

Analyzing Vehicle Fuel Saving Opportunities through Intelligent Driver Feedback

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ABSTRACT

While it is well known that “MPG will vary” based on how one drives, little independent research exists on the aggregate fuel savings potential of improving driver efficiency and on the best ways to motivate driver behavior changes. This paper finds that reasonable driving style changes could deliver significant national petroleum savings, but that current feedback approaches may be insufficient to convince many people to adopt efficient driving habits. To quantify the outer bound fuel savings for drive cycle modification, the project examines completely eliminating stop-and-go driving plus unnecessary idling, and adjusting acceleration rates and cruising speeds to ideal levels. Even without changing the vehicle powertrain, such extreme adjustments result in dramatic fuel savings of over 30%, but would in reality only be achievable through automated control of vehicles and traffic flow. Considering the effects of real-world driving conditions, efficient driving behaviors could reduce fuel use by 20% on aggressively driven cycles and by 5-10% on more moderately driven trips.

To evaluate potential receptiveness to changing driving habits, the project team conducted a literature survey of driver behavior influences and observed pertinent factors from on-road experiments with different driving styles. This effort highlighted important driver influences such as surrounding vehicle behavior, anxiety over trying to get somewhere quickly, and the power/torque available from the vehicle. Existing feedback approaches often effectively deliver efficiency information and instruction, but do not always do so in an easy way that avoids unintended consequences and helps trump other driving behavior influences. Based on these findings the report details three recommendations for maximizing fuel savings from potential drive cycle improvement: (1) Leverage applications with enhanced incentives, (2) Use an approach that makes it easy and is widely-deployable to motivated drivers, and (3) Utilize connected vehicle and automation technologies to achieve large and widespread efficiency improvements.

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INTRODUCTION

Data show that the reported fuel economy for a given vehicle can vary by plus or minus 20% across a large population of drivers [1]. Some of this variation results from differences in temperatures and road conditions encountered, but differing driver behavior also accounts for some of this spread. It stands to reason that if drivers universally adopted more efficient driving habits, then the spread in fuel economy results for any given vehicle would shift to higher values. The U.S. Department of Energy (DOE) asked the National Renewable Energy Laboratory (NREL) to evaluate the potential fuel saving opportunity from implementing driver feedback techniques and to begin evaluating which techniques may deliver the greatest aggregate fuel savings. This paper summarizes NREL's findings.

APPROACH

NREL divided the driver feedback investigation into three separate tasks: (1) quantifying the fuel saving opportunities from drive cycle modification; (2) identifying factors that influence drivers' receptiveness to adopt efficient behaviors; and (3) assessing various driver feedback approaches. NREL performed both simulations and experiments for the first task, and leveraged a conventional vehicle model from a previous study for the simulation effort [2]. The model possessed similar design and fuel economy characteristics as a midsize Chevrolet Malibu [1]. Note that this study primarily focused on conventional (rather than hybrid) vehicle performance because of DOE's interest in what driver feedback technology could do for the existing U.S. vehicle fleet, which primarily consists of conventional powertrain vehicles.

Table 1. Simulated conventional vehicle fuel savings for ideal vs. real-world cycles

Cycle Name	KI (1/mi)	Distance (mi)	Fuel Economy (mpg)		% Increase	Gallons Used		% Decrease
			Real World	Improved		Real World	Improved	
2012_2	4.55	1.3	17.0	39.5	132%	0.08	0.03	57%
2145_1	1.03	11.2	31.0	49.8	61%	0.36	0.22	38%
4234_1	0.87	58.7	30.5	52.7	73%	1.92	1.11	42%
2032_2	0.24	57.8	35.2	52.7	50%	1.64	1.10	33%
4171_1	0.16	109.4	32.7	53.1	62%	3.34	2.06	38%

The vehicle model was simulated over a variety of drive cycle conditions to observe the fuel efficiency impact. The analyzed cycles included those from a large set of real-world travel data collected in 2006 with global positioning system (GPS) devices as part of a study by the Texas Transportation Institute and the Texas Department of Transportation [3]. NREL examined the efficiency benefit from applying hypothetical modifications to the GPS drive cycles, and also observed the relative prevalence of inefficient vs. already efficient driving characteristics within the data set.

To confirm what reasonable degree of drive cycle modifications could be implemented on-road, NREL researchers variously drove an instrumented vehicle over repetitions of a “city” route with a large number of stoplights and a “highway” route with primarily interstate driving. The routes were repeated by two drivers using three different driving styles: “normal” (as the driver would normally drive); “energy conscious” (making a best effort to implement efficiency techniques while still driving safely); and “aggressive” (defined as how the driver might behave if running late to get somewhere while still doing so safely).

To evaluate driver receptiveness to feedback, NREL examined why drivers chose particular behaviors and what factors may serve as barriers to behavior change. These efforts included: (1) a literature search of driving behavior influences and issues, and (2) documenting the motivations behind driving decisions from the on-road driving experiments.

