Automobile Fuel Economy and the Driver

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The results of a study of the effect of driver characteristics and behavior on automobile fuel consumption and methods for improving driver fuel economy are presented. The fuel economy of 74 drivers was recorded for each of 10 trips over a 5.6-km (3.5-mile) urban test route on which there were 14 stops and 21 turns. Deceleration and acceleration rates as well as engine vacuum and tachometer readings were recorded for each trip. Driver fuel economy was related to the age and sex of drivers, maximum deceleration and acceleration rates, minimum engine vacuum, and maximum engine speed during accelerations. It was found that driver fuel economy is not related to the driver’s age or sex and is about the same whether or not the driver makes full stops at all intersection stop signs. Correlation between driver fuel economy and minimum engine vacuum and maximum engine speeds during acceleration was fairly good. Correlation was poor between fuel economy and maximum rates of deceleration and acceleration. The study findings include an assessment of the usefulness of the vacuum gauge in assisting drivers to conserve fuel. The data indicate that many drivers would use more fuel with the vacuum gauge than without it.

During the fall of 1975, the fuel-economy and driving habits of 74 drivers were observed as each drove a 1972 Chevrolet sedan 10 times over a 5.6-km (3.5-mile) urban test route on which there were many stops and turns (nonuniform driving). On each trip, total fuel consumption, patterns of acceleration and deceleration rates, engine vacuum readings, and engine speeds during acceleration were recorded. Pertinent remarks on driver behavior were also recorded, including observations on whether full stops were made at stop signs and whether speed was reduced near schools and hospitals. Vehicle, road, traffic, and weather conditions were the same for all trips.

The study was part of a Federal Highway Administration (FHWA) project reported on elsewhere (1). The results reveal how individual drivers affect automobile fuel consumption and how fuel economy can be improved without sacrificing driving convenience or safety.

DETAILS OF THE STUDY

Drivers

The drivers consisted of 44 men and 30 women, distributed by age as indicated below:

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Number of Drivers</th>
</tr>
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<tbody>
<tr>
<td>10-20</td>
<td>0</td>
</tr>
<tr>
<td>20-30</td>
<td>2</td>
</tr>
<tr>
<td>30-40</td>
<td>8</td>
</tr>
<tr>
<td>40-50</td>
<td>21</td>
</tr>
<tr>
<td>50-60</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
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</table>

Almost 50 percent of the drivers were in the 40- to 50-year-old group. Eleven were housewives; 29 were professionals; 29 were laborers, clerks, or salespersons; 3 were students; and 2 were retired persons. The drivers were all responsible people who agreed in advance to drive the test runs as they normally drove even if they were accustomed to exceeding the speed limit or tended to go through intersections protected by stop signs without making full stops (unless another vehicle was approaching). Each driver was in good health and accustomed to driving in urban areas.

Test Route

A sketch of the test route is shown in Figure 1. From the beginning point shown in the figure, the route followed a path over to the street that passes in front of the high school. From here the route went twice around the four-block area across from the high school and then retraced the path back to the beginning point. On each trip, the driver encountered 14 intersection stop signs, made 21 turns, and passed twice in front of a large church, a hospital, and a high school. Since traffic volumes were low and there were no traffic signals, the amount of delay at intersection stops was attributable to the habit of the driver rather than to the need to wait either for a gap in cross-street traffic or for a traffic signal to change.

Vehicle

The test automobile weighed 1996 kg (4400 lb) empty and had an eight-cylinder, 6554.8-cm³ (400-in³) engine and a three-speed automatic transmission. It was equipped with air conditioning, power steering, and front-wheel power brakes. The engine compression ratio was 8.5:1, the rear-axle ratio 3.08:1, and the frontal cross section 2.84 m² (30.5 ft²). The vehicle had H78-15 bias belted tires that carried inflation pressures of 221 kPa (32 lbf/in²).

