UMTRI-2011-34 AUGUST 2011

ECO-DRIVING: STRATEGIC, TACTICAL, AND OPERATIONAL DECISIONS OF THE DRIVER THAT IMPROVE VEHICLE FUEL ECONOMY

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Report No. UMTRI-2011-34
August 2011

Technical Report Documentation Page

1. Report No. UMTRI-2011-34	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Eco-Driving: Strategic, Tactical, and Operational Decisions of the Driver that Improve Vehicle Fuel Economy		5. Report Date August 2011
		6. Performing Organization Code 383818
7. Author(s) Michael Sivak and Brandon Schoettle		8. Performing Organization Report No. UMTRI-2011-34
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.		10. Work Unit no. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Sustainable Worldwide Transportation		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

The current members of Sustainable Worldwide Transportation include Aramco Services, Autoliv Electronics, Bosch, China FAW Group, FIA Foundation for the Automobile and Society, General Motors, Honda R&D Americas, Meritor WABCO, Michelin Americas Research, Nissan Technical Center North America, Renault, and Toyota Motor Engineering and Manufacturing North America. Information about Sustainable Worldwide Transportation is available at: http://www.umich.edu/~umtriswt

16. Abstract

This report presents information about the effects of decisions that a driver can make to influence on-road fuel economy of light-duty vehicles. These include strategic decisions (vehicle selection and maintenance), tactical decisions (route selection and vehicle load), and operational decisions (driver behavior).

The results indicate that vehicle selection has by far the most dominant effect: The best vehicle currently available for sale in the U.S. is nine times more fuel efficient than the worst vehicle. Nevertheless, the remaining factors that a driver has control over can contribute, in total, to about a 45% reduction in the on-road fuel economy *per driver*—a magnitude well worth emphasizing. Furthermore, increased efforts should also be directed at increasing vehicle occupancy, which has dropped by 30% from 1960. That drop, by itself, increased the energy intensity of driving *per occupant* by about 30%.

17. Key Words eco-driving, fuel economy, strategic decisions, tactical decisions, operational decisions, vehicle, driver, environment			18. Distribution Statement Unlimited
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. of Pages 17	22. Price

Acknowledgments

This research was supported by Sustainable Worldwide Transportation (http://www.umich.edu/~umtriswt). The current members of this research consortium are Aramco Services, Autoliv Electronics, Bosch, China FAW Group, FIA Foundation for the Automobile and Society, General Motors, Honda R&D Americas, Michelin Americas Research, Meritor WABCO, Nissan Technical Center North America, Renault, and Toyota Motor Engineering and Manufacturing North America.

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Introduction

The on-road fuel economy in the U.S. in 2008 for all vehicles averaged 17.4 mpg. This compares to 14.0 mpg achieved 85 years earlier in 1923 (see Figure 1). The average fuel economy for cars in 2008 was 22.6 mpg.

