



A report by the University of Vermont Transportation Research Center

Effects of Miles Per Gallon Feedback on Fuel Efficiency in Gas-Powered Cars

Report #10-004 | March 2010

Effects of Miles Per Gallon Feedback on Fuel Efficiency in Gas-Powered Cars

Sponsoring Agency: UVM Transportation Research Center

Co-Sponsoring Organization: Vermont Energy Investment Corporation

October 20, 2009

Prepared by:

Laura Solomon^a

Nick Lange^b

Michael Schwob^c

Peter Callas^c

^a Office of Health Promotion Research
University of Vermont
1 South Prospect Street, 429AR4
Burlington, VT 05401
(802) 656-4059
laura.solomon@uvm.edu

^b Vermont Energy Investment Corporation
255 S. Champlain Street, Suite 7
Burlington, VT 05401-4894
(802) 658-6060 x 1176
NLange@veic.org

^c Department of Mathematics & Statistics
University of Vermont
16 Colchester Avenue
Burlington, VT 05401

Acknowledgements

We would like to acknowledge the staff and management of Vermont Energy Investment Corporation (VEIC) for their generous support of this study and their assistance with data collection. We are grateful to Ron DeLong, President of Linear-Logic, for modifying the automotive computers used in the study and supplying them to us at a sharply discounted rate. We thank the employees of VEIC, Gardener's Supply, General Dynamics, Seven Days, Burlington Electric Department, and Seventh Generation for their participation in this study. Finally, we are very grateful to the UVM Transportation Research Center for funding our efforts.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the UVM Transportation Research Center. This report does not constitute a standard, specification, or regulation.

Table of Contents

Acknowledgements and Disclaimer

List of Tables and Figures

1. Introduction.....	1
1.1 Background Literature	1
1.2 Project Objectives.....	2
2. Research Methodology	3
2.1 Participants	3
2.2 Study Design and Procedure	3
2.3 Intervention.....	4
2.4 Measures	5
2.5 Sample Size	5
2.6 Data Analysis Plan	6
3. Results	7
3.1 Participation Rates	7
3.2 MPG Outcomes	7
3.3 Self-Reported Behavior Outcomes	8
3.4 Feedback About the Intervention	9
4. Implementation/Tech Transfer	10
4.1 Cost-Effectiveness Analysis	10
4.2 Application to Other Populations.....	11
5. Conclusions	13
5.1 Discussion.....	13
5.2 Suggestions for Future Research	14
References	16
Appendices	17
Tip Sheet for Lowering Your Fuel Consumption	22

List of Tables

Table 3-1. Baseline Characteristics by Condition	page 17
Table 3-2. Mean for MPG, MPH and Self-Reported Behavior Outcomes	page 18
Table 3-3. Baseline Characteristics Comparing Experimental Participants	page 19
Table 4-1. Cost-Effectiveness Assumptions	page 11

List of Figures

Figure 3-1. Percent Change in MPG by Participant.....	page 20
Figure 4-1. Months of Benefit Required to Recover Implementation Costs	page 21

1. Introduction

1.1 Background Literature

The transportation sector's contribution to global warming is responsible for 33% of United States' emissions from fossil fuel combustion^[1]. According to the US Environmental Protection Agency (EPA), a properly maintained average passenger car with annual mileage of 12,500 miles, averaging fuel consumption of 21.5 miles per gallon (MPG), consumes 581 gallons of gasoline, and emits 77.1 pounds of hydrocarbons, 11,450 pounds of CO₂, 575 pounds of CO, and 38.2 pounds of nitrogen oxides per year^[2]. Approximately 7% of all greenhouse gases released by humanity worldwide originate in the US transportation system. If current trends persist, US transportation greenhouse gases could be half again as much by 2020^[3].

Determining practical, near-term ways to reduce CO₂ emissions from transportation is critical to slowing global warming. The suggestion of a 10-year window for the avoidance of irreversible climactic catastrophe indicates that prevailing research on transportation solutions – broad implementation of alternative fuels and/or new drive train technologies – fall outside of this key time frame.

Although existing industry infrastructure and advancing technological capability are formidable challenges, the durability of cars and trucks – it takes about 16 years for the fleet to be 90% replaced^[4] – is perhaps the greatest impediment to emissions reduction in the transportation sector. Addressing the carbon contributions of cars and trucks already on the road is essential if transportation sector contributions to CO₂ reductions are to occur in the near-term.

Given the economically immutable nature of major mechanical components, nearly all approaches treat the current fleet of vehicles as lost causes for change. This ignores the important role that the vehicle operator plays in determining two of the three main factors of transportation CO₂ emissions: travel demand and fuel use rate. Correlations between these elements and driving behavior are not in question, but what is the opportunity for real improvement? Changes to the methods for presenting EPA fuel economy estimates demonstrate under-performance of past expectation on the order of 8-12% for most gas-powered cars^[5].

We could find no published US studies examining the impact of driving behavior interventions on real-world fuel economy. The few studies in the literature were conducted in Europe. A review of the European studies by the Netherlands Organization for Applied Scientific Research^[6] documents significant efficiency improvement through driving behavior changes. A subset of these behaviors have been labeled “EcoDriving” and have demonstrated efficiency improvements of 7% under average Dutch driving conditions, and effects on the order of 15-25% greater fuel economy when speed guidelines were followed^[6]. A review of a Swedish study^[7] indicates that an *intelligent speed adaption* (ISA) speed-warning device installed in the participants' vehicles reduced the amount of time participants spent above the speed limit and reduced their mean speed, although the effect decreased with time.

The unrealized fuel efficiency of most drivers is not surprising given the invisibility of actual fuel consumption feedback in most cars. Typically, fuel economy information is only accessible through personal record keeping and the mathematics of long division. This

creates a temporal and psychological disconnect between actual driving behaviors and relevant efficiency. Even when drivers bother to calculate their average MPG, these numbers are divorced in time from the conditions and context essential to their understanding: Is 23.4 MPG good or bad? What driving behaviors influence actual MPG? How much improvement can be expected?

Feedback Intervention Theory provides some guidance for understanding how familiar behaviors, such as driving habits, can be modified. According to Kluger and DeNisi^[8], feedback interventions to influence behavior are most effective when the feedback supports learning (i.e. provides new and relevant information), attracts attention to discrepancies between performance and a goal, and is evaluation neutral (i.e. does not induce affective reactions that distract attention away from the task). All of these criteria can be met by the installation of a fuel economy gauge that displays continuous, real-time MPG feedback while driving and also displays cumulative MPG averages for this trip and since installation for comparison purposes. Fortunately, all cars sold in the US since 1996 are required to conform to an on-board diagnostics standard communication protocol that allows for their simple retrofit of such devices.

