Final Report on the Fuel Saving Effectiveness of Various Driver Feedback Approaches

Jeffrey Gonder, Matthew Earleywine, and
Witt Sparks
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Milestone Report
NREL/MP-5400-50836
March 2011

Contract No. DE-AC36-08GO28308

Final Report on the Fuel Saving Effectiveness of Various Driver Feedback Approaches

Jeffrey Gonder, Matthew Earleywine, and Witt Sparks
National Renewable Energy Laboratory

Prepared under Task No. FC10.2700

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401
303-275-3000 • www.nrel.gov

Milestone Report
NREL/MP-5400-50836
March 2011

Contract No. DE-AC36-08GO28308

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information

P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/help/ordermethods.aspx

Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721

Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.

Table of Contents

List of Figures

List of Tables

1 Executive Summary

This final report builds on the findings described in the project's interim report that was completed in September 2010 (Gonder et al. 2010). That report included a fuel economy optimization analysis for particular driving maneuvers (speed, acceleration, etc.) and discussed several existing techniques for providing driver feedback about the vehicle's fuel efficiency. This report reiterates some key findings, but the interested reader should refer to the interim report for further research details. This final report quantifies potential fuel savings from driving behavior changes and identifies factors that influence driving style decisions. Findings from these two investigation areas feed into a rigorous comparative assessment of potential driver feedback approaches. The report closes with a summary of the approach assessment and recommendations for how to maximize total fuel savings.

For quantifying potential fuel savings, the project included an outer bound assessment from complete drive profile optimization (i.e., eliminating stop-and-go driving and unnecessary idling, and adjusting acceleration rates and cruising speeds to ideal levels). Even without changing the vehicle powertrain, such extreme cycle modification would result in dramatic fuel savings of 30%–60%, but could not realistically be achieved on the road today. Considering the effects of real-world driving conditions, the most aggressively driven trips could still realize fuel savings on the order of 20% from implementing efficient driving techniques. Even starting from more moderate driving styles, efficient behaviors can reduce fuel consumption by 5%–10%. Wide-spread penetration of such efficiency improvements could result in significant aggregate fuel savings.

However, unlike efficiency technologies inherently integrated into a vehicle, realizing fuel savings from behavior modification requires drivers to be sufficiently motivated to change how they drive. Important driver behavior influences include the actions of surrounding vehicles, the general flow of traffic, anxiety over trying to get somewhere quickly, and the power/torque available from the vehicle. For many drivers, the perceived value (relative to such other influences) of a fractional reduction in their fuel budget may be insufficient to trigger them to make a concerted behavior change.

Guided by the findings on achieving fuel savings and on driver behavior influences, the National Renewable Energy Laboratory (NREL) developed an assessment process for comparing the total impact potential of various driver feedback approaches. The process included assessing how well a given approach delivered effective information and efficiency instruction to the driver. Other important considerations included the approach's ease of use and how well it avoids unintended consequences that could add to a driver's reasons not to bother with the effort.

The assessment identified efficiency feedback integrated into the original vehicle instrument display/dashboard as one of the most effective approaches considered, but few existing vehicles on the road currently include such rigorous and seamlessly integrated feedback. Two of the most promising aftermarket approaches that could be applied to legacy vehicles include getting feedback from an "app" on a person's existing smart phone and/or using a dedicated device to incorporate information from the vehicle's on-board diagnostic (OBD) port. However, adoption barriers make it unlikely that even these approaches will realize very wide penetration. While the barriers are not insurmountable (purchasing a device/foregoing other uses, mounting and calibrating it in the vehicle, etc.), they will be significant for people who may not be enthusiastic about changing their driving style to begin with.

In light of these results, this report details several recommendations for maximizing the fuel savings that could be realized through drive cycle improvements. These include considering opportunities for increasing driver receptiveness to actually make behavior changes. Examples include commercial fleets where employers have some influence over vehicle operators and/or partnering with usage-based insurance for personal vehicles so that drivers could save both on insurance premiums and on fuel cost by modifying how they drive.

Another recommendation focuses on simplifying feedback to combine basic training advice with useful reference points that utilize a vehicle's existing instrument display. Section 5 gives an example of how this could be done simply by placing stickers around a typical analog speedometer.

The final suggestion discusses leveraging intelligent vehicle advancements (lane keep assist, intelligent cruise control, active collision avoidance, etc.) to enable drivers to request active "eco-assist" from their vehicles. Recent examples exist of companies retrofitting vehicles with component technologies (developed through road safety/capacity and military research) to enable fully autonomous driving mixed with regular traffic. As highlighted, further advancement and deployment of autonomous driving technology could deliver even more dramatic and compounding fuel savings.

2 Quantifying Fuel-Saving Opportunities from Specific Driving Behavior Changes

2.1 Savings from Improving Individual Driving Profiles

2.1.1 Drive Profile Subsample from Real-World Travel Survey

The interim report (Gonder et al. 2010) included results from detailed analyses on five cycles selected from a large set of real-world global positioning system (GPS) travel data collected in 2006 as part of a study by the Texas Transportation Institute and the Texas Department of Transportation (Ojah and Pearson 2008). The cycles were selected to reflect a range of kinetic intensity (KI) values. (KI represents a ratio of characteristic acceleration to aerodynamic speed and has been shown to be a useful drive cycle classification parameter [O'Keefe et al. 2007].) To determine the maximum possible cycle improvement fuel savings, the real-world cycles were converted into equivalent "ideal" cycles using the following steps:

1. Calculate the trip distance of each sample trip.
2. Eliminate stop-and-go and idling within each trip.
3. Set the acceleration rate to 3 mph/s.
4. Set the cruising speed to 40 mph.
5. Continue cruising at 40 mph until the trip distance is reached.

To compare vehicle simulations over each real-world cycle and its corresponding ideal cycle, a midsize conventional vehicle model from a previous NREL study was used (Earleywine et al. 2010). The results indicated a fuel savings potential of roughly 60% for the drive profiles with either very high or very low KI and of 30%–40% for the cycles with moderate KI values.

Table 2-1 takes the analysis of these five cycles from the interim report a step further by examining the impact of the optimization steps one at a time in isolation. As indicated by other simulations from the interim report (Gonder et al. 2010), acceleration rate reductions can deliver some small fuel savings, but avoiding accelerations and decelerations (accel/decel) altogether saves larger amounts of fuel. This suggests that driving style improvements should focus on reducing the number of stops in high KI cycles, and not just the rate of accelerating out of a stop.

Table 2-1. Simulated fuel savings from isolated cycle improvements

Cycle Name	KI (1/km)	Distance (mi)	Percent Fuel Savings			
			Improved Speed	Decreased Accel	Eliminate Stops	Decreased Idle
2012_2	3.30	1.3	5.9%	9.5%	29.2%	17.4%
2145_1	0.68	11.2	2.4%	0.1%	9.5%	2.7%
4234_1	0.59	58.7	8.5%	1.3%	8.5%	3.3%
2032_2	0.17	57.8	21.7%	0.3%	2.7%	1.2%
4171_1	0.07	173.9	58.1%	1.6%	2.1%	0.5%

Figure 2-1 extends the analysis from eliminating stops for the five example cycles and examines the additional benefit from avoiding slow-and-go driving below various speed thresholds.

Though the additional savings at any given speed threshold are not consistent across the five cycles, each cycle does show some additional savings from reducing slow-and-go in addition to stop-and-go driving. One way for drivers to reduce stop- and slow-and-go driving is to select routes with fewer stops and drive at less congested times of day. However, drivers can also reduce stops over the course of a given driving route by watching far enough ahead to anticipate when maintaining speed will result in a stop at a red light or traffic bottleneck. If the driver instead eases off of the gas pedal to start gradually decelerating early, the light could change and the traffic could clear before the driver gets there. Such an approach not only decreases accel/decel rates but also (and more importantly) their frequency of occurrence. The report will use the term "reducing accel/decel" to refer to this combination, which the results here suggest can be an important factor, particularly for high KI/city-type driving.