To complete the final assessment task, NREL tested several devices and evaluated various feedback approaches in the context of the first two tasks' findings-i.e., could the approach result in quantitative fuel savings, and are people likely to start driving more efficiently in response to it?

QUANTIFYING FUEL-SAVING OPPORTUNITIES

Hypothetical drive profile adjustments

To quantify the outer boundary fuel savings that could be achieved from drive cycle modification, the authors examined the idealized results of fully optimizing several cycles from the real-world data set mentioned above [3]. 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 [4]. 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.

As summarized in [Table 1](#), the results indicate a fuel savings potential in excess of 30%-40% from full cycle optimization. While these results would not be achievable in reality without full automation of vehicles and traffic control, it is promising to note such significant fuel savings from cycle modifications alone with no changes to the vehicle or powertrain.

[Figures 1](#) and [2](#) examine the impact of applying a few of the cycle optimization steps in isolation. For instance, the points along the vertical axis in [Figure 1](#) represent the fuel savings benefit solely from eliminating stops in the five sample cycles. This elimination of stop-and-go driving yields the greatest benefit for the high KI cycles (for which acceleration power demands tend to dominate due to a large number of stops in the unmodified cycles). The points to the right of the vertical axis in [Figure 1](#) represent the benefit of eliminating slow-and-go events below the indicated speed in addition to eliminating the stop-and-go, which results in a small additional savings for each cycle. Other simulations conducted as part of this study identified a small fuel savings benefit simply from reducing the rate of acceleration events, but the savings were not nearly as great as from avoiding accelerations and decelerations (accel/decel) altogether. This suggests that driving style improvements should focus on reducing the number of stops in high KI/city-type cycles, and not just the rate of accelerating out of a stop.

