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Fuel Economy Driver Interfaces: Design Range and Driver Opinions

Report on Task 1 and Task 2

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16. Abstract

Fuel economy driver interfaces (FEDIs) provide information to drivers about their fuel efficiency. FEDIs have become more prevalent and complicated in recent years, yet designs differ widely between vehicle makes and models and little is known about how to design FEDIs to maximize benefits while minimizing risks of distraction or unsafe driving. The purpose of Task 1 was to document the range of FEDI designs that have been used or proposed. The primary purpose was to identify features of FEDIs on late-model passenger vehicles, but this task also addresses past and current trends in FEDIs, displays in commercial and fleet vehicles, aftermarket devices and applications, and device patents. Nearly every major automotive manufacturer that sells vehicles in the United States offers at least one model with an FEDI. The most common features include current fuel economy, average fuel economy, and fuel range until empty. Some vehicles also have features that intend to guide drivers to improve their fuel economy by providing direct feedback or vehicle adaptations in response to inefficient driving behaviors. While gasoline vehicles generally have basic alphanumeric or analog gauge displays, many gasoline-electric hybrid vehicles have more complex displays that use large, full-color LCD displays and present more detailed information. As more hybrid and alternative fuel vehicles enter the market, and the cost of in-vehicle displays and sensors decreases, it is likely that increasingly complex and novel displays will be introduced in new vehicle models. The purpose of Task 2 was to collect information about vehicle owners' driving habits and opinions about FEDI designs. Focus groups were conducted with members of the general driving public and with owners of vehicles with FEDIs to assess their opinions regarding the usefulness and potential for distraction of several different FEDI designs.

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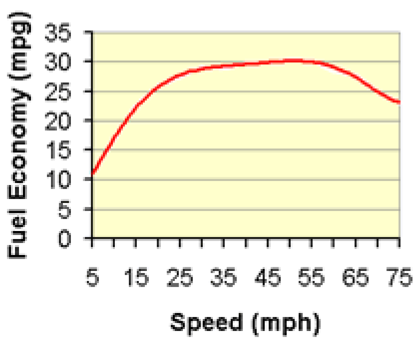
1 Introduction

1.1 Background

1.1.1 Fuel Economy and Safety

Drivers are generally aware of the effects of vehicle type and road type on fuel economy. Lighter vehicles with smaller engines are typically more fuel-efficient than heavier vehicles with larger and more powerful engines. Freeway driving is typically more fuel-efficient than driving on local roads and highways with stop-and-go traffic. Many drivers, however, do not have a clear understanding of how driving behavior influences fuel economy. Aggressive behaviors such as speeding, rapid acceleration, and rapid deceleration can reduce fuel economy, while maintaining a constant, moderate speed and avoiding aggressive maneuvers can improve fuel economy. Figure 1 shows that a vehicle maintaining a constant speed reaches peak freeway fuel economy near 50 mph, and fuel economy decreases substantially above 60 mph. Therefore, responsible driving behaviors can save money for drivers, reduce harmful emissions, and reduce demand on oil supplies.



(Source: FuelEconomy.gov)

Figure 1. Fuel economy of an example passenger car at a range of speeds

Aggressive driving does more than just reduce fuel economy; it also increases the risk and potential severity of crashes. Speeding is a prevalent behavior; nearly 80 percent of individuals in a national survey reported driving above the speed limit on freeways or two-lane roads with speed limits greater than 45 mph in the past month (Royal, 2003). In 2006, speeding was a contributing factor in 31 percent of fatal crashes, accounting for 13,543 fatalities, and NHTSA estimates the economic cost of speeding-related crashes to be more than $40 billion each year (National Highway Traffic Safety Administration, 2007). Aarts and van Schagen (2006) reviewed the research literature on speeds and crashes and found that the likelihood of crashes increases exponentially as speeds increase. They also found an elevated crash risk for vehicles that drive faster than surrounding traffic. Speeding increases crash risk for a variety of reasons. High speeds increase driver workload and attention demands and provide less time to detect and react to dangerous situations. Speeding especially reduces drivers' available reaction time when visibility is limited, such as when driving at night, in inclement weather, or when down-road sight distance is limited by a curve or other visual obstruction.

Like crash likelihood, crash severity also increases exponentially as impact speeds increase because the kinetic energy of a moving vehicle is its mass times the square of its velocity ($m * v^2$). This relationship is borne out in crash data. Bowie and Walz (1994) analyzed seven years of data of tow-away crashes and found that the likelihood of severe injury is only 2.6 percent when crash speed differentials are 11 to 20 mph, but increases to 11 percent when crash speed differentials are 21 to 30 mph and 29 percent when crash speed differentials are 31 to 40 mph.

Rapid acceleration and deceleration are also fuel-inefficient behaviors that are associated with risky driving. Rapid acceleration is often linked with speeding and may increase the likelihood of vehicle conflicts and loss of vehicle control in slippery conditions. Rapid deceleration often results from speeding because drivers must compensate for changing traffic signals, slower traffic, or unexpected road hazards. Rapid deceleration may also be the result of inattentive driving or tailgating, when the driver does not allow adequate time or following distance to brake normally if a conflict arises. Naturalistic driving research with adult and teen participants has found that drivers who have the most hard braking events are also the most likely to experience crashes or near-crashes (NHTSA, 2009; Lerner et al., in press).

Attention to fuel economy and fuel savings might also encourage drivers to take other measures that can positively influence safety, such as keeping the vehicle's engine tuned, keeping tires at their proper inflation levels, removing excess cargo from the trunk or back seat, and even taking fewer unnecessary driving trips. Advanced in-vehicle navigation systems may provide route options that minimize fuel use. This has the potential to affect crash rates by redistributing the traffic load on different roadway types. The net safety benefits of following fuel efficient navigation and trip planning strategies are not known.

Safe and non-aggressive driving behaviors provide benefits in terms of reduced likelihood of crashes and injury as well as fuel savings. Therefore, if drivers adjust their behaviors to improve fuel economy, it is also likely that they will become safer drivers at the same time. There is some concern, however, that attempts to maximize fuel economy may also lead drivers to behave unsafely. For example, drivers may tailgate behind large vehicles to reduce wind resistance, fail to accelerate rapidly enough when merging with faster traffic, drive substantially slower than surrounding traffic, or roll through stop signs without stopping. Finally, in-vehicle displays that provide real-time feedback about fuel efficiency, continuous guidance about driving behavior, or even game-like experiences may be distracting to drivers, raising safety concerns.

1.1.2 Fuel Economy Driver Interfaces

A fuel economy driver interface (FEDI) gives drivers an indication of fuel usage or efficiency. Many passenger vehicles in recent model years have FEDIs, and they have been included in some vehicle models for decades. FEDIs present fuel economy information in a variety of forms. Some show fuel economy in miles per gallon. Some provide a relative measure of economy on a scale or provide an alert if fuel economy is especially poor. Some vehicles provide options so users can choose which type of fuel economy information they would like to see.

The appearances of FEDIs vary drastically between vehicle makes and models. FEDIs can provide numerical output, analog or digital gauges, bar charts, illuminator lamps, and a variety of other display features. With the recent emergence of high resolution LCD screens in cars, detailed and complex color displays are possible, and these make feasible a variety of new FEDI concepts. FEDIs may even include vehicle-adaptive features that influence some aspect of vehicle performance in response to inefficient driver behaviors.

Gas-electric hybrid vehicles, in particular, have begun to include complex FEDIs on LCD screens. Hybrid vehicles' fuel efficiency is inherently more complicated than other vehicles because they use two energy sources: gasoline and electricity. While these vehicles can include the same FEDIs as other vehicles, they may also include additional displays such as battery voltage or direction of energy flow (gasoline powering the motor, battery powering the motor, regenerative braking charging the battery, etc.).

While FEDIs have the potential to encourage efficient and safe driving, it is possible that the displays themselves might cause distraction at the expense of attending to the roadway. Naturalistic driving research has shown that long glances (more than 2 seconds) away from the road can more than double the likelihood of a crash (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). FEDIs should be designed with good human factors principles to minimize the potential for distraction and increased driver workload. While no formal guidelines exist specifically for FEDI design, guidelines and standards are available that address the design of in-vehicle icons and symbols (ISO 2575:2004; Campbell, Richman, Carney, & Lee, 2004), controls and displays (ISO 4040:2001; Federal Motor Vehicle Safety Standard 101; Stevens, Quimby, Board, Kersloot, & Burns, 2002; Japan Automobile Manufactures Association, 2004), advanced vehicle information systems (Campbell, Carney, & Kantowitz, 1998; Green, Levison, Paelke, & Serafin, 1994; Alliance of Automobile Manufacturers, 2003), and warnings and alerts (Campbell, Richard, Brown, & McCallum, 2007). Considering the increasing availability, technological sophistication, and diversity of FEDIs, there is a clear need to understand how characteristics of these displays influence driver behavior, and to identify best practices for FEDI design to meet the desires of drivers and minimize the potential for distraction and undesirable behaviors.

1.2 Objectives of Task 1 and Task 2

The objective of Task 1 was to document the range of FEDI designs that have been used or proposed. The primary purpose was to identify features of FEDIs on late model passenger vehicles, but this task also addresses past and current trends in FEDIs, displays in commercial and fleet vehicles, aftermarket devices and applications, and device patents. FEDI displays are described and categorized. Evaluations of systems that provide feedback to drivers about their fuel economy will also consider any available research findings or evaluations related to FEDIs. Section 2 of this report describes the method by which FEDIs were identified and reviewed. Section 3 of this report includes the findings of the review.

The objective of Task 2 was to collect data on driver use and opinions about fuel economy displays by holding focus groups with members of the general driving public and with owners of vehicles that have fuel economy displays.

The results of Task 1 and Task 2 will guide the conduct of the subsequent tasks in this project:

- Task 3: Develop Interface Recommendations for a Fuel Economy Display
- Task 4: Develop a Plan to Evaluate the Influence of Fuel Economy Displays on Safety and Fuel Economy

- Task 5 (NHTSA Option): Evaluate the Influence of Fuel Economy Displays on Safety and Fuel Economy

Several of the most promising FEDI concepts identified in Task 1 and Task 2 will be formally evaluated in Task 3, and some new design concepts may be developed to improve upon existing FEDI design concepts.

2 Method

2.1 Information Search

Information provided in this report documenting the design range of fuel economy displays was obtained through searches of Internet sites, online databases of research literature and contacts with surface transportation professionals. Many of the specific vehicles documented were examined in person and photographed by Westat staff as described below in section 2.2.

The following Internet search engines and online resources were used for the information search:

- Google, Google Scholar, Google Patents, Google Images (www.Google.com);
- Yahoo (www.Yahoo.com);
- United States Patent and Trademark Office (www.USPTO.gov);
- Automobile manufacturers' Web sites;
- Transportation Research Board's TRIS Database of Transportation Research Literature;
- Washington Post (www.washingtonpost.com);
- New York Times (www.nytimes.com);
- Motor Trend (www.motortrend.com); and
- Green Car Congress (www.greencarcongress.com).

The search terms used (in various combinations) included: automotive, fuel economy display, eco, efficiency, gauge, indicator, monitor, monitoring, driver, behavior, mpg, hybrid, vehicle, fuel saving devices.

As relevant sources of information were obtained, Westat reviewed these sources, noting any additional relevant sources of information that were cited within the previously obtained sources.

Some of the relevant research papers that were identified were obtained by Westat library staff through interlibrary loans or purchase arrangements with publishers.

An e-mail solicitation was sent out to all members of Surface Transportation Technical Group of the Human Factors and Ergonomics Society. The e-mail solicitation explained the purpose of the project and requested help in identifying research on fuel economy displays or vehicle models with particularly interesting displays. Eight responses were received from this solicitation and Westat staff followed up on all of the relevant leads that were provided.

2.2 Display and Device Inventory

In order to locate vehicles with various types of fuel economy displays that could be photographed, an e-mail solicitation was sent to approximately 260 Westat staff working on-site in the Rockville, Maryland, office. The e-mail explained the purpose of the project and requested that vehicle owners who have fuel economy displays on their vehicles contact project staff if they would be willing to allow brief access to their vehicles for the purposes of photographing their fuel economy displays. Eighteen people responded to the solicitation and 16 vehicles were photographed. Also, fuel economy displays from a Belgian-made 2008 Ford S Max and a French-made 2007 Peugeot 307 were photographed by a Westat staff member in Israel. These two European models had similar FEDIs to the displays documented on vehicles sold in the United States.

Because the prevalence of fuel economy displays has increased significantly in the last few years it was important to capture the design range of displays on new vehicles. In order to document the range of these displays on current vehicle models, Westat staff visited 11 automobile dealerships in Montgomery County, Maryland, during October and November 2008. The dealerships' sales people were very cooperative in allowing Westat staff access to vehicles in their showrooms and on their sales lots for the purposes of documenting the vehicles' fuel economy displays. The 11 visited dealerships sold the following makes of vehicles:

- Acura
- BMW
- Chevrolet
- Ford
- Honda
- Kia
- Lexus
- Lincoln/Mercury
- Mercedes/Smart Car
- Saturn
- Toyota

2.3 Focus Groups With Vehicle Owners

Four focus groups were conducted during January and February 2009. The purpose of the focus groups was to gather information about participants' driving habits and opinions regarding fuel economy displays. The first two groups (Group 1 and Group 2) were composed of members of the general driving public. They were recruited through a local newspaper advertisement that solicited vehicle owners to discuss their driving habits in a focus group. Eight men and 10 women were selected to participate in either Group 1 or Group 2. They ranged in age from 18 to 72 years old (average age was 45).

A second newspaper advertisement was used to recruit vehicle owners who had either hybrid vehicles or conventional gasoline powered vehicles with fuel economy displays. They were asked to participate in a focus group about their driving habits. Some additional potential participants were recruited through an internal company announcement at Westat. No employees were allowed to participate. Ten men and 6 women were selected to participate in either Group 3 or Group 4. They ranged in age from 32 to 66 (average age was 50).

When selecting potential participants, project staff tried to balance the number of men and women, to include a wide range of driver ages, and to include a range of different vehicle types.

Most of the focus group participants resided in Montgomery County, Maryland, although a few resided in Washington, DC, and Arlington County, Virginia. Participants each received $60 compensation for their time.

The focus groups were conducted at Westat offices in Rockville, Maryland. Each session lasted approximately 100 minutes. The focus groups were video recorded and then reviewed by project staff for the preparation of this report.

The focus group moderator followed a similar question path for all four groups. General topics included:

- The impact of large changes in gasoline prices on their driving habits;
- Knowledge of and use of the information displays in their vehicles (including FEDIs if present);
- Driving behaviors that may affect fuel economy;
- Frequency of engaging in potentially dangerous driving maneuvers;
- Personal motivations related to driving (e.g., minimize impact on the environment, arrive on time, etc.);
- Reactions to a range of fuel economy display designs; and
- Desire to have fuel economy displays in the next vehicles they purchase.

Findings from the focus groups are described in Section 3.2.

3 Findings

3.1 Task 1 Findings: Design Range of FEDIs

3.1.1 Trends in FEDI Design

This section contains descriptions of various FEDIs grouped by type. Many vehicle models have similar FEDIs and not every vehicle examined has been included. The examples documented here represent the range of display designs encountered in this investigation. This section is not meant to be a comprehensive review of FEDIs, but it represents the major variations in FEDI designs that have been used to date. Descriptions and photographs of specific FEDI systems are given in Appendix A.

Information about fuel usage may be provided over several different time scales and may be provided in quantitative or qualitative formats. The four most commonly encountered quantitative measures were average fuel economy (mpg) since the last fueling event, average fuel economy for the current trip, instantaneous fuel economy (current fuel usage rate expressed in mpg), and historical fuel economy for time bins in the recent past (mpg for the past 30 minutes of driving shown for each minute). Forward-looking estimates of fuel economy are implicit in displays that show driving range remaining (miles to empty). One such system uses the average fuel economy over the previous 18 miles of driving to predict the driving range available given the current fuel level.

3.1.1.1 Prevalence of FEDIs and Associated In-Vehicle Display Technologies

A sub-goal of this project was to indicate the percentage of vehicles produced with various types of FEDIs and to indicate the percentage of new vehicles having features that would be required for implementation of a fuel economy display. Specific quantitative information on these points could not be determined because the scope this project did not allow for documenting the presence or absence of FEDIs on every vehicle model sold in the United States. Westat staff contacted a major automotive industry tracking company to see whether they have this information available, but a company spokesperson responded that they do not track this information. However, based on the vehicles examined and other information obtained for this study, the following conclusions can be drawn regarding FEDI prevalence and availability of features required for FEDIs:

- Basic fuel economy displays have been around for decades (e.g., BMW vehicles), but the number of manufacturers and models that contain FEDIs has increased in the past few years. Based on reports about features on near-future models, the prevalence of FEDIs is projected to increase further from 2008 to 2012.
- All the major automobile manufacturers whose vehicles are sold in the United States have some type of fuel economy display on at least one vehicle model. These include: Acura, Audi, BMW, Chevrolet, Ford, Honda, Lexus, Lincoln, Mercedes, Mercury, Nissan, Saab, Saturn, Subaru, Toyota, Volvo, and Volkswagen. (A notable exception is Smart; models sold in the United States do not currently have a fuel economy display.)
- One hundred percent of gasoline/electric hybrid models examined by Westat staff had some type of fuel economy display. Most provided this information on a color LCD panel. A few used a small monochrome LCD panel in the instrument cluster.
- Due to the prevalence of fuel-injection technology and electronically controlled engine operations, virtually 100 percent of new vehicles produced in 2008 and beyond have the necessary data on-board to compute instantaneous fuel economy and trip-based fuel economy measures. In fact, most if not all vehicles produced after 1996 that have an OBD-II data bus should be able to provide the necessary data for a FEDI without additional fuel usage sensors.
- The vast majority of new vehicles have an instrument panel that includes at least one digital alphanumeric display that could be used to display fuel economy information. The simplest implementation would be to adapt an existing multifunctional text display to include trip fuel economy and instantaneous fuel economy as modal display options.
- Large LCD screens, typically located in the center stack, are often used for the most complex fuel economy information (such as graphs). In 2009-2010 LCD panels in the center stack or in the instrument cluster are becoming standard equipment on some high-end models and hybrids. However, prior to 2009, on most vehicles where large LCD panels were available they were only included when the customer bought an optional package such as a navigation system or a rear-view camera. One exception is the Toyota Prius, which has a large LCD display as standard equipment even when the optional navigation/camera package was not purchased.

3.1.1.2 Gasoline Vehicle FEDIs

FEDIs have been present as standard or optional equipment on select vehicle models for decades, but have become more prevalent in recent years. Most FEDIs consist of a simple, monochrome alphanumeric display located within the instrument cluster or center console. These displays usually allow the user the see current fuel economy, average fuel economy, or fuel range. Some FEDIs show multiple measures at the same time, while others require the user to cycle through the information using a simple pushbutton control. These displays often include other types of information such as current time, odometer, outside temperature, and so forth. A small number of FEDIs include analog or digital gauges to indicate current mpg.

In addition to or instead of showing actual fuel economy using numerical output, some vehicles provide drivers with a relative, categorical measure of their fuel efficiency. The 2007 Honda Odyssey has an indicator lamp labeled “ECO” on the instrument cluster that illuminates green during efficient driving when the car automatically shuts off extra engine cylinders to save fuel. Some upcoming Nissan vehicles will have a dashboard light that informs drivers when they are driving inefficiently. A few recent and upcoming vehicle models use LCD displays to provide more complex feedback.

3.1.1.3 Gasoline/Electric Hybrid Vehicle FEDIs

Current hybrid vehicles receive their power from gasoline engines and electric batteries/motors. Most major auto makers produce at least one hybrid, and hybrids are available in a variety of classes, including small cars, sedans, SUVs, and pickup trucks. While the hybrid market is currently dominated by non-plug-in vehicles, a small but growing number of automotive manufacturers are developing plug-in hybrids that can drive moderate distances, typically 25 to 100 miles, without using any fuel. When the battery level is low, a gasoline generator is activated to recharge it. If only driven short distances between charges, plug-in hybrids essentially operate as electric vehicles. While some hybrid vehicles provide the same fuel economy information as gasoline vehicles, others have adopted more complex displays that monitor vehicle energy use and generation. Some vehicles display this information on large console LCD screens that allow for the inclusion of large amounts of information.