Our study sought to examine the extent that drivers can meaningfully and sustainably alter their driving behavior and improve their fuel efficiency through exposure to continuous MPG feedback. The adage that “your mileage may vary” correctly asserts that factors affecting fuel efficiency are complex in real-world conditions. However, it is precisely those variable conditions within which this benefit should be demonstrated. Our study was designed to determine whether nearly 30 days of exposure to continuous, real-time feedback of fuel efficiency while driving would result in significant changes in driving behavior and subsequent fuel efficiency.

1.2 Project Objectives

This study tested the impact of continuous miles per gallon (MPG) feedback on driving behavior and fuel efficiency in gas-powered cars. We compared an experimental condition, where drivers received real-time MPG feedback and a tip sheet, to a control condition without such feedback at the time the experimental participants received it. We had three study aims:

Aim 1 was to modify the fuel efficiency obtained while driving gas-powered cars. We specifically hypothesized that mean MPG would be greater in the experimental compared to the control condition during the intervention period, and this difference would be maintained during the return-to-baseline period.

Aim 2 was to modify the driving behaviors of drivers of gas-powered cars. Our hypothesis was that participants in the experimental compared to the control condition would report engaging in more fuel efficient driving behaviors during the intervention period, and this difference would be maintained during the return-to-baseline period.

Aim 3 was to explore ways to improve the feedback display among users.

2. Research Methodology

2.1 Participants

We enrolled two waves of participants. In the first wave, 13 employees (mean age=39.9 years, $sd=9.7$, 5 males, 8 females) from three Burlington, Vermont-based worksites (Vermont Energy Investment Corporation, Seven Days, and Seventh Generation) were enrolled into a small pilot study solely to test our equipment and procedures to enable us to make modifications before progressing to the main study. Participants in the second wave, which constituted the main study, were 41 employees (mean age=46.9 years, $sd=9.2$, 24 males, 17 females) from four Burlington-based worksites (Vermont Energy Investment Corporation, Gardener's Supply, General Dynamics, and Burlington Electric Department). To be eligible for either study, participants had to (a) commute to work driving their own car or truck more than 15 minutes each way; (b) drive a gas-powered vehicle (no hybrids); (c) drive a 1996 or more recent model (requirement for use of the computer device); (d) currently have no feedback device showing continuous MPG consumption or never use it; (e) not calculate their MPG every time they filled their gas tank; (f) plan to drive the same car to work each day for the next three months; (g) have no plans to move in the next 3 months; and (h) expect that any other drivers of the car will drive it a consistent amount over the next three months.

Recruitment was conducted through emails to employees describing the study and encouraging those interested to call a University of Vermont (UVM) phone number to be screened for eligibility, and if eligible, to provide written consent through the mail. All study procedures were approved by the UVM Committee on Human Research.

2.2 Study Design and Procedure

The study followed a randomized, 2-group, repeated measures design with two waves of implementation (pilot study and main study). Within each wave, participants were randomized into either an experimental or control condition. Randomization was stratified based upon worksite and aggressive driving behavior. Aggressive driving behavior was defined by answers to two screening questions indicating endorsement of typically driving more than 70 miles per hour when the speed limit is 65 miles per hour and/or self-report of driving style as somewhat or very aggressive. In each wave, a ScanGaugeII automotive computer (described below) was installed in participants' cars for 3 or 3.5 months and logged MPG data aggregated within monthly phases.

For the first month of each wave, the computer was placed in an unobtrusive location under the dashboard, was locked into blank mode with no numerical feedback, and participants were instructed to drive normally. This was the baseline (A) period. For the second month, participants randomized to the experimental (feedback display) condition were given a printed tip sheet about driving behaviors that can improve their fuel efficiency, and the computer was relocated near the steering column and locked into feedback display mode, providing continuous MPG data while the participant was driving. This was the intervention (B₁) phase. For the third and final month, the return-to-baseline A phase, experimental participants again had their computer feedback displays locked in blank mode,

and the computers were relocated under the dashboard. This phase was included to determine if any behavior changes observed during the intervention phase would be maintained in the absence of the continuous feedback. Participants randomized to the control condition remained in the no-feedback A phase for three months. At the end of the study, they received the same printed tip sheet and two weeks of the feedback display (B₂) as a courtesy for their willingness to be in the study. Thus, the study design was as follows:

	Pilot Study (n=16)				Main Study (n=41)			
Exp. Cond.	A	B ₁	A		A	B ₁	A	
Control Cond.	A	A	A	B ₂	A	A	A	B ₂

Where A was the no-feedback phase when the computer was logging MPG data but the driver did not see it; B₁ was the experimental (driving behavior tip sheet plus feedback display for one month) intervention; B₂ was the control (driving behavior tip sheet plus feedback display for 2 weeks) courtesy intervention.

The pilot study ran from January to April 2009. The main study ran from May to August 2009. Randomization to conditions within strata occurred at the end of the first month of each wave using a SAS (Cary, NC: SAS Institute Inc) random number generator procedure.

2.3 Intervention

Tip Sheet: At the beginning of each B phase, participants received a two-sided tip sheet with information explaining the feedback gauges on one side and 11 fuel-efficiency driving suggestions on the other. The first six driving suggestions described behaviors that could be followed each time the participant drove. They included: drive at moderate speeds, avoid rapid acceleration, avoid unneeded braking, quickly shift through low gears, use cruise control on flat highways, but not hilly terrains, and avoiding idling. The last five suggestions addressed broader considerations and included: remove excess weight, properly inflate tires, don't use air conditioner or defroster when not needed, consider alternate routes and times for commutes, and combine errands into one trip. (See Appendix for a copy of the tip sheet.) These suggestions were compiled using information provided by the Environmental Protection Agency, Consumer Reports, the Department of Energy, the Union of Concerned Scientists, and Car Talk.

ScanGaugeII: The ScanGaugeII is a compact automotive computer produced by Linear-Logic [<http://www.scangauge.com/>]. It is a small, form-factor computer that calculates instantaneous fuel consumption through communication with the vehicle engine control unit via the onboard diagnostics protocol (OBDII) federally mandated for all light duty vehicles from model year 1996 and later. During the feedback phase, the computer display was locked into four simultaneous numerical gauges: instantaneous MPG, instantaneous gallons per hour (GPH), current trip MPG, and cumulative MPG, and a sticker was placed on the ScanGaugeII providing the participant with their baseline (A phase) average MPG for comparison purposes. Additionally, at the beginning of the intervention phase, we provided participants with three fuel-efficiency goals representing improvements in MPG of 10%, 15%, and 20% beyond their baseline average. These goals were written on the tip sheet and placed on the automotive computer to promote driving behavior changes during the intervention period.