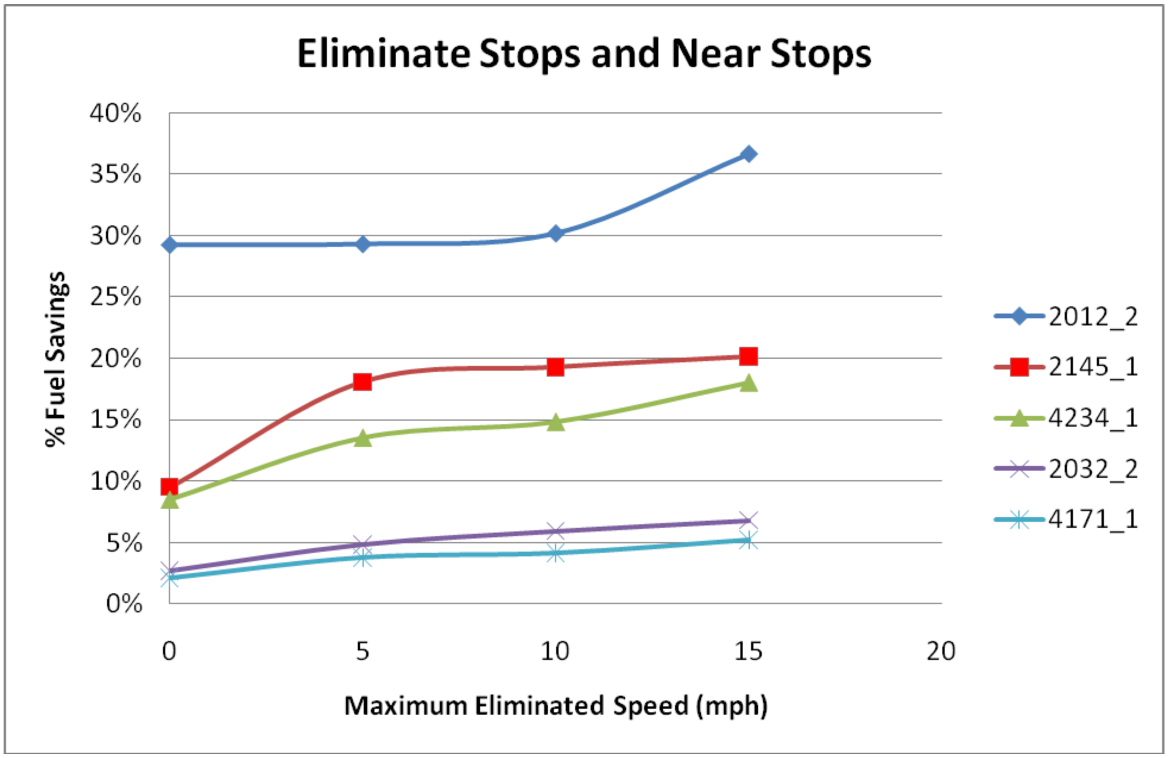

Figure 2-1. Fuel savings from eliminating stop- and slow-and-go driving

Table 2-1 also points to the importance of cruising speed optimization, particularly with respect to low-KI/highway-type driving. Figure 2-2 examines the fuel savings from speed improvement a little more closely and clarifies that the very large values in the corresponding Table 2-1 column result from significantly reducing very high driving speeds. High speeds contribute to very high fuel use because aerodynamic drag increases with the square of vehicle velocity. As a result, even more modest reductions from high speeds to around 60 mph still result in significant fuel savings.

The Table 2-1 results for eliminating idle even during short stops may be more representative of savings that a start-stop hybrid vehicle could deliver rather than what would be practical for a driver to do with a conventional vehicle. Analysis later in this section will further explore more realistic savings that a driver could realize by turning off the engine for long duration stops.

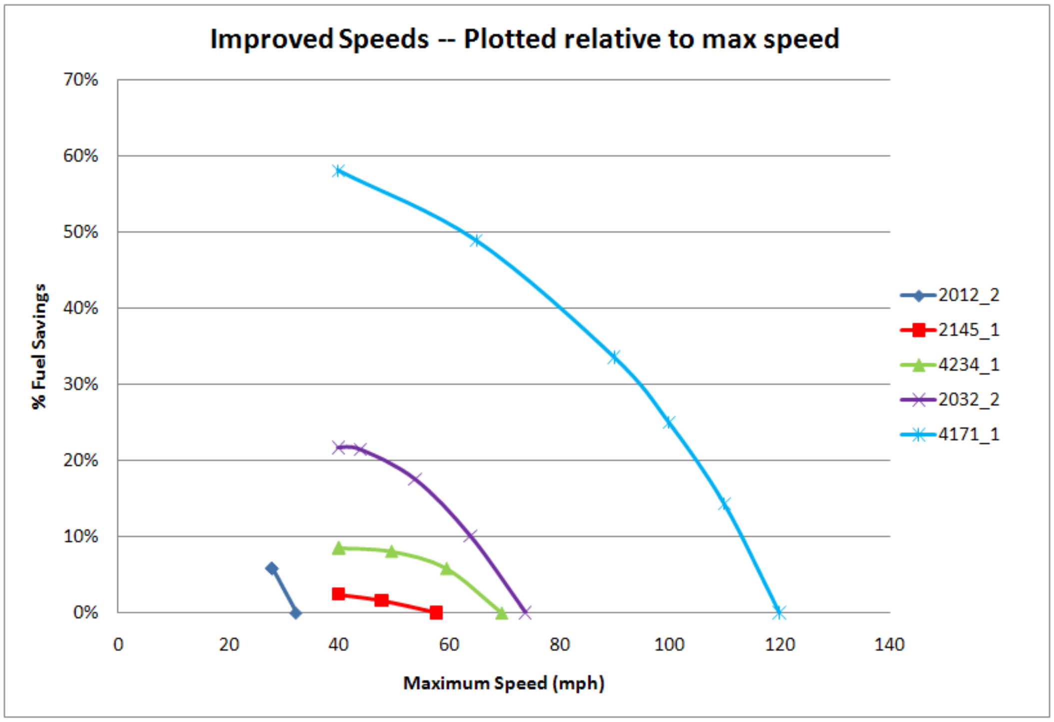

Figure 2-2. Fuel savings from optimizing vehicle speed

2.1.2 Actually Implementing Efficiency Strategies Over Repeated On-Road Routes

The analysis discussed to this point reflects theoretical savings from targeted cycle improvements that may be difficult to implement on-road. In order to observe the obstacles to efficient driving first-hand and to perform a sanity check on potential fuel savings over a constant driving route, the project team conducted a series of on-road driving experiments in the Denver area.

The two selected routes (one with city-type driving and one with highway-type driving) were designed to have cycle characterization parameters that fell in the mid range of corresponding parameters from the Texas travel survey on-road cycles (Ojah and Pearson 2008). Two drivers (M. Earleywine and J. Gonder) took turns driving the routes. While one person drove, the other sat in the passenger seat to record test observations, including apparent influences on the driver's behavior. Section IV of the interim report described the test vehicle and equipment used for recording true vehicle speed for a smart phone GPS profile evaluation study. The same test vehicle and equipment set-up were used for these driving experiments. Although this setup was able to collect reliable speed data from the vehicle's OBD port it was unable to collect reliable fuel use data. Instead, fuel use estimates were generated by simulating the collected drive profiles (with same vehicle model to be consistent with analysis using the travel survey data).

For both the city and highway routes, the drivers took turns implementing different driving behaviors. The first type of behavior was characterized as "normal," for which each driver drove as he normally would. The second behavior was "energy conscious," for which the driver attempted to drive as fuel efficiently as possible. The third behavior was characterized as "aggressive," for which the driver drove as if he were running late and hurrying to get somewhere.

Figure 2-3 shows the spread in fuel consumption results for the city route plotted against the average positive acceleration for each measured profile. The different colors represent different driving behaviors, and the different shapes represent different drivers. The legend provides an abbreviation for the driving type ("ec" for energy conscious, "norm" for normal, or "ag" aggressive) followed by the initials of the driver for the indicated cycles. Figure 2-4 provides a similar plot for the highway route, where the relative fuel consumption results are instead plotted against the average driving speed for each cycle.

