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Eco-Driving as an Emissions Reduction Strategy

Prepared by the Texas A&M Transportation Institute

Prepared for the Texas Department of Transportation

August 2013

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Air Quality and Conformity Inter-Agency Contract

Subtask 2.6, "Eco-Driving Policy Evaluation" – FY 2013

Prepared for

Texas Department of Transportation

Prepared by

Texas A&M Transportation Institute

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TABLE OF CONTENTS

List of Tables

Chapter 1. Introduction

Eco-driving is regarded as an important strategy to reduce emissions and fuel consumption in a number of countries – including, the Netherlands, Austria, Germany, and Spain – and encouraged in countries such as Canada, Japan, and the United Kingdom (International Transport Forum, 2007). Although the U.S. Department of Energy (U.S. DOE) implemented the Driver Energy Conservation Awareness Training (DECAT) program in the 1970s, the program was abandoned only after a few years. No federal program currently exists to promote eco-driving, although the potential benefits have been estimated at 11.3 billion gallons of saved fuel if every American practiced eco-driving (Barkenbus 2010).

Eco-driving – as defined in this study – entails driving a vehicle in such a manner as to ensure best energy use, and consequently, a reduction in emissions. Eco-driving is thus characterized by certain identifiable behaviors: acceleration, deceleration, speed, and gear change behavior. These behaviors involve accelerating gradually, anticipating traffic flows and signals, maintaining a consistent driving speed, and eliminating excessive idling. It is believed that these changes in driving behavior will create immediate savings in emissions and fuel usage to the entire vehicle fleet with associated reductions in greenhouse gas (GHG) emissions, fuel cost savings, as well as greater safety and comfort.

This report is an updated version of the Task 2.6 Technical Memorandum prepared in FY2012. The focus of this document is on expanding the information that was reported in that document; specifically on different aspects of eco-driving practices including their potential air quality and fuel efficiency benefits.

Chapter 2. Eco-Driving Characteristics and Strategies

Eco-driving has various aspects to its definition and some research includes automobile maintenance (i.e., regular oil changes, correct tire air pressure, etc.) while others focus strictly on driving behavior. This task focused solely on driving behavior. Edo-driving - as defined in this study - is thus characterized by certain identifiable variables: acceleration, deceleration, speed, and gear change behavior. While improved fuel economy is an outcome of eco-driving, eco-driving practices also promotes safe driving.

2.1 Eco-Driving Strategies

Eco-driving primarily consists of a variety of driving techniques that save fuel and lower emissions. Representative eco-driving involves various driving behaviors, such as maintaining a steady speed, avoiding heavy acceleration and deceleration, well anticipating the traffic flow ahead, and minimizing idling time. These behaviors will tend to smooth vehicle movements and avoid unnecessary fuel consumption, thereby reducing greenhouse emissions. Barkenbus (2010) noted that eco-driving is characterized by *"accelerating moderately (with shifts ups between 2000 and 2500 revolutions for those with manual transmissions), anticipating traffic flow and signals, thereby avoiding sudden starts and stops; maintaining an even driving pace (using cruise control on the highway where appropriate), driving at or safely below the speed limit; and eliminating excessive idling.*

The Auto Alliance, Ford, and Toyota – among others – have identified a number of strategies or driving behaviors – loosely termed eco-driving principles, tips or strategies – that will reduce fuel consumption and thereby the cost of driving, as well as reduce emissions, specifically CO_2. Below is a list and description of the key eco-driving strategies that involve driving behavior:

- Avoid rapid starts and stops/ accelerate and brake smoothly;
- Maintain a constant travel speed;
- Moderate travel speed;
- Avoid idling;
- Use the highest gear possible; and
- Minimize "warming up" time.

2.1.1 Avoid Rapid Starts and Stops

Research has shown that "aggressive driving"[1] characterized by sudden acceleration and deceleration results in 33% more fuel usage at high speeds on highways and about 5% more fuel usage when driving around town, or in congested circumstances (Saboohi and Farzaneh, 2009). Accelerating and braking smoothly thus conserve fuel. Ford (ND) reported that *"Fast starts, weaving in and out of traffic and hard braking wastes fuel and wears out some of the car components, such as brakes and tires, more quickly"*. EcodrivingUSA reported that gentle acceleration and braking can save more than $1 per gallon (EcoDrivingUSA, ND). By

[1] A study by Tzirakis, Zannikos, and Stournas (2007) on the impacts of different driving styles (i.e., "defensive" and "aggressive") revealed that aggressive driving caused fuel consumption to nearly double relative to that of defensive drivers. Emissions from the vehicles that were driven aggressively also dwarfed the emissions from the defensively driven vehicles (Tzirakis, Zannikos, and Stournas, 2007).

maintaining a safe distance between vehicles and anticipating traffic conditions, drivers will have more time to brake and accelerate gradually (Ford, ND). Toyota (ND) advised that drivers release the accelerator as soon as they see a red signal or stop signal to slow down the vehicle using the engine brake or to stop the vehicle by terminating the fuel injection. Fuel consumption can be lowered substantially by releasing the vehicle's accelerator as early as possible.