2.4 Measures

MPG monitoring: The ScanGaugeII had memory capacity beyond that required to store mileage and fuel use data over the study's 30-day periods. For each phase of the study (A-B-A), the computer stored aggregated data on the following parameters: miles driven, gallons of fuel used, average MPG, average speed, and time vehicle was on. (The redundancy between these parameters permitted quality control and error-checking of the data.) At the end of each study phase, the data were recorded by study staff, memory was cleared, and the device was re-installed until the study was completed. Comparisons of MPG data between conditions and phases constituted a test of feedback impact (our first study aim).

Survey Assessments: Near the end of each study phase, we administered a 5-minute, password-protected, internet-based survey (SurveyMonkey.com) to all study participants to assess changes in specific fuel-efficient driving behaviors over the past week. Using a 7-point rating scale, where 1=not at all, and 7=every time/all the time, participants indicated how much they followed each of six fuel-saving driving behaviors (behaviors that corresponded roughly to the first six suggestions on the tip sheet). Responses to these driving behavior questions (avoided unneeded braking, used slow acceleration, drove below speed limit, shifted quickly through low gears, applied steady pressure to accelerate, and avoided idling) were aggregated into a driving behavior index, with mean scores ranging from 1 – 7, and a higher score indicative of more fuel-efficient driving. The comparison of the index scores by condition and phase addressed our second study aim. We also looked at the responses to the individual driving behaviors by condition and phase to determine which driving behaviors changed as a function of the intervention.

The monthly questionnaire administered at the end of the feedback (B) phase included additional questions appraising the feedback display and the tip sheet. These questions asked how much participants read and found useful the tip sheet, and how useful they found the computer feedback and the individual display gauges, their appeal, and any suggestions for improvements. This information enabled us to fulfill our third study aim.

2.5 Sample Size

Based on the EPA's revisions to improve calculation of fuel economy estimates^[9], we expected the average MPG during the baseline (A) phase to be 22 and that this would increase by 15% to 25.3 MPG during the B₁ phase. This 15% increase was based on the results observed in European "Eco-driving" studies^[6]. We expected no change across the A phases in the control condition. Thus, the expected mean difference between A and B, was 3.3 MPG. With a standard deviation of 3.5, for power=.9 and two-sided alpha =.05, 24 participants per condition were needed.

The sample size for the pilot study was insufficient for formal analyses, so those data were used only for the purpose of assessing and verifying our equipment and procedures. The data from the pilot study were not pooled with the data from the main study due to the possibility of seasonality effects. The pilot study was run during the winter months where average temperatures were low, but increasing from phase to phase, whereas the main study was run during the summer months where the average temperatures were moderate and relatively constant.

2.6 Data Analysis Plan

The data analysis plan is limited to the main study data due to the insufficient sample size and possibly seasonality effects of the pilot study. All analyses were conducted using procedures of SAS v9.3. Descriptive statistics were computed using PROC UNIVARIATE to check normality of outcome measures. PROC TTEST AND PROC FREQ were computed to compare conditions at baseline using t-tests and chi-square tests. Correlations between MPG and temperature as well as MPG and gas price were run using PROC CORR. Outcome measures for the two conditions were compared using repeated measures ANOVAs via the PROC GLM procedure. Models for each outcome (MPG; self-reported driving behaviors) included terms for group (experimental or control condition) as a between-subject factor, time as a within-subject factor, and any relevant interaction terms. The primary focus of the analysis was to see if there was a condition by time interaction. The term “time” is used interchangeably with the term “phase” that has been used above; that is, the study design talks about phases A, B, A, but the results talk about outcomes at 1 month, 2 months and 3 months. The reason for this is because the phases differ by condition, but the length of time matches.

3. Results

3.1 Participation Rates

A total of 30 people called to inquire about the pilot study. Of those, 16 (53%) met eligibility criteria, signed the consent form, and were enrolled. Three people were subsequently backed out of the study due to computer malfunction in the data collection during one or more phases of the study (n=1), or medical or car problems that resulted in weeks of missing data (n=2).

A total of 65 people called to inquire about the main study. Of those, 41(63%) met eligibility criteria, signed the consent form, and were enrolled. Of those who were ineligible, 67% always calculated their MPG or had a feedback display calculating it for them, 29% planned to be away for more than a week during the study period, and 21% didn't commute to work at least 4 days/week driving their own car. (Reasons exceeded 100% because respondents could endorse more than one.) An additional 15 participants were subsequently backed out of the study analyses due to (a) computer configuration errors in data collection during one or more phases of the study (n=10), or (b) medical or car problems that resulted in weeks of missing data (n=4), or (c) scheduling issues due to vacations (n=1). Of the remaining 26 participants, 12 were in the experimental condition, and 14 were in the control condition. As seen in Table 3-1 (see Appendix), there was a significant difference between the experimental condition and control condition on transmission type ($X^2=7.95$ $p=.005$). More vehicles with automatic transmissions were in the control condition.

3.2 MPG Outcomes

Our first hypothesis was that mean MPG would be greater in the experimental compared to the control condition during the intervention period (Phase B), and this difference would be maintained during the return-to-baseline (A) period. As seen in the first row of Table 3-2 (see Appendix), we did not observe a significant (condition x time) interaction ($F=1.98$ $p=0.15$). Because there were significantly more automatic transmission vehicles in the control versus experimental condition, this main analysis was re-examined with just the automatic transmission vehicles, and the interaction effect remained roughly the same ($F=1.97$, $p=.17$).

Although the hypothesized interaction was not significant, an examination of the means revealed a trend in the expected direction. Mean MPG was comparable between conditions at baseline (M=27.8 in experimental and 27.4 in control), and increased by 8.6% in the experimental condition during the intervention period, while increasing only 1.1% during this same period in the control condition. This effect was lower than the 15% differential we hypothesized, and a between-condition analysis of differences from Phase A to Phase B was not significant ($t=1.69$, $p=0.12$, 95% CI [-0.3,4.5], 80% CI [0.6,3.6]). From intervention (B) to return-to-baseline (A), mean MPG decreased by 4.0% in the experimental condition, while increasing by 0.4% in the control condition during this same time period. Again, a between-condition comparison of differences across these time points was not significant ($t=-0.98$, $p=0.34$, 95% CI [-3.9,1.3], 80% CI [-2.9,0.4]).