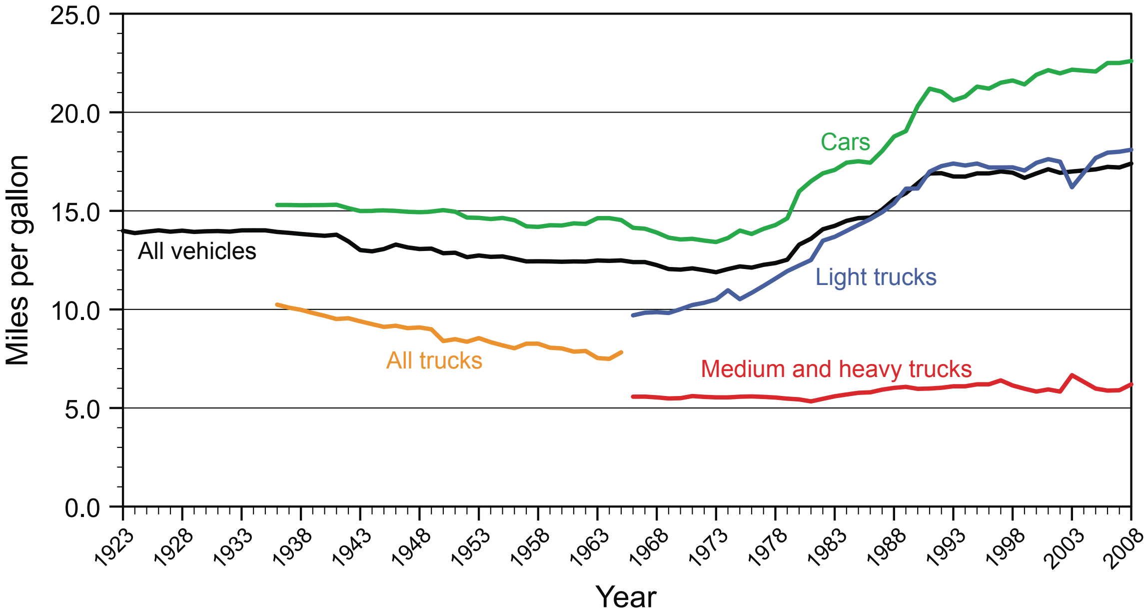

Figure 1. Mean on-road fuel economy of vehicles in the U.S., 1923-2008. The data for 1923 through 2006 are from Sivak and Tsimhoni (2009). The data for 2007 and 2008 are from FHWA (2008; 2009).

Table 1 documents the average energy intensities of various travel modes. As indicated in Table 1, not only is driving a light-duty vehicle in the U.S. currently more energy intensive than using a bus or a train, it is also more energy intensive than flying (all at current average loads).

Table 1
Energy intensity of various travel modes (RITA, 2011a).

Travel mode	Btu per occupant mile
Car	3,501
Other light-duty vehicle	3,980
Motorcycle	1,742
Airplane	2,931
Transit bus	2,656
AMTRAK	1,745

How can we improve on this performance? This report reviews how eco-driving enables drivers to maximize the on-road fuel economy of vehicles. In this report, eco-driving is used in its broadest sense: *Eco-driving includes those strategic decisions (e.g., vehicle selection and maintenance), tactical decisions (e.g., route selection), and operational decisions (e.g., driver behavior) that improve vehicle fuel economy.*

Strategic decisions

Selection of vehicle class

Table 2 presents the mean rated fuel economy of all available light-duty vehicles on the U.S. market for model year 2011. On average, a car has 38% better fuel economy than a pickup truck. (The data in Tables 2 through 4 were derived for this study from the information in EPA, 2011a.)

Table 2
Mean rated fuel economy of model year 2011 light-duty vehicles, by class.

Vehicle class	Mean mpg
Cars	23.7
Vans, minivans	19.4
SUVs, crossovers	19.2
Pickup trucks	17.2

Selection of vehicle model

The ranges of fuel economy of individual models by vehicle class are documented in Table 3. The results show that the best car is rated as being nine times more fuel efficient than the worst car. Analogously, the best pickup truck is rated as being two times more fuel efficient than the worst pickup truck.

Table 3
Fuel economy ranges of model year 2011 light-duty vehicles, by class.

Vehicle class	mpg	
	Min	Max
Cars	11	99*
Vans, minivans	11	28
SUVs, crossovers	12	32
Pickup trucks	12	24

*The best fully electric car and the best car overall: 99 mpg; the best hybrid car: 50 mpg; the best car with internal-combustion engine: 36 mpg.

Selection of vehicle configuration

There are currently 282 vehicle models for sale in the U.S. (model year 2011), with 242 models having two or more variants (e.g., engine size, number of doors, etc.). For 216 of the 242 models with two or more variants, the rated fuel economy differs among the models, depending on the variants (see Table 4). The mean range for cars is 4.3 mpg, or 18% of the mean fuel economy of all cars. Analogously, the mean range for pickup trucks is 4.9 mpg, or 28% of the mean fuel economy of all pickup trucks.

Table 4
Mean number of variants and mean fuel-economy ranges of model year 2011 light-duty vehicles, by class.

Vehicle class	Mean number of variants	Mean mpg range
Cars	5.3	4.3
Vans, minivans	5.3	3.0
SUVs, crossovers	3.8	3.3
Pickup trucks	8.4	4.9

Vehicle maintenance

Tuned engine. According to the EPA (2011b), “fixing a car that is noticeably out of tune or has failed an emission test can improve its gas mileage by an average of 4%, though results vary based on the kind of repair and how well it is done.” Fixing a faulty oxygen sensor can improve mileage “by as much as 40%” (EPA, 2011b). However, having a faulty oxygen sensor is not a frequent occurrence. Consequently, many vehicle manufacturers suggest replacement only after 100,000 miles.