2.1.2 Maintain a Constant Travel Speed

> *"It can take 20 percent more fuel to accelerate from a full stop than from 5 miles per hour"* (EcoDrivingUSA, ND).

Substantial fuel savings can be secured by maintaining a constant travel speed, because it requires more fuel "*to move a stopped vehicle than to keep a vehicle moving"* (EcoDrivingUSA, ND). This can be achieved by (i) anticipating traffic conditions, (ii) maintaining the speed necessary to move through synchronized green traffic lights, and (iii) using cruise control on the highways. For example, it has been reported that using cruise control can result in an average fuel savings of 7% if the driving is done on mostly flat terrain (EcoDrivingUSA, ND).

2.1.3 Moderate Travel Speed

EcoDrivingUSA (ND) reported a penalty of 20 cents per gallon of gas for every 5 miles over a 60 mph travel speed. Eco-DrivingUSA (ND) further reported that by *"observing the speed limit and not exceeding 60 mph (where legally allowed) can improve mileage by 7-23%"*. Ford (ND) also reported that by driving 55 mph instead of 65 mph a driver can achieve a 10-15% improvement in fuel economy.

2.1.4 Avoid Idling

EcoDrivingUSA, Ford, and Toyota advise drivers to stop the vehicle's engine as opposed to idling. Ford advises drivers to turn the vehicle's engine off in non-traffic situations (e.g., at a bank or fast food drive up window and when loading or unloading) when idling more than 30 seconds (Ford, ND). Toyota (ND) reported that a vehicle may use *"more than half a gallon of fuel for every hour spent idling"*.

2.1.5 Use the Highest Gear

Vehicles have the most power in the lowest gear, but power also translates into fuel consumption. EcoDrivingUSA (ND) recommends using overdrive gearing as much as possible to decrease the vehicle's engine speed, thereby saving fuel and engine wear. Saboohi and Farzaneh (2009) found - based on their model assumptions - that 1930 rpm was the optimal speed of the engine to minimize fuel consumption and at which point gears should be shifted for increased speed.

2.1.6 Minimize "Warming Up"

EcoDrivingUSA, Ford, and Toyota reported that today's vehicles do not need a "warm-up" before driving. EcoDrivingUSA (ND) reported that even on a very cold morning, the vehicle's engine only needs to run for 30 seconds for the oil to distribute through the engine. In fact, EcoDrivingUSA (ND) reported that a vehicle will reach its optimum temperature faster when driving gently (i.e., avoiding sudden or severe acceleration) for the first few minutes as opposed to idling.

2.2 Concluding Remarks

This Chapter listed a number of strategies or driving behaviors – loosely termed eco-driving principles, tips or strategies – that can be implemented with relative ease by all drivers in the U.S. These strategies require moderate changes to driving behaviors, but hold the potential to reduce fuel usage and thereby the cost of driving and emissions - specifically CO_2 emissions. Chapter 3 highlights a number of benefits reported in the literature associated with adopting eco-driving principles.

Chapter 3. Eco-Driving Benefits

Several benefits are associated with adopting eco-driving principles, including a reduction in CO_2 emissions, improved fuel economy with associated oil security and a reduction in oil dependency benefits, improved safety, reduced noise, and reduced driver stress, and cost savings to private vehicle users and private companies/agencies owning large vehicle fleets. This Chapter of the report summarizes the reported benefits of a number of eco-driving initiatives.