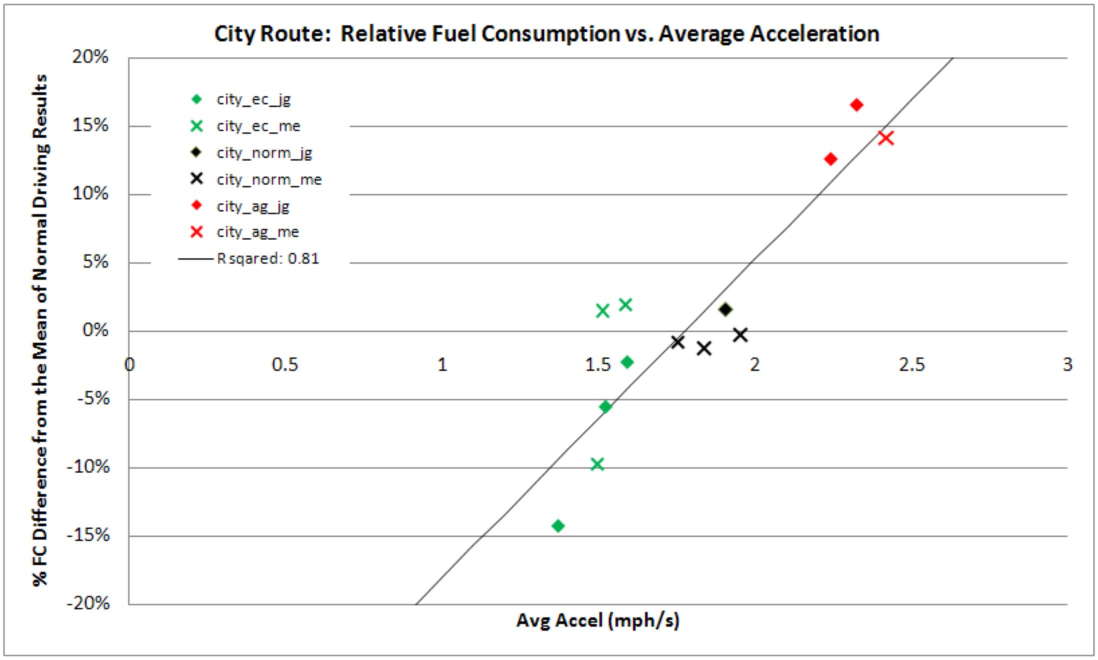

Figure 2-3. Fuel use comparison for "city" driving experiments

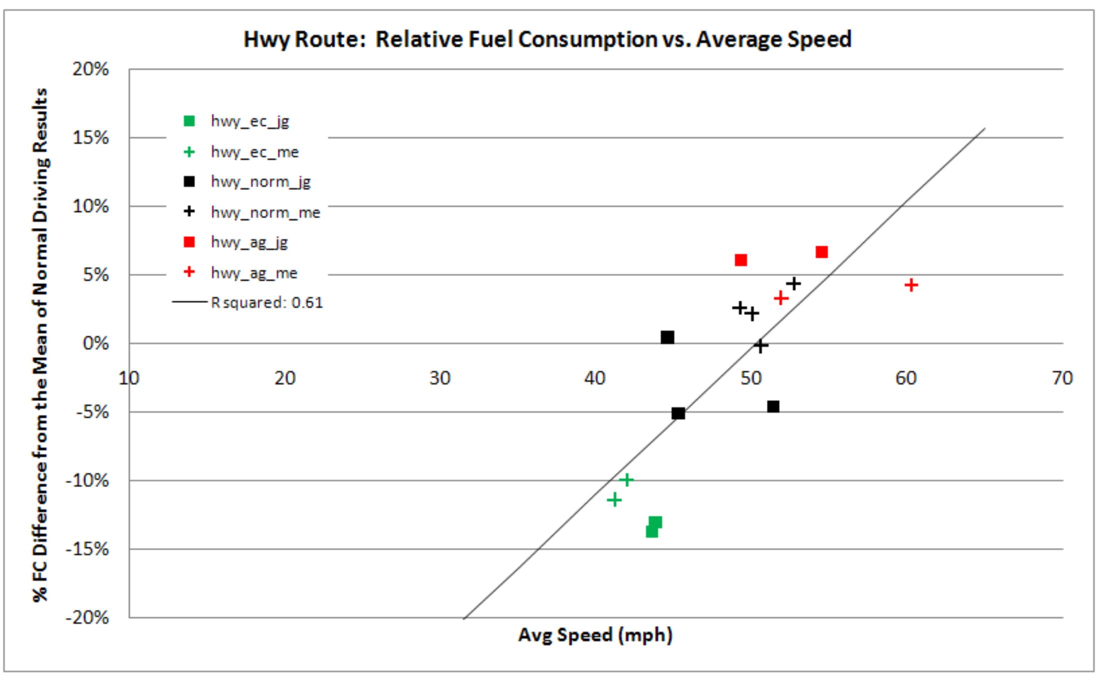

Figure 2-4. Fuel use comparison for "highway" driving experiments

Both figures show some variability in fuel consumption even when repeating a route with the same driving style. These variations likely result from differences in traffic conditions and stoplight timing from one repetition to the next. Nevertheless, fuel consumption for both routes does seem to trend lower for "energy conscious" as compared to "normal" driving and to trend higher for "aggressive" driving.

Figure 2-3 shows a 30% spread between the lowest fuel-consuming energy-conscious repetition and the highest fuel-consuming aggressive repetition of the city route. The fuel consumption differences also seem to correlate with the average positive acceleration, whereas no discernable acceleration correlation seemed to exist for the highway repetitions. This is consistent with the earlier finding that reducing accel/decel seems to carry the largest benefit in city-type driving with significant stop- or slow-and-go driving.

Figure 2-4 reveals an approximate 20% spread between the lowest fuel-consuming energy-conscious repetition and the highest fuel-consuming aggressive repetition of the highway route. The fuel consumption differences for this route seem to roughly correlate with average driving speed (whereas no such average speed correlation seems to exist for the city data). This again is consistent with the earlier findings that reducing high speeds seems to be the dominant factor for improving highway driving efficiency. While the maximum predicted savings is quite a bit higher for some the travel survey cycle adjustments, it should be noted that the top speeds for the "aggressive" NREL experiments came nowhere near those for the fastest driving vehicles in the travel survey sample.

2.2 Prevalence of Inefficient/Sub-optimal Driving

Section 2.1 analyzed potential vehicle fuel savings from changing specific driving behaviors. The prevalence of inefficient behaviors in a large real-world driving sample is assessed below, and the Texas travel survey data again provides a useful reference for this analysis (Ojah and Pearson 2008). Figure 2-5 illustrates the simulated fuel consumption results (using the color scale to the right) for each individual trip in the GPS driving sample that traversed one or more miles. The figure represents each of these nearly 4,000 trips with a small circle and positions it relative to the two axes based on the cycle characteristics (average driving speed and average positive acceleration) that seemed to correlate with fuel efficiency for the on-road driving experiments.

Previous analysis (using a national driving sample and the commonly assumed 55%/45% split between city and highway driving) suggests that an average trip speed of 42 mph makes a reasonable dividing line between city- and highway-type driving trips (SAE International 2010). To aid in this analysis, the same procedure was used to divide the second-by-second Texas trips, as illustrated by the dividing line in Figure 2-5 (with city-type trips on the left and highway-type trips on the right).

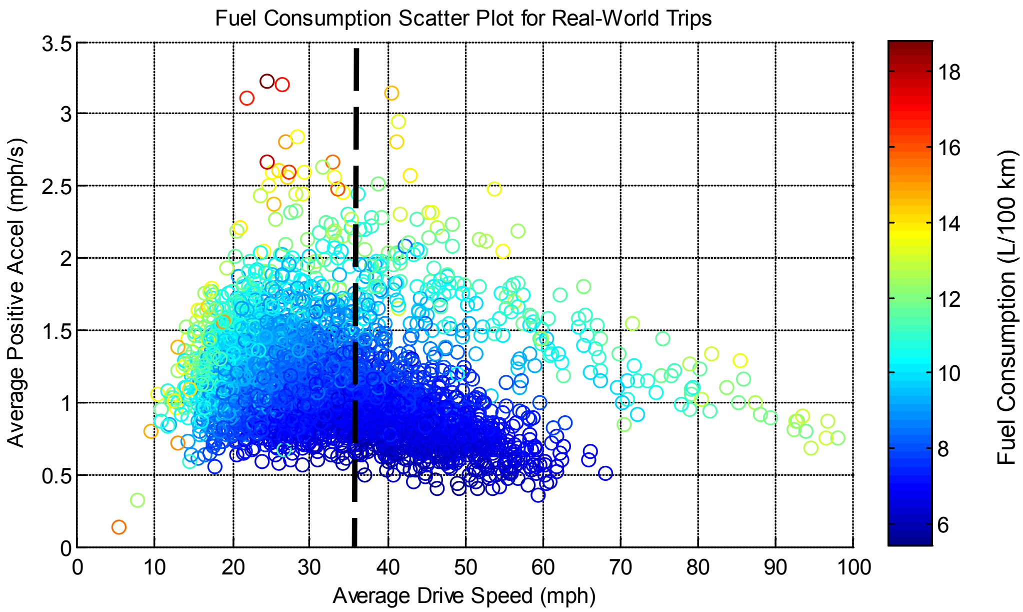

Figure 2-5. Cycle characteristics and simulated fuel consumption for nearly 4,000 real-world trips, roughly divided between city- and highway-type driving

Consistent with the on-road experiments, higher average acceleration among city trips seems to correspond with higher fuel consumption (although city trips with average speeds below 20 mph experience increased fuel consumption even with low average acceleration). For highway trips, higher average speed again seems to be the strongest indicator of poor fuel consumption (although here also high acceleration will result in high fuel consumption even at moderate average speeds).

While by no means perfect, it follows that the prevalence of city trips with high average acceleration gives a reasonable indication of the amount of driving that could benefit from feedback focused on reducing accel/decel (though such feedback could certainly provide some fuel savings in highway trips as well). The prevalence of high average speeds in the highway trip sample can similarly represent the amount of driving that could benefit from feedback focused on optimizing speed (although again, advice to maintain speeds above 20 mph could also benefit city fuel efficiency). Figures 2-6 and 2-7 present distribution plots for these cycle characteristics in the city and highway trips, respectively.