We further disaggregated the MPG data to reveal the variations among individuals in the experimental and control conditions. Figure 3-1 (see Appendix) shows the percent change in MPG from Phase A to B and from Phase B to A by participant in each condition. Among the 12 experimental participants, from Phase A to B only three increased their MPG by more than 10%. Table 3-3 (see Appendix) displays comparisons of baseline characteristics between these three experimental participants and the remaining nine experimental participants who demonstrated less than 10% improvement in MPG from Phase A to B. No significant differences were observed (all p s > 0.19); however, the small sample size makes finding any differences unlikely.

Because the 27 MPG average observed in both the experimental and control condition at baseline was greater than we had anticipated, we compared each participant's baseline MPG with the blended city/highway EPA average-rated MPG for their respective cars and aggregated these findings by condition. At baseline, experimental participants averaged 2.1 MPG more than the EPA average, an 8.2% higher fuel efficiency ($t=1.47$, $p=.17$), while controls averaged 2.9 MPG more than the EPA average, an 11.8 % higher fuel efficiency, which was significant ($t=3.45$, $p=.004$).

Because control participants showed a slight improvement in MPG over time, we examined two other variables that might have influenced fuel efficiency: gas price and temperature. The mean gas prices per gallon for May, June, and July 2009 were \$2.29, \$2.63, and \$2.59, respectively. The mean temperatures for May, June, and July 2009 were 57 degrees F, 64 degrees, and 67 degrees, respectively. There were strong correlations between MPG and gas price ($r=.91$) and between MPG and temperature ($r=.66$); however, neither was significant due to so few data points. Because the temperature and gas price data were not at the participant level, we could not enter them as covariates in our analyses.

We also looked at changes in driving speed (mean MPH) across conditions and time. As seen in the second row of Table 3-2, there was not a significant (condition x time) interaction for MPH ($F=0.83$, $p=0.44$).

3.3 Self-Reported Driving Behavior Outcomes

Our second hypothesis was that experimental participants compared to controls would report engaging in more fuel-efficient driving behaviors during the intervention period, and this difference would be maintained during the return-to-baseline period. All 26 participants were included in these analyses; any missing data was imputed using last observation carried forward. As shown in the third row of Table 3-2, analysis of the mean driving behavior index did not reveal a significant condition by time interaction ($F=1.98$, $p=.15$). There was a significant main effect for condition ($F=7.39$, $p=.012$), indicating the experimental participants self-reported more fuel-efficient driving behaviors than the controls across the study period. Further comparisons of differences from Phase A to Phase B between conditions ($t=1.47$, $p=0.15$) and from Phase B back to Phase A ($t=-1.54$, $p=0.14$) were not significant; however, the pattern of results were similar to those observed with the MPG data. Specifically, within the experimental condition, there was an 8.3% increase in the driving behavior index from Phase A to B, followed by a 5% decline from Phase B to A. During comparable periods in the control condition, the driving behavior index increased by 2% and 3%, respectively. Thus, the larger, although non-significant, increases occurred from

the baseline to the intervention period within the experimental condition, as hypothesized, but they were not as large as we had anticipated.

When we disaggregated the fuel-efficient driving behavior index and examined the driving behavior survey items individually, we found no significant condition by time interaction effects (all p s > .07). However, two driving behaviors, avoided braking and slowed acceleration, showed the strongest interaction trends ($p=0.07$ and 0.16 , respectively) in the predicted direction.

3.4 Feedback About the Intervention

Our final study aim was to obtain feedback from experimental participants about the automotive computer display and the tip sheet. All 12 of the experimental participants responded to the questionnaire administered at the end of the B phase. All reported receiving the tip sheet, and 92% reported that they read all of it, with 31% reporting they read it more than once. The information on the tip sheet contained some new information for 85% of participants. Fifteen percent reported that the tip sheet was very useful in changing the driving behaviors; 77% said it was somewhat useful.

All 12 experimental participants indicated they received MPG feedback from the ScanGaugeII. The instantaneous MPG gauge was considered useful by 92%, the cumulative MPG gauge was useful for 85%, the current trip MPG gauge was useful for 69% and the GPH gauge was useful for 8%. The majority (77%) found the display very easy to read, and 23% found the display somewhat easy to read. Sixty-nine percent considered the feedback display very appealing; 31% found it somewhat appealing. Several participants provided suggestions for improved placement of the ScanGaugeII, while another participant noted that GPH was not necessary and, instead, would have preferred feedback on total fuel used and speed.

4. Implementation/Tech Transfer

This study found an average MPG improvement of 7.5% over a one-month feedback period, an effect that 15% of the time would be observed by chance. This provides an unclear foundation for broad implementation of the fuel-economy feedback intervention. Although the appeal of a low-cost and easy-to-distribute feedback device that would improve fuel economy by 7.5% is strong, it must be tempered by an analysis of cost-effectiveness.

4.1 Cost-Effectiveness Analysis

If an intervention saves more money than it costs over its lifetime, then activities to promote or distribute the intervention can be said to be cost-effective. Often, these analyses find that there are interventions with intuitive appeal that may not actually pay for themselves on strictly economic grounds. The verdict may differ depending on where specific boundaries of cost and benefit are drawn. Such is the case with this intervention.

Our data suggest, owing largely to the small sample size, an interval of 95% confidence ranging from -1% to 16%. Thus, it is unlikely that the average effect would be negative. Because negative effects can be expected to be minimal, the analysis can be limited to a consideration of the cost-effectiveness as applied to the average participant experience. Therefore, the following analysis focuses only on the average individual, and the US averages of 12,500 miles per year, 22 MPG, and a behavioral feedback intervention providing the study-observed 7.5% improvement in MPG.

In consideration of the uncertain nature of fuel prices, and the variability in the degree and duration of savings from the intervention, a simple payback approach was applied to the cost-effectiveness question. The simple payback period is the amount of time it takes to realize financial savings to recoup the initial cost of the intervention without consideration for future discount rates or fuel escalation. The limits of simple payback in this instance are such that were the price of gas to increase faster than the rate of inflation, then the payback period would be overstated. The opposite would be true were inflation to outpace the price of fuel. Conveniently, the competing effects due to time are presumed to balance out, and the current monetary values and price of fuel (\$2.50/gallon) are used.

Because the savings from this intervention can result only through a sustained influence on driving behavior, and because we only followed participants for one month post-intervention, the persistence of the suggested savings is difficult to estimate. Although the electronic components of the intervention could easily operate for at least as long as the car is driven, the longevity of the device, itself, provides only an upper limit to the lifetime of the savings. With scant literature guidance to help discern the degree of the persistence of the savings beyond that suggested by our study's single month of intervention, our analysis looked at the effect of persistence on the cost-effectiveness of the intervention at various implementation costs.