3.1.1.4 Electric Vehicles

The first mass-produced all-electric vehicle, General Motors’ EV1, was produced for a short run beginning in 1996. Since then, few electric vehicles have been produced for the consumer market. Advances in batteries and other vehicle technologies, however, have increased the feasibility of all-electric vehicles. In late 2010, Chevrolet plans to release the Volt, a moderately priced electric vehicle. The Volt is expected to get 40 miles on a single charge, with a small gasoline engine to generate electricity when the battery gets too low. A photo of the Volt’s driver display, which includes a color LCD dashboard and a touchscreen center console display, is shown in Figure 2. General Motors has also developed a larger, luxury, electric concept car called the Cadillar Converj, although there are currently no plans to make a production model. Electric vehicles are also available from relatively small companies that only make electric cars. Beginning in 2006, Tesla began selling an electric roadster that is reported to get up to 244 miles on a single charge, significantly more than the EV1’s 60 miles. In 2011, Tesla will release the Model S, an electric vehicle modeled like a sedan. The Model S is expected to get 300 miles on a single charge, and can be charged at any electric outlet. Phoenix Motorcars manufactures a pickup truck and an SUV; the company reports that each is capable of travel at highway speeds and can travel more than 100 miles on a full charge. Zap manufactures a range of electric cars intended for low speeds and low daily mileage as well as one model reportedly capable of achieving highway speeds and traveling more than 100 miles on a full charge. Th!nk cars are currently only available in Europe, and are designed for city driving at low speeds and short distances. The Fisker Karma, which will begin shipping in mid-2010, is another electric vehicle aimed at the luxury market. It reportedly has a range of 50 miles on a full charge, and the battery is charged by a gasoline generator thereafter. Most electric vehicles are either in preproduction or have been made available in very small numbers, so little information is available about the energy usage/economy displays of these vehicles.

(Source: cars.about.com – detail of original photo)

Figure 2. 2011 Chevy Volt dashboard and center console touch screen display (pre-production)

All-electric vehicles do not use gasoline, so mpg information cannot be calculated. There is no metric that has come to replace mpg as the standard information unit for electric vehicles, though electric efficiency could be reported using a metric such as miles per kilowatt hour (mi/kWh) or kilowatt hours per mile (kWh/mi). Electric vehicles generally get significantly less driving range (miles) from a fully charged battery than either conventional or gas/electric hybrid vehicles get from a full tank of gas. Therefore, the range that an electric vehicle can travel before running out of electricity is essential information that is provided in the few available electric vehicles models. Tesla vehicles also show battery level using a display similar to that of many portable electronic devices such as cell phones and digital cameras.

3.1.1.5 Vehicle Adaptation

It is possible for vehicles to influence driver behavior through active adjustments to vehicle performance. As described here, vehicle adaptation only includes vehicle features that are intended to influence the driver; this does not include "hidden" features that the driver does not experience directly, such as speed governors or features that do not directly relate to fuel economy such as gearshift indicators. One example of such a system is the Nissan Eco Pedal, which adds resistance to the gas pedal if excessive, inefficient acceleration is detected. The resistance can be overcome by additional pressure on the gas pedal. Nissan claims that this system can improve fuel economy by 5 to 10 percent. However, a similar technology was evaluated on four postal delivery vans in Sweden. Results showed that hard accelerations were significantly reduced, but there was only a small reduction in emissions and no significant reduction in fuel consumption (Larsson & Ericsson, 2009). Though few vehicle adaptation systems currently exist, there is potential to improve driver behavior through learning because drivers are guided toward fuel-efficient behaviors. These systems, however, must be designed to avoid interfering with necessary driver behaviors or emergency maneuvers.

3.1.1.6 Aftermarket FEDI Devices

Few stand-alone FEDI devices exist. The ScanGauge II is popular among car aficionados because it taps into vehicles' OBD-II output for accurate readings of fuel economy, engine rpm, battery voltage, and more.

3.1.1.7 Aftermarket Applications for Nomadic Devices

As computer and communication technologies become more powerful, more flexible, smaller, and less expensive, nomadic devices are finding new and novel uses. Cell phones and other devices that contain on-board accelerometers and GPS technology are already being used as platforms for FEDI applications. While few fuel economy applications currently exist, it is likely that their use will grow as more people adopt the requisite technologies. The small screens of many nomadic devices make them less than ideal for displays to be used while driving. Another drawback to FEDI on nomadic devices is that, unless they have some way to automatically communicate with the vehicle's information network, fuel data must be entered manually each time fuel is purchased. No FEDI applications for nomadic devices were found that are designed for hybrid vehicles.

3.1.1.8 Post-Drive Fuel Economy Reporting

A recent development enabled by the prevalence and ease of wireless and wired data transfer is post-drive fuel economy reporting, in which fuel economy and/or other vehicle metrics are transferred to a nomadic device or home computer for users to review. In some cases, this information may be available on an in-vehicle display screen. Reporting systems intended for use outside the vehicle or while the vehicle is stationary are not subject to the same human factors requirements as systems intended for use while driving, and may display more extensive and complicated information. Some reporting systems have a built-in social or competitive aspect, in which drivers can compare their fuel efficiency to others'. For instance, the Nissan CARWINGS Eco-drive system (currently available only in Japan) lets drivers see information about their recent trips and ranks their fuel efficiency relative to other drivers of the same vehicle model. The Fiat eco:Drive program has similar features, and also independently rates driver behavior on four measures, and shows projected reductions in fuel costs and CO_2 emissions attributed to their driving behavior.

GreenRoad's Safety Center takes another approach to reporting. While most fuel economy devices are intended to directly aid the driver, Safety Center monitors vehicle activity and reports back to an authority figure (a supervisor in fleet applications or a parent in consumer applications). Drivers may also receive reports. Safety Center is primarily marketed as a safety system, but is also touted for its potential to reduce fuel costs by encouraging conservative driving.

3.1.1.9 Fuel Economy Displays on Heavy Trucks

Heavy vehicle manufacturers are increasingly incorporating technology that allows fleet supervisors to monitor driver and vehicle performance. Fuel use statistics are available to the truck driver.

3.1.2 Patent Review

A search of U.S. patents identified 41 patents that were related to providing information about a vehicle’s fuel economy. Among these, several were concerned only with sensor technologies or with the computation of fuel usage rate. Other patents were concerned with related topics such as calculating the driving range of the vehicle given the current amount on fuel on board. All of the search results were reviewed and 11 patents were identified that were deemed to be most relevant to the purposes of the present task, to document the design range of fuel economy displays. The 11 most relevant patents are listed chronologically in Appendix B. All of these tend to include the concept of information delivery to the driver. However, this review of patents was not particularly helpful for uncovering innovative user interface design concepts for FEDIs.

3.1.3 Research Review

There are few documented studies that have evaluated the effectiveness of in-vehicle fuel economy displays. The range of research studies on fuel economy displays is described in Appendix C. Some studies reviewed were descriptions of new FEDI system designs but lacked empirical data for validation. Other studies were aimed at determining the effectiveness of a particular product and were sponsored or conducted by the manufacturer or developer of the device. The U.S. Environmental Protection Agency has also conducted independent evaluations of many devices that are claimed to save fuel. Some of these devices, such as GASTELL (Automotive Devices, Inc.) were designed to modify driver behavior. Many early evaluations of vacuum gauge displays found that they did not improve drivers’ fuel economy. More recent studies of more advanced technologies have generally found that FEDIs can help drivers to improve their fuel economy. For example, researchers from the Netherlands and Sweden have developed a sophisticated fuel-efficiency support tool that, in simulator studies, reduced fuel consumption by 16 percent compared to normal driving without the device. The systems that have demonstrated positive results often consider a broad array of vehicle metrics including fuel usage rate, acceleration and braking parameters, speed, and driving context. Feedback provided to drivers may include actual fuel economy, a categorical rating of fuel economy (e.g., good, fair, poor), or guidance for ways to improve fuel efficiency.

The relationship between driver behavior and fuel economy is complex. Studies have shown that strategies for achieving optimal fuel economy differ by roadway type and traffic conditions. On freeways with free flowing traffic, fuel economy is largely determined by a vehicle-specific optimal speed. On the other hand, achieving optimal fuel economy for city driving in the context of traffic lights, congestion, and variable traffic speeds is much more complex. Feedback from instantaneous fuel economy displays is only one source of information that the optimally fuel efficient driver should consider. Drivers should also anticipate conditions ahead so that braking and idling are minimized, and they should choose routes that avoid congestion and frequent stops.

There are a few research studies that are ongoing and final results are not yet available. For example, a large-scale FOT is currently underway in Europe. This study includes a Fuel Efficiency Advisor system that is being evaluated on heavy trucks.

3.1.4 Task 1 Conclusions

Task 1 identified a wide range of FEDI concepts. Despite the variety of displays, few research studies have evaluated FEDIs to determine whether they are understandable, informative, desirable, and whether they meet human factors design criteria. As such, there is little basis to determine which display concepts are more promising. Task 2, described in the following section, was intended to provide new information about drivers' reactions to various FEDI concepts, feelings about fuel economy, and preferences for fuel economy information. The findings from Task 1 and Task 2 will be used in Task 3 to select a subset of promising FEDI concepts which will then be formally evaluated.

3.2 Task 2 Findings: Focus Groups

Four focus groups were conducted in Rockville, Maryland, with vehicle owners to discuss their driving habits and behaviors that they believe affect fuel economy, and to record their reactions to various fuel economy display designs. Methodological details about conducting these groups are in Section 2.3.

Participants in Group 1 and Group 2 (General Drivers Groups) were selected from the set of adult drivers who responded to an advertisement requesting participants for a focus group to discuss driving habits. Participants in Group 3 and Group 4 (Hybrid & FEDI Owners Groups) were selected from a set of volunteers who responded to a second advertisement requesting vehicle owners who have a hybrid vehicle or a fuel economy display (i.e., mpg) in their vehicle to participate in a focus group to discuss driving habits.

3.2.1 Responses to Changes in Gasoline Prices and Ways to Improve Fuel Economy

The four focus groups were conducted during January and February 2009 after local gasoline prices had fallen to approximately $1.85 per gallon. The recent rapid drop in prices followed an increase from less than $2.00 per gallon in 2005 to over $4.00 per gallon in 2008. Project staff members wondered if the focus group participants' reactions to the fuel economy display concepts and examples presented would be affected by the current relatively inexpensive price of gasoline. Also, it was of interest to know how much, and in what ways, participants modify their driving behavior in response to changes in fuel prices. It is possible that the widespread acceptance and use of future FEDIs will be affected by fuel prices.

Nearly all of the 34 participants agreed that they made some change in driving habits during 2008 in response to high gasoline prices. Most said that the changes that they made were more or less permanent, although a few participants said that they had relaxed some of their fuel saving strategies in response to the current low prices for gasoline. All participants agreed with the view that the current low prices for gasoline were only temporary and they expected prices to rise again soon.

Only a few participants said that they did not change their driving behavior in response to fuel prices. One participant said that she would not change her driving habits because of gasoline prices.

"No, I just have to go where I have to go so [the fuel price] doesn't matter." (Female, 68)

Participants who reported that high gasoline prices had inspired them to change their driving habits mentioned the following:

- Most participants said that they gave more thought to planning their trips, including reducing unnecessary trips and combining trips to do errands.
- Some participants eliminated trips by having other people pick up items for them while they were out, and shopping online rather than driving to a store.
- A few participants mentioned that they had started sharing rides (carpooling) and walking places more often.
- Several mentioned cutting back on pleasure trips and reducing the amount of vacation-related driving.
- A few participants mentioned that they reduced the grade of gasoline that they used in their vehicles.
- One participant said that he had retired from his job earlier than he would have otherwise because of daily transportation costs.
- One participant maintained a strict monthly gasoline budget and did not drive after the monthly budget had been exhausted.
- Several participants had replaced their vehicle with a smaller model that had better gas mileage (some examples were Honda Accord to Honda Fit; Buick Regal to Toyota Corolla; full-size pickup truck to smaller pickup with a four-cylinder engine). In one case, a participant mentioned purchasing a hybrid vehicle because of high gasoline prices. Interestingly, the majority of hybrid vehicle owners reported being motivated by environmental concerns when they purchased their hybrid vehicles rather than by concerns about fuel prices. An owner of a conventional vehicle summed up the thinking in Group 2, *"Certainly most of us would say if you are going to get a car, you'd get one that gets the best mileage for the buck and one that isn't going to affect the environment. All of these are issues that we weren't really tuned into years ago." [Female, 72]*
- One participant said that he traded vehicles with his spouse so that the more fuel-efficient vehicle would be used for the longer daily commutes. Another participant who owns a hybrid vehicle reported doing more driving as a result of high gasoline prices because her friends always asked her to take them places because she has the most fuel-efficient vehicle.

Some new driving behaviors that emerged as a result of high gasoline prices were mentioned. These included trying to "drive gently" and encouraging other family members to "drive gently" and pulling through parking spaces to avoid the need to back up (to save gas by eliminating extra time spent in parking lot maneuvers). A few participants mentioned coasting, and another mentioned careful planning her route to avoid making left turns.

"I focused a bit more on coasting . . . I'd see the red light and say, OK, I might as well just coast up to it and kind of drive a bit more gently . . . Now that gas prices are down I am not so much focused on economizing my trips or planning my trips but I try to stick to driving gently." (Male, 49)

"Everybody laughed at me. If I had a list of places that I wanted to go I would map out routes that allowed me to make as few left turns as possible because that way I wasn't sitting in traffic at a light wasting any kind of energy." (Female, 54)

Nearly all of the participants in Group 3 and Group 4 knew their vehicle's typical gas mileage in miles per gallon. By contrast, only half of the participants in Group 1 said that they knew this. Some participants in Group 1 said that they thought about fuel economy more often in terms of range (miles traveled per tank of gasoline, rather than miles per gallon) and they noted that their range depended on the season and type of driving (city versus highway). There was some discussion about fuel displays that indicate the number of miles to empty. Those who had this feature liked it, and several of the participants who did not have this type of information display expressed an interest in having that information. Only a few participants in Groups 1 and 2 reported that they regularly reset their trip odometer each time they filled their gasoline tank as a way to keep track of fuel economy although several said that they had used this method at some point in the past.

Participants were asked if they know about specific things that can either increase or decrease their fuel economy. Most agreed that speeding reduced fuel economy and that drivers should slow down, but a few explained that each vehicle has an optimal speed and that using the highest gear is most fuel-efficient.

Other suggestions for improving fuel economy included:

- Keeping your car well-maintained;
- Keeping tires properly inflated;
- A few participants mentioned not using the air-conditioning, and shutting down as many other powered accessories in the vehicle as possible. Another participant mentioned that Toyota hybrids have an Eco button that he believed was intended to limit the maximum amount of energy used for the air conditioning or heater;
- One participant suggested that the type of music playing in the car may affect driving style and fuel economy. Another participant suggested that the driver's mood may affect driving style and fuel economy;
- One participant said that she used to charge her gasoline purchases but got rid of her gasoline charge card and now paid cash. She thought that she tended to purchase less gasoline as a result;
- A hybrid vehicle owner said that he tried to not use his brakes a lot to maintain forward momentum, and a few other participants discussed the need to look far down the road ahead (beyond the vehicle immediately ahead of them) to see other vehicles' tail lights in the distance. This allowed them to coast more often; and

- Approximately three-fourths of the participants in Group 4 said that they looked far ahead to see traffic signals so that they could try to time their arrival at the intersection during the green phase. Another participant in Group 3 suggested that looking at countdown pedestrian signals can be useful for anticipating when the traffic signal light will change. Another participant mentioned speeding up to make it through traffic lights before they turned red so that he didn't have to stop.

"I think the best thing is if you look far enough ahead on the road that you can anticipate the stoplights, because if you bring the car to a stop and start all over again you would use more power than if you looked ahead to see a red light. Wow! If I start slowing down and take my foot off the gas now and just coast, by the time I get there the traffic will have moved." (Male, 47)

Participants in all groups were asked about their knowledge of "drafting" as a method to improve fuel economy. Approximately one third of participants had heard about this technique, which involves driving closely behind another larger vehicle at high speeds in order to reduce the wind resistance on your own vehicle to increase your gas mileage. Many participants thought that this was "crazy" and very dangerous. Only one participant (in Group 1) admitted to having done this.

"Yeah, I do it. Like I said, it's a game to me to get the best mileage." (Male, 47)

Participants were also asked about rolling through stop signs as a way to improve fuel economy. One participant said that she did this regularly, but only within her neighborhood.

3.2.2 Potentially Dangerous Driving Habits and Crash Experience

It is of interest to know whether drivers who have fuel economy displays drive differently (more or less safely) than those who do not have FEDIs. All focus group participants were asked to write down the number of collisions that they had been involved in while they were driving during past 10 years. They were told not to count minor collisions that occurred when backing out of or pulling into a parking space. They were also asked to rate themselves on how frequently they engaged in various driving behaviors. The choices on the rating scale presented were: Almost Never, Rarely, Sometimes, Frequently, or Almost All the Time. The behaviors to be rated included:

- Driving more than 10 mph above the posted speed limit;
- Driving more than 20 mph above the posted speed limit;
- Braking hard;
- Accelerating rapidly ("jack rabbit" starts);
- Tailgating (follow the vehicle ahead closely);
- Changing lanes to get around slower drivers; and
- Taking turns quickly.

Two participants in Group 2 were aware that they had FEDIs in their vehicles. For comparison purposes their responses were combined with those from Groups 3 and 4. The responses from FEDI owners (n = 18) were then compared to responses from those (n = 16) who did not have (or possibly did not know that they had) a FEDI in their vehicle. Figure 23 shows the proportion of participants with and without FEDIs who said that they engaged in the specific behavior listed at least sometimes (this includes the responses: Sometimes, Frequently, or Almost All the Time). For the item "Change lanes to get around slower drivers," the proportion of participants who said that they did this Frequently or Almost All the Time is shown. The final pair of bars to the far left shows the proportion of participants who experienced at least one collision within the past 10 years of driving. Although the sample sizes used for these comparisons are small, the results suggest that vehicle owners who have a FEDI may be less likely to engage in aggressive driving behaviors and less likely to be involved in a collision than those who do not have a FEDI. It should be noted that this comparison does not control for differences in drivers' ages and differences in vehicle types. The drivers with FEDIs were approximately five years older, on average, than drivers without FEDIs, and 11 of the 18 vehicle owners with FEDIs drove hybrid vehicles while all of the vehicle owners without FEDIs drove conventional passenger vehicles.

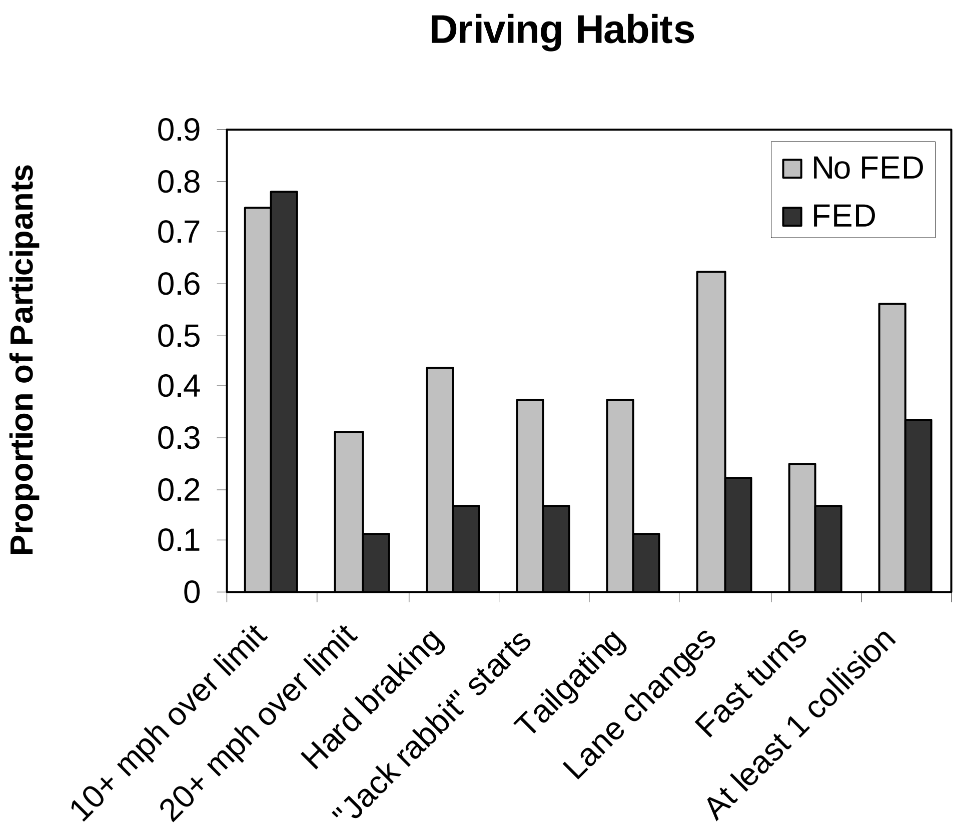


Figure 3. Comparing the driving habits of focus group participants who had and did not have fuel economy displays

3.2.3 Motivations While Driving

The use of in-vehicle fuel economy displays and preferences for various FEDI designs may depend on the drivers' level of concern with fuel costs, or with fuel usage as it relates to environmental harm. It would be useful to know how important these motivations are to drivers in comparison to other motivations such as having fun while driving, avoiding crashes, etc. Based on the discussions that occurred within the groups, it became clear that there are some notable differences between hybrid vehicle owners and conventional vehicle owners in their opinions about fuel economy displays. In general, hybrid vehicle owners were much more interested in having fuel usage and energy management information available to them as drivers. It is possible that these differences in opinion stem from the differences in experiences with, or level of exposure to FEDIs; or they may be related to more basic differences in values and motivations of people who chose to be early adopters of hybrid vehicles as compared to the general driving public.