Tires. Rolling resistance of tires varies among different tires of the same size. TRB (2006) estimates that a 10% change in *nominal* rolling resistance will result in a 1-2% change in fuel economy. Furthermore, *in-use* rolling resistance is influenced by tire inflation, with a 1 psi drop reducing fuel economy by about 0.3% (EPA, 2011b).

Engine oil. Engine oil influences vehicle mileage. For example, if 5W-30 is recommended, using 10W-30 oil can lower mileage by 1-2% (EPA, 2011b).

Tactical decisions

Selection of road type

Different road types result in different average speeds and different profiles of acceleration and deceleration. Consequently, fuel economy differs by road type. For example, a recent Canadian study (National Resources Canada, 2009) found that the average fuel economy on highways with a posted speed of 80 km/h (50 mph) or more is about 9% better than on other roads.

Selection of grade profile

Maximum grade has a strong effect on fuel economy. For example, Boriboonsomsin and Barth (2009) found that, in a particular scenario with the same origin and destination but two alternative routes, a flat route yielded 15-20% better fuel economy than a hilly route.

Dealing with congestion

Congestion can be considered within the context of route selection as well because drivers in some situations can avoid congested routes. The Highway Capacity Manual (TRB, 2000) classifies level-of-service (i.e., congestion) into the following six categories: A (free flow), B (reasonably free flow), C (stable flow), D (approaching unstable flow), E (unstable flow), and F (forced or breakdown flow). Using these level-of-service categories, Facanha's analysis (2009) indicates that, depending on vehicle type and road type, the reduction in fuel economy from service level A to service level F can range from 20-40%. Furthermore, that study shows that the largest drop in fuel economy is from service level E to service level F.

Weight

According to the EPA (2011c), an extra 100 pounds in a vehicle (e.g., extra cargo) can reduce fuel economy by up to 2%, with smaller vehicles being affected more.

On a related note, the average adult in the U.S. in 2002 was about 24 pounds heavier than in 1960 (Ogden, Fryar, Carroll, and Flegel, 2004). This weight gain results in a reduction in fuel economy of up to about 0.5%.

Operational decisions

Idling

Idling uses a quarter to a half gallon of fuel per hour (EPA, 2011c), depending on engine size and accessories in use. Edmunds recommends turning off the engine when the expected idle time is more than a minute (Edmunds, 2005), while according to the EPA (2011c), "it only takes a few seconds worth of fuel to restart your engine." In one specific test, Edmunds (2005) found that turning the engine off during each of 10 idle periods lasting two minutes each on a 10-mile course improved mileage by 19%.

Speed/rpm

For most internal-combustion engines, fuel economy is an inverted-U-shaped function of speed/rpm. For example, a particular V6 engine used in 2007 Honda Accords produced, in naturalistic driving, peak fuel economy of 31.6 mpg at 61 mph, with the fuel economy dropping to 21.2 mpg at 90 mph (a drop of 33%) and 21.8 mpg at 30 mph (a drop of 31%) (LeBlanc, Sivak, and Bogard, 2010).

Use of cruise control

Edmunds (2005) estimates that using cruise control improves mileage at highway speeds by about 7%.

Use of air conditioner

Using the air conditioner can reduce mileage by 5-25% (EPA, 2011d; Wilbers, 1999). However, when not using the air conditioner is paired with opening the window(s), the increased aerodynamic drag above a certain speed can more than compensate for the fuel savings (Haworth and Symmons, 2001).

Aggressivity of driving

In a test performed by Edmunds (2005), moderate driving yielded, on average, 31% better mileage than aggressive driving.

LeBlanc et al. (2010) found in naturalistic driving that, for both speed keeping and accelerating from rest, the 10th and 90th percentile mileage of individual drivers using the same vehicle differed by about 20%, although some of that variation is expected to result from factors other than the degree of aggressive driving.

Discussion

Table 5 summarizes the effects of factors influencing vehicle fuel economy. As is evident from Table 5, the factor with the largest effect is vehicle-model selection.

Table 5
Summary of the effects of factors influencing vehicle fuel economy.