3.1 Fuel Economy Benefits

In the U.S. several academic studies have estimated the fuel economy benefits of adopting eco-driving strategies. These studies vary greatly in their objectives and approaches. For example, Barth and Boriboonsomsin (2009) explored the fuel savings benefits associated with providing drivers with real time information on an optimal or *"suggested"* speed using simulation and real-time freeway traffic data (speed, density, and flow) - thereby adhering to the eco-driving principles of maintaining an even driving pace and avoiding sudden starts and stops. Barth and Boriboonsomsin (2009) reported a 10 to 20% reduction in fuel consumption using modeling tools that simulated a variety of freeway traffic scenarios. Specifically, the simulations revealed higher fuel and CO_2 emissions savings in more congested traffic scenarios. A limited real-world experiment on SR91 in California involving two vehicles – one received real time optimal speed information and the other served as the control vehicle – that made various runs in congested and non-congested traffic situations confirmed the estimated reductions from the simulation models. The real-world experiment revealed fuel and CO_2 emissions reductions of 13 and 12%, respectively.

In 2010, Booriboonsomsin, Vu, and Barth reported on a study conducted in Southern California that evaluated the fuel consumption impact of onboard feedback devices that provide instantaneous fuel economy information to drivers. An eco-driving device (i.e., Eco-Way by Earthrise Technology) was installed on the vehicles of the participating drivers. Although the study objectives were shared with the participants and they were provided with a hand-out detailing eco-driving principles, the participants did not receive any formal training in eco-driving techniques. The results from a sample of 20 drivers revealed average fuel savings of 6% in the city and 1% on the highway. Individual results; however, varied significantly from -5% to +24% in the city and from -12% to +13% on the highway. Drivers' responses to a questionnaire that was administered at the end of the study revealed that 40% of the participating drivers already practiced eco-driving principles and that the number of drivers could increase to 95% if the price of fuel reached $4.40 per gallon.

Symmons and Rose (2009) conducted a field test in which a small group of heavy-duty vehicle drivers underwent an eco-drive training course. The training particularly focused on progressive gear shifting and progressive braking, "flowing" the vehicle and forward scanning of the road ahead. The result demonstrated that the eco-driving training could achieve up to a 27% reduction in fuel consumption by heavy-vehicle drivers.

In 2008, it was reported that in pilot tests performed by Ford Motor Company and Pro Formance Group in Phoenix, Arizona, hands-on training of drivers by eco-driving experts resulted in significant improvements in fuel economy. Certified master eco-driving trainers trained 48 drivers to improve their fuel economy through smoother breaking and acceleration, monitoring their RPMs, and driving at a moderate speed over a four-day period. The results – as verified by the Sports Car Club – showed an average fuel economy improvement of 24%. The results varied from a 6% fuel economy improvement to an improvement in excess of 50% (Ford Motor Company, 2008).

A number of international studies have also reported fuel economy improvements similar to the U.S. studies listed above. For example, Azzi, Reymond, Mérienne, and Kemeny (2011) reported fuel savings of 5 to 10% if drivers are provided instant feedback. Two forms of feedback were used in a dynamic driving simulator at the Technical Center for Simulation of Renault: a visual display and a haptic gas pedal. The visual display provided instant fuel consumption information and included a speedometer that changed colors given how efficiently the vehicle was driven. With the haptic petal, drivers were provided information - "forced feedback" - on optimal pedal position. In other words, the rigidity of the pedal would increase to force drivers to accelerate slower. The authors also reported a significant decrease in emissions, but did not observe any substantial difference in the emissions savings realized between the two feedback devices. Van Mierlo et al (2004) also found that adopting an eco-driving style could reduce fuel consumption by 5 to 25%. Tests were conducted on a dynamometer using engine cycle data that were developed from on-road tests. Finally, a pilot study in Greece in 2006 reported mixed results. This may be partially attributed to the very small sample size: three buses made only two trips each. The three buses traveled the same route first employing traditional driving behavior and then by applying eco-driving techniques. The average reduction in fuel consumption reported with eco-driving techniques was 10.2% (Zarkadoula, Zoidis, Tritopoulou, 2007).

The use of intelligent transportation system (ITS) technologies, such as real-time signal information, provides the opportunity to supply forecasts of external factors to the vehicle and predict a fuel-optimal strategy. Such dynamic eco-driving advice can be implemented using real-time traffic sensing and telematics, allowing for a traffic management center to communicate in real-time with equipped vehicles. The overall goal of dynamic eco-driving is to smooth the traffic flow (and thereby decreasing fuel consumption) by dynamically advising vehicles to travel at specific speeds.

Barth and Boriboonsomsin (2009) investigated the concept of dynamic eco-driving and proposed a dynamic strategy which takes advantage of real-time traffic sensing and telematics to monitor traffic speed, density, and flow, and then communicates in real-time back to the vehicles. They found that by providing dynamic advice to drivers, approximately 10–20% in fuel savings and lower CO_2 emissions can be achieved without a significant increase in travel time.