Focus group participants were asked to consider their own driving and rate the importance of each of several potential motivations by writing a number on a piece of paper. They were asked to apply the following 6-point rating scale:

0 = Not at all important
1 = A little bit important
2 = Somewhat important
3 = Important
4 = Very important
5 = Extremely important

Table 1 shows each of the motivations that participants were asked to rate. For each motivation listed, the average importance rating is given separately for conventional vehicle owners and for hybrid vehicle owners. Although the sample sizes are small, there are some apparent differences. The largest differences between the average ratings from these two types of vehicle owners were observed for reducing negative environmental impact of driving; getting the best possible fuel efficiency; and reducing fuel costs. Hybrid vehicle owners tended to rate these three motivations as being more important than did conventional vehicle owners. These three motivations may be particularly relevant to the acceptance and use of FEDIs. It is possible that hybrid vehicle owners had these concerns prior to purchasing their vehicle and that these motivations played a role in their purchase decision. Alternatively, owning a hybrid vehicle with an elaborate fuel economy display may shape the owner's opinion about the importance of getting the best possible fuel efficiency from a vehicle, reducing negative impacts of driving on the environment, and reducing fuel costs. However, it should be noted that the information presented on the FEDIs of the participants' vehicles did not include any direct indications of harmful emissions created or cost of fuel used.

Table 1. Conventional vehicle owners' and hybrid vehicle owners' mean importance ratings for motivations related to driving

Motivations Related to Driving	Conventional Vehicle Owners (n = 23)	Hybrid Vehicle Owners (n = 11)
Avoiding collisions	4.9	4.8
Being on time for appointments	4.0	4.1
Avoiding getting lost	3.7	3.6
Getting the best possible fuel efficiency from your vehicle	3.6	4.2
Avoiding traffic congestion	3.6	3.3
Reducing your fuel costs	3.4	4.0
Reducing the negative impacts of your driving on the environment	2.9	4.1
Getting to your destination as soon as possible	2.8	2.4
Having fun while driving	1.8	2.1
Using your time driving to get something else done (e.g., phone conversation, eating)	1.2	0.7

Another way to compare conventional- and hybrid-vehicle owners' motivations is by ordering them by their mean importance ratings. Table 2 shows the rated motivations listed in descending order of importance for conventional-vehicle owners and for hybrid-vehicle owners. The center column shows the average importance rating for motivations listed in the right and left columns. This table shows that conventional-vehicle owners and hybrid-vehicle owners have close agreement in their mean ratings of importance for avoiding crashes, being on time for appointments, and avoiding getting lost. This table is also useful for understanding how differently some other motivations are for conventional- and hybrid-vehicle owners when they are shown on an ordinal scale of importance. As was noted above, hybrid-vehicle owners placed much more importance on getting the best possible fuel efficiency from their vehicles, reducing the negative impacts of their driving on the environment, and reducing fuel costs than did conventional-vehicle owners.

Table 2. Motivations related to driving ordered by their mean importance ratings

Conventional Vehicle Owners (n = 23)	Mean Importance Rating	Hybrid Vehicle Owners (n = 11)
Avoiding collisions	4.9	
	4.8	Avoiding collisions
	4.2	Getting the best possible fuel efficiency from your vehicle
	4.1	Reducing the negative impacts of your driving on the environment; Being on time for appointments
Being on time for appointments	4.0	Reducing your fuel costs
Avoiding getting lost	3.7	
Getting the best possible fuel efficiency from your vehicle; Avoiding traffic congestion	3.6	Avoiding getting lost
Reducing your fuel costs	3.4	
	3.3	Avoiding traffic congestion
Reducing the negative impacts of your driving on the environment	2.9	
Getting to your destination as soon as possible	2.8	
	2.4	Getting to your destination as soon as possible
	2.1	Having fun while driving
Having fun while driving	1.8	
Using your time driving to get something else done (e.g., phone conversation, eating, etc.)	1.2	
	0.7	Using your time driving to get something else done (e.g. phone conversation, eating, etc.)

3.2.4 Use of In-Vehicle Displays

Focus group participants discussed their use of the various dashboard displays in their vehicles. Some participants thought that their displays were easy to understand and that they had learned to use them without any assistance. Several other participants said that they learned about their displays from the vehicle owner's manual. A few participants admitted that they didn't know what some of their displays meant, and one participant said that she rarely looked at any of her dashboard displays.

"I generally know what the [various displays] are but there's an electronic display and you scroll through it, and it has all these different functions. I don't know what all of the different functions are." (Female, 32)

"I don't really look at the dashboard unless something is flashing or beeping." (Female, 31)

The most frequently used display by drivers in all four groups was the speedometer. Other displays that participants mentioned as being useful to them or that they used frequently were:

- Fuel gauge. Several participants liked their text display that shows miles-to-empty as an indication of fuel remaining. *"[First] it says like 325 miles to E, so I usually look at it when it says 50 miles to E, then I look at it more so that I know when I need gas." (Female, 18);*
- Fuel economy display (mpg) [More information on FEDI use is given below];
- Odometer – especially the trip odometer. A few participants said that they reset it and used it quite a bit. One participant said that she used it constantly for her work, to get reimbursed for mileage;
- Compass;
- Radio display and controls – mentioned by several people as a frequently used display, and mentioned by another participant as a distracting display;
- Tachometer;
- Outside temperature – several participants mentioned this, and a few said that they looked at it quite often;
- Check battery light;
- GPS (navigation system). One participant mentioned using his vehicle's GPS every trip. He said that it could be distracting and that it was difficult to operate; and
- Backup camera.

3.2.5 Use of Fuel Economy Driver Interfaces

Participants in Groups 3 and 4 were asked about their use of fuel economy displays and how frequently they looked at them relative to other displays in their vehicle. Hybrid vehicle owners with more sophisticated FEDIs tended to say that they looked at their FEDIs much more often than did conventional vehicle owners. Several hybrid vehicle owners said that they regularly looked at their FEDIs as often as they looked at their speedometer, or that their FEDI was the second most viewed display after the speedometer.

“I look at it as much as I look at my speed. It sort of becomes part of my gauge glancing.” (Female, 54)

“When I’m glancing down at the speedometer I’m also glancing at my fuel efficiency.” (Female, 59)

Participants who have FEDIs that are only accessible by scrolling through a list of other displays tended to look at their FEDIs much less often than those who have displays that are visible continuously. A few participants wished that they had a dedicated display for fuel economy so that they could look at it more often.

“I don’t look at it as much as I should because you have to scroll through to get it and it defaults [to another display]. I would love it if it were right there on the dash like the speedometer.” (Male, 49)

One participant who had both an instantaneous FEDI and a trip average FEDI said that he rarely looked at the instantaneous FEDI but checked the trip average fuel economy approximately once every hour or every half hour. (He mentioned that he had to scroll through displays to see that one.) However, another participant said that he found the analog instantaneous FEDI in his hybrid Toyota Camry much more useful than the digital average FEDI that he had in another vehicle. This is mostly because he believed that the location was better in the Camry and because he found the instantaneous information to be much more useful. He said that he looked at the instantaneous FEDI often.

3.2.6 Reactions to Examples of Fuel Economy Displays

All of the focus group participants were shown a series of slides depicting a range of fuel economy display designs and related concepts. The focus group moderator explained each example (one at a time) and then solicited feedback on that example from participants. At the beginning of this exercise, participants were asked to focus their comments on the following:

- Pros and cons of this fuel economy display?
- How useful would it be?
- How distracting would it be?
- Would you want to have a fuel economy display like this?

The moderator did not mention vehicle makes or models and did not indicate whether any of the systems are currently available. However, several of the slides included recognizable vehicle manufacturers’ names or logos and some participants, especially those in Groups 3 and 4, were already familiar with some of the displays.

Example 1: Digital fuel economy multifunction display and analog instantaneous economy gauge

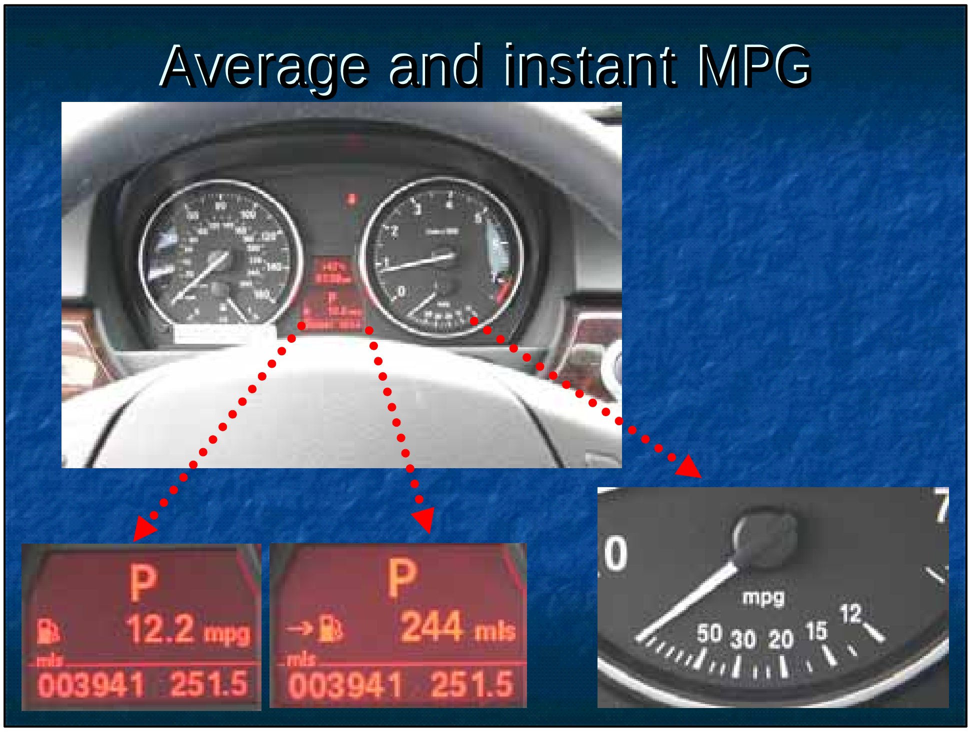


Figure 4. Example 1: Digital display for average fuel economy and analog display for instantaneous fuel economy

Explanation to Participants

This vehicle has a fairly simple fuel economy display within the instrument cluster that allows the user to select between current fuel economy and fuel range. The FEDI shows average fuel economy for the current tank of gasoline.

This vehicle also has an analog current fuel economy gauge. This shows your instantaneous fuel economy which may change from moment to moment. For example, the value will generally be higher if you are going downhill than if you are going uphill, and will be lower when you press down on the gas pedal to accelerate.

Participants' Reactions

Participants in Groups 1 and 2 had mixed reactions to these displays. Several participants thought that the instantaneous FEDI was useless.

"If it's going to raise the price of the car I don't want it. It's just something else to break." (Female, 45)

One participant said that he would prefer a digital display to the analog display. However, another participant pointed out that a digital display for instantaneous fuel economy would be changing so frequently that it would be nearly impossible to read. Another pointed out that the dedicated analog display was good because he didn't have to press a button to read it. A few participants saw some value in the instantaneous display.

“It’s an interesting concept.” (Male, 51)

One participant thought that the instantaneous FEDI would be useful for teaching his teenager about fuel-efficient driving, but said that he would prefer a simple indicator light rather than the potentially distracting gauge. Several other participants also thought that the instantaneous display could be distracting for the driver.

“That [gauge] on the right, if you’re looking at that while you’re driving, you obviously got some problems.” (Male, 53)

Of the two digital displays shown for average fuel economy and driving range, several participants thought that the range indication was useful, but they were less positive about the trip fuel economy display.

“I would like to know how many miles I have left. I do some long distance driving, and I think that it [miles to empty information] would be helpful.” (Female, 68)

“I think that the one that tells you how many miles you have left is the only one I would care about.” (Female, 45)

Participants in Groups 3 and 4 were much more accepting of having FEDI displays like these in their vehicles than were the participants in Groups 1 and 2. Participants in Group 3 and 4 also had many more specific comments about the design of the displays, but generally thought that the information presented was useful. One participant summarized it this way: *“The information is useful; it’s just the delivery of information that’s the problem.” (Male, 42)*

Only a few participants in Groups 3 and 4 did not think that the instantaneous FEDI provided any useful information, but several participants didn’t care for the “look” of the displays.

- The dash was too busy, a cleaner layout would be preferable
- Too boring
- Very “old school” gauges, very “retro”
- Numbers were too small
- Not easy to see at a glance
- *“My first impression is that it is not very interesting from a color perspective.” (Male, 38)*
- The color is difficult to read. *“If that’s the color it is I wouldn’t even try to read that while I was driving.” (Female, 54)*; *“Does the industry care about seven percent of the population who are colorblind?” (Male, 66)*

Other specific comments and suggestions include the following:

“I think it’s an adequate display and I don’t think it would be particularly distracting [. . .] I think the instantaneous mpg is more appropriate on the speedometer than on the tachometer. That’s just a feeling.” (Male, 59)

“I am wondering why the one on the right is analog. It kind of strikes me because all this other data is in digital format. (Male, 49)

"I do find the instantaneous analog [display] more interesting to me [. . .] 18, 20, and 19 wouldn't register to me. I like to see the movement." (Male, 38)

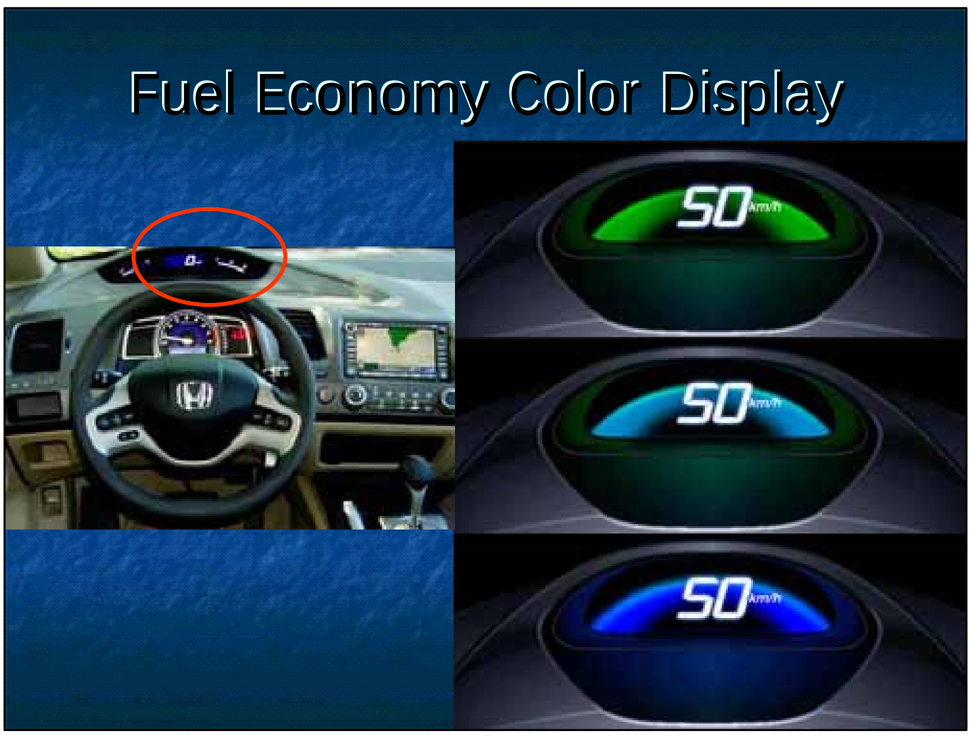
One participant suggested that the information would be better presented through a speech interface.

"You know that they have GPS [navigation systems] that talk. Why couldn't there be a button on the steering wheel that you push that would give you this information since you filled up? [It would say] 'You're getting blah, blah, mpg; you have blah, blah miles that you can drive until you need gas.'" (Female, 54)

Another participant commented that he prefers the vertical movement of the indicator for instantaneous fuel economy on his vehicle.

"My gauge for continuous mpg is up and down rather than at the bottom like that, and as you have better gas mileage this yellow line goes up toward the 50 on a blue background that is easy to see . . . I think that [the example shown] would be pretty hard to see." (Male, 60)

Example 2: Color-coded fuel economy display



(Sources: familycar.com - left photo; Honda.com - right column photos)

Figure 5. Example 2: Fuel economy colored arc display

Explanation to Participants

This vehicle has a digital speedometer located high on the dashboard. It is shown within the red oval on the slide. The speedometer display also has a colored arc which indicates the current level of fuel efficiency. This is an indication of instantaneous fuel economy, but instead of using a *gauge with numbers, different colors are shown. Green indicates very good fuel economy, deep blue indicates poor fuel economy, and the lighter grayish blue color indicates medium fuel economy. This display encourages the driver to try to drive in a manner that saves fuel by keeping the display green as often as possible.*

<u>Participants' Reactions</u>

Within Groups 1 and 2 several participants did not find the display useful, but some other participants in these groups liked it. The overall reactions to this concept were much more positive than the reactions to the first example.

"I think it would be useful. It could almost be like a game between you and your spouse." (Female, 46)

"So you get a little video game while you drive. I like it. I'll take it!" (Male, 53)

Some participants thought that this display would be less distracting than the previous displays shown in Example 1. One participant thought that the high location on the dashboard was a good design because he wouldn't have to look down as far to get the information. Another participant liked the simplicity of the display:

"I think that it's easier to respond with color, you don't even have to think, it's just a color." (Female, 46)

A few participants thought that the colors used for the display would be confusing. Participants in each group suggested that green, yellow, and red would be more appropriate.

"I think that they should do green, yellow, red, like a stop light." (Female, 45)

Within Groups 3 and 4, the reactions to this display were mixed. Some participants wanted more quantitative information about their fuel economy, while others liked the simplicity of this display. Participants found this display to be:

- More useful than the "swinging gauge" in Example 1;
- More subtle; and
- Well located (but one woman preferred a more traditional, lower location for the speedometer).

One participant thought that the display was not at all distracting: *"[The display] is just matter of fact." (Female, 34)*

However, another participant was concerned because he thought that the location and brightness of the display could pose a problem.

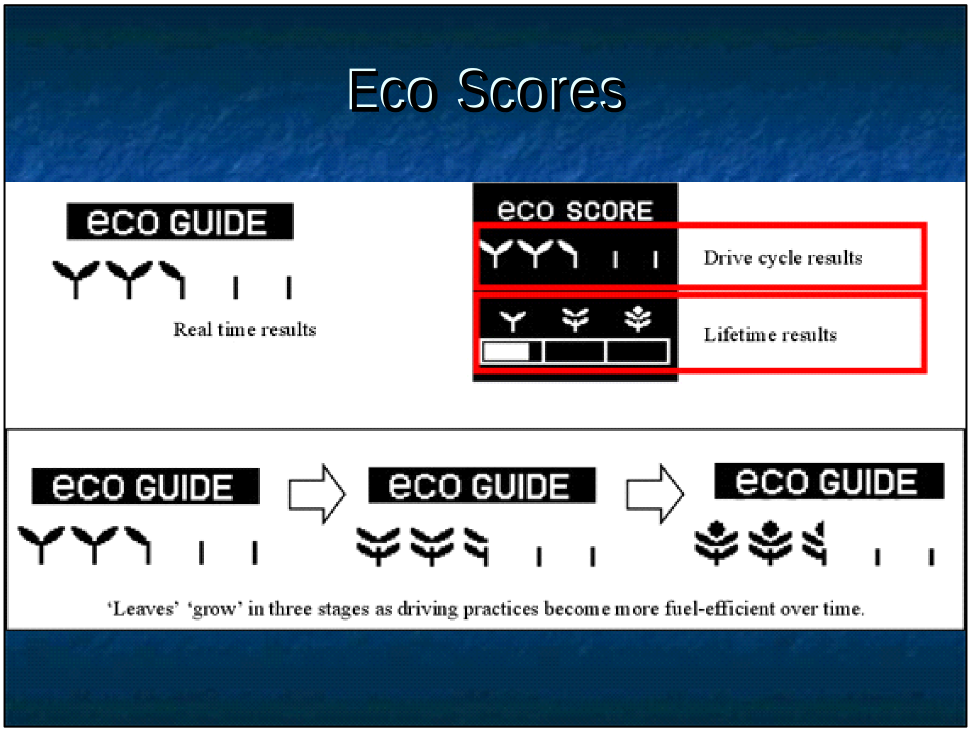
"You're putting something in that potentially could be very bothersome, but if you give me a good brightness control maybe it would be better [. . .] and I personally have my suspicions that maybe an analog [gauge] might be better for the peripheral vision of your eye." (Male, 66)

Some participants felt that this display didn't provide enough information.

