -0.022 | 0.702 |
| Sample Size | 81 | 81 | 20 | 20 | 16 | 16 | 45 | 45 |

**Table 4.25: Results of fuel economy analysis of Phase I/II/III data (divided by hybrid / non-hybrid)**

| Vehicle/ Phase | Hybrid | (Phase I/II) | Non-Hybrid | (Phase I/II) | Hybrid | (Phase I/III) | Non-Hybrid | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.132 | 0.118 | -0.033 | 0.083 | 0.14 | 0.108 | -0.08 | 0.0022 |
| Training | -0.167 | 0.161 | 0.018 | 0.495 | -0.157 | 0.226 | 0.036 | 0.368 |
| Feedback | -0.17 | 0.138 | 0.022 | 0.377 | -0.184 | 0.157 | 0.018 | 0.62 |
| Training & Feedback | 0.280 | 0.077* | -0.008 | 0.826 | 0.206 | 0.241 | -0.017 | 0.76 |
| Sample Size | 29 | 29 | 57 | 57 | 25 | 25 | 57 | 57 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.26: Results of idling rate analysis of Phase I/II data**

| Vehicle/ Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.24963 | 0.269 | 0.463 | 0.274 | -0.141 | 0.763 | 0.448 | 0.179 |
| Training | -0.05926 | 0.862 | -0.72 | 0.325 | 0.906 | 0.219 | -0.517 | 0.302 |
| Feedback | -0.15739 | 0.653 | -0.159 | 0.826 | 0.344 | 0.624 | -0.483 | 0.323 |
| Training & Feedback | -0.01589 | 0.974 | 0.551 | 0.580 | -0.995 | 0.328 | 0.457 | 0.520 |
| Sample Size | 105 | 105 | 21 | 21 | 35 | 35 | 49 | 49 |

**Table 4.27: Results of idling rate analysis of Phase I/III data**

| Vehicle/Phase | Overall | (Phase I/III) | Sedan | (Phase I/III) | SUV | (Phase I/III) | Pickup Truck | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.87 | 0.02 | 0.92 | 0.23 | 0.78 | 0.42 | 1.18 | 0.033 |
| Training | 0.1 | 0.92 | 0.21 | 0.79 | 0.92 | 0.87 | -0.52 | 0.53 |
| Feedback | -0.43 | 0.53 | 0.87 | 0.72 | 0.04 | 0.97 | -0.99 | 0.14 |
| Training & Feedback | -0.19 | 0.91 | -1.36 | 0.4 | -0.32 | 0.93 | 0.32 | 0.93 |
| Sample Size | 103 | 103 | 21 | 21 | 34 | 34 | 48 | 48 |

**Table 4.28: Results of idling rate analysis of Phase I and first month of Phase II data**

| Vehicle/ Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.5492 | 0.019 | 1.082 | 0.117 | 0.45 | 0.259 | 0.238 | 0.326 |
| Training | -0.724 | 0.033* | -1.422 | 0.188 | -0.666 | 0.274 | -0.334 | 0.318 |
| Feedback | -0.472 | 0.15 | -1.705 | 0.211 | -0.221 | 0.661 | -0.116 | 0.722 |
| Training & Feedback | 0.734 | 0.109 | 2.518 | 0.143 | -0.076 | 0.922 | 0.244 | 0.587 |
| Sample Size | 79 | 79 | 20 | 20 | 17 | 17 | 42 | 42 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.29: Results of idling rate analysis of Phase I and second month of Phase II data**

| Vehicle/Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | -0.1751 | 0.35 | -0.309 | 0.178 | -0.523 | 0.233 | 0.008 | 0.98 |
| Training | 0.05 | 0.852 | 0.136 | 0.7 | 0.213 | 0.772 | -0.115 | 0.793 |
| Feedback | 0.1575 | 0.568 | -0.084 | 0.851 | 1.14 | 0.065* | -0.209 | 0.625 |
| Training & Feedback | -0.2942 | 0.445 | 0.225 | 0.689 | -1.292 | 0.182 | 0.054 | 0.928 |
| Sample Size | 76 | 76 | 19 | 19 | 15 | 15 | 42 | 42 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.30: Results of idling rate analysis of Phase I/II/III data (divided by hybrid / non-hybrid)**

| Vehicle/ Phase | Hybrid | (Phase I/II) | Non-Hybrid | (Phase I/II) | Hybrid | (Phase I/III) | Non-Hybrid | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.435 | 0.271 | 0.209 | 0.449 | 1.31 | 0.08 | 0.84 | 0.09 |
| Training | -0.56 | 0.316 | 0.095 | 0.830 | -0.73 | 0.43 | 0.43 | 0.63 |
| Feedback | 0.298 | 0.63 | -0.252 | 0.554 | -0.09 | 0.97 | -0.54 | 0.53 |
| Training & Feedback | -0.198 | 0.801 | 0.022 | 0.972 | -0.18 | 0.93 | -0.197 | 0.74 |
| Sample Size | 27 | 27 | 75 | 75 | 27 | 27 | 76 | 76 |