Figure 4-1 (see Appendix) plots the months of benefit required to recover the intervention cost for two different implementation models. The continuous model assumes that feedback devices are distributed to drivers and are never removed. The training model assumes a one-month period of feedback before removal. The assumptions used to generate the cost-effectiveness curves are shown in Table 4-1.

Table 4-1. Cost-Effectiveness Assumptions

<i>Implemented Model</i>	<i>Continuous</i>	<i>Training</i>
Admin Cost per Driver	\$20	\$30
Drivers per Device	1	8
Retail Cost per Device	\$170	
Intervention Cost per Driver	\$190	\$51
First Month's Benefit	7.5%	7.5%
Benefit After One month	7.5%	2.9%
Annual Miles Driven	12,500	
Average Baseline MPG	22	
Price per Gallon of Gas	\$2.50	
Time to Cost Recovery (months)	22	13

The lower curve in Figure 4-1 depicts the time it takes to recover implementation costs for the training model (assuming a 2.9% MPG savings from baseline level each month after training), and the upper curve reflects the time it takes to recoup implementation costs for the continuous feedback model (assuming a 7.5% MPG savings from baseline level each month of feedback). On each curve, we indicated the point at which our particular feedback intervention recoups its initial costs, given the above assumptions. For the continuous feedback model, the break-even point comes at 22 months; for the training model the cost-recovery point occurs at only 13 months. So, while the training model produces a lower impact on MPG, the expenses are lower due to the distributed cost of the feedback device among multiple drivers.

Figure 4-1 may also be used to assess other approaches to implementation. Program designers can identify cost-effective constraints on overhead costs for a presumed duration of benefit. Alternatively, if administrative costs for the intervention are defined, then the savings persistence necessary for cost-effectiveness can be found. Of course, the projections are only as good as the assumptions on which they are based, and one assumption that was not tested in the current study was how multiple months of habituation to feedback might influence the beneficial effects.

4.2 Application to Other Populations

The above economic analysis assumes that the average US driver is sufficiently similar to our study participants to justify expectations of the suggested effect. However, our study did not pay drivers to participate nor draw a random sample from work sites, so enrollment depended on the active interest of volunteers. It is likely that our study participants represented a distinct population looking to improve their MPG. While this group may have been more motivated to improve their fuel economy, they may also have had less than average room for improvement in fuel efficiency. Regardless of which of these competing factors dominate, extrapolation of our study findings to the general population of US drivers may be premature.

Further, any distribution of the feedback device to drivers at large would likely require inclusion of carefully-crafted motivational messages to encourage drivers to attend to the information provided by the feedback gauges. The ease with which benefits can be accrued

with an already-motivated sample may not be replicated when participants have to be convinced of the advantages of changing their driving habits. These differences could strongly impact the size and duration of any beneficial effects.

Finally, because fuel economy is related to the mix of road speeds and traffic encountered, deviations from the driving profile of the average study participant might hinder the applicability of the study findings. This is noted because trends found in our disaggregated driving behavior index suggested that avoiding braking and slowing acceleration were driving behaviors most associated with the intervention effect. The frequency and contribution of these behaviors varies by road type and traffic density, so the driving environment of the participants could set constraints on the magnitude of the feedback effects.

5. Conclusions

5.1 Discussion

Although we did not observe a significant condition by time interaction, the trends were in the hypothesized direction for the MPG outcomes and the index of self-reported driving behaviors. With each outcome variable, we saw slightly greater improvements from Phase A to Phase B among the experimental participants than among the controls. Participants in the experimental condition showed a diminution of their initial gains when the feedback was no longer available, while control participants remained stable or continued to improve across time. This overall pattern suggests that the presence of the feedback was having some influence. When we disaggregated the driving behavior index, this same pattern was most evident in the individual driving behavior, avoided unnecessary braking, but it was present for several other behaviors as well. This convergence of evidence lends support to our hypotheses even though the individual tests failed to reach significance.

There are several possible reasons why we did not observe a significant effect for our intervention. First, as previously mentioned, our participants appeared to be a biased sample of fuel-efficient drivers as evidenced by the comparison to EPA MPG averages. Specifically, our participants averaged between 6.5% - 11.8% greater fuel efficiency at baseline than the combined highway and city averages estimated for their cars by the EPA. Furthermore, this EPA estimate may be an inflated measure of fuel efficiency because it does not reflect real-world driving conditions (e.g., cold temperature operation, use of air conditioning, etc.), suggesting that our participants were even more fuel-efficient drivers at baseline than the general population. This selection bias may have resulted in less room for improvement with the feedback intervention than might be expected among the general population of drivers.

On the other hand, data logged by uncalibrated ScanGaugeII computers can be in error by up to 10% in either direction according to the manufacturer. Logistical constraints in participant interaction did not allow for device calibration in accordance with manufacturer instruction. Fortunately, errors in calibration are known to be constant over time, so this inaccuracy did not effect within-subject changes across study phases. However, it may have systematically distorted our absolute MPG readings, making it less clear how our sample's fuel efficiency compared to the EPA averages noted above.

A second reason we did not observe a significant effect for our intervention may be due to the presence of considerable noise in our data from inconsistent driving schedules, irregular car use, use by other drivers, and other confounding factors. Although we asked about many of these variables in our screening interview, and deemed callers ineligible if they endorsed them, many who were entered into the study subsequently reported these driving inconsistencies on the monthly questionnaires. Because our sample size was small, we could not back participants out of the analyses on the basis of these confounding factors. However, we acknowledge that inconsistencies in these variables across our 3-month study period may have undercut our ability to detect real differences among study phases.

Related to the above concern, we were also hampered by our inability to collect more finely differentiated data than monthly aggregated MPG and MPH. It would have been good to have had data from smaller driving units (e.g., daily MPG or MPG per trip) to observe changes in routine drives across the study phases. With such data, we could have limited

analyses to daily commutes, so that changes in driving behaviors might be observed within the constant of the trip itself. Due to time constraints associated with the manual recording of data from the automotive computers, and due to the limitation of the computer to collect time-stamped data, we were unable to obtain records that might have revealed more specific intervention effects.

Thirdly, based on the Eco-Driving literature, we anticipated observing a 15% difference between experimental and control participants during the intervention phase of the study. In retrospect, that expectation was overly optimistic, as Eco-Driving interventions usually include ongoing personal driving feedback from trained instructors^[6]. In contrast, our simple, much less costly, feedback display and tip sheet was not likely to generate comparable results. However, we did see about a 7% differential effect in MPG and driving behavior between the experimental and control conditions, about half the effect size found with some Eco-Driving instruction. This differential effect, while not significant in our study, holds promise for the feedback intervention, particularly in light of its lower cost and wider opportunity for dissemination.