Equipment

A photoelectronic fuel meter, a vacuum gauge, an accelerometer, and an engine tachometer were used in the
Figure 1. Test route.

Figure 2. Driver fuel economy versus driver age and sex.

vehicle to collect data. Each was mounted so that readings could be made by the observer without distracting the driver. All data were recorded manually by the observer.

The photoelectronic fuel meter, which was mounted out of sight in the trunk, measured fuel consumption with dependable accuracy for all weather conditions and vehicle operating conditions likely to be encountered in automobile driving. A small display panel on the front seat next to the observer gave fuel consumption in units of 0.004 L (0.001 gal). The vacuum gauge gave intake manifold vacuum to the nearest 2.54 cm (1.0 in) of mercury, the accelerometer gave acceleration and deceleration rates to the nearest 0.61 m/s² (2 ft/s²), and the tachometer gave engine speed to the nearest 100 revolutions/min.

Procedure

The drivers made their runs during the months of September, October, and early November of 1975. Air temperatures and wind conditions are generally stable at this time of the year. Runs were made each day between 2 and 8 p.m., partly to make it convenient for drivers who worked during the day and finished work late in the afternoon. No runs were made when it was raining, when air temperature was below 16°C (60°F), or when wind speed exceeded 4.8 km/h (3 miles/h).
Each driver, accompanied by the observer, drove over the test route 10 times. The only break between test runs was between the fifth and sixth trips. Fuel consumption, engine vacuum, acceleration, deceleration, and engine speed were recorded by the observer for each trip. Data recorded for each driver's first trip were used for checking purposes only, since the first trip was made to familiarize the driver with the route and to help him or her to overcome any initial tendency to drive in a stilted or unnatural manner.

RESULTS

Observed relations between fuel economy and the driver’s sex and age, maximum deceleration and acceleration rates, minimum engine vacuum, and maximum engine speed during acceleration are shown in Figures 2-6. The observed effect on fuel economy of the driver’s making or not making full stops at intersection stop signs (in daylight) is given below (1 km/L = 2.35 miles/gal):

<table>
<thead>
<tr>
<th>Stopping Habit</th>
<th>Number of Drivers</th>
<th>Avg Fuel Economy (km/L)</th>
</tr>
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<tbody>
<tr>
<td>Full stop</td>
<td>41</td>
<td>4.28</td>
</tr>
<tr>
<td>Slowdown only</td>
<td>33</td>
<td>4.42</td>
</tr>
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Each driver’s fuel economy was computed by dividing the total trip distance by the total fuel consumed on each trip and averaging for all trips. Each driver’s maximum deceleration and acceleration rates were determined by reviewing the recorded patterns of deceleration and acceleration rates for all trips and selecting the consistently highest values. A high rate of deceleration or acceleration recorded for only one or two trips was rejected. The consistently lowest engine vacuum reading recorded for most of a driver’s trips was selected as the minimum engine vacuum reading for that driver. Similarly, the consistently highest recorded engine speed during accelerations (in second gear just before upshift into high gear) was used as the driver’s maximum engine speed during acceleration.

Sex and Age

Figure 2 shows fuel economy versus driver sex and age. Men and women drivers in each age group have about the same fuel-economy characteristics, and these change little from one age group to another. Fuel economy appears to be independent of both the sex and the age of the driver.

Driver Behavior at Stop Signs

The table above indicates the impact on fuel economy of driver behavior at intersection stop signs. Fuel economy for drivers who customarily make full stops is 4.28 km/L (10.06 gal/mile), and the average fuel economy for those who merely slow down to a crawl before accelerating across the intersecting street is 4.42 km/L (10.39 gal/mile). Evidently, whether or not a driver is careful to make full stops at stop signs does not have much effect on fuel economy.