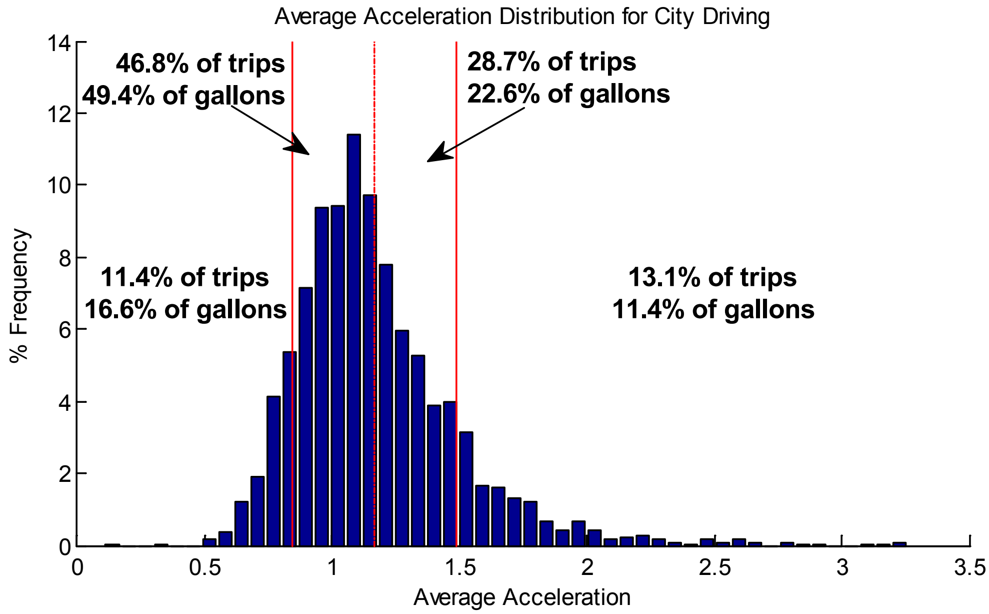

Figure 2-6. Average positive acceleration distribution in city trips

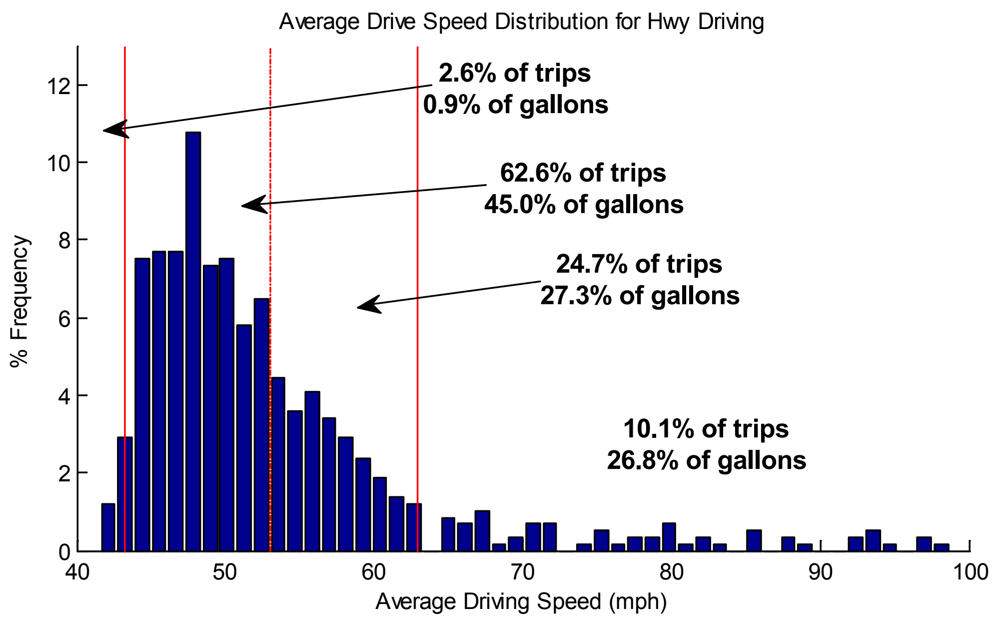

Figure 2-7. Average driving speed distribution in highway trips

The histograms in Figures 2-6 and 2-7 include a dashed line at the mean value for the distribution and a solid line at plus and minus one standard deviation from the mean. These lines divide the distribution plots into four sections, which could be assumed to represent four opportunity levels for improvement from driver feedback. In Figure 2-6 for instance, city trips with little to no acceleration improvement potential account for roughly 17% of the gallons consumed in the city-type driving trips. Similarly, city trips with medium-low, medium-high, and very high acceleration improvement potential represent roughly 49%, 23%, and 11% of fuel use, respectively.

One interesting observation from the analogous divisions in Figure 2-7 is that while only 10% of highway trips seem to have high improvement potential with respect to average driving speed, these trips represent roughly 27% of highway fuel use. Two factors accounting for this relatively large fuel use contribution include: (1) a high fuel consumption rate for all trips in this section due to the large aerodynamic drag that accompanies high driving speeds, and (2) the fact that high speed trips tend to cover large distances and therefore require more fuel.

To evaluate the potential savings from eliminating long idle periods, the idle times of all the real-world driving profiles were reduced to no more than 30 seconds, and the fuel saving was compared to the original fuel used on the given trip. Figure 2-8 displays the fuel savings distribution and three dividing lines: (1) next to the bin for cycles saving no fuel, (2) at the mean savings percentage, and (3) at the mean plus one standard deviation. While not perfect (overestimation may result from impossible idle reductions assumed by this analysis, and underestimation may result from limitations in the GPS data processing procedure to capture idling longer than two minutes), Figure 2-8 provides at least one reference point regarding the extent to which idle reduction feedback could support aggregate fuel savings.

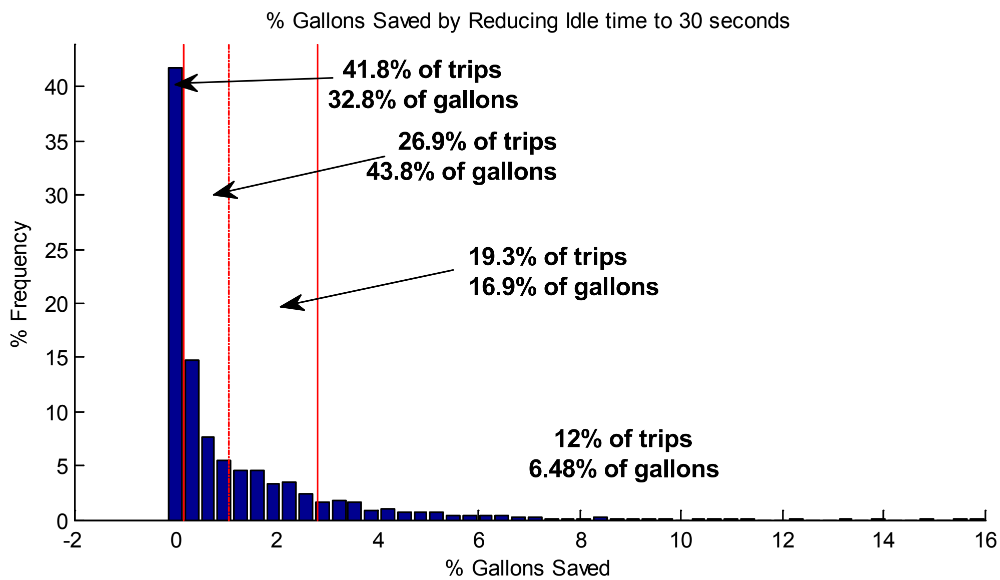

Figure 2-8. Distribution of fuel savings from eliminating long idle periods

3 Identifying Factors that Influence Drivers' Receptiveness to Adopt Efficient Behaviors

NREL consulted with experts in social science and human factors engineering for advice on what type of feedback drivers would be most receptive to receiving. The experts recommended focusing effort on understanding the context for the behaviors that could lead to fuel savings if changed. Assessing feedback approaches against the specific context would be more fruitful than framing the question around identifying the "best" specific stimulation type (light, sound, color, text, etc.). To improve contextual understanding of driving behavior influences, this section summarizes the results from a literature review and from observations during the on-road driving experiments of considerations that impact driving style decisions.

3.1 Literature Review of Driving Behavior Influences and Issues

A review of prior research found a number of studies involving fuel economy, driving behavior, and general human behavior as relating energy-saving practices. These findings are summarized below.

3.1.1 Potential for Fuel Savings

There is broad consensus from prior research that vehicle fuel savings of 10% is possible through modified driver behavior (a finding also supported by this study). Such savings can be attained through reasonably moderate behavior modification without resorting to extreme "hyper-miling" techniques. One-third of all U.S. drivers adopting eco-driving techniques would achieve an annual savings of 33 million metric tons of carbon dioxide (CO_2) and a cost savings of $7.5–15 billion (Barkenbus 2010).

Barkenbus proposes that achieving significant fuel savings through driver behavior changes requires substantial investment in a multi-faceted approach involving:

1. Public education
2. Driver feedback
3. Regulatory actions
4. Economic and policy incentives
5. Social marketing.

3.1.2 Driver Behaviors

The driving behaviors that affect fuel economy are well understood through existing research and are further supported by this study's findings. Those behaviors include:

1. Speed during highway driving.
2. KI or frequency and intensity of braking and acceleration (van der Voort et al. 2001).
3. Frequency of stops – faster acceleration is acceptable if it means that a stop is avoided (Evans 1979).
4. Timing of gear changes (van der Voort et al. 2001) – not a focus in the present study due to the current market dominance of automatic transmission vehicles.