**Table 4.31: Results of overall safety score analysis of Phase I/II data**

| Vehicle/Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.127 | 0.033 | 0.234 | 0.168 | 0.029 | 0.757 | 0.136 | 0.15 |
| Training | 0.025 | 0.787 | 0.02 | 0.941 | 0.24 | 0.12 | -0.087 | 0.517 |
| Feedback | -0.284 | 0.002* | -0.268 | 0.3 | -0.24 | 0.11 | -0.32 | 0.023* |
| Training & Feedback | 0.071 | 0.589 | -0.095 | 0.802 | -0.15 | 0.47 | 0.275 | 0.158 |
| Sample Size | 107 | 107 | 24 | 24 | 35 | 35 | 48 | 48 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.32: Results of overall safety score analysis of Phase I/III data**

| Vehicle/Phase | Overall | (Phase I/III) | Sedan | (Phase I/III) | SUV | (Phase I/III) | Pickup Truck | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.44 | 0.03 | 1.18 | 0.131 | 0.04 | 0.74 | 0.264 | 0.112 |
| Training | -0.35 | 0.27 | -0.56 | 0.686 | 0.06 | 0.76 | -0.356 | 0.137 |
| Feedback | -0.47 | 0.12 | -0.79 | 0.566 | -0.25 | 0.22 | -0.31 | 0.18 |
| Training & Feedback | 0.5 | 0.26 | 0.47 | 0.81 | 0.017 | 0.95 | 0.57 | 0.08 |
| Sample Size | 114 | 114 | 26 | 26 | 37 | 37 | 51 | 51 |

**Table 4.33: Results of average acceleration score analysis of Phase I/II data**

| Vehicle/Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.07 | 0.6 | -0.047 | 0.873 | -0.28 | 0.196 | 0.3297 | 0.15 |
| Training | -0.058 | 0.782 | 0.219 | 0.659 | 0.529 | 0.13 | -0.51 | 0.124 |
| Feedback | -0.35 | 0.088* | 0.204 | 0.66 | -0.232 | 0.483 | -0.64 | 0.055* |
| Training & Feedback | 0.0002 | 0.999 | -0.785 | 0.262 | -0.229 | 0.638 | 0.414 | 0.381 |
| Sample Size | 107 | 107 | 24 | 24 | 35 | 35 | 48 | 48 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.34: Results of average acceleration score analysis of Phase I/III data**

| Vehicle/Phase | Overall | (Phase I/III) | Sedan | (Phase I/III) | SUV | (Phase I/III) | Pickup Truck | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.26 | 0.078 | -0.08 | 0.77 | -0.16 | 0.47 | 0.8 | 0.001 |
| Training | 0.13 | 0.57 | 0.58 | 0.2 | 0.47 | 0.18 | -0.9 | 0.009* |
| Feedback | -0.28 | 0.19 | 0.77 | 0.10 | -0.39 | 0.23 | -0.68 | 0.039* |
| Training & Feedback | 0.09 | 0.77 | -1.28 | 0.046* | -0.036 | 0.94 | 0.72 | 0.13 |
| Sample Size | 112 | 112 | 25 | 25 | 36 | 36 | 51 | 51 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.35: Results of average braking score analysis of Phase I/II data**

| Vehicle/Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | -0.08 | 0.531 | 0.13 | 0.66 | 0.15 | 0.48 | -0.19 | 0.32 |
| Training | 0.19 | 0.34 | -0.11 | 0.81 | 0.079 | 0.82 | 0.26 | 0.35 |
| Feedback | -0.08 | 0.68 | 0.02 | 0.96 | -0.49 | 0.15 | 0.015 | 0.956 |
| Training & Feedback | 0.17 | 0.57 | 0.59 | 0.37 | -0.04 | 0.942 | 0.27 | 0.5 |
| Sample Size | 107 | 107 | 24 | 24 | 35 | 35 | 48 | 48 |

**Table 4.36: Results of average braking score analysis of Phase I/III data**

| Vehicle/Phase | Overall | (Phase I/III) | Sedan | (Phase I/III) | SUV | (Phase I/III) | Pickup Truck | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.37 | 0.017 | 0.57 | 0.12 | 0.11 | 0.62 | 0.47 | 0.05 |
| Training | -0.24 | 0.31 | -0.13 | 0.82 | 0.056 | 0.87 | -0.47 | 0.17 |
| Feedback | -0.53 | 0.019* | 0.09 | 0.87 | -0.76 | 0.025* | -0.56 | 0.09* |
| Training & Feedback | 0.52 | 0.11 | -0.24 | 0.77 | 0.36 | 0.46 | 0.78 | 0.11 |
| Sample Size | 112 | 112 | 25 | 25 | 36 | 36 | 51 | 51 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.37: Results of average cornering score analysis of Phase I/II data**

