13 Oct 1977

The Operator’s Guide For Minimizing Energy Costs

Charles Dare
Missouri University of Science and Technology

Frank A. Gerig
Missouri University of Science and Technology

THE OPERATOR'S GUIDE FOR MINIMIZING ENERGY COSTS

Charles E. Dare and Frank A. Gerig, Jr.
University of Missouri-Rolla
Rolla, Missouri

Abstract

The consumption of petroleum by transportation activities is increasing despite the finite limits on its supply. This paper concentrates on the motor vehicle driver, his driving habits, and guides to reduced fuel consumption which would enable the individual to curtail wasteful practices with respect to vehicle operation.

1. INTRODUCTION

According to the American Petroleum Institute, the United States consumed more oil and imported more oil during 1976 than in any previous year. Fuel consumed for highway transportation purposes also reached an all-time high as vehicle miles traveled surpassed all previous records. More than ever before, the U.S. is vulnerable to any action that would curtail the supply of petroleum. With our transportation system almost completely dependent on petroleum or natural gas, an oil or gas shortage would necessitate immediate changes in our personal mobility.

It is the intent of this report to present the data pertaining to U.S. transportation fuel consumption in a meaningful manner. Certain government policies and other forces which have been at work to generate increased highway vehicle petroleum use will be explored. The potential for reducing gasoline consumption at the basic level of the individual driver will be discussed, and a review of operator's or driver's guides for improving gasoline mileage will be presented. Finally, several alternatives and actions will be suggested which should be implemented at the earliest possible date to help avoid the next public clamor for gasoline as the demand will eventually exceed the supply.

2. PETROLEUM CONSUMPTION

2.1 THE TRANSPORTATION SECTOR

The U.S.D.O.T. publication, Energy Statistics[1] shows that during the year 1950 the transportation sector of the U.S. used 1,248.8 million barrels of petroleum, and by 1972 this utilization had increased to 3,213.0 million barrels annually. During this same period transportation consistently accounted for 24 or 25 percent of the nation's total energy consumption, all types of energy considered. The data in Table 1 shows that the transportation sector consumption has increased steadily as have the other uses of petroleum. Using these data, it may be shown that transportation accounts typically for 50 to 53% of the total petroleum consumed.

2.2 HIGHWAY FUEL USE

From another view point, it is revealed that in 1950 automobiles used 9 percent of the energy consumed in the U.S., trucks used 3.9 percent, and buses used 0.3 percent; while in 1972 the corresponding proportions were 13.6 percent for autos, 5.8 percent for trucks, and 0.2 percent for buses[2]. During 1975, the 137,917,200 registered motor vehicles traveled 1,330,074,000,000 vehicle miles in the process of consuming 108,984,000,000 gallons of gasoline[3].

The data shown in Table 2 summarizes fuel consumption for highway purposes, with the preliminary total estimate for 1976 shown. From 1950 to 1975 passenger car consumption of petroleum tripled; this was also the trend for truck utilization of petroleum. Buses were consuming about 1.2 times as much fuel in 1970 as in 1950 due to a substantial increase in school bus transport. It is a fact, however, that commercial buses consumed less fuel in 1975 than in 1950.

Table 2 also shows that the use of gasoline declined slightly in the period 1973 to 1974, but the most recent estimates reveal substantial increases since that time. In fact, the increase from 1975 to 1976 is approximately 5.7 percent.

3. OUR DEPENDENCE ON PETROLEUM INTENSIVE TRANSPORTATION MODES

Any discussion of the type presented in this paper would be incomplete if some consideration were not given to the factors which have created our nation's insatiable demand for and dependence on petroleum. With respect to transportation, it must be conceded that the convenience, reliability, and comfort of the automobile offers an affluent society an alternative for transportation which is difficult to match. However, it must also be recognized that certain key events have occurred and forces have been exerted which have left the public with practically no choice for satisfying their mobility requirements.

3.1 UNRELIABLE TRANSIT

It is of great significance that during the years from 1947 to 1963 there were 811 major transit strikes in the United States[4]. Faced with the necessity for traveling to work, to the grocery store, to the doctor, and seeking to remove themselves from the uncertainty of transit availability, American families drew upon half a decade of savings to equip themselves with at least one, and perhaps two, automobiles. Indeed, it was very easy to make the transition from antiquated and unreliable public tranpsortation to the mass-produced private automobile.