5. Time to Collision (TTC) values – van der Voort et al. (2001) define this metric as the following distance from one car to another divided by the speed difference, in the case that the second car is overtaking the first. The study observed that drivers following an efficiency regimen tended to have fewer instances of small TTC values. This metric directly relates to KI: if the driver is trying to reduce KI, he or she will avoid rapidly approaching another vehicle and then braking to avoid collision.

3.1.3 Effect of Social Norms on Driver Behavior

Wilde (1976) identified two "axes" of norms that influence driver behavior: Legal or regulatory norms, and informal or social norms. The study posits that drivers who violate either or both of those norms are more likely to be involved in accidents because other drivers are unable to predict their actions. This conclusion is supported by evidence that drivers who travel at close to the median speed of traffic on a highway are less likely to be involved in accidents than drivers who tend to drive either faster or slower than that speed.

This finding suggests that:

1. A driver-feedback approach may have greatest success at getting drivers with very high speeds and accelerations to slow down by leveraging the natural pressure to conform more closely to the behavior of the surrounding traffic.
2. However, to the extent that driver-feedback devices encourage behavior outside the social norm for a given situation, drivers may be less willing to follow that advice because of social pressure to conform to informal norms.
3. Drivers that do follow feedback advising behavior outside normal parameters (for example, driving at a more efficient 55 mph on a roadway where the median speed is 70 mph) may put themselves at additional risk of accident.

Other research into consumer behavior related to home energy efficiency indicates that significant and lasting behavior change is possible under the right circumstances. Following a natural disaster that interrupted electricity distribution, the city of Juneau, Alaska, cut its electricity consumption by more than 30 percent. After repairs were completed, energy consumption remained 10% lower than pre-event levels (Ehrhardt-Martinez 2010).

Research suggests that social norms can be a powerful motivator in behavior change. Once such study reports that providing social comparisons can motivate households to reduce energy consumption (Allcot 2009). Residential energy consumption data are available via the utility in a top-down form that can be used to provide such comparisons. However, an analogous data set does not exist for transportation fuel use, so it is more difficult to apply such social comparisons to this domain.

The iPhone driver feedback application Bliss Trek (no longer available) attempted to do this by linking to a user's Twitter account and allowing the user to broadcast driving efficiency scores—in effect creating a competition among users. While this feature was broadcast-only, one could envision that the application could add the current highest score among application users to the device's real-time feedback to further enhance the immediacy of the competition.

3.1.4 Potential for Adoption and Use of Feedback Systems

A study of the impact of fuel economy on vehicle purchase decisions interviewed 57 households prior to 2007. The study found that most households do not have a realistic grasp of how much money they spend in a week, month or year on fuel. This result indicates that the modest fuel savings that may be associated with driver behavior modifications may not be sufficient to incentivize their adoption. The study also found that fuel economy was not named as a concern when purchasing a vehicle among most of the middle- to high-income participants (Turrentine and Kurani 2007).

In a more recent survey, Consumer Reports (2009) found that prospective vehicle buyers listed fuel economy as a top factor of interest. This survey was conducted in the wake of the 2008 fuel price spike, suggesting a possible temporary increase in concern for fuel economy. In a recent survey in Japan, J.D. Power Asia Pacific (2010) found improved customer satisfaction with auto dealers in cases where those dealers provided advice for maximizing fuel economy when driving. This further supports the thesis that consumers do have some interest in fuel economy with the right encouragement.

Taken together, these studies suggests that although consumers do have an interest in improving fuel economy, that interest is closely tied with fuel prices and perhaps also an emotional response to rapid increases in fuel price. Absent such high or increasing price conditions, potential fuel cost savings alone may not be a sufficient motivator to change driving behavior.

A recent California study of the effect of driver feedback on fuel economy included a user survey of background, likelihood, and attitude toward eco-driving. The 20 participants in the survey were concerned about climate change (7.3 on a scale of 10) and likely to adopt eco-driving techniques in the near future (7.4). They are unlikely (3.9) to purchase a driver feedback device, but likely to use one (8.0) if it comes standard with their next vehicle (Boriboonsomsin et al. 2010).

This research indicates that simply building a driver feedback device and hoping that consumers will purchase and use it will not lead to significant fuel savings overall. There must be some additional incentive or partnership that either offsets the cost of the device or provides some other benefit to incentivize its use.

Other considerations that can impact adoption and use of feedback systems include:

1. A finite time window may exist in which to educate feedback device users. For instance, after trying out efficiency lessons for a month or so, a driver will likely start paying less and less attention to instantaneous feedback instruction.
2. Feedback provided at different time scales and tied in with different events may be useful. For instance, in addition to real-time instruction while driving, cumulative feedback could be provided every few hundred miles when refueling and/or every few thousand miles when getting an oil change, etc.
3. Different solutions may work better for people with low motivation vs. those with high motivation to adopt efficient driving behaviors.

4. Feedback is most effective when it highlights benefits/savings rather than punishment/penalty, when it helps minimize any negative impacts of the behavior change, and when it specifically relates to a person's own experience/context (e.g., provides fuel economy relative to that for other drivers of the same vehicle and in the same area).

3.1.5 Design of Driver Feedback Systems

The simplest driver feedback system, an instantaneous fuel economy gauge, was evaluated in a 1977 study involving 140 test vehicles, half of which were equipped with an instantaneous fuel economy meter. Drivers were instructed to attempt to save fuel over a 12-week period. The study found that meter-equipped vehicles had on average 3% lower fuel consumption than non-equipped vehicles; however, the authors reported that they did not find this difference to be statistically significant.

Instantaneous fuel economy gauges are not especially helpful in urban driving because they do not address specific behaviors. A hypothetical driver simply attempting to maximize instantaneous fuel economy may simply try to creep along as slowly as possible (Evans 1979).

A more recent study of driver feedback systems built into existing vehicles concluded that the most effective systems provided a binary (yes/no) indication of whether or not current behavior is efficient (Graving et al. 2010). This study focused only on existing displays, so it provides little insight into which other general design elements are most effective. It also focused on a person's initial ability to interpret a display and did not take into account the display's effectiveness after the driver became accustomed to it.

3.1.6 Potential for Driver Distraction

Young and Regan (2007) looked at research into driver distraction caused by a variety of in-car devices, including entertainment systems, navigation systems, and mobile phones. The most relevant research to this study involves the level of driver distraction caused by navigating a vehicle with the aid of a navigation system. This line of research was chosen for comparison because driver feedback systems do not require the driver to provide any information to the device, only to receive and process information from the device.

The review cited research that compared a head-down electronic map, a head-up turn-by-turn guidance display with head-down electronic map, voice guidance with head-down electronic map, and paper map. The study measured driving speed, workload, navigation errors, and reaction time to external events while interacting with the navigation system.

The voice guidance/electronic map system resulted in better performance with lower workload ratings, faster mean speeds, and lower numbers of navigational errors. The study also reports that eyes-off-road times and the level of cognitive effort required to complete a task are indicators of the level of driver distraction.

From this research, we conclude that:

1. A voice or audible feedback mechanism may be preferable from a driver distraction point of view because it does not require the driver to look away from the road to take in the

information. An audio-only approach may also be more convenient for the user if it eliminates the need to mount an aftermarket display and potentially run wires to it.

2. The information provided should be made as simple to understand as possible to minimize the cognitive effort required to process it.

Van der Voort et al. (2001) suggest two approaches to providing feedback: tactical and strategic. Tactical is instantaneous feedback on acceleration, braking, and speed. This, to a large degree, is the approach taken by most of the devices surveyed as part of this study. Strategic feedback analyzes driving behavior over some time period and advises the driver in specific terms how to improve fuel economy, for example, “Let off the accelerator sooner when slowing.” The DriveGain iPhone application provides this type of advice in addition to a visual tactical display.

Because of its real-time nature, it would be difficult to present tactical feedback audibly, but strategic feedback can certainly be presented this way. Van der Voort et al. (2001) did not investigate the effects of these two feedback approaches separately. Future research may be warranted to determine whether a tactical, strategic, or combined approach is best (van der Voort et al. 2001) (Evans 1979).

In reviewing existing feedback devices, NREL found the cognitive effort required to interpret and understand the visual and audible feedback was not excessive. However, because visual systems do require taking eyes off the road, they should be designed and placed so that information can be pulled off of them with only a quick glance (less than two seconds) and conform to guidelines for mitigating driver distraction potential (Welk 2011).

3.2 Considerations Impacting Efficient Driving Decisions: Observations from On-Road Driving Experiments

To evaluate the effectiveness of a driver feedback mechanism, it is important to understand other influences on driver behavior that may or may not cause the driver to not take the advice of the feedback mechanism. To gain a better understanding of these issues, the vehicle passenger during the on-road driving experiments described in Section 2 recorded observations about various factors that influenced the driver.