Xia et al. (2011) found that there are indirect network-wide energy and emissions benefits for the overall traffic, even at low penetration rates of the dynamic eco-driving technology-equipped vehicles. Their study result showed that the maximum fuel saving and emission reduction occurs during medium congestion levels, i.e. a traffic volume of 300 vehicles/lane/hour and with low penetration rates (5% ~ 20%).

Eco-driving also has attracted interest from automobile manufacturers. Nissan has developed an on-board eco-driving support service composed of a navigation system and telematics center to promote and deploy eco-driving habits on the road. It's found that by using the system effectively, an average of 18% fuel consumption improvement can be achieved (Satou et al. 2010).

Asadi and Vahidi (2010) developed a cruise control system which utilized constrained optimization to minimize the probability of approaching a stop line during a red phase by varying the speeds within an interval and achieved 47 percent consumption deduction. Barth et al. (2011) have developed a dynamic eco-driving system by using the signal phase and timing information for signalized corridors. The system consists of an arterial velocity planning algorithm that attempts to minimize vehicle fuel consumption and emissions. The proposed control logic for the optimal velocity tries to minimize the fuel consumption. It is minimizing the total tractive power demand and the idling time while ensuring that the optimal velocity is less than or equal to speed limit. Through a series of simulations they showed that their velocity planning algorithms can result in approximately 10% to15% fuel economy improvement over a standard baseline case without the velocity planning.

Rakha and Kamalanathsharma (2011) proposed an eco-driving framework which yields the most fuel-optimal speed profile for a vehicle approaching a signalized intersection using V2I communication capabilities. The VT-Micro model was used to estimate fuel consumption for various alternative speed profiles and determine which the optimum is. They divided vehicle trajectories into the trajectory upstream and downstream of the traffic signal stop-line. A combined optimum was calculated using mode-specific fuel consumption and emission levels for vehicle deceleration, cruising/idling, and acceleration modes.

Sun et al. (2013) developed a dynamic eco-driving speed guidance strategy (DESGS) with application of real-time signal timing and vehicle positioning information. In their study, an optimization-based rolling horizon and a dynamic programming approach were put forward to track the optimal guided velocity for individual vehicles along the roadway segment. A piecewise model showing the relationship between the fuel rate and vehicle specific power (VSP) was used to estimate the fuel consumption and emissions. A case study was conducted in which 15 drivers attended the speed guidance experiments using multi-vehicle driving simulators, the test result showed that the number of stops is significantly reduced and fuel consumption and CO_2 emissions can be reduced by approximately 25% for the vehicles with DESGS as compared to the vehicles without speed guidance.

Table 3.1 provides a summary of the reported fuel economy improvements secured in different countries and projects. From Table 3.1 it is clear that the short-term results – recorded after eco-driving training – shows a substantial improvement in average fuel economy, ranging from 5 to 15%. In test conditions, such as eco-driving competitions, some results showed a 20 to 50% improvement in fuel economy. The mid-term impacts – defined as less than three years – shows a more modest improvement in fuel economy of 5% if there is no continuing incentives, such as ongoing feedback or training. Given continuous feedback, fuel economy improvements of 10% are reported (International Transport Forum, 2007). Finally, few studies exist on the long-term fuel economy improvements associated with eco-driving training, but those that have looked at the fuel economy benefits associated with providing once-off training at companies with truck and bus fleets without any subsequent follow up (either ongoing feedback or training) reported only a 2 to 3% fuel economy improvement (International Transport Forum, 2007).

Table 3.1: Fuel Economy Benefits Obtained in Various Countries and Projects

Country	Method	Short-term (%)	Mid-term (%)
Netherlands	National programme	10-20	5-10
Austria	National programme	10-15	5-10
Japan	Smart driving contest	25	
Japan	Idle stop driving	10	
Japan	Ecodrive workshop	12	
Japan	Average mileage workshop	26	
Sweden	Driver training courses	5-15	
Austria	ÖBB Post Bus Best Practice training courses, competition, monitoring, feedback	10	
Austria	Eco-driving competitions for licensed drivers	30-50	
Austria	Mobility management for company fleets	10-15	
Germany DVR	• National novice drivers programme • Professional fleet drivers <7.5t • Driver training courses for passenger cars (evaluation)	 6-10 10-25	6-10 6-8 10-15
Deutsche Bahn	Training courses, monitoring, feedback, rewards		3-5
Shell		5-20	
Ford	Training courses and trip/driving style analysis	25	10
FIA – AASA		15	
FIA – Plan Azul		14	
FIA – ADAC		25	
FIA – öATMC		6	
FIA – JAF		12-16	
Nissan		18	
UK	Freight Best Practice	10	
UK – Lane Group			4
UK – Walkers			9