Finally, we would like to comment on our difficulty with study recruitment. Although our recruitment messages attempted to appeal to potential participants by asking “Want to try to enhance your fuel efficiency and reduce your carbon emissions while driving?” we struggled to enroll an ample number of drivers who met our eligibility criteria. Nearly 750 people were employed across the four worksites from which we recruited, yet only 65 contacted us about the study, and many who called were ineligible because they always calculated their MPG or already had a feedback display calculating it for them. Although it would be comforting to conclude that interest was low because people were already driving in a fuel-efficient manner, it is more likely that the recruitment message attracted those already striving to improve their fuel efficiency, and failed to attract the vast majority of drivers. One reason may have been that gas prices averaged \$2.02 per gallon in April 2009 during our recruitment period, in contrast to an average of \$3.98 per gallon in July 2008, when we were planning the study. We speculate that this contrast effect in cost of gas may have temporarily diminished motivation to improve fuel efficiency while driving.

5.2 Suggestions for Future Research

The results of our study, while inconclusive, are promising, and suggest the need for a larger study powered to test a more modest, yet meaningful, effect on fuel efficiency. Just a 7.5% improvement in MPG with a relatively inexpensive intervention could translate into many tons of reduced CO₂ emissions across the transportation sector. For that reason, we have the following study recommendations.

First, the study design could be enhanced by expanding the time in each of the study phases to insure greater stability in driving behaviors during the baseline phase, to increase the length of exposure to the feedback during the intervention phase, and to get a better sense of the maintenance of any behavior changes during the return-to-baseline phase. Our study was constrained by cost and time considerations. We expect that three months in each phase would be ample to test the impact of the feedback intervention as a training tool. However, it is possible that the feedback intervention works best when it is available continuously, and not removed. This continuous feedback approach is in contrast to the training feedback approach, and could be tested separately.

Secondly, we suggest that the automotive computer be programmed to include time-stamped data so that finer-grained analyses of MPG changes could be conducted. These analyses could include, for example, examination of changes by phases in commuter trips or in weekend versus weekday driving to determine where the feedback has its greatest impact.

Thirdly, we recommend the use of financial incentives to recruit a larger sample of more representative drivers into the study. This would not only help insure enrolling an adequate sample size, but would likely broaden the pool of interested drivers beyond those who are already employing fuel-saving strategies, thereby enhancing the generalizability of the findings.

Finally, we suggest incorporating a formal cost/benefit analysis into any future study to serve as a mechanism for determining the relative merits of a feedback intervention as opposed to other, more costly ways to change driving behaviors (e.g., Eco-Driving training). Such an approach would allow policymakers to project potential gains in fuel efficiency and environmental impact across interventions requiring different levels of effort and cost.

References

1. Bogo, J. "Report Sees Dire Future for Warming's Impact on U.S. Transport." *Popular Mechanics*, Vol. 185, No. 3 (March 11, 2008) pp 76-79.
2. Davis, SC Diegel, SW, Boundy RG, Transportation Energy Data Book: Edition 28. US Department of Energy (2009).
3. Mazza P. "Transportation and Global Warming Solutions." *Climate Solutions*, Vol. 16 (May 2004).
4. DeCicco J, Fung F. "Global Warming on the road: The climate impact of America's automobiles." Environmental Defense, Washington, DC (2006).
5. Jensen C. Mileage ratings are still estimates, though closer to reality. *New York Times*, Sept. 16, 2007.
6. Vermeulen RJ. "The effects of a range of measures to reduce the tail pipe emissions and/or fuel consumption of modern passenger cars on petrol and diesel." *TNO Report*. Dec. 2006. [IS-RPT-033-DTS-2006-01695]
7. Warner HW, Aberg, L. "The long-term effects of an ISA speed-warning device on drivers' speeding behavior." *Transportation Research Part F*, Vol 11, (2008) pp. 96-107.
8. Kluger AN, DeNisi A. "The effect of feedback interventions on performance: A historical review, meta-analysis, and a preliminary feedback intervention theory." *Psychological Bulletin*, Vol. 19, No. 2 (1996), pp. 254-284.
9. Office of Transportation and Air Quality. "Final Technical Support Document: Fuel Economy Labeling of Motor Vehicles, Revisions to Improve Calculation of Fuel Economy Estimates." Environmental Protection Agency, Dec. 2006, <http://www.epa.gov/fueleconomy/420r06017.pdf> (Accessed 2007).

Appendices

Table 3-1. Baseline Characteristics by Condition (n=26)

	Total	Control	Exper	p-value
Mean Age (SD)	47.2 (9.2)	49.3 (7.2)	44.7 (10.9)	0.21
Gender				
Male	58%	50%	67%	
Female	42%	50%	33%	0.39
Education				
HS degree	4%	7%	0%	
Some college	15%	14%	17%	
College degree	54%	50%	58%	
> College degree	27%	29%	25%	0.80
Worksite				
VEIC	8%	7%	8%	
BED	4%	7%	0%	
GS	42%	43%	42%	
GD	46%	43%	50%	0.82
Mean Mins one-way (SD)	34.5 (13.9)	34.3 (12.2)	34.8 (16.1)	0.94
Mean Miles one-way (SD)	22.2 (12.2)	24.0 (12.5)	20.0 (11.9)	0.41
Transmission				
Automatic	69%	93%	42%	
Manual	31%	7%	58%	0.005
Speed				
60-65 MPH	23%	14%	33%	
66-70 MPH	46%	50%	42%	
>70 MPH	31%	36%	25%	0.51
Driving Style				
Very cautious	12%	22%	0%	
Somewhat cautious	69%	57%	83%	
Somewhat aggressive	15%	14%	17%	
Very aggressive	4%	7%	0%	0.25

Table 3-2. Means (and Standard Deviations) for MPG, MPH, and Self-Reported Driving Behavior Outcomes by Condition and Time (n=26)