3.2 THE EXTENDED INTERSTATE SYSTEM

In the decades following World War II, it was deemed desirable to establish a wide spread network of multi-lane freeways to provide safe and efficient automobile transport, and for defense purposes. Originally conceived as a highway system that would serve intercity travel demands, the National System of Interstate and Defense Highways was ultimately extended through highly populated urban areas, even penetrating the central business districts in some cases. These high speed freeways not only opened new vistas for long distance travel and vacations, but they also made it more convenient for the urban areas to sprawl out from the central city, with the freeway becoming the preferred means for making urban area trips. In essence, everyone who contributed to the

Highway Trust Fund, which was established by the 1956 Federal Aid Highway Act, was contributing toward a program which had a by-product of effectively eliminating alternate transportation modes in most of our larger urbanized areas.

3.3 OTHER FACTORS

Once society was equipped with private conveyance, the desire for more of the same was enhanced by Federal policy and legislation promoting and perpetuating highway development. During this same era, the 1950's and 1960's, little if any concern was evident for creating a balanced transportation system; and most certainly there was only token support for anyone interested in exploring motive power sources which might replace the gasoline fired internal combustion engine.

4. POTENTIAL FOR REDUCING HIGHWAY PETROLEUM USE

4.1 VEHICLE RELATED FACTORS

Numerous vehicle related factors have contributed to the dramatic increase in highway vehicle petroleum consumption. The Federal Highway Administration has summarized the relative influence of several general factors contributing to increased passenger car fuel consumption as follows during the period 1950 to 1972.

(1) Increased vehicle population: 85% contribution

(2) Increased use per vehicle: 8% contribution, and

(3) Increased fuel consumption per mile traveled, 7%.

With more than 135,000,000 vehicles being currently registered in the U.S., it is apparent that a slight change in the fuel economy of the motor vehicle fleet should have a noticeable influence on gasoline consumption.

To illustrate several of the more significant vehicle related variables, certain data will be presented from the testimony of Fred L. Hartley, President, Union Oil Company of California, before the Senate Committee on Commerce in 1973[5]. In one of his examples he showed that if a vehicle with a 10 to 1 compression ratio had been able to achieve 15 miles per gallon; then with a lower compression ratio, say 8 to 1 which would be required with new unleaded fuels, the mileage would drop to 14.1 miles per gallon. Therefore, with other factors held constant, the move to unleaded fuels for catalyst equipped cars would increase fuel consumption by about 6 percent for those cars.

Another vehicle characteristic which Hartley discussed was vehicle weight. For a weight ranging from 2,000 pounds to 5,000 pounds, he illustrated reports which estimated the loss in fuel economy to be at the rate of about 0.25 mile per gallon per 100 pounds in city driving. Thus, city drivers in 5,000 pound cars could expect 4 miles per gallon less than if they were driving 3,400 pound cars. It is interesting that in everyone of the 11 years from 1958 to 1968, the best-selling weight class was the standard car class of about 4,000 pounds per vehicle. Since 1966, the average weight of this class had steadily increased to about 4,400 pounds by 1973, and to 4,500 pounds by 1975.

Closely related to the vehicle weight is the engine size, as measured by horsepower. Test results were shown by Mr. Hartley which indicated a 1 mile per gallon loss in fuel economy for each 120 horsepower in the range from 100 to 400 horsepower. Those familiar with the history of automobile engine development are aware of the fact that in the early 1950's the most powerful engines in luxury cars were on the order of 160 to 180 horsepower. However, the mid 1950's saw the beginning of the great American horsepower race with so much concern for performance in the 0-60 mph test, the top speed, and race track records. During this era, engines were built exceeding 400 horsepower. It was during this era, that most of the popular auto road test magazines decided to stop reporting fuel economy results as a part of their analysis of Detroits creations, due to lack of interest in this statistic by their readers.

4.2 VEHICLE SPEED

The force required to move an automobile through the air is generally related to the coefficient of air resistance for the vehicle, the projected frontal area, and the speed of the vehicle relative to the air. After about 25 miles per hour, the aerodynamic drag becomes very substantial because the velocity is squared calculating this type of resistance.

To illustrate the influence of passenger car speed on fuel economy equations were developed by the Federal Highway Administration which relate vehicle speed, resistance to motion, engine horsepower and fuel consumption. A computer program was developed by the Civil Engineering Department at the University of Missouri-Rolla and is run as a classroom exercise. A set of results is shown in Table 3 where the vehicle was a medium sized passenger car. For this vehicle, gas mileage is somewhat insensitive to speed increases up to about 45 mph; then the influence of air and rolling resistance becomes so large that fuel economy is reduced approximately 25 percent between 45 mph and 65 mph, and approximately 17 percent between 55 mph and 65 mph.