Deceleration and Acceleration Rates

Maximum deceleration rates indicate whether a driver’s fuel economy is good or bad only if the driver does not coast before braking. When a driver operates at open throttle nearly up to a stop point and then quickly brakes to a stop, more fuel is used than would be used if the driver either applied the brakes over a longer distance for a gradual stop or coasted almost up to the stop point before applying the brakes. Whereas low deceleration rates are always associated with good fuel economy during slowdowns, high deceleration rates are associated with poor fuel economy only if the vehicle is operated at open throttle up to the point of brake application. An analysis of study data indicates that the deceleration rate by itself is not a good indicator of driver fuel economy. The maximum deceleration rates observed for the 74 drivers are plotted versus driver fuel economy in Figure 3. Drivers who had low maximum deceleration rates had better fuel economy. However, the coefficient of correlation was only 0.4, and the coefficient of determination was 0.16. No more than 16 percent of the variation in driver fuel economy can be attributed to the maximum deceleration rate; 84 percent is attributable to all other factors.

Acceleration rates affect fuel consumption because of the way in which vehicles respond to acceleration demand and not because more energy is needed for rapid acceleration. The actual energy required to increase velocity from a stop or from a given velocity to a higher velocity equals one-half the product of the difference in the squares of the initial and final velocities times the mass. It is independent of the acceleration rate.

There are, however, two factors in the response of vehicles to acceleration that do result in more fuel being consumed for the higher rates of acceleration: (a) operation of the carburetor power jet, which injects a quantity of fuel into the intake manifold when the accelerator pedal is depressed sharply, and (b) delay in upshifting in order to develop the torque necessary for a high rate of acceleration. The power jet often wastes fuel because, instead of discharging the exact amount of fuel to fit demand, it usually discharges some excess fuel to ensure firm acceleration. Delay in upshifting means higher engine speeds during acceleration, which in itself adversely affects fuel consumption. When an automobile is accelerated by an even pressure on the foot throttle (no sharp jabs) and upshifting occurs at or near the minimum upshift speeds, the fuel consumed during acceleration is the same for all rates of acceleration up to 10 km/(h/s) [6.2 miles/(h/s)] (1, pp. 146-149).

The effect of the driver’s acceleration rates on automobile fuel economy is shown in Figure 4, where observed maximum rates of acceleration are plotted versus fuel economy for the 74 drivers in the study. There is a definite drop in fuel economy at the higher maximum acceleration rates, but the coefficient of correlation is 0.5 and the coefficient of determination is 0.25. Only 25 percent of the variation in fuel economy is attributable to variation in maximum acceleration rates.

By themselves, neither deceleration rates nor acceleration rates correlate closely with driver fuel economy. For good fuel economy on deceleration, drivers need not apply the brakes for long, gradual slowdowns but need only take their foot off the accelerator and coast to the stop point, where they may stop suddenly if they wish. Fuel economy on acceleration will be the same at any rate of acceleration up to about 10 km/(h/s) [6.2 miles/(h/s)] if drivers apply a uniform pressure on the throttle (no sharp jabs) and upshift as close to the minimum upshift speeds as possible.

Accelerometer, Vacuum Gauge, and Tachometer

It has been suggested that accelerometers, engine vacuum gauges, or engine tachometers be installed in automobiles to help drivers improve their fuel economy. Many automobiles are already equipped with dashboard engine vacuum gauges for this purpose. Correlations

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<table>
<thead>
<tr>
<th>Deceleration Rate</th>
<th>Fuel Economy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>0.16</td>
</tr>
<tr>
<td>Coefficient of determination</td>
<td>0.4</td>
</tr>
<tr>
<td>No more than 16 percent</td>
<td>84 percent</td>
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between fuel economy and the appropriate dial readings are about the same for the vacuum gauge and the engine tachometer ($r = 0.6$), as shown in Figures 5 and 6, respectively; they are less for the accelerometer ($r = 0.4$ for the maximum deceleration rates shown in Figure 3 and 0.5 for the maximum acceleration rates shown in Figure 4). The devices that measure values most closely related to fuel economy are the vacuum gauge and the engine tachometer.