Source: International Transport Forum, 2007

3.2 Vehicle Emissions Benefits

In the U.S., it has been reported that in 2005, approximately 113 billion gallons of motor fuel were used in cars owned by households and that a 10% reduction in fuel usage (or 11.3 billion gallons) achieved through adapting eco-driving principles would result in a decrease of almost 100 million metric tons of CO_2 (Barkenbus, 2010). Even if only one-third of U.S. drivers adopt eco-driving strategies, Barkenbus (2010) projected that 33 million metric tons of CO_2 could be saved.

In 2008, the City of Denver launched a program called "Driving Change", which uses telemetry technology to provide each participating driver with *"individualized, online emissions and driving dashboards"*. Participants are provided with details of their CO_2 emissions and their driving behavior, including idling and aggressive driving events (hard braking, fast starts), that result in increased emissions, as well as the cost of the excess fuel used. About 160 City vehicles and 240 citizen vehicles participated in the program. The findings from the Driving Change pilot program showed that in a seven month period (May to November) participants achieved a 10% improvement in CO_2/ mile as a result of reduced engine idling, fast accelerations, and fast stops. Specifically, it was found that idling decreased by more than 35% among participating drivers. It was also found that driver education is an important factor in securing the benefits of eco-driving. For example, participants that received more extensive education on the program's goals reduced engine idling by more than 40% (Enviance, 2009).

"From May through November, idling decreased by more than 35% among participating vehicles, which equates to a reduction of 5 minutes of idling (or a little less than 1 pound of CO_2) per vehicle, for every hour of operation" (Enviance, 2009).

The European Union (EU) European Climate Change Programme projected in 2001 a potential 50 million ton CO_2 reduction per year from road traffic if 15 EU countries adopted eco-driving techniques, resulting in a cost saving of approximately €20 billion (Luther and Baas, 2011). Under European Union regulations, eco-driving is required as part of introductory driver education classes. High fuel prices are also an added incentive for adopting eco-driving principles. Eco-driving programs typically comprise highly visible public campaigns, sessions devoted to driver training, employer targeted campaigns, and eco-driver training at special events, such as motor shows (see Chapter 4).

Finally, the Department of Environment and Conservation (West Australia) estimated a saving of eight million liters (or $12 million) of diesel and an associated 22,000 ton reduction in CO_2 emissions if all light commercial vehicles in Western Australia reduce their idling by three hours per week over a year (Luther and Baas, 2011).

3.3 Safety Benefits

The safety benefits of adopting eco-driving principles are not as well researched. Luther and Baas (2011) reported a few case studies that have been conducted to illustrate the safety benefits of adopting eco-driving principles. These were limited to:

- Cannon Company (Switzerland) reporting that 350 service drivers that received eco-driver training consumed 6.1% less fuel, drove 22% more kilometers per accident, and was involved in 35% fewer accidents in total;
- Hamburger Wasserwerke (Germany) reporting a 6% improvement in fuel usage and a 25% reduction in accidents and associated costs eleven months after drivers received eco-driving training; and
- Alexander Petroleum (New Zealand) reporting a 17.8% improvement in fuel consumption and a 50% reduction in the number of safety incidents after the company implemented eco-driving, among other measures.

3.4 Other Benefits

In addition, other benefits associated with eco-driving mentioned in the literature include a potential reduction in:

- noise;
- criteria pollutants because of an improvement in fuel economy;
- vehicle running costs (tire wear and tear, and vehicle maintenance);
- driver/passenger stress, and
- improved traffic flow (Luther and Baas, 2011).

Ando and Nishihori conducted an analysis on how many cars kept in following and how many cars gave up the following and then overtook a car driven according to eco-driving strategies. They found that the percentage of car following time behind the eco-driving car was about 76% which demonstrates that an eco-driving car may affect the following cars to drive economically and ecologically even when the drivers may not be active eco-drivers themselves.

Hallihan et al. examined the effects of a hybrid-interface on eco-driving behavior and driver distraction. Measures of accelerations and eye movements were collected during simulated drives to test these potential impacts. Their study showed that while using the hybrid-interface, significant reductions in acceleration from a stop were observed compared to when driving without using the hybrid-interface.