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

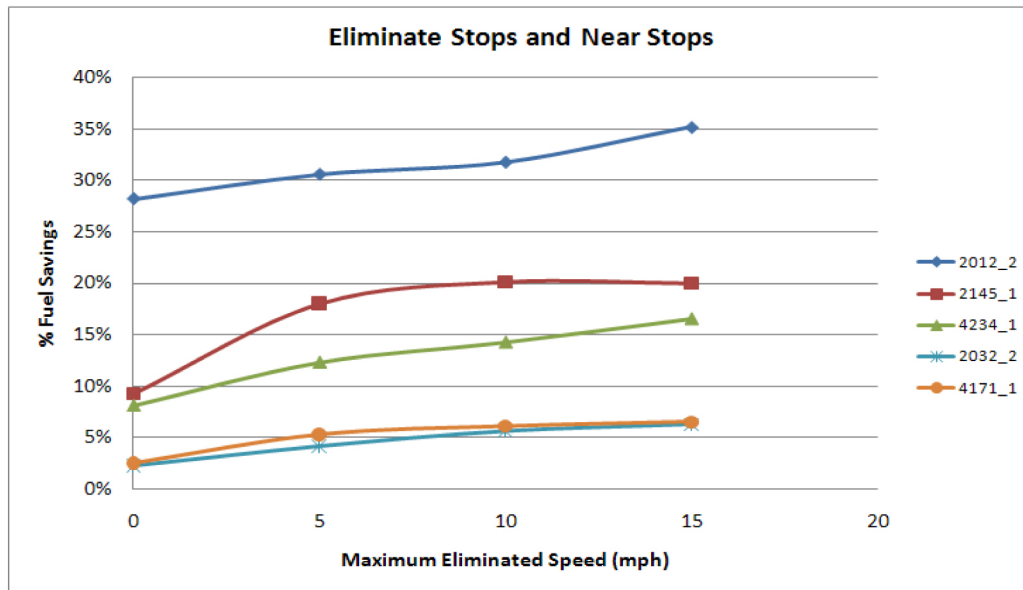


Figure 1. Fuel savings from eliminating stop- and slow-and-go driving

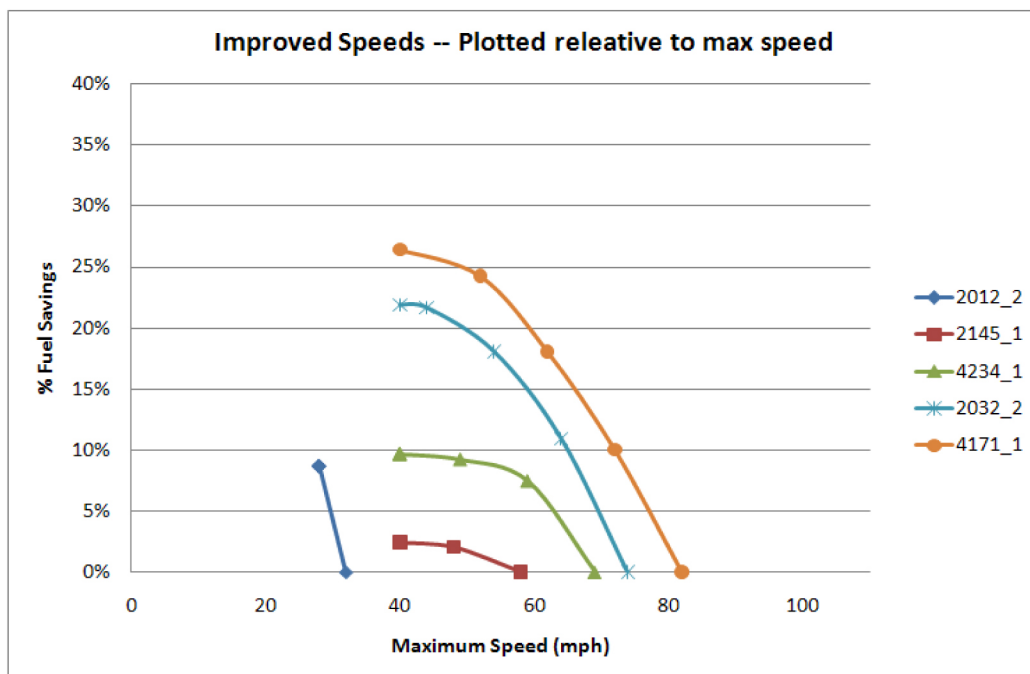


Figure 2. Fuel savings from optimizing vehicle speed

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.

Figure 2 examines the fuel savings from incremental speed optimization and highlights that the largest speed improvement savings result from cycles with the highest driving speeds. These tend to be the cycles with the lowest KI

values (where aerodynamic road loads dominate in highway-type driving). Since aerodynamic drag increases with the square of vehicle velocity, even modest reductions from very high speeds result in significant fuel savings.

Implementing efficiency strategies over repeated on-road routes

The analysis discussed to this point reflects theoretical savings from targeted cycle improvements that may be

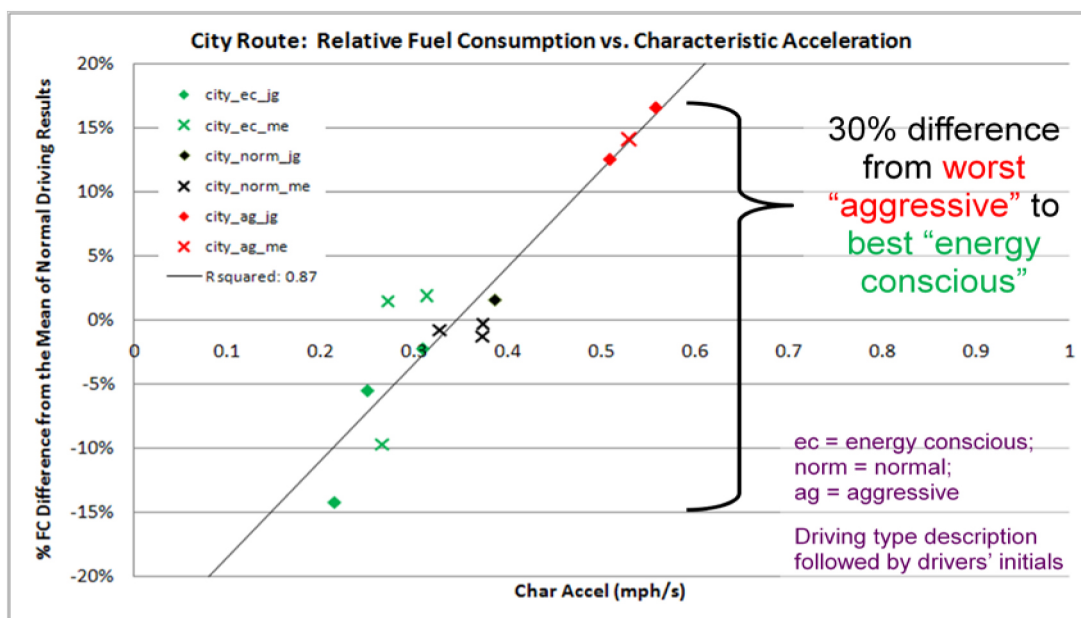


Figure 3. Fuel use comparison for "city" driving experiments

difficult to implement on-road. 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 [3]. 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. A Mercedes C100 test vehicle was used for the driving experiments, and second-by-second data were collected from the vehicle's on-board diagnostic (OBD) port. Chassis dynamometer testing verified the accuracy of the vehicle speed data collected from the OBD port, but unfortunately reliable fuel use data could not be collected. Instead, fuel use estimates were generated by simulating the collected drive profiles using the aforementioned conventional vehicle model (to be consistent with the travel survey data analysis). As described in the Approach section, each route was repeated with three different driving styles.

Figure 3 shows the spread in fuel consumption results for the city route plotted against the characteristic 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" for aggressive) followed by the initials of the driver for the indicated cycles. Figure 4 provides a similar plot for the highway route, where the relative fuel consumption

results are instead plotted against the aerodynamic driving speed for each cycle [4].

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 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 apparent correlation between fuel consumption differences and characteristic acceleration 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 events.

Figure 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 aerodynamic speed, which is again 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 of the travel survey cycle adjustments, it should be noted that the top speeds for the "aggressive" NREL experiments were much lower than those for the fastest driving vehicles in the travel survey sample.