The engine vacuum gauge displays (in centimeters of mercury) the vacuum in the intake manifold developed by the pumping action of the engine pistons. Vacuum will be high if the throttle plate is closed (when a vehicle is idling or coasting) but will drop as the interior of the manifold is opened to the atmosphere at progressively wider throttle openings. Although vacuum is affected by engine speed and ambient air pressure, it is basically a measure of throttle opening. The gauge can help drivers to save fuel by letting them know when and for how long the throttle opening is excessive. In many automobiles, throttle opening is excessive when engine vacuum falls below about 25 cm (10 in) of mercury.

The tachometer gives engine speed in revolutions per minute. During acceleration, readings increase with vehicle speed except for a drop-off each time a transmission upshift takes place. Since fuel is consumed with every engine revolution, keeping engine speed down by early upshifting will promote fuel economy. The tachometer will also help drivers to save fuel by identifying minimum upshift speeds (on level roads) and by letting them know when engine speeds during acceleration are excessive. In many automobiles, engine speed during acceleration should not exceed about 2000 revolutions/min.

Both the vacuum gauge and the tachometer provide the driver with engine information related to fuel economy, particularly during acceleration. The engine tachometer, however, has two distinct advantages over the vacuum gauge:

1. The tachometer provides more information for the driver than the vacuum gauge. It not only gives engine speed at all road speeds but also can be used to identify minimum upshift speeds and to indicate when upshift takes place. This helps drivers to upshift at as low an engine speed as possible, either by manually shifting in a manual-shift automobile or, in an automatic-shift vehicle, by momentarily increasing engine vacuum by closing the throttle to force upshift. The vacuum gauge only indicates throttle opening.

2. As a tool for conserving fuel, the tachometer is probably less distracting to the driver than the vacuum gauge. During acceleration, tachometer readings rise
Figure 5. Driver fuel economy versus minimum engine vacuum.

MINIMUM ENGINE VACUUM ON ACCELERATION (IN. OF HG.)

Figure 6. Driver fuel economy (for 58 drivers) versus maximum engine speed during acceleration.

MINIMUM ENGINE VACUUM ON ACCELERATION (MM. OF HG.)

MINIMUM ENGINE VACUUM ON ACCELERATION (IN. OF HG.)

steadily (except for drop-offs when upshifts take place) so that a few quick glances by the driver are all that is needed. The vacuum gauge, on the other hand, requires almost constant observation.

In the 1975 FHWA study (1, pp. 20-27), it was found that drivers accustomed to accelerating very rapidly—at rates greater than 10 km/(h/s) (6.2 miles/(h/s))—at engine vacuums of less than 25 cm (10 in) of mercury might save fuel by using a vacuum gauge. But almost 50 percent of other drivers would use more fuel by trying to drive in conformance with vacuum gauge readings than they would use without the gauge.

Information developed in the study reported in this paper indicates the potential of the tachometer in helping drivers to save fuel. Further research is needed, however, to determine whether the instrument would actually contribute to fuel conservation and be safe to use.

Whether or not the average driver would even try to save fuel by using a dashboard instrument designed to help conserve fuel has not been investigated. This would depend on the driver's attitude toward fuel conservation, the amount of the driver's attention that would be taken from other driving tasks, and the extent of driver response required.

SUMMARY

The findings of this study indicate that fuel economy is not much affected by either the age or the sex of drivers or by whether drivers make full stops at stop signs. For normal ranges of deceleration and acceleration rates, the speed-change rate by itself is not important to fuel economy. If vehicles are coasted for a distance before the brakes are applied, fuel economy during deceleration is good regardless of the final rate of deceleration. On acceleration, drivers should avoid sharp jabs on the foot throttle and delays in upshifting. A smooth, steady acceleration at any acceleration rate up to 10 km/(h/s) (6.2 miles/(h/s)) provides good fuel economy.