"My initial reaction is that it is helpful to see the full range of gas mileage. If you just know good, bad, or better, it's not that helpful." (Male, 38)

"It's like an idiot light. You don't have to think much about it, but there's not much information there [. . . but] I think there's an advantage to it. You don't have to read it. You can just see it with the speedometer up high on the dashboard. You get a clear view out the window and you just know how you're doing from the color. You wouldn't have to focus on it necessarily." (Male, 59)

<u>Example 3: Eco scores</u>



(Source: Edmunds.com)

Figure 6. Example 3: Eco scores

<u>Explanation to Participants</u>

This slide does not show the entire display in the vehicle, but it presents a concept for giving the driver feedback about how fuel efficient he or she has been driving. Instead of showing numbers, driving scores, called eco scores are presented on a display in the vehicle. The eco score is shown by small plant icons. The more leaves that you have on the plants, the more fuel efficient you have been driving. This type of score can be shown in real time as you are driving, and you can also see your average score after a trip, or your long term, "lifetime score," which we'll assume you could reset at some point if you chose to do so.

We are interested in getting your reaction to the concept of presenting feedback to the driver about fuel economy with a scoring system like this.

<u>Participants' Reactions</u>

None of the participants in Groups 1 and 2 liked the eco score concept. Some laughed while hearing the explanation.

One woman remarked, *"I feel like it's a Pacman machine!"*

Participants found the scoring system confusing, overwhelming, and were not sure that they would understand what the scores were telling them while they were driving. One participant expressed some concern that she wouldn't know how to learn what the display meant. Another participant suggested that showing monetary values or symbols rather than leaves might be preferable.

Many participants in Groups 3 and 4 also were not enthusiastic about the eco score concept. One called it, "too esoteric." However, a few thought the concept might be promising, depending on how it is implemented. Some thought that it might work OK if it was a set of scores that the driver accessed after they had finished driving, perhaps if it was e-mailed to them or if they downloaded the scores from the vehicle via a Bluetooth link. One participant stood out as the only one in Group 3 who really liked the concept.

"If it was something [to view after the drive] I could see a lot of people liking the leaf [display] because I work at a school [. . .] and I can see that for some people, for visual people, it would be excellent." (Female, 34)

Another participant in Group 4 could envision himself using the display.

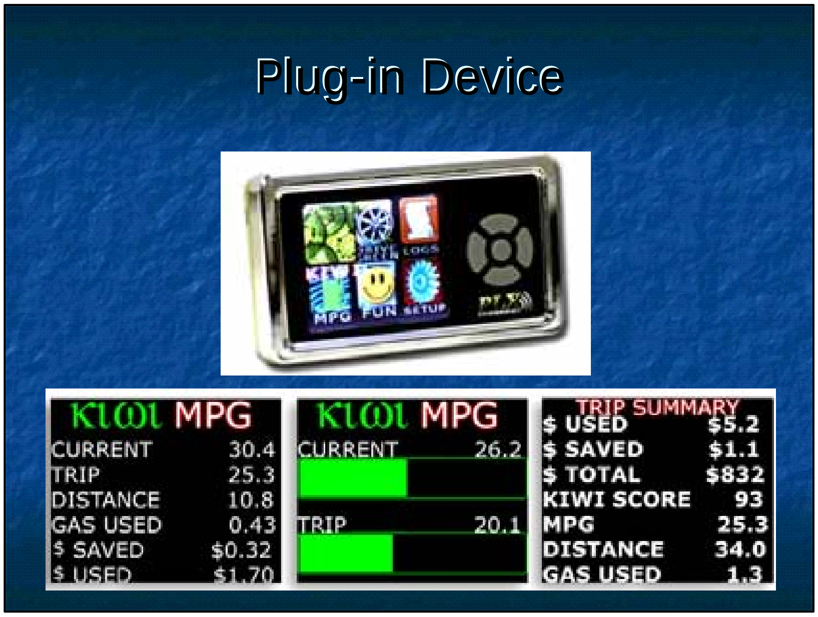
"I'd go through phases where I'd be competitive with myself and get caught up with it, then kind of forget about it. Then I'd get back into it." (Male, 37)

Another participant wanted more specific information about mileage per gallon.

"When I see 60 mpg [I know what it means], when I see four leaves it doesn't mean a lot." (Male, 38)

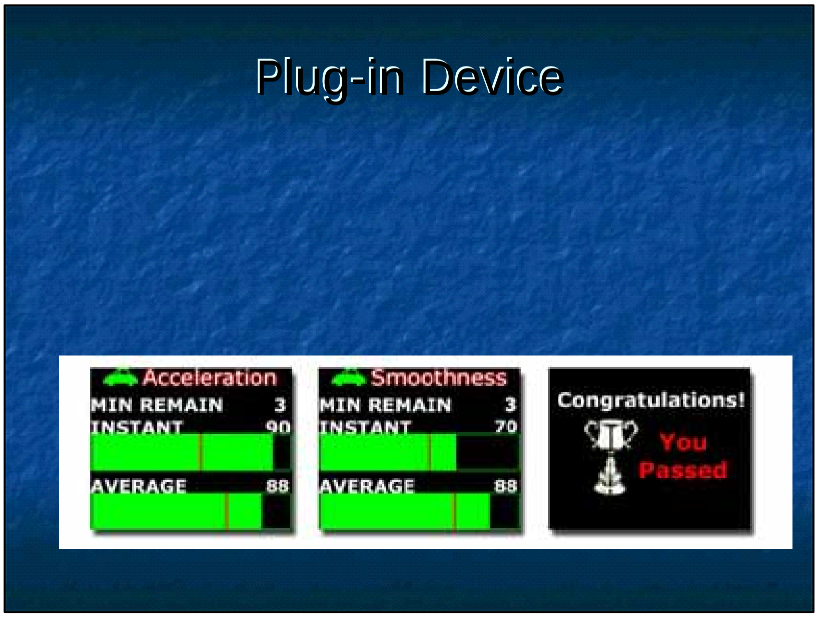
There were a few concerns expressed about the leaf measure for lifetime average. Participants worried that someone else driving their car could ruin their average. Others said that they resented the lifetime average measure and found the whole leaf concept to be condescending if it is intended to appeal to people with environmental concerns.

Example 4: Plug-in aftermarket device with fuel economy information and training



(*Source: plxkiwi.com)*

Figure 7. Example 4: Plug-in device, information screens



(*Source: plxkiwi.com)*

Figure 8. Example 4: Plug-in device, training screens

Explanation to Participants

This device is not part of a vehicle's original equipment. It is purchased separately by the vehicle owner. It is about the same size as a cell phone and you connect it with a cable to the vehicle's OBD-II port, which can be found under the dashboard.

This device provides several pieces of information related to your fuel usage including instantaneous (current) miles per gallon and average miles per gallon. It also shows the amount of gasoline used on a trip and the fuel cost for the gasoline used. We will assume that the driver must enter fuel costs whenever he or she purchases gasoline.

This device also provides training and feedback on your driving style to help you improve your fuel efficiency. It measures several components of driving style, including acceleration and smoothness. It provides scores based on each of these, and you'll see a reward trophy when you have achieved a certain score.

Participants' Reactions

Participants in Groups 1 and 2 generally would not use this device themselves, although one participant thought that it would be useful in a Driver's Education class for parents to teach their teenagers about driving. Some participants thought that the device had a game-like quality and worried that it would be too distracting in the vehicle. A few thought the information might be useful if the data were viewed later.

"It's a guy toy. Girls don't like games like that." (Female, 45)

"I think that if it is something you definitely weren't doing while driving maybe it would be interesting, but to me it reminds me of a cell phone." (Male, 51)

Several participants expressed concern about the possible cost of the device and that they would not be willing to pay much for it.

"It probably costs too much and does not give you enough in return." (Female, 46)

"I think for people concerned about conserving energy and gas costs, they are not going to spend money on [that device]. It's a foolish way to spend [your money]." (Female, 72)

There were also concerns from people in all four groups about how difficult the device would be to install and plug in. One participant said that he was surprised that the device could not connect wirelessly to the vehicle. Another participant warned about the difficulties of connecting to the OBD-II connector.

"Interfacing to the OBD-II connector can be a bear because some of them are behind the ash tray, some are here, some are there [. . .]" (Male, 53).

Participants in Groups 3 and 4 were generally more positive about Example 4 than were participants in the other groups. A few participants liked seeing the monetary data elements, but one participant wanted to know exactly how dollars saved were calculated and said that the dollars saved measure would bother him if it was based on some subjective criteria. A few other participants liked the training aspects of the system, but felt that it may not be highly effective for an experienced, knowledgeable driver.

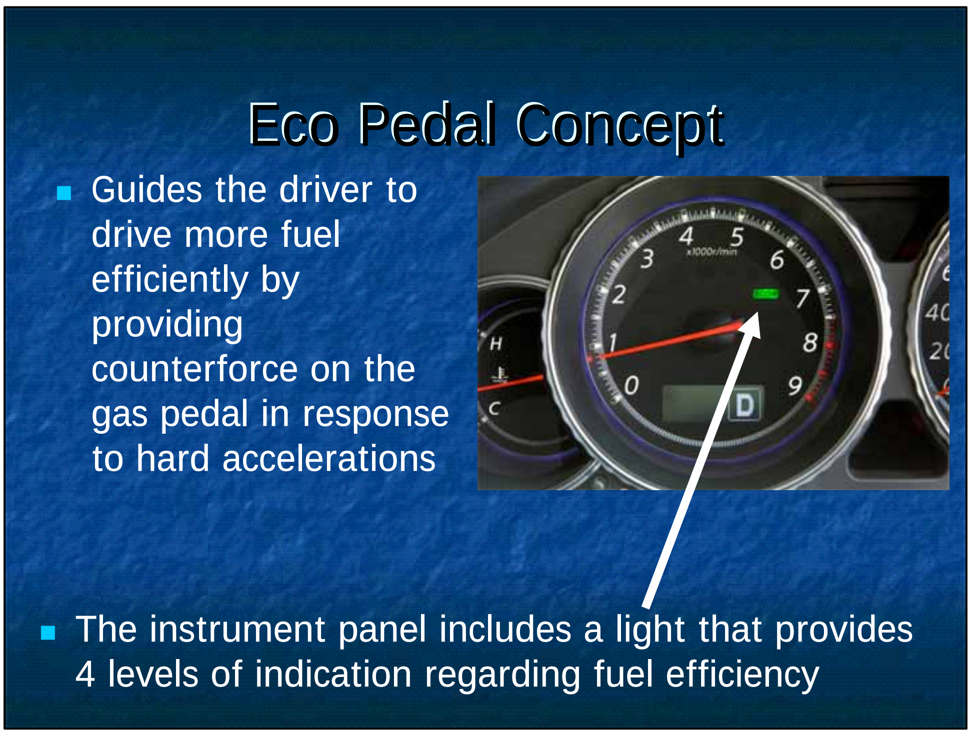
Three participants mentioned that they might like to be able to look at their driving data over a longer period of time, perhaps monthly, and would like to be able to download the data (perhaps wirelessly to a Blackberry device) so that they could do some analysis later. One said that he would like to see some other trip-related data such as tire pressure, time, and outside temperature to see how these factors affect gas mileage.

"I'd like to see trends. I'd like to offload data and be able to put it in a spreadsheet or better yet, a desktop application."(Male, 49)

Others expressed negative opinions about the usefulness of the data. One woman said that the device would not change her driving behavior at all because she would still have to go all of the places that she has to go.

"If you're on the road a lot or if you're a gear head or engineer and you like getting all that data [. . .] otherwise, I don't see a reason for it." (Male 42)

<u>Example 5: Eco Pedal Force Feedback</u>



(Source: Nissan-global.com)

Figure 9. Example 5: Eco pedal system

<u>Explanation to Participants</u>

When the system is turned on, the accelerator pedal pushes back against the driver's foot to help guide the driver to accelerate in a fuel-efficient manner. The "push back" force from the pedal may be easily overcome if the driver pushes harder. The concept here is an active training mechanism to help the driver learn to drive in a more optimal, fuel-efficient manner. The driver may choose to turn the system off.

The eco pedal light on the dashboard is off when vehicle is stationary, green when driver is applying appropriate pressure on the gas pedal, flashing green when the driver is applying almost-unfavorable pressure, and amber when the driver is applying unfavorable pressure.

Participants' Reactions

Unlike many of the other examples discussed, opinions about this system were not more favorable in Groups 3 and 4 than in Groups 1 and 2. There were many participants in all groups who did not like the system, yet there were a few in each group who did like it and said that they would consider using it themselves.

"I wouldn't turn [the system] off if I had it." (Male, 51)

"I like that light, [even though] everyone is sort of against it. I think that it's great to have detailed information, and I do think you should have that, but it's kind of nice to catch a color out of the corner of your eye without having to put too much thought into it." (Female, 32)

Participants in all four groups expressed concerns about the safety of the pedal device. They worried that in critical situations it might delay their reaction time enough to cause a crash, or that people might be startled, or panic when they felt the resistance. Others thought that the pedal system simply would be annoying or distracting and would be turned off.

"I think I'd like the light more than the pedal. The pedal would scare me." (Female, 23)

"I just think that people don't pay attention enough while they are driving [. . .] It's just something to distract them even more." (Female, 45)

Most felt that giving the driver the option of turning the system off was a good idea, although one participant expressed some concern that the driver may get used to the system and then react differently (overcompensate) when the system was off (or on). Another participant wondered if there would be a problem switching between cars (i.e., what would happen if a driver got used to the system then drove another family member's car that didn't have the system?).

As a system for training the driver to drive in a more fuel-efficient manner, one participant said that he might use the system temporarily for a month or two but then turn it off and never use it again, or he might use the system but then get used to it and stop paying any attention to it. Some participants thought that the system would be useful for some drivers (but not for themselves). For example, one participant expressed the view that the system would work best for new drivers, because highly experienced drivers have a fixed driving style that would be difficult to change.

"It's also good for people who constantly get tickets, the lead foots." (Female, 35)

A few participants worried about the cost of the system including the cost of repairs if it broke. Some would want the system if the costs were modest.

"If this was a $100 option on my new car, I'd buy it." (Male, 53)

There was only one suggestion for a design change for this system. One participant thought that the eco light could be supplemented or replaced by auditory feedback, perhaps a chime.

Example 6: Hybrid vehicle, large graphical displays

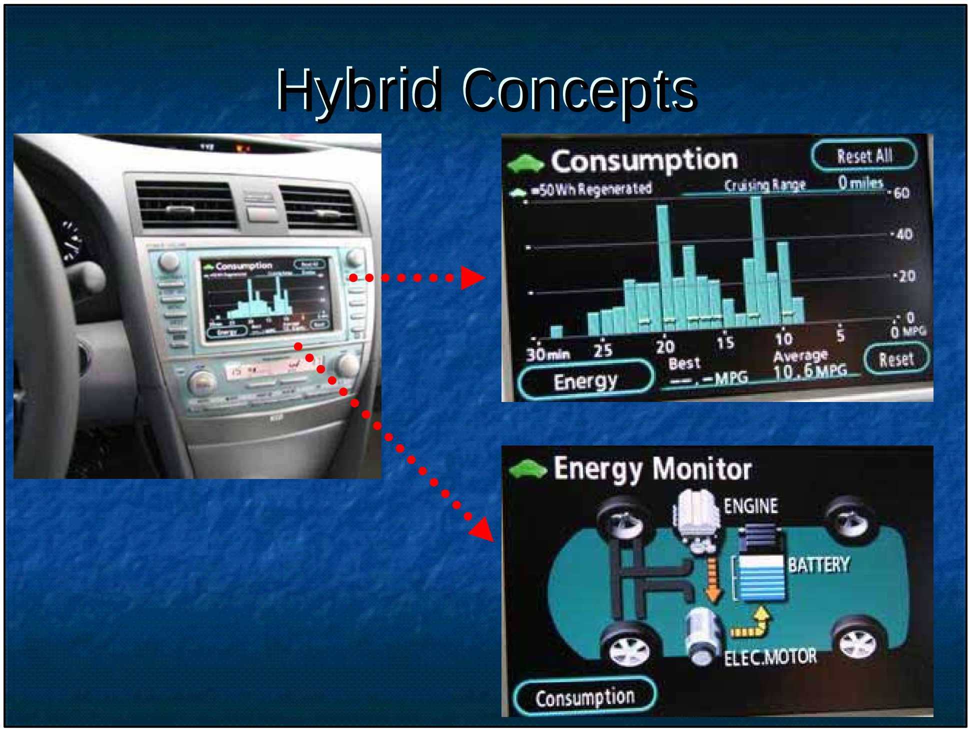


Figure 10. Example 6: Hybrid vehicle, large graphical displays

Explanation to Participants

The center console has a 7-inch color display that allows the driver to select from two information screens: Consumption or Energy Monitor. The Consumption screen shows a histogram of current fuel consumption as well as average consumption in one-minute intervals. Over time the bars shift to the left and new bars appear on the right. Energy Monitor shows the current battery level of the car as well as the flow of energy in the car. Energy for driving can come from the battery or gasoline engine, and braking can generate energy to charge the battery.

Participants' Reactions

Several participants in Groups 3 and 4 were familiar with the concepts shown in this slide because they owned Toyota hybrid vehicles, and in general, participants in Groups 3 and 4 were more positive about this example than were participants in Groups 1 and 2. Most participants in Groups 1 and 2 thought that the Energy Monitor screen was silly or useless, and they thought that the bar graph would be too distracting for the driver. They didn't think that the information would be useful, and one participant said that he didn't want to have to think about the reasons for their historical pattern of minute-to-minute fuel economy.

"That's fine for something for the passenger to do [but not the driver]." (Male, 67)

"I think that's a terrible layout first of all and I think it's extremely confusing to read and digest." (Male, 53)

"It would be distracting and agitating [. . .] plus, I'd be thinking, Should I be doing this?" (Female, 45)

"With this [bar graph display] it's like, what did I do bad? How many minutes ago was that big tall [bar]? What was I doing then?" (Male, 43)

One participant suggested that the information might be easier to read while driving if it was displayed in another format, perhaps as a pie chart. The only owner of a hybrid vehicle in Group 2 said that she has a similar display on her Prius, but does not look at it.

In Groups 3 and 4, several people had hybrid vehicles with similar displays. One woman said that she loves her bar graph display and is addicted to it. Another owner said that he likes the large size of the display and that he thinks it is very intuitive. A few participants explained why they like the bar graph display on their vehicles.

"For trips that I do like driving to work and back, (things I do everyday), I can tell what parts I get good gas mileage and bad gas mileage. It might be that if I know a hill is coming up, I try to accelerate so that I can coast a little more. [With the graph] I know the result." (Male, 37)

"I do find myself changing how I am driving if I can see that by maintaining a certain speed or not accelerating faster that it affects my mpg." (Female, 54)

At least one participant did not think that the display would be distracting to the driver.

"After the trip something like that would be interesting. You could critique your wife's driving! I don't think that after using it awhile that it would be particularly distracting [although] I would like it in front of me rather than to the side." (Male, 59)

Other participants commented on the position of the display. A few mentioned that it was too low in the example shown.

Regarding the Energy Monitor screen, a few participants said that they have this display but never use it. Others liked it and found it useful.

"It's what I look at all of the time. I love it. [. . .] I think it's cool. I try to keep the arrows going a certain way. I know if I'm going up a hill all of the arrows will be pushing me. I just love the arrows!" (Female, 44)

Another participant, who does not have this display in his vehicle, thought that the displays could be too distracting.