One of the main observations from the on-road driving experiments was that driving at slow speeds and slow accelerations can annoy other drivers on the road. During more than one of the energy-conscious test drives, another driver honked impatiently in response to gradual accelerations. Slow speeds also cause the driver to pay more attention to vehicles behind rather than vehicles ahead since the vehicles ahead were often pulling away and the vehicles behind were tailgating. It was also observed that free-flowing traffic will often drive slightly above the posted speed limit.

In light traffic conditions, it can be easier for a motivated driver to implement fuel-efficient techniques because of not having to worry so much about holding up the vehicles behind. However, lighter traffic can also make it more difficult to drive fuel efficiently if cars are whizzing by on the left. Heavier traffic will increase the number of stops, but can also decrease the magnitude of accelerations and of high speeds. Therefore, heavy traffic has the potential to decrease the fuel consumption of an aggressive driver, although it will likely increase the fuel consumption of most vehicles if it forces additional stop-and-go traffic flow.

A particular driver may not exhibit the same types of driving behavior all of the time. If a driver is pressed for time and in a hurry, he or she will most likely drive more aggressively. If a driver is just out driving around as a sightseeing tourist with no specific time or destination in mind, he or she will tend to drive more slowly and accelerate more slowly, making it easier to drive more efficiently.

Relative to driving aggressively, driving energy-efficiently at slower speeds and lower accelerations requires less attention from the driver. An aggressive driver constantly looks ahead for opportunities to change lanes and pass other vehicles, whereas a more fuel-efficient driver can just stay in the right lane and let other vehicles pass him or her.

For powerful vehicles, it can be difficult to go at slower cruising speeds that require maintaining very light pressure on the gas pedal. Owners of powerful/sporty vehicles would also have paid a purchase premium to get a high performance vehicle and so may be reluctant not to take advantage of its full capability. It may also be true generally that fuel-efficiency feedback will have to compete against people having "more fun" driving in a sporty manner. Note that over time the vehicle market as a whole has demonstrated consumer preferences for weight and performance rather than for less powerful/slower and inherently more fuel-efficient vehicles (EPA 2010).

While considering whether a financial hardship might lead a person to change driving habits, it was noted that they may be more likely to find alternative travel modes such as public transportation, walking, biking, carpooling, etc. A driver with an acute need to reduce fuel cost might expect greater savings from such a mode change. For instance, starting a carpool and splitting fuel cost could cut expenses in half, whereas it would be difficult to achieve 50% fuel savings just by driving more efficiently.

4 Assessing Various Driver Feedback Approaches

The interim report included a survey of various existing driver feedback approaches and general comments about their strengths and weaknesses. This section contains a more rigorous assessment of the approaches in order to compare them on the basis of their fuel saving potential. This effort inherently requires some subjectivity, so the most valuable outcome may be the process developed to make the comparisons and the key considerations it takes into account. The presented values represent the authors' best effort to impartially quantify an aggregate fuel savings range that each approach could reasonably deliver. This involved applying the insights gained throughout the project that were summarized in the previous two sections.

4.1 Estimating the Savings Potential for Three Types of Behavior Change

The first step in the assessment process involves estimating the savings a feedback device would deliver if it completely succeeds in correcting inefficient driving habits. As described in Section 2, it is useful to divide prospective efficiency improvement behaviors into three general categories: (1) accel/decel reduction and smoothing, (2) speed reduction/optimization, and (3) idle time reduction.

Table 4-1 provides ballpark savings estimates for each of these behavior categories. The very high, medium-high, and medium-low values for per cycle fuel savings and frequency of occurrence are roughly distilled from the detailed analysis in Section 2. The combination of these values produces the bold percentage under each behavior heading, which is intended to approximate the aggregate fuel savings that could be achieved from maximum adoption of the particular behavior. Note that these values are not meant to be precise, but rather to provide a reasonable reference point for use in the next sub-section.

Table 4-1. Approximate savings potential for key behavior/advice categories

		Accel/decel reduction and smoothing	Speed reduction/ optimization	Idle time reduction
Per cycle fuel savings potential	Med-low	5%	8%	0.5%
	Med-high	15%	15%	2%
	Very high	30%	35%	10%
Frequency of opportunity occurrence in general population	Med-low	30%	20%	30%
	Med-high	15%	15%	15%
	Very high	8%	10%	5%
Combined savings opportunity (per cycle magnitude * frequency of occurrence)	Med-low	1.5%	1.6%	0.2%
	Med-high	2.3%	2.3%	0.3%
	Very high	2.4%	3.5%	0.5%
	Total	**6%**	**7%**	**1%**

4.2 Organizing Pertinent Considerations to Enable Detailed Side-By-Side Comparisons between Different Driver Feedback Approaches

The interim project report presented a number of approaches to driver feedback as summarized below:

- General Advice Sources – easily accessible but provide no feedback on actual driving behavior and have no competitive theme. They have the potential for a moderate overall impact.
- Driver Training Courses – unlikely to be attended by large numbers of drivers. They provide feedback on actual driving behavior. Because of limited participation, overall impact is expected to be low.
- Conventional Dashboards – many new vehicles provide both instantaneous and average mpg readouts. These displays are accessible by large numbers of people and, while the feedback provided is not extensive, the high penetration rate and ease of accessibility means they have the potential to have broad impact.
- Hybrid Vehicle Dashboards – typically have more robust feedback mechanisms built in and are highly accessible. Current purchasers of hybrid vehicles tend to be interested in fuel economy and so may be expected to utilize such information. Impact is only expected to be moderate due to the low market penetration of these vehicles.
- Smart Phone Applications – have robust feedback and may have a competitive theme, but the barriers to use are high, requiring availability of a smart phone and purchase of software and vehicle mounting devices. Lack of direct vehicle interface in most cases means that actual fuel economy cannot be determined. Impact is expected to be low due to low adoption rates.
- GPS Navigation Systems – some recent systems have driver feedback functionality built in. Without an accelerometer, though, the feedback is low-fidelity. As with smart phone applications, users must purchase and install the device. Expected impact is low.
- Offline Feedback Systems – largely limited to fleet users and require professional hardware installation. They do provide robust feedback and have the added advantage of not requiring driver attention. Because fleets may have more influence over their drivers' behavior, the impacts for fleets that use this approach may be significant.

Two additional approaches were evaluated during the second half of the project:

- Dedicated Aftermarket Feedback Devices – These are generally dashboard-mounted devices with a wired or wireless connection to the vehicle's OBD port. The OBD connection provides the device with a high-quality data feed, including fuel flow rate, engine load, and vehicle speed. This allows the device to present throttle intensity as a surrogate for acceleration without the need for an accelerometer and the associated calibration requirements. However, these devices tend to be costly (on the order of $200) and still require installation and setup.
- Haptic Pedal Feedback – In this approach, driver feedback is provided by means of a vibrating accelerator pedal. When the driver accelerates at a rate greater than what the on-board computer deems efficient, the accelerator pedal vibrates to notify the driver to accelerate more gently. This approach would need to be built into the vehicle and would have similar advantages to original equipment manufacturer-integrated dashboard feedback.

Table 4-2 summarizes the estimated fuel savings range that each of these general approach categories could obtain. The green column, “Can the Approach Work?”, rates how well a particular approach could provide effective information and driver instruction on each of the three key behaviors (accel/decel, speed, and idle time). The blue column, “Are People Likely to Use It?”, rates the level of difficulty and barriers involved in using the approach.

Due to the subjective nature of the rating process and the potential variability between specific approach implementations, the rows “Low Potential” and “High Potential” permit rating scores to be entered as a range (on a scale of 0–10). The authors attempted to assign the scores with as narrow a range as possible, but in some cases had to assign a score covering the full range.

For instance, feedback using an OBD-connected aftermarket device was given a score ranging from 6 to 10 for the approach’s ability to effectively convey information and instruction on improving accel/decel behavior. The low end score of 6 was based on critiques for a particular example device (instruction metrics could be simpler/clearer, etc.), and the high end score of 10 was based on the fact that the OBD can supply all that is needed to satisfy this assessment category. For the same approach type, the ability to effectively convey information and instruction on reducing idle time was given the full span from 0 to 10. The 10 score again reflects the fact that all necessary information (engine status, gear information, etc.) is available from the OBD, and the low-end score of 0 results from the fact that one examined example contained no feedback on idling.

The right-most column, “De-rated Opportunity,” summarizes the range of overall fuel savings that each approach category could be expected to deliver. These values represent the culmination of the assessment methodology and are based on the total potential fuel saving percentages identified above for each of the three key behaviors. To perform this calculation, the total opportunity values were de-rated using the scores in the blue and green columns. For example, starting from the 6% total potential for reducing inefficient accel/decel behavior, the high range ratings for the “OBD-Connected Aftermarket Device” feedback category are 10 for “Can the Approach Work?” and 4 for “Are People Likely to Use It?” This results in a “De-rated Opportunity” of 6% multiplied by 10/10 and then 4/10, resulting in a high range estimate of 2.4% fuel savings for this behavior category.