3.5 Concluding Remarks

A number of studies that have demonstrated the benefits (e.g., fuel savings and emissions) are based on data collected immediately following training or have been simulated using simulation modeling tools. There seems to be a need for a more rigorous evaluation of the intermediate and longer term benefits of adopting eco-driving principles and the best options to retain those benefits (e.g., feedback devices, one-on-one training, shorter training sessions, information campaigns etc.).

Chapter 4. Implementing Eco-Driving Programs

> The success of eco-driving programs is a function of increasing the *"motivation for eco-driving"* and providing drivers with the *"practical skills for eco-driving"* (Satou, Shitamatsu, and Sugimoto, 2010).

Eco-driving has been embraced and is well established in Europe, and has been encouraged in countries, such as Canada, Japan, and the United Kingdom. Eco-driving programs, such as ECODRIVEN[2] (2006 to 2008), TREATISE[3] (2005 to 2007), and ECOWILL[4] (2010 to 2013), had and have been successfully implemented in Europe and many European countries have implemented their own eco-driving programs under the umbrella of Eco-Driving Europe (Luther and Baas, 2011). This Chapter of the report summarizes the different types of programs that have been implemented to educate and train people about eco-driving as well as to motivate them to adopt eco-driving principles.

4.1 Driver Training

The literature review revealed a variety of different training models:

- incorporating eco-driving into basic driver's education and including in driver license tests;
- providing eco-driving training for licensed drivers;
- intensive training targeted at owners of large fleets; and
- public information campaigns targeted at licensed drivers to make them aware of eco-driving principles.

Some countries, such as Finland, incorporated eco-driving principles into the educational part of the driving test, but drivers are not assessed on eco-driving principles. On the other hand, countries such as the Netherlands, Germany, and Switzerland have included eco-driving training in their formal driver licensing tests. This required the changing of manuals, training driver instructors, training examiners, developing a method and material to test drivers on their eco-driving skills, and informing the public about the changes (Luther and Baas, 2011).

In Europe, a number of multi-national car companies have developed training programs that target professional drivers/fleets, private drivers, and driving instructors. For example, Ford offers a wide range of training programs in a number of European countries (e.g., Germany and Portugal). Similarly, Toyota has developed a series of training programs that have been presented in collaboration with local partners in the United Kingdom, Spain, Belgium, Norway, and Iceland. Nissan has also provided eco-driving training sessions in Japan and China and

[2] The ECODRIVEN campaign distributed materials aimed at improving driving behavior, energy efficiency, and traffic safety to national and local stakeholders – i.e., car dealers, fuel companies, touring clubs, drivers' associations, driving schools and municipalities - in Austria, Finland, the Czech Republic, Belgium, Poland, France, Greece, the United Kingdom, and the Netherlands (Luther and Baas, 2011).

[3] The TREATISE project (2005-2007) focused on encouraging organizations rather than individuals to adopt initiatives, such as eco-driving, to reduce greenhouse gas emissions (Luther and Baas, 2011).

[4] ECOWILL involves (1) integrating and standardizing eco-driving education and examination in driving schools, (b) developing and implementing short duration (one hour) training courses for licensed drivers, and (c) capacity building to ensure qualified eco-driving instructors. The program is being implemented in the following 13 European countries: Austria, Croatia, Czech Republic, Finland, Germany, Greece, Hungary, Italy, Lithuania, Poland, Spain, the Netherlands, and the United Kingdom (Luther and Baas, 2011).

Nissan and Peugot have participated in fuel consumption competitions - the El Grand Prix in Yokohama City, Japan and the first pan-European eco-driving challenge, the Peugeot eco-cup, respectively. Ford also provides web-based information at www.drivingskillsforlife.com on eco-driving skills (Luther and Baas, 2011).

A number of examples also exist in the U.S. and overseas of large fleet owners that have invested in eco-driver training. In the U.S., the Milwaukee Department of Public Works implemented the first eco-driving training program of its kind in September 2008. The program involved the training of drivers working for the City of Milwaukee Department of Public Works and Veolia Water Milwaukee. The drivers received eco-driving classroom instruction, behind-the-wheel training, pre-and post-testing, and a Fleet Training Manual. The reported benefits were a 10.42% improvement in miles per gallon of fuel consumed. In Australia, LinFox Logistics developed and implemented an eco-driving training program for all its employees. The training program addresses topics such as idling, acceleration, and gear changing. Training is provided weekly in 20-minute sessions at company depots (Luther and Baas, 2011).