"I see a very strong distraction element with screens that you can change [. . .]. To be able to watch it and learn from it could take your attention off driving." (Male, 66)

Example 7: Hybrid vehicle, small multifunction fuel economy displays and large analog instantaneous mpg consumption display

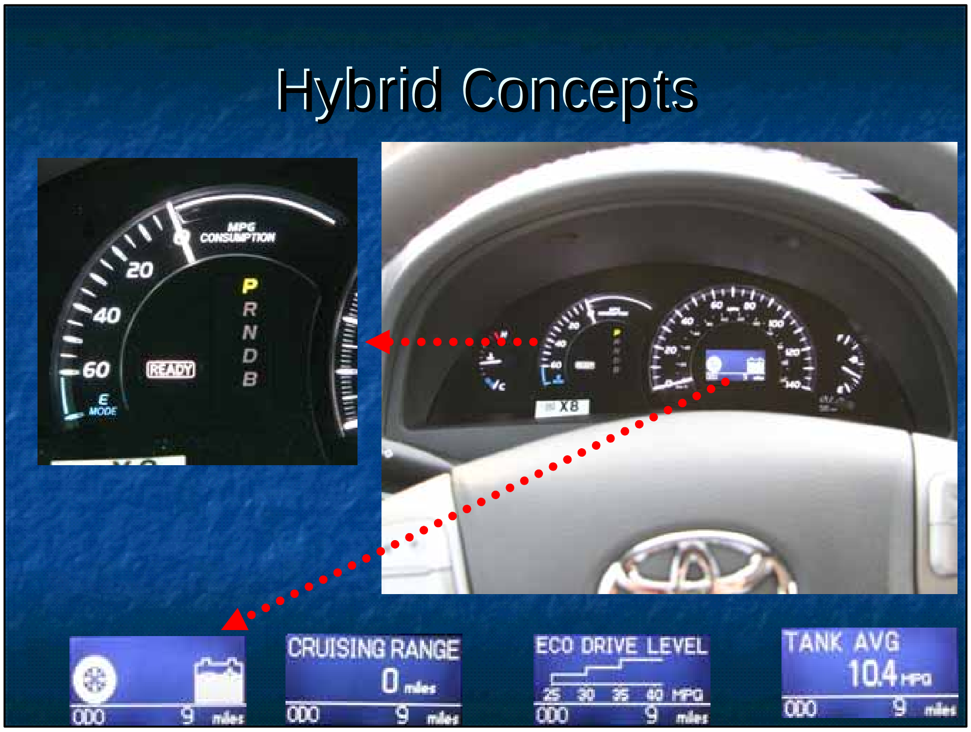


Figure 11. Example 7: Hybrid vehicle, small average mpg displays and large analog instantaneous mpg consumption display

Explanation to Participants

The instrument cluster includes a small display inside the speedometer where the user can select from a number of different information displays, including four screens that are related to fuel economy. The left display shows a simplified version of the Energy Monitor display that shows how electrical energy is being used or generated (the arrow is not shown here). The second display from the left shows the driving range remaining until there is no more fuel. The bottom-left display shows the average fuel economy for the current trip as a horizontal bar chart. The display on the far right shows average fuel economy since the last time the car was refueled.

This vehicle also includes a current fuel consumption gauge on the dashboard. This gauge is linear, with 5 mpg tick marks and an "E Mode" label at the bottom to indicate that the car is running on battery alone.

Participants' Reactions

There were few comments on these displays from participants in Groups 1 and 2. Although several participants thought that the fuel range (miles to empty) was useful, they did not think that the other small screen displays were useful. Although some admitted that the large fuel-consumption display would be easy to read, they did not think that the information that it provided was useful. A few participants thought that there were too many optional screens for the driver to select.

In Groups 3 and 4 several participants preferred the design of the analog fuel consumption gauge shown in this example to the analog fuel consumption gauge shown in Example 1. They liked the size of the display, the orientation of the display, and the movement of the needle.

"*Personally, I like it a lot especially the e-mode at the bottom. It shows when you are only on battery power so you don't have to look at the other picture [display]." (Male, 38)*

Most also liked the fuel range and tank average mpg information.

"I like that [eco drive level, trip mpg] like you mentioned. For trips you take everyday to work or whatever you can make note of it each day to see if it changes if you did something different, or if there is less traffic [. . .] It's simple and you don't have to figure it out." (Female, 32)

There were several comments that the display was too small and some participants did not like the exclusive modal nature of the display. They wanted to see more than one piece of information at the same time without having to push a button to select the different screens.

"The disappointing thing is that it's small and it's only one thing at a time. This is also where you see the thermometer, so if you want to know the temperature outside you have to flip over to it and flip back." (Male, 38)

Another participant did not mind the scrolling aspect of the display.

"I like it as long as you can scroll through with a button on your steering wheel." (Female, 54)

Example 8: Hybrid vehicle, user configurable displays

(Source: autoblog.com)

Figure 12. Example 8: Hybrid vehicle, user configurable displays

(Source: autoblog.com)

Figure 13. Example 8: Hybrid vehicle, graph and leaf displays

Explanation to Participants

This dashboard display for a hybrid vehicle is configurable by the driver. As a driver you can choose to see or not see several of the gauges. The displays on the left have to do with battery power, but today we will only concentrate on the right side displays which have to do with gasoline fuel economy. The possible displays include gasoline fuel level, instantaneous fuel economy (mpg), and two alternative graphical representations of average fuel economy over time. One of these is a bar graph similar to the bar graph display that we saw in the earlier example. It shows fuel economy in one minute intervals over the past 30 minutes. Let's assume that this display could be changed by the driver to show fuel economy over 5 minute intervals or longer intervals rather than one-minute intervals. The leaf display shows you how you are doing with your fuel economy in a picture format. As you drive in a more fuel efficient manner more leaves are added to the picture. As you drive in a less fuel efficient manner leaves are taken away.

Participants' Reactions

Most of the participants in Groups 1 and 2 thought that the displays were too overwhelming and game-like. They did appreciate the fact that drivers could choose to not see everything at once, but they were concerned that too many displays would be distracting. One participant, who did not like these displays, compared the system to, "picking screen savers." Another commented that there were too many displays for the average driver but that maybe they would be good for an engineer or automobile enthusiast. One participant thought that the position of the bar graph was better in this example than in Example 6 because it was closer to the driver's line of sight. The leaf display was not well received by Group 1 and Group 2 participants.

"That's just ridiculous. It's hard enough for people to change the station on the radio even if it's in the wheel. To me you're just asking for trouble." (Female, 45)

Although she did not admit to liking the leaf display for herself, one participant thought that some people might like the leaves.

"It depends on the kind of person you are." (Female, 18)

Among those in Groups 3 and 4, the reactions to this example were mixed, but these participants were more accepting of the design concepts in this example than were the participants in Groups 1 and 2. Many liked the configurable nature of the display and some positive comments were given about the location of the gauges. One participant suggested that different display configurations could be saved for different drivers.

A few participants thought that the 30-minute timeline for the bar graph was too short. They would prefer to see a longer period of time (at least one hour). One participant wanted to see each bar be equal to one hour for long trips.

None of the participants particularly liked the leaf display for themselves, but a few thought that other people might like it. Someone suggested that younger people might like these displays but that they may not be able to afford them. Another participant commented that liking this display depends more on the person and less on their age. She used her children as an example. She said that one would like it and the other would not. Another participant commented that she liked the leaf concept but preferred the one shown previously in Example 3. A large majority of participants did not find the leaf display to be useful. One participant asked, *"Can I choose to put the [outside] temperature there instead?" (Male, 66)*

Comments from other participants included:

- *"Simpler is better;"*
- *"That is fine for an 8-year old;"*
- *"That is over the top;"* and
- *"You're not supposed to be driving to get a gold star."*

One participant said that he would prefer to receive dollar signs or some other representation of money rather than leaves, and another participant said that he liked the simple phrase, "Excellent" that is provided at the end of a trip on the hybrid Toyota Camry display when good fuel economy has been achieved.

<u>Example 9: Post-drive analysis system and online community</u>

(Source: motorauthority.com)

Figure 14. Example 9: Post-drive analysis system and online community

<u>Explanation to Participants</u>

This is a system that allows users to download driving data to a personal computer for reporting and analysis. Your vehicle would have a USB port that you would use to download your driving data after a trip, once a week, or whenever you like. This system allows users to track their mileage, fuel economy, and emissions. The application analyzes the data from the drive and provides users with a performance report and tips to improve fuel economy. A separate report is prepared for each driving trip. The application provides users with an overall index of fuel *efficiency performance for each trip, on a scale from 1 to 100. Drivers receive feedback about individual behaviors that influence fuel economy (speed, acceleration, deceleration, gear changes) on a five-star scale and recommendations for improvements to driving style. The application also has an on-line community aspect where you can compare your fuel economy to other community members who have your same model vehicle.*

<u>Participants' Reactions</u>

There were several participants in each group who liked this example and nearly all of the participants in Groups 3 and 4 liked at least some aspects of this concept. Most of them indicated that they would like to use it at least once.

"I could see [myself] using this on a fairly regular basis actually." (Female, 54)

"The [in-vehicle] display should be giving you the information that you need that is vital to the trip you are on right now and everything else should be downloadable [. . .] Comparing yourself to the same [model] car owners would be useful if you could whittle that down to maybe the same ZIP code or ZIP code area." (Male, 42)

"I think that it's good and it would generate a lot of interest [. . .] Maybe it's not something that someone would be dedicated to for the rest of their lives, but I think it's a great idea!" (Female, 32)

"I think that it's a great concept, but I don't think I'd use it, or I might be interested in using it intensively for a week or two, but I don't think that I'd have a long term interest. Unless I was one of the best guys [in the competition], then I may really get intense on it for the competition!" (Male, 59)

A few participants said that they would use the system once or twice, or for some other limited period of time.

"I like the idea of this [system] and I like the idea of trending. I suspect that over a period of time that once I'm satisfied that I've topped off or leveled off at what I can do I'd probably stop using it. But I'd feel that I had optimized my driving, my behavior, and my use of the car which is really what the goal is." (Male, 49)

One participant thought that the system might be too sophisticated for some drivers.

"Most people can't even check their e-mail." (Female, 45)

Another participant expressed some concerns about data security on the Internet.

Participants liked the ability to see historical trends, and appreciated the possibility of getting personalized specific advice on how to modify their driving to achieve greater fuel economy. Reactions to the community and competitive aspects of this system were mixed. Many were not interested in those aspects but thought that they were a good idea for other drivers.

Only a few participants said that they would definitely not use a system like this.

"It's not for me. I'd rather go on Facebook." (Female, 23)

"This is all cool stuff, but do you want to spend that much time analyzing your driving habits? I don't." (Male, 53)

3.2.7 Desire to Have a Fuel Economy Display on Next Vehicle Purchased

At the end of each focus group session, the moderator asked whether participants would like to have any type of fuel economy display on their next vehicle. Participants in Groups 1 and 2 were mixed about whether they would want a FEDI. Most said that if they were going to have any type of FEDI in their vehicle it must be very simple. A few wanted a display like Example 2, or a simple text display of average mpg and range (miles to empty). They were clear that they did not want any of the more complicated in-vehicle displays. Some thought that they would try using a system like Example 9, where they could look at driving data while they were not driving.

All of the participants in Groups 3 and 4 said that they would like some type of FEDI on their next vehicle. Some participants liked the idea of having historical driving data and a lot of data about their vehicle available to them to view outside of their vehicles, perhaps on mobile electronic devices or home computers. Example 9 was the overall favorite, although the configurable dashboard (Example 8) was the favorite of at least one participant. Several of the hybrid-vehicle owners were happy with the FEDIs that they already had in their vehicles.

3.2.8 Discussion of Focus Group Findings

There were clear differences between the opinions expressed by participants in Groups 1 and 2, which were composed from members of the general driving public, as compared to the opinions of participants in Groups 3 and 4, which were composed of people who had purchased hybrid vehicles or conventional vehicles equipped with a FEDI. In general, Group 1 and 2 participants were resistant to having additional information displays added to vehicles. They expressed concerns about the negative safety impact of FEDIs, primarily because of the potential for increasing driver distraction, and about the possibility of direct interference of the device with the driver in emergency situations (in the case of the Eco pedal). In addition to safety concerns, some participants in Groups 1 and 2 worried that the cost to the consumer of adding FEDIs to the vehicle would not be matched by the benefits achieved.

Participants in Groups 1 and Group 2 wanted to see a minimal amount of fuel economy data on in-vehicle displays. A few were open to the idea of a qualitative color display (Example 2). Other participants tended to prefer information about driving range until empty and trip average fuel economy.

Many participants in Groups 3 and 4 were comfortable seeing more sophisticated fuel economy displays in the vehicle, and several were especially interested in downloading driving data for later viewing and analysis. Example 2 was generally viewed favorably by several participants in each of the focus groups, although some in Groups 3 and 4 also wanted to have more quantitative information. For those who were interesting in having an in-vehicle indication of instantaneous fuel consumption, some participants in Groups 3 and 4 were comfortable with a large, vertically oriented analog display. Those shown in Example 7 and Example 8 were preferred to the one shown in Example 1.

Participants in all groups wanted to know what the potential fuel savings would be in their vehicles if they had a fuel economy display and made changes to their driving behavior so that they were driving in a more fuel-efficient manner. Some seemed slightly frustrated by the fact that the focus groups discussed so many different concepts for proving driver feedback without providing any estimates about the potential payoff in terms of fuel savings.

Participants also pointed out that most of the fuel economy displays and other feedback devices shown as examples didn't provide specific guidance to the driver about how they could improve their driving to be more efficient. (An exception to this may be the Eco pedal concept presented in Example 5.) The idea presented in the final example (9), of providing individualized online analysis and feedback about specific steps that can be taken to improve the fuel efficiency (e.g., shift earlier between second and third gear, etc.) was viewed favorably by many participants.

The focus groups conducted in this study had some limitations that should be considered in future research.

- There were relatively few younger participants (ages 18-35). Future evaluations of FEDIs (in Tasks 3, 4, 5) should plan to include more participants in this age range.
- Participants were recruited in Montgomery County, Maryland. This area is primarily urban. Only one participant mentioned that he lived in a rural area. The motivations of rural drivers or drivers who have long daily commutes may differ from the sample of drivers in the present study. Future research should consider how many miles vehicle owners drive per week. The participants in the present study were all chosen because they said that they drive their vehicles at least four times per week.
- The FEDI examples presented did not include any quantitative indications of driving impact on the environment (such as vehicle emissions). Several of the hybrid vehicle owners in Groups 3 and 4 said that they were more motivated by environmental concerns than by fuel use or fuel prices when they purchased their vehicles. Although they did not like the "leaf" displays for fuel economy they might be motivated by emissions data or some other quantitative measure of environmental impact.

4 Conclusions

4.1 Discussion of Findings

In Task 1, project staff documented the design range of fuel economy displays, including current, past, and concept displays. The task also included a review of FEDI patents, fleet vehicle feedback devices, historical trends, and a projection of trends for future FEDIs. The review found that FEDIs have existed in passenger vehicles for decades, and that in recent years they have become especially prevalent, diverse, and complex. Every major automotive company that sells vehicles in the United States offers at least one vehicle model with a FEDI. FEDI designs vary within and between auto companies. Displays range from simple text output and analog gauges to complex color displays on LCD display panels. Enhancements in mobile computing technology and connectivity, along with reductions in device size and cost, have fueled growth in multifunction aftermarket technologies capable of displaying fuel economy information, as well as networked devices that allow users to download fuel economy information to a personal computer and compare their performance to others' in an online community.

Task 2 used the findings of Task 1 as a starting point for further investigation of various FEDI concepts. Four focus groups were convened; two with the general driving public and two with drivers of hybrid vehicles or other vehicles with FEDIs. Participants discussed their feelings about fuel economy and driving behaviors, and provided feedback about nine different FEDI display concepts, representing the range of current and upcoming FEDI displays and technologies. Participants had differing opinions about the FEDI concepts. Drivers who currently had FEDIs in their vehicles had more positive attitudes toward FEDIs in general, and the more complex and innovative displays in particular. Basic text and gauge displays were generally received favorably, though some participants recommended changing the appearance of the displays or questioned the importance of the information. Instantaneous fuel economy displays, in particular were controversial. Some people thought that there was some value in having them, but others thought that they were worthless, and likely to be distracting and annoying for the driver. This suggests that there is a need for some level of configurability of displays, so that drivers may choose to hide displays that they don't find useful.

A display that changes color in response to fuel economy was also generally well-received, although some people wanted additional quantitative information. Vehicle adaptation technology was received unfavorably by most participants because of concerns that taking control away from the driver could be dangerous in some situations though some thought it would be a useful tool for some drivers to learn how to drive efficiently. In those cases, participants thought that the device would be used for a limited period of time and then turned off and not used again after the initial learning phase was over.

Complex graphical information such as energy flow diagrams, fuel economy history bar charts, and game-like displays were generally seen as excessive and distracting by drivers who did not have FEDIs, but drivers with FEDIs had more mixed opinions, considering them interesting and useful for some drivers, but also as a potential distraction if used improperly. Many participants were interested in the post-drive reporting technology as a way to evaluate their performance and track their improvement over time. Some were interested in the social and comparative aspects of the technology, while others thought that they would not bother to review their reports, or would lose interest in it over time.

Together, Tasks 1 and 2 provided important information about the range of FEDIs, as well as drivers' reactions to these displays and recommendations for improvement and future innovations. The next task in this project, Task 3, will use these findings along with accepted human factors principles to develop interface recommendations for FEDIs. The diversity of current and upcoming FEDIs shows that there is no accepted best practice for FEDI interface design. Although none of the display concepts discussed in the focus groups stood out as a clear favorite, some concepts appear to be especially promising for future consideration:

- Simple, qualitative, color-coded indication of current fuel economy
- Post-drive reporting, feedback, and social comparison
- Text and analog gauge displays

It is important to note that FEDI concepts are not likely to be a one-size-fits-all solution. The focus group findings made clear that FEDI preferences are, to some extent, a matter of personal taste. Though basic text and gauge displays were received favorably by most participants, the reactions to other concepts were more mixed. Drivers who currently have FEDIs in their vehicles, or who are particularly concerned about fuel economy, may be interested in displays with more extensive features and options to track and improve their fuel economy. These fuel-conscious drivers often cited reducing their own vehicle's polluting emissions as their primary reason for minimizing their fuel usage, so FEDIs that address environmental emissions may be useful for this group. Other concepts raised by participants in the focus groups include providing drivers with information about the costs savings achieved by their driving behavior and on-road tips to improve fuel economy. Yet another possibility is the use of gallons per mile (gpm) as a measure of fuel economy. Although drivers are accustomed to mpg, research by Larrick and Soll (2008) suggests that gpm (actually gallons per hundred miles) gives drivers more concrete information about their fuel usage, the cost of fuel, and allows them to make more accurate comparisons between different vehicles' fuel economy.

Another reason that there is not likely to be a single "best" FEDI is that hybrid vehicles have some unique characteristics that may influence ideal FEDI design for these vehicles. Current hybrid vehicles use a combination of two energy sources: gasoline and electricity. Depending on the vehicle model and driving conditions, hybrid vehicles may use gasoline, electricity, or both at any given time. While fuel economy can still be measured in mpg of gasoline, additional measures of interest include battery level, battery drain or charge rate, current source of power, and so forth. The behaviors and driving conditions that influence fuel economy in hybrid vehicles may also be different than for non-hybrid vehicles. For example, acceleration and high speeds may require the gasoline engine, whereas coasting, deceleration, and slow speeds may only require battery power. The future will also bring vehicles that run solely on electricity (or electricity with a backup internal combustion engine), hydrogen fuel cells, and possibly other fuels. These novel power sources may have their own unique requirements for FEDIs.

Game-like displays, which give drivers scores or other feedback as a reward for fuel efficiency, were not received well by most focus group participants. This concept, however, may be worthy of further exploration. The concepts explored in the focus group used growing plants to indicate fuel efficiency. Participants did not like this feedback structure, but there may be other feedback structures that would be more acceptable to drivers. Participants were also concerned that these displays could be too complicated and distracting. These types of displays could be most appealing to younger drivers, however, younger drivers are also less adept than adults at sharing attention while driving (Chisholm, Caird, Lockhart, Teteris, & Smiley, 2006), and therefore distraction and misappropriation of attention are particular concerns for this group. A key need for game-like displays is to find ways to make the displays meaningful and rewarding, yet not distracting or excessively engaging. Simple, easy-to-understand feedback, consistent with human factors design principles, will be essential to achieving driver acceptance of these displays.

4.2 Next Steps

In Task 3, a set of at least eight FEDI concepts will be developed, representing the most promising concepts identified in Tasks 1 and 2, as well as new and improved concepts inspired by the findings of these tasks. Although FEDI concepts were originally envisioned as single displays, it is clear from the findings in Task 1 that many existing FEDI concepts are, in fact, more complex feedback systems that may include multiple displays and modalities. Each concept display or concept system will include a justification for inclusion, a detailed description of functions and goals, and a visual representation. Based on discussions with NHTSA, a subset of these concepts will be selected for further evaluation of each concept's interface comprehension, usability, desirability, glance patterns, distraction, and estimated impact on driving behavior. Testing may include quantitative and/or qualitative methods. The findings for each FEDI concept will be evaluated and a set of recommendations for two FEDI interfaces will be developed. The study methods, findings, and recommendations will be compiled in the Task 3 Final Report.