| Vehicle/Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | -0.17 | 0.21 | 0.39 | 0.23 | 0.0037 | 0.99 | -0.46 | 0.0115 |
| Training | 0.33 | 0.114 | -0.12 | 0.83 | 0.35 | 0.42 | 0.48 | 0.0637* |
| Feedback | 0.10 | 0.63 | -0.59 | 0.24 | 0.01 | 0.98 | 0.39 | 0.13 |
| Training & Feedback | -0.38 | 0.214 | 0.21 | 0.77 | -0.47 | 0.44 | -0.53 | 0.15 |
| Sample Size | 107 | 107 | 24 | 24 | 35 | 35 | 48 | 48 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.38: Results of average cornering score analysis of Phase I/III data**

| Vehicle/Phase | Overall | (Phase I/III) | Sedan | (Phase I/III) | SUV | (Phase I/III) | Pickup Truck | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.1 | 0.51 | 0.49 | 0.13 | 0.03 | 0.92 | -0.04 | 0.85 |
| Training | 0.07 | 0.79 | 0.25 | 0.62 | 0.26 | 0.59 | -0.05 | 0.88 |
| Feedback | -0.05 | 0.82 | 0.07 | 0.89 | -0.37 | 0.4 | 0.19 | 0.53 |
| Training & Feedback | -0.12 | 0.71 | -0.92 | 0.2 | -0.05 | 0.94 | 0.06 | 0.89 |
| Sample Size | 112 | 112 | 25 | 25 | 36 | 36 | 51 | 51 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.39: Results of average lane handling score analysis of Phase I/II data**

| Vehicle/Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.18 | 0.12 | 0.025 | 0.95 | 0.09 | 0.66 | 0.277 | 0.0524 |
| Training | -0.14 | 0.43 | -0.113 | 0.857 | 0.08 | 0.82 | -0.275 | 0.17 |
| Feedback | -0.29 | 0.11 | 0.007 | 0.99 | -0.4 | 0.223 | -0.31 | 0.134 |
| Training & Feedback | 0.29 | 0.26 | 0.077 | 0.93 | 0.033 | 0.945 | 0.572 | 0.055* |
| Sample Size | 107 | 107 | 24 | 24 | 35 | 35 | 48 | 48 |

**Note:** A p-value with “*” represents a statistically significant result at the 0.1 level.

**Table 4.40: Results of average lane handling score analysis of Phase I/III data**

| Vehicle/Phase | Overall | (Phase I/III) | Sedan | (Phase I/III) | SUV | (Phase I/III) | Pickup Truck | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.16 | 0.26 | 0.05 | 0.90 | 0.09 | 0.68 | 0.27 | 0.12 |
| Training | -0.33 | 0.13 | -0.53 | 0.43 | -0.1 | 0.78 | -0.43 | 0.09* |
| Feedback | -0.16 | 0.43 | 0.69 | 0.32 | -0.52 | 0.13 | -0.21 | 0.37 |
| Training & Feedback | 0.21 | 0.49 | -0.53 | 0.57 | 0.25 | 0.62 | 0.53 | 0.13 |
| Sample Size | 112 | 11 2 | 25 | 25 | 36 | 36 | 51 | 51 |

**Note:** A p-value with “*” represents a statistically significant result at the 0.1 level.

**Table 4.41: Results of average speeding score analysis of Phase I/II data**

| Vehicle/Phase | Overall | (Phase I/II) | Sedan | (Phase I/II) | SUV | (Phase I/II) | Pickup Truck | (Phase I/II) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | 0.11 | 0.07 | -0.023 | 0.83 | 0.02 | 0.83 | 0.18 | 0.079 |
| Training | -0.014 | 0.88 | 0.09 | 0.62 | 0.22 | 0.16 | -0.16 | 0.25 |
| Feedback | -0.36 | 0.000104* | -0.089 | 0.6 | -0.32 | 0.04* | -0.46 | 0.00217* |
| Training & Feedback | 0.12 | 0.38 | -0.4 | 0.13 | -0.034 | 0.88 | 0.4 | 0.055* |
| Sample Size | 107 | 107 | 24 | 24 | 35 | 35 | 48 | 48 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.

**Table 4.42: Results of average speeding score analysis of Phase I/III data**

| Vehicle/Phase | Overall | (Phase I/III) | Sedan | (Phase I/III) | SUV | (Phase I/III) | Pickup Truck | (Phase I/III) |
|---|---|---|---|---|---|---|---|---|
| Group | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Intercept | -0.01 | 0.93 | -0.27 | 0.42 | 0.05 | 0.78 | 0.11 | 0.49 |
| Training | -0.02 | 0.91 | 0.86 | 0.16 | -0.25 | 0.39 | -0.26 | 0.28 |
| Feedback | -0.19 | 0.3 | 0.21 | 0.73 | -0.19 | 0.47 | -0.40 | 0.08* |
| Training & Feedback | 0.38 | 0.16 | -0.08 | 0.92 | 0.24 | 0.54 | 0.53 | 0.12 |
| Sample Size | 114 | 114 | 26 | 26 | 37 | 37 | 51 | 51 |

**Note:** A p-value with "*" represents a statistically significant result at the 0.1 level.