Level	Factor	Effect
Strategic	Vehicle class	38%
	Vehicle model	800% all cars; 355% cars excluding fully electric; 227% cars excluding fully electric and hybrids; 100% all pickups
	Vehicle configuration	18% cars, 28% pickups
	Out-of-tune engine	4-40%
	Tires with 25% higher rolling resistance	3-5%
	Tires underinflated by 5 psi	1.5%
	Improper engine oil	1-2%
Tactical	Route selection: road type	variable
	Route selection: grade profile	15-20%
	Route selection: congestion	20-40%
	Carrying extra 100 pounds	≤2%
Operational	Idling	variable
	Driving at very high speeds	30%
	Not using cruise control	7% (while at highway speeds)
	Using air conditioner	5-25%
	Aggressive driving	20-30%

The importance of vehicle-model selection is illustrated by the following example. Let's consider the least fuel-efficient car (11 mpg), and the most fuel-efficient car with an internal-combustion engine (36 mpg). Let's further assume that the driver of the car with the worst mileage follows all remaining good eco-driving practices, while the driver of the car with the best mileage disregards all of them. Following the remaining best eco-driving practices will result in no change in fuel economy for the car that gets 11 mpg; the nominal and actual fuel economy will be the same. By contrast, the car that nominally gets 36 mpg will experience a reduction to 19.8 mpg in actual fuel economy (a reduction of 45%) as a result of disregarding all remaining eco-driving practices, as shown in Table 6.

Table 6
Cumulative effects of disregarding good eco-driving practices (after vehicle selection) on the most fuel-efficient car with an internal-combustion engine.

Factor (effect on performance)	Fuel economy (mpg)
Nominal performance	*36.0*
Aggressive driving[a] (25% drop)	27.0
Driving at excessively high speeds[b] (6% drop)	25.4
Route selection (road type, grade, and congestion)[c] (6% drop)	23.9
Out-of-tune engine[d] (4% drop)	22.9
Tires with increased rolling resistance[e] (4% drop)	22.0
Using air conditioner[f] (4% drop)	21.1
Excessive idling[g] (2% drop)	20.7
Extra weight[h] (1.5% drop)	20.4
Improper oil (1.5% drop)	20.1
Under-inflated tires[i] (1.5% drop)	19.8

[a] Not using cruise control included.

[b] Driving at very high speeds on 20% of the total distances driven.

[c] Two possible routes (with different road types, grade profiles, and/or levels of congestion) are available 20% of the total distance driven.

[d] Faulty oxygen sensor (infrequent in relatively new vehicles) could result in a fuel-economy drop of 40%.

[e] Replacement tires with 25% higher rolling resistance than originally equipped tires.

[f] Used during 25% of the total distance driven. At very high speeds the windows are up.

[g] Turning off the engine during two 1-minute idle periods per each 10 miles.

[h] Extra 100 pounds of cargo.

[i] Underinflation of all four tires by 5 psi.

The information in Table 6 can be interpreted as the cup being half full or the cup being half empty. On one hand, one can conclude that decisions concerning vehicle-selection are dominant for on-road fuel economy. On the other hand, one can also conclude that not following the remaining good eco-driving practices can still lead to a major reduction in on-road fuel economy—cumulatively by about 45%.

The analysis in this report concentrated on fuel economy *per vehicle*. However, the average occupancy of a light-duty vehicle in the U.S. dropped from 2.0 in 1960 to 1.4 in 2009 (RITA, 2011b). This represents a 30% drop in vehicle fuel economy *per occupant* (before adjusting for different occupant weight). Consequently, increased car-pooling, to at least the level of the 1960s, would go a long way to improve the energy intensity of driving per occupant.

Summary

This report presented information about the effects of decisions that a driver can make to influence on-road fuel economy of light-duty vehicles. These include strategic decisions (vehicle selection and maintenance), tactical decisions (route selection and vehicle load), and operational decisions (driver behavior).

The results indicate that vehicle selection has by far the most dominant effect: The best vehicle currently available for sale in the U.S. is nine times more fuel efficient than the worst vehicle. Nevertheless, the remaining factors that a driver has control over can contribute, in total, to about a 45% reduction in the on-road fuel economy *per driver*—a magnitude well worth emphasizing. Furthermore, increased efforts should also be directed at increasing vehicle occupancy, which has dropped by 30% from 1960. That drop, by itself, increased the energy intensity of driving *per occupant* by about 30%.

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