Table 4.1 summarizes the different training models adopted by countries that have implemented or promoted eco-driving programs/principles. From Table 4.1, it is evident that all the European countries listed have adopted a multi-faceted training model that include eco-driving education and or testing as part of their formal driving tests and training programs targeted at licensed drivers and vehicle fleets.

Table 4.1: Training Models Adopted

Country	School-Based Education	Driving Test (Educational Only)	Formal Driving Test	Licensed Drivers	Fleet Owners	Other
Finland		♦*	♦	♦	♦	
Netherlands	♦		♦	♦	♦	Educating trainers Provide incentives for purchasing instantaneous feedback devices
Germany			♦	♦	♦	Training programs for fleet owners include: full day training, half day training, and training snacks
Switzerland			♦	♦		Wide range of courses – on the road and in driving simulators - for passenger vehicle and truck drivers.
United Kingdom			♦**	♦	♦	Targeted trainers and all employees in company (not

Country	School-Based Education	Driving Test (Educational Only)	Formal Driving Test	Licensed Drivers	Fleet Owners	Other
						only company drivers) Training programs vary: 50 minute lessons, eco-driving simulators together with trained instructors, and combination of theoretical training and practical implementation for van fleets.

* 1995 until 1998, when became part of the formal driving test

** Drivers can, however, not fail the test because they did not exhibit eco-driving behavior.

Source: Based on information included in Luther and Baas, 2011.

In addition, Canada adopted two eco-driving programs called Auto$mart that targets novice drivers and Fleet$mart that targets heavy vehicles. The Auto$mart program has many components that are mostly targeted at developing training materials (i.e., training modules, training packs that include CD-ROMS, videos, and handouts, workshop based training, and train-the-trainer workshops) and incorporating eco-driving principles and information into the driver licensing process. Similarly, the Fleet$mart program includes a driver training component that promotes improved fuel economy and provides drivers with defensive-driving techniques. The program includes tailored training sessions for highway trucking, forestry trucks, urban delivery trucks, coach buses, transit buses, and school buses (Natural Resources Canada, ND). In general, eco-driving information can be included with relative ease into existing driver training manuals.

Finally, a number of countries have invested in public information campaigns targeted at licensed drivers to increase awareness of eco-driving principles. Barkenbus (2010) reported that all the European countries that are promoting eco-driving programs have embarked on a multi-media campaign that highlights not only the emissions savings, but rather the cost savings, enhanced safety benefits, and lifestyle and cultural attractiveness of such programs. Canada's Auto$mart program is also embarking on social marketing and campaigns that will target a specific issue, such as aggressive driving or excessive idling. Table 4.2 summarizes the different information campaigns that have been adopted by countries in Europe that have implemented or promoted eco-driving programs/principles.

Table 4.2: Public Information Campaigns

Country	Magazines/ Newspapers	Television	Internet	Radio	Workshops/ Conferences	Promotional Material/Events	Comments
Finland	♦	♦	♦				Targeted at licensed drivers and organization employees
Netherlands	♦	♦	♦	♦	♦	♦	Targeted licensed drivers, fleet owners, and intermediaries
Germany	♦	♦	♦			♦*	Targeted at young drivers
United Kingdom	♦	♦	♦	♦		♦**	National competition to find UK's most efficient driver. Ford sponsored prize of £20,000 of energy saving products.
Japan			♦			♦	Promotion at Tokyo Motor Show using eco-driving simulator (2007) and announced eco-driving month in 2010
Australia						♦	Distribution of pamphlets only
New Zealand						♦	Bi-annual Energywise Rally

Country	Magazines/ Newspapers	Television	Internet	Radio	Workshops/ Conferences	Promotional Material/Events	Comments
							and distribution of brochure containing eco-driving tips

* Promotional material include flyers and neckbands for mobile phones and keys.

** Outdoor posters and posted eco-driving messages on the backs of buses. In 2009, the Scottish Government also funded a campaign that included filling station, billboard, and breakfast and drive-time radio advertising.

Source: Based on information included in Luther and Baas, 2011.

In the U.S., Martin, Chan, and Shaheen (2012) conducted a controlled stated response study with approximately 100 University of California at Berkeley faculty, staff, and students to assess the effectiveness of static eco-driving web-based information. A comparison of the experimental and control group revealed that exposure to eco-driving information on the internet influenced people's driving behavior and maintenance practices. The experimental group's distributional shift was statistically significant, particularly for key practices including: lower highway cruising speed, driving behavior adjustment, and proper tire inflation. Fewer participants; however, significantly changed their maintenance practices, which suggests intentional altering of driving behavior is easier than adopting better maintenance practices. A comparison of before- and after-surveys found that 57% of the experimental group improved their eco-driving behavior, while 43% made no change or worsened. The results of this study seem to indicate that a relatively low cost information dissemination campaign, such as web based information dissemination, can result in modified driving behavior – albeit it might be a relatively small percentage of drivers.