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6 Appendix A: Fuel Economy Displays

6.1 Gasoline Vehicles

BMW – fuel economy display

Figure 15. BMW fuel economy display with analog gauge (2008 328i)

System basics: Original equipment on many BMW models.

System description: The system includes both a digital alphanumeric display and an analog instant fuel economy gauge. The analog gauge has been a standard feature in most BMW models since the 1990s.

Features: The alphanumeric display allows the user to view average fuel economy or fuel range.

Display characteristics: The alphanumeric display is located on the fourth line of a five-line display encompassing two display panels. The analog gauge is located below the tachometer and shows instant mpg on a logarithmic scale from 12 to an unnamed maximum. Due to the logarithmic scale, higher fuel economy is displayed at decreasing resolution.

Controls: User can choose which fuel economy information to display on the alphanumeric display using a bidirectional control on the turn signal stalk.

Feedback: Quantitative information is presented. The system does not provide advisory feedback nor does it provide guidance about how to change driving behavior to improve fuel economy.

<u>Audi – driver information display and trip computer</u>

Figure 16. Audi average fuel economy display

System basics: Original equipment on Audi models, including 2004 Audi A4.

System description: User can choose to view average fuel consumption, instant fuel consumption, or fuel range.

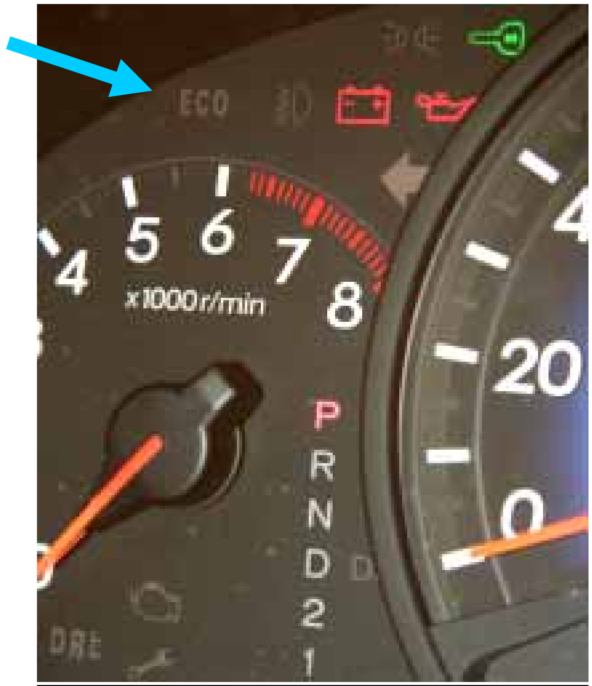
Features: Shows average fuel consumption, instant fuel consumption, and fuel range. Average fuel consumption is displayed in mpg since memory was last cleared by the user. Instant fuel consumption is shown in mpg. The fuel consumption is recalculated in intervals of 33 yards. The most recent fuel consumption is shown when the vehicle is stopped. Fuel range shows how far the vehicle can travel at the current fuel usage rate with the amount of fuel left in the tank. Fuel range is recalculated every 10 miles.

Display characteristics: Display is located in the center of the instrument cluster, on the center line of a three-line display. Text and separator lines are red against a dark gray background. The system displays average fuel economy for the current trip or since the last time the user manually reset the display.

Controls: User operates system through two hard control switches located on the windshield wiper arm.

Feedback: Quantitative information is presented. The system does not provide advisory feedback nor does it provide guidance about how to change driving behavior to improve fuel economy.

Honda variable cylinder management with ECO light



(Note: arrow added to show ECO light location)

Figure 17. Honda ECO light display (not illuminated) in 2009 Honda Odyssey

System basics: Included in the 2009 Honda Odyssey EX-L and Touring models.

System description: The variable cylinder management system shuts down either two or three of the six cylinders to save fuel when cruising at a constant speed with low demand on the engine. The ECO light is illuminated when cylinders are shut down.

Features: The variable cylinder feature is fully automatic and the only indication given to drivers of its use is the illumination of the ECO light. The ECO light may turn on and off many times in the course of a trip as engine demands change.

Display characteristics: The ECO light is located just above the tachometer at the top left of the instrument cluster. The ECO light is at the left of other dashboard indicator lights. The light illuminates green when cylinders have been shut down.

Controls: None.

Feedback: Drivers can learn to become more fuel efficient by attempting to drive in a way that keeps the ECO light on as much as possible.

Links / references:

- http://automobiles.honda.com/odyssey/features.aspx?Feature=vcm
- http://www.motortrend.com/auto_news/news_030618_hon/index.html
- http://en.wikipedia.org/wiki/Variable_Cylinder_Management

<u>Lexus – multi-information display</u>

Figure 18. Lexus instrument cluster – average fuel economy

System basics: Original equipment in Lexus models, including 2008 Lexus ES 350.

System description: This system allows the user to cycle through four fuel economy related displays within the instrument cluster.

Features: The system displays average fuel economy, average fuel economy since most recent refueling instant fuel economy, and fuel range.

Display characteristics: The display is located in the center of the instrument cluster, above the gear state indication. All displays show numerical information except for the instant fuel economy display, which shows fuel economy on a line with 30 mpg increments from 0 to 90 mpg. Outside temperature is displayed below the fuel economy displays.

Controls: User cycles through various displays by pressing “DISP” button on steering wheel. User can press and hold button to reset compatible displays.

Feedback: Quantitative information is presented. The system does not provide advisory feedback nor does it provide guidance about how to change driving behavior to improve fuel economy.

Mercedes-Benz BlueEFFICIENCY fuel economy display

(Source: paultan.org)

Figure 19. Mercedes-Benz BlueEFFICIENCY display

System basics: A new FEDI design from Mercedes-Benz is available on three new C-Class models given the BlueEFFICIENCY label. BlueEFFICIENCY models are designed to improve fuel economy by up to 12 percent through improved aerodynamics, lighter materials, energy management, and a more efficient engine. Models are not currently available in the United States

System description: Most of the fuel-saving features of the BlueEFFICIENCY models are invisible to the driver. However, the instrument cluster includes a prominent FEDI and a gearshift indicator.

Features: The instrument cluster includes a display that simultaneously shows both current fuel economy and fuel range.

Display characteristics: The display is located in the center of the speedometer. Current fuel economy is displayed on a monochrome, horizontal bar graph ranging from 0 to 80 mpg in 20-mpg increments. The bar graph is on a linear scale, unlike analog gauges which are often logarithmic. Fuel range is displayed numerically below the current fuel economy display.

Controls: None.

Feedback: System does not provide any advisory feedback nor does it provide guidance about how to change driving behavior to improve fuel economy.

Links / references:

- http://www.emercedesbenz.com/Feb08/28_001040_Mercedes_To_Add_Three_Extra_Economical_BlueEFFICIENCY_Models_To_The_C_Class_Range.html
- http://www.drive.com.au/Editorial/ArticleDetail.aspx?ArticleID=49726
- http://paultan.org/archives/2008/03/07/w204-mercedes-benz-c-class-blueefficiency/

Chrysler Fuel Pacer (1970s)

(Source: valiant.org)

Figure 20. Chrysler Fuel Pacer

System basics: Appeared as an option on various Chrysler/Dodge models from 1974 through 1978, including the Plymouth Valiant and Dodge Dart. The concept arose in response to fuel shortages in the United States prior to its release; the option was expected to cost $10 to $12.

System description: A light on the vehicle's front left fender illuminates when the driver presses the gas pedal excessively and inefficiently. The same light was used as the left turn signal indicator. The light is illuminated when the manifold vacuum level drops below a threshold amount. The manufacturer intended the system to help drivers conserve fuel by using less than the vehicle's full power when accelerating. The fuel pacer press release stated that designers expected urban drivers to use 10-percent less fuel with the system.

Features: The system illuminates a light to inform the driver of inefficient acceleration.

Display characteristics: The fender light, which is exterior to the vehicle cabin, is within the driver's forward field of vision. As a simple manifold vacuum based indicator, the light would instantly turn on or off depending on vacuum level, and could flicker on and off if the vacuum level is fluctuating near the activation threshold. According to the fuel pacer press release, system designers opted to use the fender light rather than a dashboard gauge because the light is an "active system" that demands drivers' attention without making them look away from the road.

Controls: None.

Feedback: System provides minimal advisory feedback from the fender light. Drivers may learn to drive in a manner that keeps the light off as much as possible.

Links / references:

- Chrysler Motors Corporation (Press release: December 12, 1973). New "fuel pacer" systems helps drivers see the light and conserve on gas.
- http://www.valiant.org/dart/1975.html
- http://www.nybclub.org/m-r/engine/FuelPacer/index.htm
- http://www.imperialclub.org/Repair/Fuel/pacer.htm

6.2 Hybrid Vehicles

Toyota/Lexus hybrids (with large, color touch screen LCD display)

Figure 21. Toyota Camry hybrid (2009) consumption display (L) and energy monitor (R)

System basics: The LCD touch screen display is standard equipment in the Prius and Lexus hybrid vehicles, and is an option in some other Toyota hybrids. Some vehicles have both the large LCD screen described here and the small, monochrome LCD described below.

System description: The system includes two primary fuel economy display screens: a consumption display and an energy monitor. The consumption display shows current, best, average, and past fuel economy. The energy monitor shows the current flow of energy between the battery, engine, electric motor, and wheels. These displays vary slightly between vehicle models.

Features: The consumption display shows fuel economy over the last 30 minutes in a bar graph. Current fuel economy is shown in the rightmost bar, and each bar to the left represents fuel economy for one minute of time in the current trip. Within each bar, green car icons represent electric energy generated by the vehicle. Average fuel economy (updated every 10 seconds) and best fuel economy (best 1-minute economy for the current trip) are shown at the bottom of the screen. Fuel range (“cruising range”) is shown at the top of the screen. The energy monitor shows a schematic of the vehicle’s power system. Arrows are shown to indicate the current flow of power. In the figure above, for example, the vehicle is stopped and the engine is shown powering the electric motor, which in turn is charging the battery.

Display characteristics: The display is a full-color, 7-inch LCD touch screen located in the vehicle’s center console. In addition to fuel economy, the display can also show radio station presets, the optional GPS navigation system, or the optional backup camera image. The display also has a night mode, featuring darker colors and a lower brightness, when the vehicle’s headlights are turned on. Displays differ somewhat between vehicle models.

Controls: A “soft key” located on the bottom left of the display lets the user switch between the consumption display and the energy monitor. Additional soft keys on the consumption display allow the user to reset the average and best economy displays, or reset all displays. The driver can also switch between display screens using hard controls on the steering wheel.

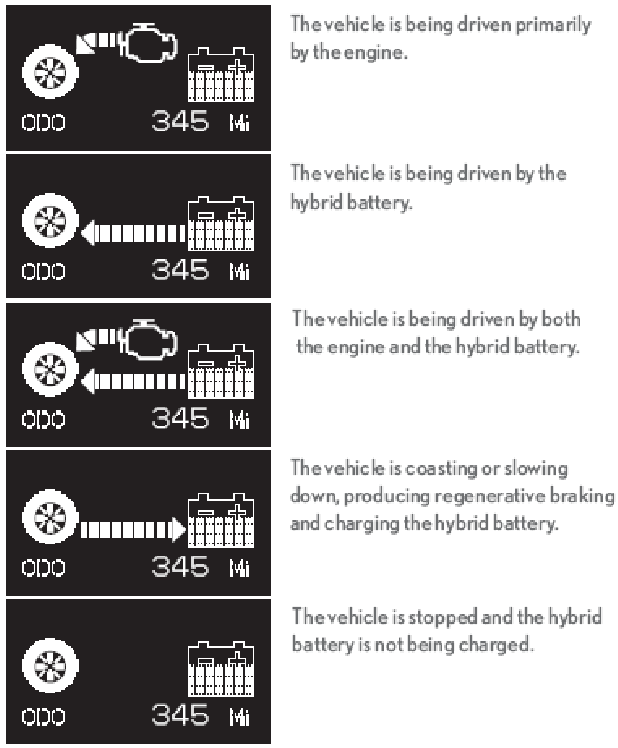
Feedback: Although it provides detailed information about fuel economy over time and electrical power use, the system does not provide any advisory feedback nor does it provide guidance about how to change driving behavior to improve fuel economy.

Links / references:

- http://www.toyota.com/prius-hybrid/photo-gallery.html
- http://www.toyota.com/camry/photo-gallery.html
- http://www.toyota.com/highlander/photo-gallery.html
- http://www.lexus.com/models/RXh/features/interior/energy_monitor.html

<u>Toyota/Lexus hybrids (without large LCD display)</u>

Figure 22. Toyota Camry hybrid (2009) instrument cluster with current fuel economy gauge and multi-information display



(Source: Toyota Camry owner's manual)

Figure 23. Toyota Camry (2009) energy flow modes

System basics: This display configuration is available in some Toyota and Lexus hybrid models, and in some models may be accompanied by the large LCD display screen described above.

System description: The system includes two display components: a current fuel economy gauge on the left side of the instrument cluster and a multipurpose LCD display within the speedometer.

Features: The current fuel economy gauge shows current economy in mpg, and includes blue marker labeled "E MODE" to indicate that the car is running solely on battery power. The outside border of the arc gauge contains a blue light that glows brighter when fuel efficiency is good, and dimmer when fuel efficiency is poor (see right inset image in Figure 22 for brighter state that occurs during regenerative braking). There are four levels of brightness: 0 to 25 mpg (light off), 26 to 30 mpg (light dim), 31 to 35 mpg (light medium), and 36 mpg and up (light bright). The multipurpose LCD display can show average fuel economy for the current tank of gas, fuel range, eco drive level (current fuel economy), and energy flow. There are five possible energy flow modes, which are shown in Figure 23.

Display characteristics: The current fuel economy gauge shows fuel economy from 0 to 60 mpg in 20-mpg increments, with 5-mpg minor tick marks. The multi-information display is about 2 inches diagonal and has a white legend on a dimly backlit background.

Controls: The driver can switch between displays on the multi-information screen by pressing the DISP button on the steering wheel.

Feedback: On some models (e.g., Camry hybrid), "EXCELLENT!" is displayed below the eco drive meter when the vehicle is turned off, if the trip fuel economy averaged more than 35 mpg.

Links / references:

- http://www.toyota.com/prius-hybrid/photo-gallery.html
- http://www.toyota.com/camry/photo-gallery.html
- http://www.toyota.com/highlander/photo-gallery.html
- http://www.lexus.com/models/RXh/features/interior/energy_monitor.html

Ford/Ideo – Smart Gauge with EcoGuide

(Source: Ford via autoblog.com)

Figure 24. Ford Smart Gauge - "Empower" mode displays

System basics: Original equipment expected in 2010 Ford Fusion/Mercury Milan Gas-Electric Hybrid models.

System description: Interactive system provides four levels of information to the driver from a basic “inform” mode to an information-rich “empower” mode. System acts as a coach to drivers providing real-world feedback to maximize fuel economy. User learns about display through built in tutorial mode.

Features: Customizable system displays four levels of information. “Inform” mode provides fuel level and battery charge level. “Enlighten” mode additionally shows tachometer and electric vehicle mode indicator. "Engage" mode additionally shows battery output power and engine output power. This is the default mode. "Empower" mode additionally shows accessory power consumption, engine pull-up threshold and adds power to wheels. All levels show odometer, gear the vehicle is in, engine coolant temperature, fuel economy history, instant fuel economy, trip data including miles to empty, trip fuel economy, and time elapsed fuel economy. System allows user to display long-term fuel efficiency as traditional chart in 10-, 20-, 60-minute intervals or as display that shows growing bright green leaves/vines (see rightmost section of displays in Figure 10). More vines and leaves appear as fuel economy improves, and vines and leaves disappear as fuel economy decreases. The instant fuel economy gauge can be hidden by the user at any of the four information levels. A shutdown screen allows users to view previous days' data and fuel economy performance.

Display characteristics: Two 4.3-inch (800 x 600 pixels) LCD multicolor displays located on either side of the large analog speedometer. System can show a variety of fuel-efficiency measures, as well as green leaves/vines that grow or shrink depending according to current fuel efficiency. Displays are highly customizable by the user.

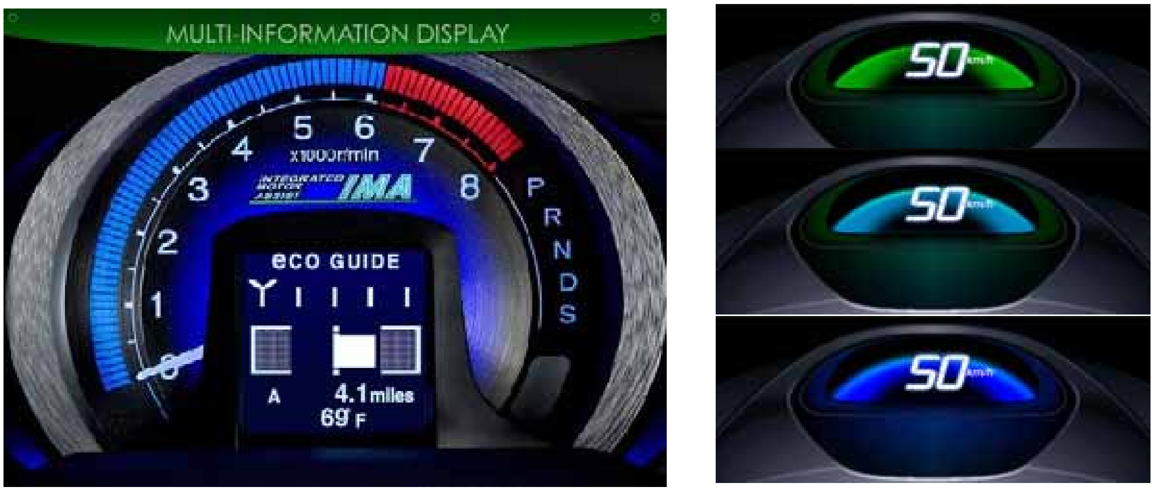
Controls: Users interact with the system using the multifunction buttons on the steering wheel.

Feedback: Ability to see long-term fuel efficiency as green leaves/vines that grow as user drives more efficiently or disappears as user drives inefficiently.

Links / references:

- http://www.ford.com/about-ford/news-announcements/press-releases/press-releases-detail/pr-ford26rsquos-smartgauge-with-29300
- http://www.autoblog.com/2008/10/29/video-ford-smartgauge-with-ecoguide-in-action/

Honda – Ecological Drive Assist System (Eco Assist)



(Source: honda.com)

Figure 25. Honda Eco Assist multi-information display (L) and speedometer (R)

System basics: Original equipment in 2010 Insight Hybrid.

System description: The system has two main features. ECON mode is activated by the driver and automatically optimizes fuel use by adapting engine and transmission parameters. The system also provides a range of real-time, trip, and long-term fuel efficiency measures aimed at helping drivers to improve their efficiency over time with a system that rewards efficient driving.

Features: Real-time information is provided through changes to the speedometer background ("Ambient Meter") color. The speedometer glows green when the driver exhibits fuel-saving behaviors such as smooth acceleration and braking. Less fuel-efficient driving makes the gauge glow blue-green, and it will glow blue when aggressive acceleration or braking consume excess fuel. In the instrument cluster, the Eco Guide feature provides a real-time relative indication of the driver's fuel efficiency. An electronic gauge shows a bar to the right of center when the driver brakes inefficiently and a bar to the left of center when the driver brakes inefficiently. The driver's goal is to keep the bar as small as possible on either side. Above the gauge is a display that provides an overall trip efficiency indication. As a driver continues to drive efficiently, leaves appear on the empty stalks. When the vehicle is turned off at the end of a drive, the overall trip score is shown in addition to a bar showing overall progress toward efficient driving. When a new level of long-term efficiency is reached, a "trophy" is awarded in the display.

Display characteristics: Color changes to speedometer background indicate fuel efficiency. A multicolor electronic display screen within the tachometer includes a linear gauge and a simple display of leaves on stalks. The display can be changed to show other measures such as fuel range and instantaneous fuel economy.

Controls: Driver can press a button on the dashboard that activates ECON mode, which is indicated by a green, stylized leaf icon in the instrument cluster.