Table 4-2. Device assessment matrix with quantified fuel savings estimates

		Can the Approach Work? Information and instruction effectively conveyed? (0-10)			Are People Likely to Use It? Easy to use, avoids unintended consequences and trumps other behavior influences? (0-10)			De-rated Opportunity			
		Accel/Decel	Speed	Idle	Accel/Decel	Speed	Idle	Accel/Decel	Speed	Idle	Total
OBD-Connected Aftermarket Device	Low potential	6	8	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	High potential	10	10	10	4	4	4	2.4%	2.8%	0.4%	5.6%
	Comments	+ Heads-up display of mpg & accel/speed metrics + Progressively more challenging lessons/tutorials - May require calibration - Benefit vs. confusion of multiple metrics - No idle feedback			+ Easy connection to OBD - Included mount did not readily work - Significant purchase price ($200) - Drained car battery when not driven - Unable to pass all lessons - Distraction potential			Examples PLX Kiwi Eco Way			
Smart Phone Apps (using device GPS and/or accelerometer)	Low potential	5	6	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	High potential	8	8	4	4	5	4	1.9%	2.8%	0.2%	4.9%
	Comments	+ Accelerometer provides fairly good feedback + GPS provides fairly good speed readouts - Idle feedback limited w/o OBD - No feedback of actual mpg w/o OBD - Occasional accuracy issues (e.g., in tunnels, etc.)			+ No need to buy device if you already have a phone - May interfere with other uses of phone - Requires mounting in vehicle - Accelerometer requires calibration			Examples DriveGain GreenMeter			
OEM Dashboards	Low potential	8	8	5	1	1	1	0.5%	0.6%	0.1%	1.1%
	High potential	10	10	10	7	7	5	4.2%	4.9%	0.5%	9.6%
	Comments	+ Some are very well designed (Fusion, Insight) + Access to OBD data for high fidelity feedback (Idle not really a feedback issue for HEVs)			+ No installation/configuration required + Always in front of you + Access to OBD data - high fidelity feedback - Not all vehicles so equipped - Even fewer include improvement instruction			Examples Ford Fusion Honda Insight			
GPS Navigation Devices with Feedback Integrated	Low potential	2	6	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	High potential	4	8	4	4	5	4	1.0%	2.8%	0.2%	3.9%
	Comments	+ GPS provides fairly good speed feedback - No accelerometer; derivation from speed low-fi - Idle feedback limited w/o OBD - No feedback of actual mpg w/o OBD - Occasional accuracy issues (e.g., in tunnels, etc.)			+ Multi function (nav, eco-driving) means lower cost + May be already installed + Could include routing advice around traffic - May need to toggle off of nav screen for feedback - Cost to trade in/buy new to get one with feedback			Examples Garmin Eco-Route			
Offline Analysis/Driver Training	Low potential	5	5	5	0	0	0	0.0%	0.0%	0.0%	0.0%
	High potential	7	7	7	4	4	4	1.7%	2.0%	0.3%	3.9%
	Comments	+ Device can access the right data - Customized advice for driver - No real-time feedback			+ Zero potential for distraction - Requires recalling training - Requires remembering to log into feedback site - No support for putting concepts into practice			Examples Driving Change by Enviance Fiat Eco Drive: Website Report			
Haptic Pedal Feedback	Low potential	6	2	0	1	1	0	0.4%	0.1%	0.0%	0.5%
	High potential	9	5	0	7	4	0	3.8%	1.4%	0.0%	5.2%
	Comments	+ Integrated with vehicle computer data + Immediate feedback at point of application - May only address extreme throttle requests (and not promote complete smoothing)			+ No installation / configuration + No visual distraction - Must be calibrated to avoid people turning it off - Must have an equipped vehicle			Examples Ford SAE paper Nissan ECO Pedal			

5 Conclusions and Recommendations

5.1 Summary Findings

This study has shown that adopting efficient driving behaviors can result in fuel savings on the order of 20% for aggressively driven trips. Even starting from more moderate driving styles, efficient behaviors can reduce fuel consumption by 5%–10%. Wide-spread penetration of such efficiency improvements could result in significant aggregate fuel savings. However, unlike efficiency technologies inherently integrated into a vehicle, realizing fuel savings from behavior modification requires drivers to be sufficiently motivated to change how they drive. Important driver behavior influences include the actions of surrounding vehicles, the general flow of traffic, anxiety over trying to get somewhere quickly, and the power/torque available from the vehicle. For many drivers, the perceived value of a fractional reduction in their fuel budget may be insufficient relative to such other influences to trigger them to make a concerted behavior change.

For individuals who are willing to consider changing how they drive, the feedback mechanism they turn to for guidance will need to give them effective instruction on how to drive more efficiently and provide them useful reference point information (e.g., current fuel economy, acceleration rate, vehicle speed, etc.). Other important considerations for a feedback approach include its ease of use and how well it avoids unintended consequences that could add to a driver's reasons not to bother with the effort. The previous section applied all of these criteria to evaluate various existing methods.

5.1.1 Assessment Highlights

The assessment points to comprehensive feedback seamlessly integrated into the original equipment manufacturer (OEM) instrument cluster as one of the most promising methods. Unfortunately, of vehicles on the road today, only hybrid and other advanced technology vehicles seem to provide such comprehensive and seamlessly integrated feedback. (This perhaps reflects the heightened efficiency awareness of consumers in the hybrid vehicle market segment). Some conventional vehicles do display their current fuel economy, but few provide rigorous coaching on how to improve it. Many vehicles do not even provide this level of feedback, which obviously hinders the benefit that dashboard-integrated approaches can deliver to the existing vehicle fleet.

The most promising aftermarket approaches identified include: getting feedback from an "app" on a driver's existing smart phone and/or using a dedicated device to incorporate information from the vehicle's OBD port. Regarding the quality of feedback information and instruction, OBD connection provides a slight advantage (from data inputs such as reported vehicle fuel economy and idle time). However, speed/acceleration data either from the OBD or from the GPS/accelerometer on a non-connected smart phone can provide the feedback basis for the most critical fuel efficiency behaviors.

With respect to adoption barriers, these two aftermarket approaches do not fare as well. Both require mounting a device in the vehicle such that the information display is visible but does not distract the driver. An OBD connection requires purchasing a dedicated device to obtain the vehicle data. The app approach gets around the expensive device purchase requirement for those who already own a smart phone, but requires users to firmly mount and calibrate the device (to get quality accelerometer data) and to give up other uses of the phone while driving (such as making a phone call, listening to music or getting directions). These barriers are not insurmountable, but can be significant for people who may not be enthusiastic about changing their driving style to begin with.

5.2 Recommendations to Maximize Fuel Savings

5.2.1 Leverage Applications with Enhanced Incentives

Commercial vehicle fleets present one application where fuel savings motivation can significantly outweigh the influences that work against behavior change in personal vehicles. Commercial vehicles tend to use a lot of fuel, so fleet managers strongly encourage their drivers to adopt efficient behaviors. Fleets may in many cases already implement some sort of driver training and incentive program. Working with such a motivated segment of drivers could allow larger scale refinement and evaluation of particular feedback techniques, leading to further deployment of the best fuel saving approach or approaches.

Getting large numbers of people to drive their personal vehicles more efficiently could also be accomplished through increasing their incentive to do so. One way to achieve this could be to work collaboratively with insurance companies that are beginning to implement usage-based insurance (Progressive Insurance 2011). The principle behind usage-based insurance is that insurance companies can better assess risk if they have direct measurements of things like distance driven and frequency of high speeds and accelerations. The companies are willing to give policyholders a discount on their premiums in exchange for installing a device in their vehicle that can provide this information. Because these same factors that contribute to insurance risk also increase fuel use, a single device could be enhanced to monitor as well as give feedback on improving such behaviors. Drivers could then realize a double benefit from adjusting their driving style: reducing their expenses for fuel as well as for auto insurance.

5.2.2 Prepare a Simple and Widely Deployable Approach

Many people may remain reluctant to change driving habits as long as fuel prices hold steady (in order, for instance, to avoid potential angry honks/dirty looks from others for driving or accelerating too slowly). However, recent history illustrates the potential for gasoline prices to rise year after year by 10%–20% (Energy Information Administration 2011) and for this to trigger significantly increased public interest in saving fuel (Consumer Reports 2009). Gasoline prices may soon resume their upward rise, which could create a receptive environment for large deployment of an easy and straightforward driving efficiency tool.

NREL devised the simple concept described below while considering how to implement the project findings and benefits of various existing approaches into an understandable and unobtrusive efficiency guide (Gonder 2011). The general principle behind the proposed method is that an interested driver can learn the basic tenets of efficient driving from a website or short video, but it is helpful to have a corresponding in-vehicle reference point to really understand how to implement them. Aftermarket devices and original equipment manufacturer feedback displays can provide this function, albeit with limited penetration potential as discussed above. On the other hand, all vehicles contain a basic set of status gauges (speedometer, tachometer, etc.) that could be used to provide the most important driving efficiency reference information.