4.2 Vehicle Feedback Devices

Microprocessor advancements have enabled accurate and inexpensive devices that measure and display fuel use and many multi-national car companies are installing them in some of their models. Most of these gauges display three constant readings: real-time miles per gallon (mpg), a five minute average mpg, and a trip duration mpg. These onboard devises educate drivers instantaneously on their fuel consumption and therefore enables drivers to make conscious decisions when driving. The literature suggests that instantaneous feedback is key to the success of eco-driving programs. There is largely consensus that information provided to users about fuel consumption improves fuel economy[5] (International Transport Forum, 2007) while others have recommended a conversion to a fuel price savings in vehicle feedback devices to ensure continued usage of these devices (Satou, Shitamatsu, and Sugimoto, 2010).

As mentioned, a number of multi-national car companies are investing in eco-driving technologies. Ford has implemented EcoMode in a number of Ford vehicles that provide drivers with instant feedback on speed, gear shifting behavior, and on how smoothly the vehicle is driven. The instrument panel includes three flowers with five petals each. The more economical a vehicle is driven, the more petals are illuminated (Luther and Baas, 2011). Similarly, Honda is installing the ECON mode on their hybrids that automatically adjusts the vehicles performance characteristics to the most fuel efficient operation. This includes the use of the air conditioner, engaging the idle stop sooner, and maximizing regenerative breaking. Honda has also developed a dash board graphic, a leaf, which will change color and adding leaves, to inform the user if they are achieving maximum fuel efficiency. Nissan and Fiat are also installing dash board visuals to keep their drivers informed (Barkenbus 2009).

Drivers can also invest in a device, such as the ScanGauge or Eco-Way, that is an external device, that can be plugged into a 1996 or newer model vehicle, which will give a numerical readout of instantaneous mpg as well as fuel efficiency over the trip's duration (Barkenbus 2009). A subsidy/rebate for a vehicle feedback device to drivers that have successfully completed a certified eco-driving training course could aid in promoting eco-driving programs, but could also address the concern that drivers would revert back to their old driving habits as time passes (Barkenbus, 2010).

4.3 Financial Incentives

Drivers that have successfully completed a certified eco-driving training course and demonstrates eco-driving principles on the road could be provided a reduced insurance rate (Barkenbus, 2010). No information on existing programs that link reduced insurance premiums to eco-driving or eco-driver training was; however, found in the literature.

4.4 Social Marketing

Since many of the programs are often geared towards the younger generation, using social media as a forum for drivers to post their results and engage others in comparing and discussing the results may thus be attractive. Social networking sites, such as MySpace or Facebook, could thus provide this forum (Barkenbus, 2010).

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[5] There is some evidence that instrumentation alone can secure a 5% improvement in fuel economy (International Transport Forum, 2007).

4.5 Concluding Remarks

This Chapter highlighted a number of programs that have been implemented to educate people about eco-driving and to motivate people to adapt eco-driving principles. The next Chapter presents a testing protocol to assess driver behavior during controlled and real-world conditions, the measurement/estimation of fuel usage and emissions, and an assessment of the effectiveness of different programs (training, feedback devices, and a combination of training and feedback devices) in securing fuel economy and emissions benefits.

Chapter 5. Concluding Remarks

Europe has been at the forefront of studies on relating driver behavior changes to fuel consumption and emissions output. The literature reviewed as part of this study highlights numerous benefits associated with adopting eco-driving principles to include reduced fuel consumption, emissions benefits, and improved safety. A number of countries have thus invested substantial resources to achieve these benefits.

Short term fuel economy improvements ranging from five to 50% have been reported in the literature. However, in many instances these studies have been conducted under controlled conditions (i.e., measures have been taken at a test track or as part of eco-driving competitions) and usually immediately following eco-driving training. Also, many of the studies uncovered do not document the testing protocol adopted with the result that the reliability of the estimated energy and emissions benefits are questionable. A more rigorous evaluation is thus needed to determine the short and intermediate benefits of adopting eco-driving principles, specifically with respect to emissions benefits. There is also a need to understand and measure fuel and emission benefits in real world conditions.

Chapter 6. References

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