Feedback: When the system is on, the "Ambient Meter" in the background of the speedometer changes colors to provide a relative indication of fuel economy: green is efficient, blue-green is moderate, and dark blue is inefficient. A gauge and a leaf display indicate real-time and overall trip efficiency.

Links / references:

- http://automobiles.honda.com/insight-hybrid/blog.aspx
- http://www.leftlanenews.com/honda-details-new-insights-eco-assist-efficiency-optimizer.html

6.3 Electric Vehicles

Tesla Roadster dashboard display

(Source: Tesla Roadster owner's manual)

Figure 26. Tesla Roadster dashboard display

System basics: The Tesla Roadster is one of few currently available all-electric vehicles, and achieves significantly higher mileage and on a single charge than most electric vehicles. It is also unique as a performance-oriented sports car. The energy display is located below the tachometer, and includes an ammeter, which reports the energy flowing to or from the battery in amps, as well as overall charge remaining in the battery-shaped display.

System Description: The Roadster has a simple energy-use display and shows current energy discharge or charge rate and battery life remaining. In the numerical display at the bottom right, the driver can display either the number of miles remaining before a charge is required, odometer, or trip odometer. The Roadster also has a color touchscreen display to the lower left of the dashboard through which the driver can adjust settings for a number of vehicle parameters, including battery charging.

Features: The system is limited to a simple display of battery charge, energy flow, and battery range.

Display characteristics: The energy use display uses a monochrome LCD display with numerical information, a bar that supplements the numerical energy flow data with a graphical indication of energy flow. A hollow bar extends to the right of the centerline when the battery is being discharged and a solid black bar extends to the left of the centerline when the battery is being charged. The battery life display is similar to displays used for other portable electronic devices such as cell phones and digital cameras.

Controls: Controls are limited; the only feature that the driver can control is the type of information shown in the lower right corner (battery range, odometer, trip odometer).

Feedback: None.

Links / References: www.teslamotors.com

6.4 Vehicle Adaptation Systems

<u>**Nissan – ECO Pedal**</u>

(Source: Nissan-global.com)

Figure 27. ECO indicator light

System basics: Expected to be available in select 2009 Nissan and Infiniti models.

System description: The system monitors driver gas pedal pressure and responds with a counterforce on the pedal if the driver is accelerating too quickly. The purpose of the ECO pedal is to inform drivers when they are using excess fuel and to teach more efficient behavior. Nissan research suggests that the ECO pedal can improve fuel efficiency by 5 to10 percent.

Features: The instrument panel includes a light that provides four levels of indication regarding fuel efficiency. The driver can choose to turn the system off.

Display characteristics: “Eco-driving indicator” is located in instrument panel on the speedometer and provides feedback related to the ECO pedal. The indicator lamp is off when the vehicle is stationary, green when the driver is applying appropriate pressure, flashing green when the driver is applying almost-unfavorable pressure, and amber when the driver is applying unfavorable pressure.

Controls: None.

Feedback: The ECO pedal uses tactile pressure to serve as an alert and to limit the driver's inefficient behavior. The instrument panel includes a light that provides four levels of indication regarding fuel efficiency.

Links / references: http://www.nissan-global.com/EN/NEWS/2008/_STORY/080804-02-e.html

6.5 Aftermarket Devices

Linear Logic – ScanGauge II

(Source: scangauge.com)

Figure 28. ScanGauge II menu screen (L) and display screen (R)

System basics: Aftermarket user-installed digital multi-gauge/trip computer/scan tool. Works with almost any OBD-II equipped vehicle made after 1996.

System description: Processes OBD-II data streams into useful information in a virtual gauge format. The display can be mounted within the vehicle.

Features: 12 built-in gauges, up to 25 additional gauges (depending on vehicle). Device allows entry of fuel price to calculate actual cost per mile. Allows user to program custom gauges.

Display characteristics: Monochromatic 5x7 pixel per character dot matrix. 15 character x2 line LCD. Displays up to 4 virtual gauges at once with real time output. Variety of backlight colors to match vehicles built-in instruments.

Controls: Five buttons on front of unit control all features.

Feedback: System does not provide any advisory feedback nor does it provide guidance about how to change driving behavior to improve fuel economy.

Links / references: http://www.scangauge.com

PLX Devices – Kiwi

(Source: plxkiwi.com)

Figure 29. Kiwi unit and information screens

System basics: Portable fuel-saving device that connects to OBD-II port and provides driver feedback.

System description: The system is similar in size and appearance to a cell phone or iPod. It provides feedback to drivers on how to “drive green” and optimize the efficiency of their vehicle by modifying their driving behavior. The device is designed to provide a fun, game-like experience.

Features: The device has several features or modes that are accessible by navigating through a menu system. Simple text displays show the fuel economy in miles per gallon (instantaneous, and average mpg for trip), trip distance, fuel used (gallons), cost of fuel saved, and cost of fuel used. An overall Kiwi score and horizontal bar graph shows green driving performance on a scale from 0 to 100.

Display characteristics: The device has a 2.2-inch color LED display that is designed to be mounted near the dashboard. There are several colorful display screens that may be selected.

Controls: The user interacts with the system through a five-button interface that is arranged in a circular pattern. It includes four directional buttons for menu navigation and a center button for selecting a menu option.

Feedback: The system provides visual feedback including a composite “Kiwi Score” that consists of four elements of driving behavior (smoothness, drag, acceleration, and deceleration).

Links / references:

- http://plxkiwi.com/wordpress/
- http://www.squidoo.com/reviewkiwisavegas
- http://www.juicedhybrid.com/PhotoDetails.asp?ShowDESC=N&ProductCode=KIWI_

Vacuum gauge

Figure 30. A modern vacuum gauge

System basics: Factory-installed or aftermarket round analog gauge can be installed on any vehicle.

System description: Vacuum gauges are diagnostic tools that date back to the early days of internal combustion engines. Though the gauge does not measure fuel economy directly, it can be used to give a general qualitative indication of instantaneous fuel economy. When an engine is idling, its manifold vacuum will be about 20 inches of mercury. As the accelerator is pressed and the throttle opens, the manifold pressure will become closer to atmospheric pressure gradually eliminating the vacuum and consuming more fuel. When the vehicle is decelerating with no accelerator use, the vacuum will be higher meaning that less fuel/air mixture is flowing into the engine. These gauges have some drawbacks. The qualitative fuel economy portion of the display will be meaningless unless the engine is normally aspirated and carbureted. Also, as a fuel economy gauge it is much more useful for a large engine vehicle. In a newer compact vehicle, for example, the mass of the vehicle would be low and the engine displacement small. That engine would be working at high output which would look in efficient to a vacuum gauge but be very economical in reality. Since most domestic vehicles did have large displacement engines at the time of the 1973 oil crisis, vacuum gauges became a very popular accessory for years thereafter.

Features: Displays the strength of the partial vacuum in the engines intake manifold. Usually the range is 0 to 30 inches of mercury.

Display characteristics: These gauges have been made by many manufacturers for decades. Usually they are a simple rotating needle analogue display with a circular dial between two and three inches in diameter. Newer models may be self-illuminated. The arc through which the needle sweeps may be divided into several zones which indicate whether the current fuel economy is good, fair, poor, etc. On some gauges the different zones are color coded (red for poor, green for good).

Controls: None.

Feedback: Some vacuum gauges include descriptors around the perimeter of the gauge to note whether fuel economy is good, fair, poor, etc.

Links / references:

- http://en.wikipedia.org/wiki/Manifold_vacuum
- http://auto.howstuffworks.com/1974-1978-amc-matador4.htm
- http://www.viragotech.com/fixit/FuelEconomyEngineEfficiencyPower.html
- http://www.earlycuda.org/tech/vacuum1.htm
- http://www.iwemalpg.com/Vacuum_gauge.htm

6.6 Applications for Nomadic Devices

Hunter Research and Technology – GreenMeter (version 1.0)

(Source: http://hunter.pairsite.com/greenmeter/)

Figure 31. GreenMeter carbon footprint (L) and fuel economy (R) displays

System basics: Downloadable application for Apple iPhone or iPod Touch

System description: GreenMeter can compute your vehicle's power and fuel usage characteristics, and help evaluate your driving style to increase efficiency, reduce fuel consumption and cost, and lower your environmental impact. GreenMeter uses the device's internal accelerometer to measure forward acceleration and compute engine power, fuel economy, fuel cost, carbon footprint, and oil (barrels) consumption. This system does not make use of GPS.

Features: The upper portion of the screen shows one of six different graphs, which can be switched by tapping the screen. The available graphs include engine horsepower, fuel economy, fuel consumption, fuel cost, carbon footprint (tons/10,000mi), and energy impact (oil barrels/10,000mi). The graphs show the level of each quantity across a speed range (0-100 mph). With the exception of fuel economy, all six graphs consist of a stacked bar showing portions due to rolling resistance (purple), aerodynamic drag or wind resistance (blue), and acceleration (red). The purple and blue portions are determined by vehicle characteristics and speed. The red acceleration portion is directly under driver control and can be minimized with careful throttle inputs. Together, these contributions stack up to show the total level. Drivers can use this information, in whichever graph modes are most relevant to them, to see the impact of speed and acceleration, and then choose the combination which results in the best compromise between performance and efficiency.

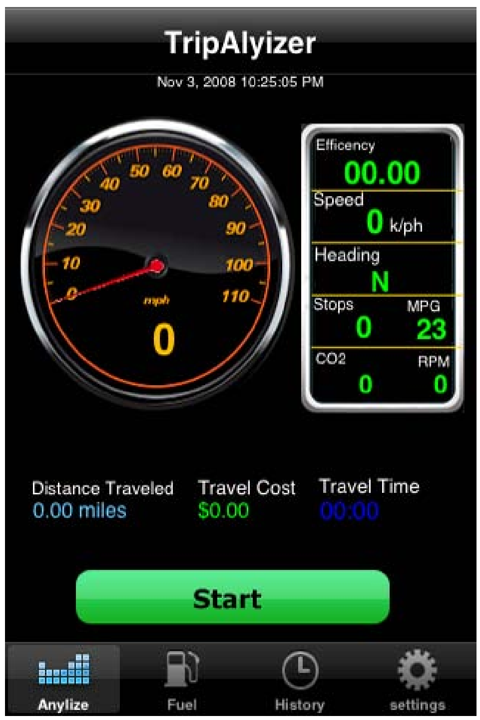
Display characteristics: Bar charts, linear indicator displays, and text fields are used. Extensive color-coding is used.

Controls: The user interacts with the system by pressing soft buttons on the iPhone or iPod touch screen. The user must enter information about several vehicle characteristics during the setup process.

Feedback: The primary form of feedback is the acceleration display. This display shows the current level of forward acceleration on a scale of 0 – 0.2g. Two thin indicator lines show the average acceleration and peak acceleration since the last time the reset button was pressed. There is no audible feedback.

Links / references: http://hunter.pairsite.com/greenmeter/

Surich Technologies, Inc. – TripAlyizer (version 1.1)



(Source: www.surichtech.com/)

Figure 32. TripAlyizer display screen

System basics: Downloadable software application for Apple iPhone.

System description: Takes advantage of the unique features of the iPhone 3G utilizing the phone's GPS, speaker, and accelerometer to determine speed, direction, distance traveled, cost per trip, time spent, “carbon footprint,” and drive efficiency percentage for each trip. The company claims that fuel savings of 20 to 30 percent are possible by improving driving habits and that this application helps the user to achieve this.

Features: Shows trip fuel economy, travel cost, number of stops, distance traveled, and an “efficiency score.” According to the company Web site, “The TripAlyizer calculates your trip efficency by measuring your average rate of acceleration, total idle time, total number of stops, speed, and total time spent in your car’s ‘sweet spot.’ Based on these values a percentage is then calculated for a trip.” This program also enables the driver to keep track of fuel use and offers reminders when it is time for an oil change.

Display characteristics: Text fields of various sizes and colors are displayed along with a large speedometer. Text to speech is used to provide auditory feedback.

Controls: The user interacts with the system by pressing soft buttons on the iPhone touch screen. The user must enter information about gasoline purchases so that system can calculate average mpg.

Feedback: Provides visual display that includes multiple text fields and a speedometer. One field is a composite “efficiency score.” It is not clear how frequently this score is updated. Version 1.1 has text-to-speech capability.

Links / references:

- http://iphoneapplicationlist.com/2008/10/28/tripalyizer/
- http://www.surichtech.com/mobile/TripAlyizer/index.htm

Fiat eco:Drive

(Source: www.motorauthority.com)

Figure 33. Fiat eco:Drive computer interface

System basics: Application available for Fiat 500 and Grande Punto vehicles equipped with Microsoft "Blue&Me" USB port. The application allows users to view trip reports on a personal computer and can be downloaded for free. Vehicles with the requisite Blue&Me technology are not currently available in the United States.

System description: Utilizes Microsoft "Blue&Me" system's USB port and records details related to driving style. User transfers data to a personal computer using a USB hard drive. The data is not intended to be viewed while driving, nor is there an option to view any instantaneous data. The system tracks fuel usage over time and provides users with a summary of performance on a variety of measures as they relate to fuel economy.

Features: Application interface allows users to track their mileage, progress, and emissions. The application analyzes the data from the drive and provides users with a performance report and tips to improve fuel economy. A separate report is prepared for each driving trip. The application also has a component called eco:Ville that lets users compare their performance with other application users.

Display characteristics: The application is viewed on a personal computer after a drive is complete. The display shows an index of fuel economy performance ("eco:Index") as well as projected savings in terms of CO2 emissions and money. The display also gives drivers feedback about individual behaviors and provides recommendations for improvements to driving style. It also shows a line chart that tracks overall fuel economy for each driving trip in the recent past.

Controls: Users view information using a PC interface. There are no in-vehicle controls.

Feedback: The application provides users with an overall index of fuel efficiency performance for each trip, on a scale from 1 to 100. Each 20-point increment is color coded from red (lowest) to green (highest). Drivers receive feedback about individual behaviors that influence fuel economy (speed, acceleration, deceleration, gear changes) on a five-star scale (with half-star increments), and the application provides recommendations for improvements to driving style. According to the Car Tech blog on CNET.com, there will be a social aspect to eco:Drive called "Ecoville," which will allow users to see the status of the community and how many drivers are utilizing the system.

Links / references:

- http://www.fiat.com/cgi-bin/pbrand.dll/FIAT_COM/home.jsp
- http://reviews.cnet.com/8301-13746_7-10073239-48.html
- http://www.motorauthority.com/gallery/fiat-ecodrive-software.html

Nissan CARWINGS Eco-drive

(Source: ZerCustoms.com)

Figure 34. Nissan Japan “Eco-Drive check” (L) and “Eco-Drive ranking” (R) displays

System basics: This system, which was announced in Japan in 2007, encourages drivers to be conscious of and improve their fuel economy. The system expands upon the CARWINGS navigation system which provides users with the most fuel-efficient route to a destination. The CARWINGS system is not available in the United States.

System description: The system informs drivers of their average fuel economy for each trip and allows them to compare with their previous trips and with other drivers.

Features: The system has three main components. “Eco-drive check” informs drivers of their average fuel economy and trend in usage over time. “Eco-drive ranking” informs drivers of their average consumption history, compares their efficiency against other drivers with the same vehicle model, and displays annual fuel expense savings attributed to efficient driving. Drivers are ranked as bronze, silver, gold, or platinum (the 10 percent of drivers who are most fuel-efficient are platinum). “Driving advice” provides drivers with tips for improved fuel economy.

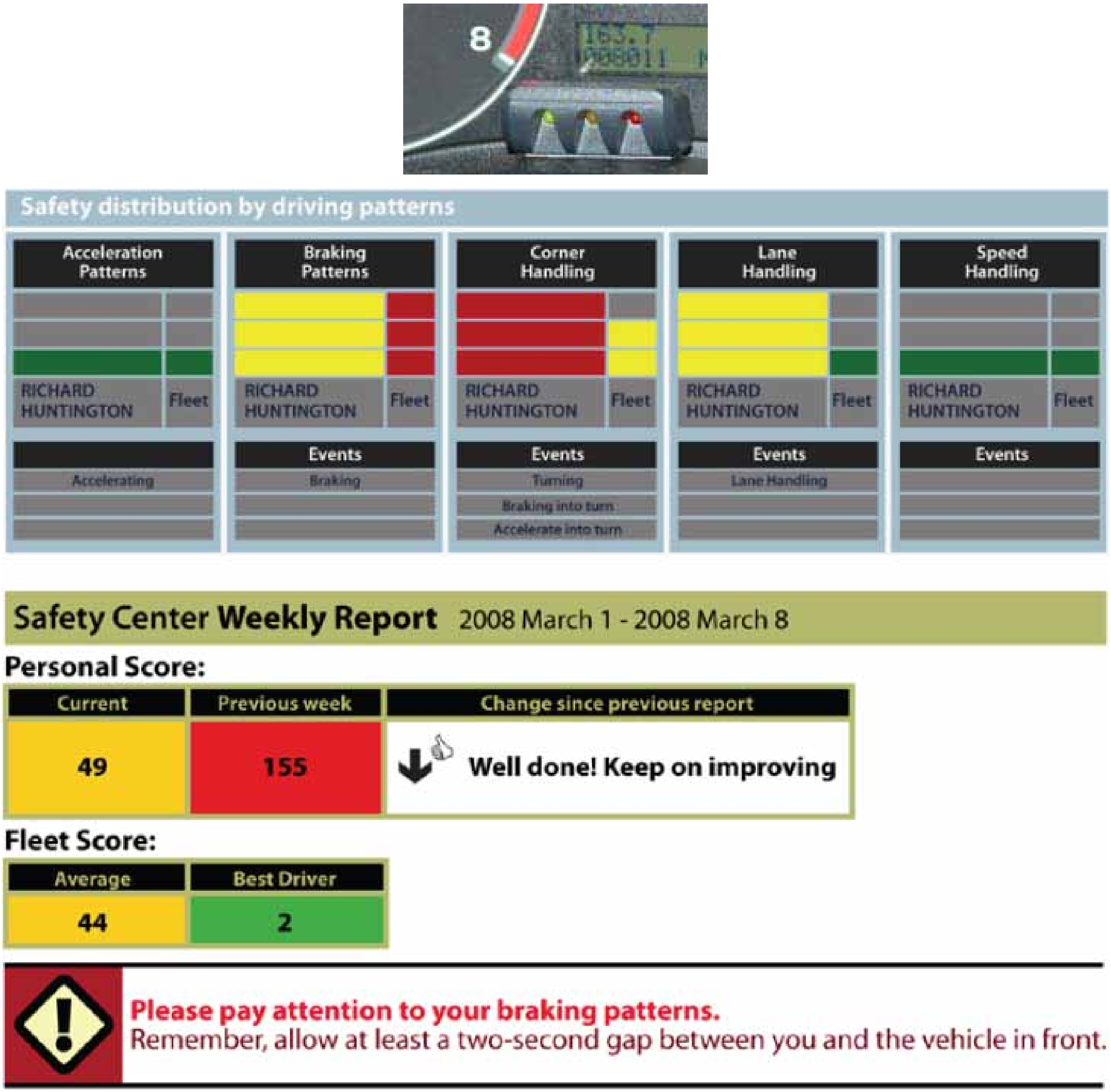
Display characteristics: Full-color visual displays show drivers’ fuel economy, trends, and ranking.

Controls: Details are not known at this time.

Feedback: Details are not known at this time.

Links / references: http://www.nissan-global.com/EN/NEWS/2008/_STORY/080204-01-e.html

GreenRoads – Safety Center



(Source: GreenRoad.com)

Figure 35. GreenRoad Safety Center display (top) and report information (bottom)

System basics: Safety Center is an aftermarket device primarily used in vehicle fleets to reduce crashes and improve fuel economy. It has also been used in programs for novice teen drivers.

System description: System combines real-time feedback, virtual coaching, and reporting to improve driver safety and fuel economy. The system evaluates drivers' speed, acceleration, braking, lane changing, and cornering. Drivers are given feedback and tips for improvement. A study by GreenRoad found that safe drivers used 7 to 11 percent less fuel than risky drivers.

Features: Drivers receive real-time information about their driving and reports are sent to drivers and/or supervisors. Drivers' behaviors are scored and compared to the fleet average, and trends in driver behavior can be tracked over time.

Display characteristics: The display consists of three indicator lights – green, yellow, and red – located below the center of the instrument cluster.

Controls: None.

Feedback: The green light indicates safe driving, yellow requires attention, and red indicates risky driving. Additional feedback and guidance is provided to drivers and supervisors via post-drive electronic reporting.