	Cond.	1st month	SD	2nd month	SD	3rd Month	SD	F	p-value
MPG	E	27.8	(8.9)	30.2	(10.3)	29.0	(9.3)	1.98	0.15
	C	27.4	(6.9)	27.7	(6.9)	27.8	(6.8)		
MPH	E	32.4	(5.1)	31.8	(4.3)	32.5	(5.4)	0.83	0.44
	C	36.1	(5.5)	37.2	(6.0)	36.7	(4.4)		
Driving behavior index	E	5.21	(0.56)	5.64	(0.58)	5.36	(0.74)	1.79	0.18
	C	4.58	(0.93)	4.67	(1.40)	4.81	(0.90)		
Avoided braking	E	5.58	(0.90)	5.83	(0.58)	5.58	(0.67)	2.85	0.07
	C	4.71	(1.59)	4.67	(1.50)	5.43	(1.16)		
Slowed acceleration	E	5.25	(1.71)	5.50	(1.17)	5.58	(0.67)	1.88	0.16
	C	4.50	(1.79)	4.33	(1.61)	4.79	(1.12)		
Drove below speed limit	E	2.92	(1.78)	4.17	(1.75)	3.67	(1.87)	0.61	0.44
	C	2.86	(1.83)	3.08	(1.68)	3.64	(1.91)		
Shifted quickly through low gears	E	5.25	(1.66)	5.83	(0.83)	6.00	(0.63)	0.70	0.50
	C	4.29	(1.90)	5.08	(1.83)	4.15	(2.19)		
Applied steady pressure	E	6.08	(0.51)	6.17	(0.39)	5.73	(0.90)	0.78	0.46
	C	5.36	(1.15)	5.08	(1.68)	5.15	(0.99)		
Avoided idling	E	6.17	(0.94)	6.33	(1.15)	6.18	(0.98)	0.18	0.84
	C	5.79	(1.31)	5.75	(1.91)	5.85	(1.07)		

Table 3-3. Baseline Characteristics Comparing Experimental Participants With Greater Than 10% Increase in MPG from Phase A to Phase B to Experimental Participants With Less Than 10% MPG Increase

	>10% Increase	<10% Increase	p-value
Mean Age (SD)	50.7 (9.6)	42.7 (11.1)	0.29
Gender			
Male	67%	67%	
Female	33%	33%	1.00
Education			
Some college	33%	11%	
College degree	33%	67%	
> College degree	34%	22%	0.55
Worksite			
VEIC	33%	0%	
GS	33%	44%	
GD	34%	56%	0.19
Mean Mins one-way (SD)	43.3 (20.8)	31.9 (14.5)	0.31
Mean Miles one-way (SD)	22.2 (11.5)	19.3 (12.6)	0.74
Transmission			
Automatic	33%	44%	
Manual	67%	56%	0.74
Speed			
60-65 MPH	33%	33%	
66-70 MPH	33%	45%	
>70 MPH	34%	22%	0.91
Driving Style			
Somewhat cautious	67%	89%	
Somewhat aggressive	33%	11%	0.45

Figures

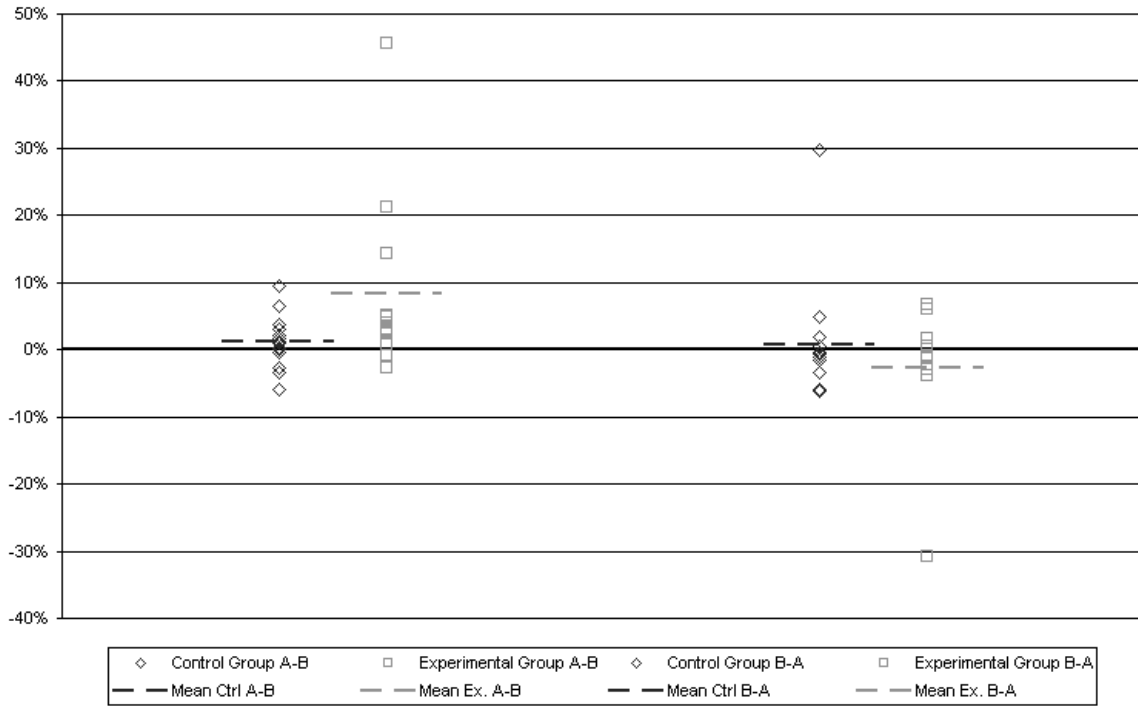


Figure 3-1. Percent Change in MPG from Phase A to B and from Phase B to A by Participant Within Condition (n=26)