Simply adding “landmarks” to those gauges would provide drivers with distinct vehicle operation reference points to help implement efficient driving instructions.

Figure 5-1 shows an example of how a simple set of instructions combined with speedometer enhancements could provide driving efficiency feedback. This concept could accomplish with inexpensive stickers on an existing analog gauge what would otherwise require a legacy vehicle owner to re-purpose a smart phone or purchase and mount another expensive device. Ideally, a website (also viewable by smart phone) could expand upon the six listed tips and be interacted with at each fill-up to track progress. Note how the focus to remain between roughly 20-60 mph and to minimize speed fluctuation (keeping acceleration low) aligns with the most fuel-efficient trips plotted in Figure 2-5.

1. Watch the road, obey the law and drive safely (contributing to an accident will NOT save fuel).
2. Avoid speeds below ~20 mph and above ~60 mph (mpg progressively worsens in these regions).
3. Hold speed at a steady value in the 25-55 mph range (e.g., keep centered on or between the color bars).
4. Slow down by letting off on the gas rather than by using the brake, and do so early to minimize time at very low speeds.
5. Above 10 mph, accelerate slowly (so that at least 2–3 sec passes for every 10 mph increase in speed).
6. Turn off engine when parked (do not idle).

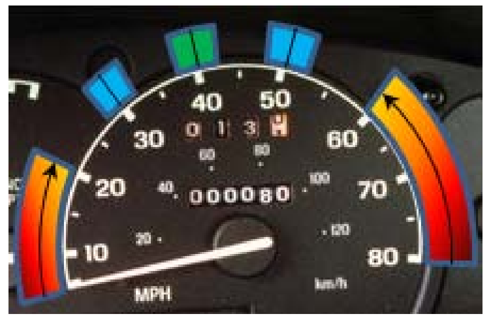

Figure 5-1. Example general advice with simple accompanying in-vehicle reference tool

5.2.3 Make It Increasingly Automatic

Another way to address the challenges of driver motivation and to increase adoption of efficient behavior is to give the vehicle more responsibility. New vehicles increasingly include safety and convenience features such as lane keep assist, adaptive cruise control, and early brake application for imminent collision avoidance. The technologies to produce these features could be used to create “green driving assist” in which the vehicle intelligently selects optimal acceleration/deceleration rates and cruising speeds. The driver’s full attention could then remain on the road to ensure safe operation (rather than occasionally diverting attention to a feedback device).

Over the past 20 years, research driven by highway safety, capacity improvement, and defense applications has dramatically advanced intelligent vehicle technologies toward even further levels of automated control. Google recently installed some of the developed component technologies in several Toyota Priuses, which have since autonomously driven thousands of miles on California roads (Markoff 2010). An Italian company has similarly retrofitted vehicles and last year demonstrated an autonomous drive from Rome, Italy, to Shanghai, China (VisLab 2010).

Continued autonomous driving advancements with an energy-efficiency focus could enable fuel savings to approach those this project calculated for complete drive profile optimization. Those savings ranged from 30%–60% over a variety of drive cycles with no changes to the vehicle. Another benefit of automation is that rather than having to convince people to change, they will instead demand the technology (independent of fuel price) for its added benefits: e.g., increased convenience and productivity and reduced accidents and time spent in congestion. The improved safety, traffic flow, and guidance aspects could also enable compounding benefits from reducing vehicle weight and powertrain size, or even connecting vehicles to electric power while driving—each of which has been shown to deliver dramatic additional fuel savings.

6 References

Allcot, H. (October 2009). “Social Norms and Energy Conservation.” Prepared for the Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology.

Barkenbus, J. N. (2010). “Eco-driving: An Overlooked Climate Change Initiative.” *Energy Policy* (38:2); pp. 762–769.

Boriboonsomsin, K.; Vu, A.; Barth, M. (2010). *Eco-Driving: Pilot Evaluation of Driving Behavior Changes*. Riverside, CA: College of Engineering—Center for Environmental Research and Technology, University of California Riverside.

Consumer Reports. (August 2009). “Car Buyers are Thinking American, with Ford, GM Up; Chrysler Down.” Accessed January 2011, from www.consumerreports.org.

Earleywine, M.; Gonder, J.; Markel, T.; Thornton, M. (September 2010). “Simulated Fuel Economy and Performance of Advanced Hybrid Electric and Plug-in Hybrid Electric Vehicles Using In-Use Travel Profiles.” *Proceedings of the 6th IEEE Vehicle Power and Propulsion Conference (VPPC).* Lille, France.

Ehrhardt-Martinez, K. (April 2010). “Policy Innovations and People: Active Participants in the Energy Revolution.” Prepared for the ACEEE 30th Anniversary Symposium: Energy and the Economic Imperative, April 2010. Washington, D.C.

Energy Information Administration, EIA. (February 2011). “Petroleum and Other Liquids—Data on Prices.” Agency website, http://www.eia.doe.gov/petroleum/data.cfm. Accessed February 16, 2011.

Environmental Protection Agency, EPA. (November 2010). “Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2010.” Technical Report EPA-420-R-10-023.
http://www.epa.gov/otaq/cert/mpg/fetrends/420r10023.pdf; pp. 5-34.

Evans, L. (1979). “Driver Behavior Effects on Fuel Consumption in Urban Driving.” *Human Factors: The Journal of the Human Factors and Ergonomics Society* (21:4); pp. 389-398.

Gonder, J. (February 2011). “Simple training aid for fuel economy improvement driver coaching.” NREL Record of Invention No. ROI-11-00049.

Gonder, J.; Earleywine, M.; Sparks, W.; Fauria, K. (September 2010). “Interim Report on the Fuel Saving Effectiveness of Various Driver Feedback Approaches.” Technical Report Deliverable to the U.S. Department of Energy Vehicle Technologies Program.

Graving, J. S.; Rakauskas, M. E.; Manser, M. P.; Jenness, J. W. (2010). “A Binary Response Method to Determine the Usability of Seven In-Vehicle Fuel Economy Displays.” *Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting*. pp. 1546-1550.

J.D. Power Asia Pacific. (September 2010). "Advising Vehicle Owners on How to Improve Fuel Economy Has a Notable Positive Impact On Satisfaction with the New-Vehicle Sales Process."

Markoff, J. (October 2010). "Google Cars Drive Themselves, in Traffic." New York Times Article, http://www.nytimes.com/2010/10/10/science/10google.html. Accessed February 20, 2011.

Ojah, M.; Pearson, D. (August 2008). "2006 Austin/San Antonio GPS-Enhanced Household Travel Survey." Texas Transportation Institute.

O'Keefe, M.; Simpson, A.; Kelly, K.; Pedersen, D. (2007) "Duty Cycle Characterization and Evaluation Towards Heavy Hybrid Vehicle Applications." *Society of Automotive Engineers Paper No. 2007-01-0302.*

Progressive Insurance. (February 2011). "Snapshot – Auto Insurance Discount." Company website, http://www.progressive.com/snapshot/. Accessed February 22, 2011.

SAE International. (September 2010). "Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using Travel Survey Data." Surface Vehicle Information Report SAE J2841.

Turrentine, T. S.; Kurani, K. S. (2007). "Car Buyers and Fuel Economy?" *Energy Policy* (35); pp. 1213-1223.

van der Voort, M.; Dougherty, M. S.; van Maarseveen, M. (2001). "A Prototype Fuel-Efficiency Support Tool." *Transportation Research Part C: Emerging Technologies* (9:4); pp. 279-296.

VisLab (October 2010). "VisLab's challenge successfully accomplished: the autonomous vehicles reached Shanghai Expo." Press release, http://vislab.it/media/press/21-VisLab%20-%2021-VIAC-done.pdf. Accessed February 20, 2011.

Welk, D. (January 2011). "Mitigating Driver Distraction with Smart Phone Connectivity…" Presentation from *The Winning Path to Connected Vehicle Solutions Telephone/ Webcast.* SAE International.

Wilde, G. J. (1976). "Social Interaction Patterns in Driver Behavior: An Introductory Review." Human Factors: The Journal of the Human Factors and Ergonomics Society (18:5); pp. 477-492.

Young, K.; Regan, M. (2007). *Driver distraction: A review of the literature.* Sydney, NSW: Australasian College of Road Safety.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
March 2011

2. REPORT TYPE
Milestone report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Final Report on the Fuel Saving Effectiveness of Various Driver Feedback Approaches

5a. CONTRACT NUMBER
DE-AC36-08GO28308

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jeffrey Gonder, Matthew Earleywine, and Witt Sparks

5d. PROJECT NUMBER
NREL/MP-5400-50836

5e. TASK NUMBER
FC10.2700

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/MP-5400-50836

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
This final report quantifies the fuel-savings opportunities from specific driving behavior changes, identifies factors that influence drivers' receptiveness to adopting fuel-saving behaviors, and assesses various driver feedback approaches.

15. SUBJECT TERMS
fuel saving behavior; driver incentives; driver feedback; fuel-efficient driving

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPHONE NUMBER *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18