Links / references:

- http://www.greenroad.com/documents/greenroad_quickguide.pdf
- http://www.greenroad.com/documents/fuel-consumption.pdf

6.7 Heavy Trucks

__Volvo Trucks__

Figure 36. Volvo Trucks' trip-based fuel statistics (Europe)

Figure 37. Volvo truck dashboard with multifunction display

System basics: Volvo Link Sentry and Volvo Action Service are information communication services that provide remote diagnostic assistance to the driver (similar to On-Star). Volvo engineers can diagnose engine problems remotely and direct the driver to the nearest service facility. Information is transmitted to the driver for display on an LCD panel.

System description: The system tracks fuel usage over time and provides users with a summary of performance on a variety of measures as they relate to fuel usage.

Features: Application interface allows users to track their mileage, fuel consumption, and percent of fuel used on idling and for power take-off (PTO) systems. AdBlue is the percentage of diesel fuel mixture that contains an urea-based additive, and EconomyZone refers to the percentage of time that the engine was operated in a zone near the most economical engine speed (RPM). The application analyzes the data from the drive and provides users with a performance report and tips to improve fuel economy. A separate report is prepared for each driving trip.

Display characteristics: The driver's display is a rectangular color LCD panel approximately 7 inches across the diagonal. It appears to be retractable down into the dash board.

Feedback: Visual display only for fuel economy measures. Weekly summary reports on driving performance are available for fleet managers and drivers.

Notes: Kenworth Truck Company (2008) also has an available digital fuel economy display for drivers. Kenworth's Driver Information Center / Multi-function Highline Display provides a display of trip average miles per gallon and instantaneous feedback. The information center also provides an RPM sweet spot display that shows drivers the most fuel-efficient RPM zone.

Links / references:

- http://www.volvo.com/trucks/na/en-us/business_tools/sentry/sentry.htm
- http://www.kenworth.com

7 Appendix B: Patents Related to Fuel Economy Displays

Title: Fuel economy monitoring system for engines of vehicles

Patent Number: 3,922,909

Date Accepted: 1975

Abstract: A fuel economy monitoring system for vehicle engines including a linear diaphragm vacuum motor connected to the intake manifold. Movement of the diaphragm is indicated by means of a multicolored filter and lamp arrangement that transmits colors through a fiber optic bundle; colors are quickly observable by a driver within his peripheral vision to indicate by the observed engine intake manifold vacuum how the driver's throttle settings are affecting the fuel economy of the engine.

Title: Motor vehicle economy measuring instrument

Patent Number: 3,977, 238

Date Accepted: 1976

Abstract: A device is disclosed for providing an operator of a motor vehicle with a continuous indication of gas mileage and engine efficiency and operating conditions as well as an indication of the effect the operator's driving habits have upon fuel economy. A vacuum gauge device is provided, the input of which is coupled to a source of vacuum from the intake manifold of the vehicle's internal combustion engine. Two numeric scales are provided and are imprinted upon the scale plate of the gauge. A first scale calibrated in miles per gallon (or kilometers per liter) indicates the rate of fuel consumption independent of road conditions or vehicle load. The second numeric scale is calibrated in miles per hour corresponding to efficient engine operation. A reading on that scale higher than the steady speed at which the vehicle is traveling indicates less than peak operating efficiency. A marker may also be provided upon the gauge scale that indicates the proper intake manifold pressure for efficient operation during engine idling conditions. Means may also be provided adjusting out changes in readings caused by changes in atmospheric pressure.

Title: Average fuel consumption rate measuring system

Patent Number: 4,002,062

Date Accepted: 1977

Abstract: An average fuel consumption rate measuring system wherein the distance traveled by a vehicle per unit fuel consumption is computed and indicated to let the driver know the driving conditions of the vehicle and instruct the driver in economical driving. Namely, a first electrical signal is generated for every predetermined distance traveled by the vehicle and the signals are integrated to indicate the total distance traveled, while on the other hand a second electrical signal is generated for every predetermined amount of fuel consumed by the vehicle and the signals are integrated to indicate the total fuel consumption, and one of the integrated value is divided by the other to indicate an average fuel consumption rate.

Title: Fuel consumption rate indicating system for a vehicle

Patent Number: 4,136,389

Date Accepted: 1979

Abstract: This disclosure deals with a system for indicating to the driver of a vehicle the operating efficiency of a vehicle. The system senses the speed of the vehicle and a characteristic of the fuel supply system that is indicative of the fuel consumption. These two factors are combined in a dividing circuit that produces a signal indicating the fuel consumption rate which is a measure of the operating efficiency. This signal is fed to an indicator that displays the fuel consumption rate to the operator of the vehicle.

Title: Fuel consumption signaling system

Patent Number: 4,398,174

Date Accepted: 1983

Abstract: A fuel consumption signaling system for signaling both efficient and inefficient fuel consumption conditions in the engine of a motor vehicle is herein disclosed. The system comprises an alarm circuit connected in series with an indicator circuit including an indicator light connected in parallel with a vacuum-operated switch pneumatically connected to the engine manifold. An electric potential sufficient to actuate the alarm circuit, but insufficient to actuate both the indicator light and the alarm circuit, is applied across the series connected indicator and alarm circuits. When the engine is consuming fuel efficiently, the vacuum switch is open, and the electric potential is divided between the indicator circuit and the alarm circuit. The divided potential is sufficient to illuminate the indicator light, but insufficient to actuate the alarm circuit. However, when the engine consumes fuel inefficiently, the vacuum switch closes, shunting the entire electric potential across the alarm circuit, thereby actuating it. The signaling system may also include an automatic throttle plate control.

Title: Method and apparatus for indicating mileage corresponding to remaining fuel for vehicles

Patent Number: 4,400,779

Date Accepted: 1983

Abstract: A method and apparatus for indicating mileage corresponding to remaining fuel for vehicles includes a microprocessor connected to receive input signals respectively indicating a traveled distance and a consumed fuel quantity in a predetermined short period. During such time when quantity of fuel remaining in the tank is above a certain threshold level, the mileage corresponding to the remaining fuel is calculated by multiplying the remaining fuel quantity by fuel consumption (Km/l) which substantially corresponds to the average fuel consumption during a period between two recent successive fillings of the fuel tank. After the remaining quantity of fuel has reduced below the threshold level, the value of the fuel consumption is updated by increasing the weight of the momentary fuel consumption which reflects the actual running condition. The microprocessor repeatedly calculates the mileage at predetermined intervals and the numerical value of the calculated mileage corresponding to the remaining fuel is displayed on a display unit digitally.

Title: Economical driving device

Patent Number: 4,570,226

Date Accepted: 1986

Abstract: An economical driving indicator device for an automotive vehicle with an internal combustion engine, of the type indicating the instantaneous consumption of the vehicle per unit of distance traveled. The device monitors continuously the characteristics of the vehicle and transmits the monitored characteristics to a processing unit that determines the instantaneous real unit consumption, and the theoretical optimum unit consumption; and displays this information on a dial in the form of lighted areas composed of bar segments and an index indicating optimum consumption. The invention assists the driver in obtaining as economically as possible an optimum driving speed.

Title: Method and apparatus for calculating corrected vehicle fuel economy

Patent Number: 4,845,630

Date Accepted: 1989

Abstract: A method and apparatus for calculating a corrected fuel economy rate. A fuel-consuming engine that propels a ground vehicle has at least one fuel rate sensor for measuring the fuel consumption rate of the engine. The apparatus further comprises a sensor for measuring the distance traveled by the ground vehicle. Digital counters accumulate pulse counts from the sensors and the pulse counts are processed by a microprocessor to calculate the distance traveled by the ground vehicle, the fuel consumed by the engine, and the change of the kinetic energy of the vehicle. The microprocessor then corrects the fuel consumed by subtracting the weighted change of the kinetic energy of the vehicle over the sampling period. The microprocessor then calculates the ratio of the distance traveled to the corrected fuel consumed to produce a corrected fuel economy rate or its reciprocal. The ratio can be displayed on a digital display.

Title: Fuel economy display for vehicles

Patent Number: 5,693,876

Date Accepted: 1997

Abstract: An improved fuel economy device computes a filtered rate of change of instantaneous fuel economy or a filtered instantaneous fuel economy and repetitively updates a graphical display depicting the current fuel economy. The fuel economy can be displayed as a percentage of a target fuel economy, programmed by the driver or other operator of the vehicle.

Title: Fuel-use efficiency system for a vehicle for assisting the driver to improve fuel economy

Patent Number: 6,092,021

Date Accepted: 2000

Abstract: A fuel efficiency monitoring and display system for a vehicle dynamically evaluates vehicle performance parameters to detect conditions that cause excessive fuel consumption. The conditions include increased aerodynamic drag due to excessive speed, high RPM, braking and accelerating, excessive idling, and rapid throttle movements. The system dynamically estimates gross vehicle weight, roadway grade, and drag factor from monitored parameters and uses these estimates to detect inefficient fuel use. The system indicates to the driver when inefficient fuel use is detected. For example, it displays a measure of excess fuel consumed and messages indicating actions that can be taken to improve fuel economy in response to detecting inefficient fuel use.

Title: Internet-based method for determining a vehicle’s fuel efficiency

Patent Number: 6,988,033

Date Accepted: 2006

Abstract: The invention provides a method and device for characterizing a vehicle's fuel efficiency and amount of fuel consumed. The method features the steps of: 1) generating a data set from the vehicle that includes vehicle speed, odometer calculation, engine speed, load, and mass air flow; 2) transferring the data set to a wireless appliance that includes i) a microprocessor, and ii) a wireless transmitter in electrical contact with the microprocessor; 3) transmitting a data packet comprising the data set or a version thereof with the wireless transmitter over an airlink to a host computer system; and 4) analyzing the data set with the host computer system to determine a status of the vehicle's fuel efficiency.

8 Appendix C: Relevant Research Studies

The U.S. Environmental Protection Agency has conducted independent evaluations of many devices designed to save fuel. The vast majority of these did not prove to be effective. Some of the devices tested were designed to save fuel by changing driving behaviors. One example of such a device is GASTELL (Automotive Devices, Inc.), which was designed to save fuel by warning the driver about overly aggressive driving. The device operated by sensing vehicle manifold vacuum levels and providing audible and visual feedback to the driver whenever the vacuum level dropped below a preset level. The feedback unit was designed to be mounted on the vehicle dash panel. In a series of dynamometer tests and on-road studies with the device installed in four different vehicles, the EPA testers found only one driver/vehicle combination that showed any positive effect of the device on fuel economy. Based on these results, the EPA concluded that only drivers who have overly aggressive driving habits or other habits that involve excessive throttle manipulation could benefit from using the device. They also cautioned that any benefit would depend on the driver having a vehicle with fuel economy response characteristics that favorably matched the activation setting of the device, and that the driver would need to respond consistently to the device signal by refraining from aggressive driving (Barth, 1981).

The relationship between drivers' behavior and fuel economy is complex. On freeways with free flowing traffic, fuel economy is largely determined by vehicle speed where *increases* in speed beyond a vehicle-specific optimal speed (e.g., 50 mph) *reduce* fuel economy. Evans (1979) has reviewed several previous studies that show that for a given vehicle traveling at more modest average speeds within urban traffic, there is a strong linear relationship between total trip time and fuel consumed per unit distance. However, drivers who were given different sets of instructions on how to drive experienced significant differences in average fuel economy on urban roadways depending on the instructions that they followed. In one such study (Chang, Evans, Herman, & Wasielewski, 1976) seven different instruction sets were used and in some cases an in-vehicle fuel economy display was provided. This display involved the use of a vacuum gauge fuel economy meter with a dial divided into three color regions: green indicated good fuel economy, red indicated high power (and reduced fuel economy), and orange indicated intermediate power and fuel economy. The results from this study showed that in urban driving, focused attention on keeping instantaneous readings from the fuel economy meter in the green region (low acceleration) did not lead to the best fuel economy and increased trip time considerably. The complexity of the urban environment requires drivers to stop at traffic signals, slow for other traffic, and so forth. Fuel use during periods of idling while stopped was costly in terms of fuel economy. Drivers generally achieved lower fuel consumption by adjusting their speed to avoid as many stops as possible, even when this involved some rapid acceleration maneuvers to take advantage of green lights.

Evans (1979) pointed out that there is a basic problem with instantaneous fuel economy displays as a means to optimize driver behavior in an urban setting, because achieving optimal fuel efficiency on a given trip involves a very complex set of environmental factors that are outside of measurable vehicle parameters. For urban driving situations, he suggested that drivers may effectively reduce fuel consumption with the following strategies:

1) Anticipate conditions ahead so that braking is minimized. Do not accelerate to a higher speed than required if you must later slow down or stop.

2) Avoid stopped delays. Avoid using fuel when idling.

3) Use low acceleration levels, unless a higher level will contribute to achieving actions 1 and 2 above.

Claffey (1979) studied 74 drivers who drove the same vehicle (1972 Chevrolet sedan) over a fixed urban test route to determine how fuel efficiency was related to driver characteristics. He found that fuel economy was not related to the driver's age or sex. The study findings also included an assessment of the usefulness of the vacuum gauge in assisting drivers to conserve fuel. The data indicated that many drivers would use more fuel with the vacuum gauge than without it. Claffey concluded that the vacuum gauge is of little value as a dashboard instrument to help drivers save fuel, although it might be helpful for a minority of drivers who drive in an erratic manner to drive more smoothly.

A researcher from Fiat Auto (Italy) reported on an "Electronic Dashboard Device Suggesting the Driving Behavior for Improvement in Fuel Consumption" (Perri, 1982). This study investigated how fuel consumption is related to power requirements and engine speed. The author developed a rather complex car dashboard display that is a graph-type representation of engine speed (RPM) on the abscissa and log HP (horsepower) on the ordinate. The current working point of the engine is displayed within this graph as a lighted point within an LED matrix. Within the plane represented in the display, there are three colored regions that characterize three levels of fuel economy. The current vehicle speed and fuel consumption are also shown on the display in text boxes. The device was tested on a single FIAT vehicle. Based on these tests, the driving behavior recommended as "best" is that which produces high accelerations at low engine speeds and high gear ratios, but avoids full loading of the engine.

Researchers from the Netherlands and Sweden have developed and tested a sophisticated fuel-efficiency support tool that provided specific advice to the driver on how to change behavior to increase fuel economy (van der Voort, Dougherty, & van Maarseveen, 2001). The system is based on a normative model that identifies the present driving context and calculates the optimal behavior within this context. If the driver's actual behavior deviates from the optimal behavior, the device provides advice to the driver on a text screen display on how to improve his or her behavior. The system operates on inputs from existing sensors in the vehicle that measure speed, rotational velocity of the engine, clutch position, gear position, gas pedal position, braking force, steering angle, and headway. Headway measurements are used to determine if some specific piece of proposed advice, such as telling the driver to accelerate harder when there is a slower vehicle ahead, would be unsafe and counterproductive. Any unsafe advice is suppressed.

The user interface for the device includes a textual display that presents advice messages such as, "Shift earlier from 2nd > 3rd," and an accompanying LED array of red, orange and green lights that indicate the extent of deviation between actual and optimal driving behavior. Results from experiments in a driving simulator indicated that drivers using the support tool were able to reduce fuel consumption by 16 percent compared with normal driving and compared to a 9-percent reduction which was achieved by simply asking drivers to drive in a fuel-efficient manner without using the support tool. Greater improvements in fuel economy were observed in urban driving environments as compared to non-urban environments.

Researchers in Australia have described the conceptual, design, and implementation frameworks for an "Eco-Drive Agent" system (Ton, Smith, Haworth, & Regan, 2005). Unlike many previous FEDI systems that have focused on improving fuel economy only by monitoring vehicle-related parameters such as throttle position, engine speed, and gear shift position, the Eco-Drive Agent was envisioned to incorporate ITS information about the vehicle and road traffic as well as information about the vehicle. The system had four basic functions: Learning, Assessment, Advising, and Adapting. The implementation of the system relied on three artificial neural network-based models representing the relationships between road traffic, driver behavior, and vehicle performance.

More recently, German researchers have studied methods for motivating drivers to respond to feedback about fuel consumption (Kern, Holleis, & Schmidt, 2008). They conducted a focus group to help develop new aids for drivers to become more energy efficient. They asked participants about their concerns about technologies that create awareness of fuel consumption and showed paper prototype screen designs for a fuel economy display that embodied a "Personal Best" motivational strategy in which drivers would strive to achieve greater fuel economy than they had achieved in the past. Participants were shown representations including bar graphs, a simple number representation, or a red light when current fuel consumption was higher than the personal best. The focus group discussions revealed that participants were generally unaware of the costs associated with individual trips in their vehicle. Although they demonstrated that they were capable of reasoning about costs associated with driving, they usually did not. The participants suggested that the "Personal Best" approach could be extended to a community of drivers to see how one compares to others driving similar routes.

GreenRoad Technologies (2008a) has described evidence from their own internal studies for a relation between measured driving behaviors and fuel economy. Their driver monitoring/feedback device uses pattern recognition algorithms to identify and monitor up to 120 different maneuver types such as braking, lane changing, passing, speed and acceleration. The data is transmitted in a continuous stream from an in-vehicle device to a Web server where it is analyzed. Instant feedback is given to the driver in the form of red, yellow, and green lights mounted on the dashboard. Drivers are classified according to the aggressiveness of their driving style (driver risk index) into Green (low risk), Yellow (medium risk), or Red (high risk) scores. GreenRoad maintains that the risk index is an estimate of the driver's risk of future involvement in an automobile crash.

GreenRoad has found that their risk index classification is related to drivers' average fuel economy. GreenRoad staff analyzed 55 individual drivers over several months and found that those drivers who were classified at Green drivers enjoyed average fuel economy that was 2 mpg more than the fuel economy scores of Red drivers.

A research study conducted in Sweden evaluated the effects of an "acceleration advisory tool" that added resistance to a vehicle's accelerator pedal when excessive, fuel-inefficient acceleration was detected (Larsson & Ericsson, 2009). Drivers could override the resistance by pressing harder on the accelerator pedal. The system was evaluated on four small postal delivery vans driven on three different routes. Data were collected for six weeks prior to acceleration advisory activation, and for four weeks with it active. Results showed that hard accelerations and decelerations were reduced, but there was only a small reduction in emissions and no significant reduction in fuel consumption.

The literature search uncovered information about other relevant studies or product trials that are either planned or currently underway but not yet complete:

- Stagecoach Group in the United Kingdom is currently conducting a six-month trial with devices from GreenRoad Technologies. The devices will be installed in 60 buses at Barrow-in-Furness in Cumbria. Approximately 100 drivers will participate (GreenRoad Technologies, 2008b).
- Researchers from the University of California, Davis, are conducting "a qualitative field test of the effects of driver feedback on automotive fuel consumption." This study will evaluate experimental feedback through a consistent interface to a group of drivers who also may have other feedback mechanisms already in their vehicles. This study is funded by the California Department of Transportation (Transportation Research Board, 2008). A report of the results from this study is not yet available.
- A large-scale field operational test of advanced vehicle technologies is currently underway in Europe. The "euroFOT" project involves 28 partners throughout Europe and is supported by the European Commission 7th Framework Programme of Information Society Technologies. More than 1,500 equipped vehicles with data loggers will be driving over a period of approximately 1 year in various European countries. The technologies being evaluated include Forward Collision Warning, Adaptive Cruise Control, Speed Limiter, Blind Spot Information System, Lane Departure Warning and Impairment Warning, and Curve Speed Warning. A Fuel Efficiency Advisor system also will be evaluated on heavy trucks as part of this study (EuroFOT, 2008). This system is part of Volvo Truck's Dynafleet information system which provides in real time the current location of vehicles, their fuel consumption, messages, driving times, and service intervals. On-board functions for the driver and follow-up reports in the back-office system encourage fuel-efficient driving.
- Driving Change Study – Although this study is not directly concerned with fuel-efficient driving, it is relevant for inclusion in this review because it addresses similar changes in driver behavior based on feedback from in-vehicle devices. Approximately 400 people who live in Denver, Colorado, are being recruited to participate in a study that is aimed at reducing greenhouse gas emissions from vehicles by means of an in-vehicle device that provides feedback to drivers through a Web site (Driving Change, 2008). The technology used in the study is being supplied by Enviance and Cartasite. It consists of two greenhouse gas measuring devices that are installed in the vehicle. These devices also record information on driving behaviors (hard braking events, fast acceleration events, hard turn events, mileage, operational time, and idle time) and transmit data via cell phone network to an operations center. Drivers may log on to a Web site to see personalized "dashboard" graphs that allow them to review their carbon dioxide emissions and specific driving behaviors impacting those emissions.
- Transport Canada has completed initial plans to develop and study the effectiveness of devices that provide real-time display of vehicle operating costs based on data available through the OBD-II data bus (Taylor & Lee-Gosselin, 2006). The study has not yet been carried out.

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NHTSA
www.nhtsa.gov