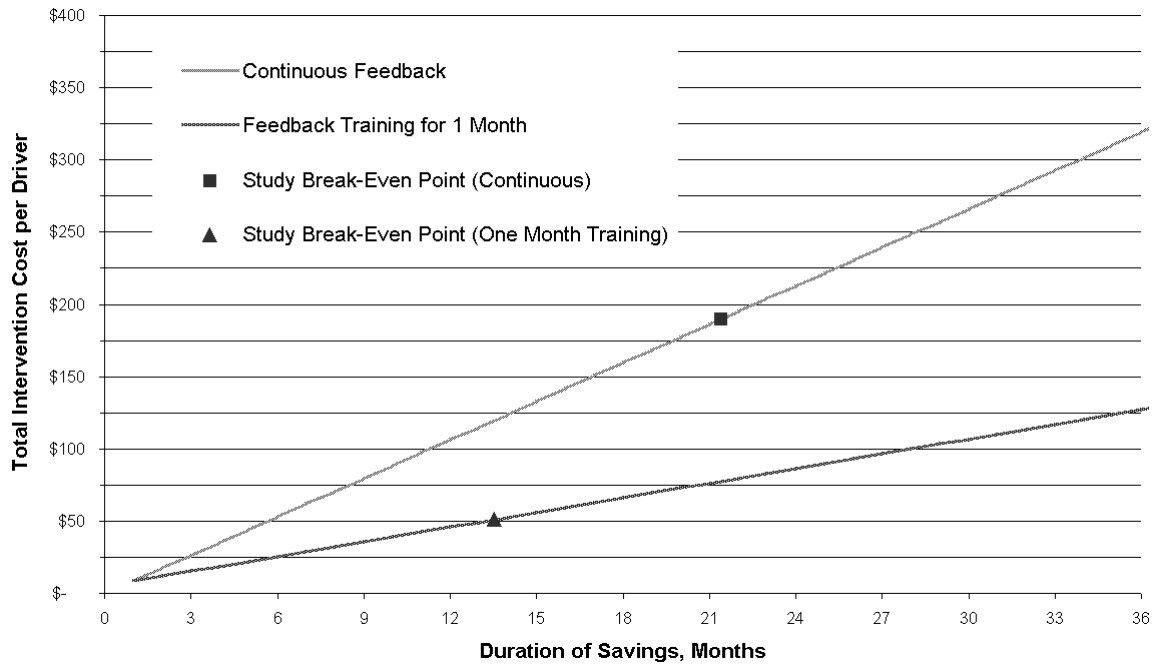


Figure 4-1. Months of Benefit Required to Recover Implementation Costs for Two Intervention Models.

Last month's average MPG: _____

Tip Sheet for Lowering Your Fuel Consumption

The small automotive computer we installed in your car is a ScanGaugeII. It is set to give you continuous feedback while you're driving so that you can more clearly see how your driving behaviors influence your fuel consumption. The absolute fuel consumption feedback may be off by about 10% in either direction in some cars; however, you can still benefit by using the feedback to improve your relative fuel efficiency. There are four numbers displayed on the device:

- The **upper left number (AVG)** is the average cumulative miles per gallon (MPG) you've been getting since we set up the computer to give you feedback. This number changes very slowly because each new day's MPG information gets averaged into the data from all the previous days. The more this number goes up, the greater your improvement in fuel efficiency. When it rises, it means you're averaging more miles for each gallon of gas consumed.
- The **lower left number (TRP)** is the average cumulative miles per gallon you've been getting since you most recently turned on the car (i.e., for this trip). It will reset each time you turn on your car provided your car has been off for more than 5 minutes. As you commute to work each day, you may become familiar with your typical fuel consumption during that trip. Over time, that feedback may help you determine ways to change your driving behavior so you can increase the number of miles per gallon you get, particularly during your commute. The higher this number, the better your fuel efficiency.
- The **upper right number (MPG)** is your moment-to-moment miles per gallon. Although there is a several second delay, this number reflects instantaneous fuel consumption. It can range from 0 if you're not moving (because you're traveling no miles) to 9999 if you're coasting downhill (because you are traveling while using no fuel). This number can jump around a lot. A higher number indicates better fuel efficiency. This instantaneous feedback may help you notice what driving behaviors lower your fuel efficiency (give you less MPG) and what behaviors raise your fuel efficiency (give you more miles per gallon).
- The **lower right number (GPH)** is your moment-to-moment reading of gallons of gas used per hour (GPH). You may be less familiar with this, but it can be quite informative. Although there is a several second delay, it basically reflects how much pressure you're putting on the accelerator. The more pressure you're applying to the accelerator, the higher the GPH number will go. The higher the GPH number, the more gallons of gas you're using (per hour). This number will be less than 1.0 (when you're idling and putting no pressure on the accelerator) and may go to 4.0 or more (when you're putting extreme pressure on the accelerator). Keeping this number low means that you're using fewer gallons of gas per hour. If you have a regular commute that takes about 30 minutes one-way, and if the GPH number hovered mostly around 2.0, then that would mean that you're using about 1 gallon of gas for that 30-minute commute. Of course, the number will vary quite a bit depending on how much gas you're putting into the engine through your pressure on the accelerator. Try to figure out what strategies help you keep this number lower rather than higher.

Although the ScanGaugeII has other feedback gauges than the four described above, we have locked it into these four selected gauges for this study, so please don't try to tinker with the feedback device, and please don't unplug it, as that will result in a loss of data. If the device is accidentally unplugged, please contact Nick Lange at 860-4095 x1176 right away. We greatly appreciate your cooperation with this.

Improving fuel efficiency when you drive is a way to save money and reduce your carbon emissions. You can lower your gas consumption by changing your driving behaviors. We have compiled driving tips from information provided by the Environmental Protection Agency, Consumer Reports, the Department of Energy, the Union of Concerned Scientists, and Car Talk.

11 Ways to Improve Your Fuel Efficiency While Driving

1. Drive at moderate speeds. With higher speeds, you increase wind resistance. By reducing highway speed from 65 to 55 MPH, you can improve fuel efficiency by up to 15% (i.e., 15 miles on the highway at 55 vs 65 MPH adds less than 3 minutes, but can increase your miles per gallon by 15%).
2. Avoid rapid acceleration when possible. Start slowly from a stop when in town, and don't try to increase speed when going up a hill on the highway. Let the car go a little slower. Hard acceleration burns more gas.
3. Avoid unneeded braking. Braking wastes the gas you used to accelerate. Anticipate traffic and intersections in advance so you can slow the car by taking your foot off the accelerator and coasting. Avoid tailgating because that requires more braking.
4. If you have a manual transmission, avoid RPMs of over 3000 in lower gears. If you have an automatic transmission, press the gas enough to get the car moving, then let up on the accelerator to allow the transmission to shift into higher gear.
5. Use cruise control and overdrive gears on relatively flat highways to help you keep to moderate speeds. However, cruise control on hilly roads may lead to greater acceleration on hills which would lower fuel efficiency, so consider your terrain before setting cruise control.
6. Avoid idling when not in traffic. Idling wastes gas because you're not moving, so if you're waiting in the car for more than 10 seconds, turn the car off. It takes less gas to restart the car than it does to let it idle. Even in very cold temperatures, it takes less than a minute to warm up the engine for driving.
7. Remove excess weight from your car. It takes more gas to move more pounds. Also, remove empty roof-top racks when you're not using them. They create aerodynamic drag.
8. Keep your tires properly inflated. This can reduce the amount of drag your engine must overcome. Check your tire pressure once a month.
9. Turn off your air conditioner and/or defroster when you don't need them. They cause your car's engine to work harder.
10. Consider alternate routes to and from work and/or alternate commute times to avoid traffic that might lead to more fluctuations in speed, more braking, or more idling.
11. Whenever you can, combine your errands and activities into one trip. That way, your car's engine is more likely to remain warm and run more efficiently. Starting a cold engine for each trip will reduce fuel economy and increase pollution.