The vacuum gauge is of little value as a dashboard instrument to help drivers save fuel. Although it might encourage the minority of drivers who customarily drive in a highly erratic manner to drive more smoothly, it would not help most drivers to conserve fuel. In fact,
a substantial number of drivers would use more fuel in attempting to adjust their driving to the vacuum gauge. In addition, since the gauge should be monitored most closely during vehicle acceleration if it is to be useful, it could add a dimension of danger by distracting the driver's attention at these critical times.

The generality of the study results is somewhat diminished by the small size of the driver sample, the use of only one test vehicle, and the fact that the percentage of well-educated drivers in the sample probably exceeds that in the total driving population. However, the specific import of the study results is quite dependable. Other studies of the effect of driver characteristics and behavior on automobile fuel consumption have arrived at similar conclusions (2, 3).

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REFERENCES


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A Real-World Bicycle-Performance Measure

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A reliable and valid measure of the behavior of bicyclists in normal traffic is urgently needed for progress in bicycle safety. A measure developed based on observations by trained coders is presented. Types of bicycling behavior identified as critical for safety were drawn from accident and research data and a model of safe operator behavior. The reliability of observations depends on unambiguous definition of types of behavior and avoidance of information overload as well as intensive training. Only those types of behavior that occur frequently and are critical for safety are included. Three types of locations are used: (a) controlled intersections where the major variable is path, (b) midblock entrance, and (c) uncontrolled intersections were the variable of concern is search. Coding each type of location requires using a different form. Inter-coder reliability was very high for all forms. This technique was used to evaluate the bicycling behavior of approximately 600 elementary-school children and more than 3000 junior-high-school students on two occasions. This is the most extensive survey of bicycling behavior available. It shows a very high error rate for all maneuvers and the greatest numbers of errors occurring on left turns and in search patterns. The instrument was shown to be both sensitive and reliable and is equally useful for measuring adult bicycling behavior.

Recently, traffic safety education has been extended to the elementary-school level and bicycle-safety curricula have burgeoned. It is advisable to evaluate the various options while there is still variability in the air, lest the nation's standard curriculum be cast in concrete before there is any evidence of effectiveness, as happened in the area of driver education.

In order to evaluate the effectiveness of bicycle-safety curricula, a reliable and valid criterion measure is necessary. A survey of the literature revealed no such measure. Accident data are not suitable in this area, even if one believes that they are the ultimate criterion, because, on the one hand, crashes are too few in any single jurisdiction to provide a reliable measure and, on the other hand, summing over a large number of jurisdictions introduces so many possibly relevant differences that the data would be meaningless. The proper kinds of validity to strive for are content validity, where the domain of relevant behaviors is sampled, and construct validity, where a model of traffic interaction is used to define safe bicycling behavior. If validity is defined in this way, it is possible to develop a measure that can be used to evaluate bicycle-safety curricula.

In their work, Cross and DeMille (1) reported no evidence that lack of skill in controlling the bicycle was a cause in any significant number of accidents. Therefore, range tests are not suitable for evaluating safe performance. Since interaction with traffic is of paramount importance in safe bicycling, a proper measure of bicycle performance must permit the evaluation of the bicyclist's ability to interact with traffic. We discovered no way to do that except to observe bicyclists in natural traffic situations. All artificial situations were either unacceptable to school authorities or failed to provide opportunities for interaction of any reasonable degree of complexity or risk.

PARAMETERS OF BICYCLIST PERFORMANCE

An appropriate measure for safe bicycle-riding behavior should sample bicycle-automobile interactions at a number of kinds of intersections and at midblock, where several other kinds of situations exist. Ideally, bicyclists should be unaware of any observation of their behavior; they must not be told that they are to take a test and then be given a set route. Their behavior must be free of constraints, and observation must be as unobtrusive as possible.