4.3 DRIVING HABITS

The automobile driver is a creature of habit, and quite frequently, his vehicle operation habits are not of the type that produce good fuel economy. More overt examples of this are the variations seen in vehicle speed, even on open highways; unnecessarily rapid acceleration from stopped positions; racing the motor while idling; and idling for extended periods while parked.

4.3.1 Acceleration Habits

Acceleration habits markedly affect fuel economy, yet drivers still seem to feel the urge to accelerate in unnecessarily short time periods. During an acceleration from 20 to 25 mph, fuel economy is decreased by 42% if the driver accelerates at 4 mph/second in 2nd gear as opposed to 2 mph/second in 3rd gear. Acceleration from a stop to normal traffic speed requires 15% more fuel at high rates as opposed to moderate rates.

4.3.2 Speed Variations

Variations in vehicle speed, as well as absolute speed also increase fuel consumption. The Federal Energy Administration has estimated a 1.3 mile per gallon loss when speed is varied repeatedly over a range as small as 5 mph, as compared to steady speed operation.

4.3.3 Trip Patterns

Numerous tests have shown fuel economy is highly related to trip pattern. The data indicate many short trips beginning with a "cold start" are far more costly per mile than long trips, or consecutive trips made with a warmed up engine and drive train. Trips of five miles or less make up 15 percent of miles driven, but consume more than 30 percent of all auto fuel. To further illustrate the economy effects of trip length, a typical family car could be used for ten 40-mile trips, or one hundred 1-mile trips, each requiring 25 gallons of gasoline. These data should not be interpreted as a suggestion to drive a long distance for any given trip, but rather one should take advantage of a warmed-up vehicle condition to combine numerous short trips in a single trip with several stops. Of course, the short trip pattern will contain numerous low speed cyclic (stop-and-go) operations which will significantly reduce the overall miles-per-gallon, but it would still be more efficient than beginning each trip with the engine cold.

4.3.4 Urban Driving Test

One recent investigation[6] concerning gasoline consumption in urban traffic seems to be especially pertinent to the subject of driving habits. In this study, a 16.8 mile suburban route was used consisting of 56 signalized intersections. An instrumented vehicle kept accurate measurements on fuel, time, distance, and temperature. The vehicle was a 1974 sedan, with a V-8 engine, 2 barrel carburetor, with a weight of 4,980 pounds fully equipped. Drivers were to run the test course according to different driving characteristics according to different driving characteristics according to these instructions: (1) drive normally with traffic, (2) minimize trip time, (3) use vigorous acceleration and deceleration, (4) minimize fuel consumption, (5) maintain vacuum gauge fuel economy meter in green range, (6) maintain vacuum gauge fuel economy meter in green or orange range, and (7) drive like a hypothetical very cautious driver.

The results of this experiment which included 34 test runs are summarized in Table 4, except for data obtained under instruction 5. These data were omitted since only 1 run was made under that driving instruction. With instruction 4, which achieved the best mileage, drivers used their best judgment with respect to speed and acceleration to reduce stops and delays on the road. This driving strategy reduced the amount of time spent idling at red lights and resulted in smoother vehicle operation. The poorest fuel economy was obtained by those using vigorous acceleration and deceleration under instruction 3. It is significant that drivers under instruction 4, achieved 31% better gas mileage than those under instruction 3, and almost 12% better gas mileage than those under instruction 1 who were driving normally with traffic.

4.3.5 Vehicle Maintenance

There are many aspects of vehicle maintenance which contribute from rather small to rather significant impacts on fuel economy. Items such as air filter replacement and regular oil changes have a small influence on fuel consumption, yet should not be overlooked. Other factors, such as tire inflation, front-end alignment, engine timing, brake adjustment, and spark plug condition are of greater importance. One source[7] has estimated the following penalties in fuel economy due to poor maintenance, as shown in Table 5. While each of these items may have a rather small contribution, a vehivehicle which is poorly maintained in general, may suffer a loss in fuel economy of as much as 20 percent.

5. OPERATOR'S GUIDES

Operator's guides for proper automobile operation have been available for generations. These publications were usually available from automobile dealers and manufacturers, however in recent years several government agencies have issued fuel economy documents for various purposes. Several types of these publications will be briefly reviewed.

5.1 FUEL ECONOMY THROUGH PLANNED DRIVING

This booklet, issued by Chrysler Corporation in 1949, was a well illustrated guide which clearly described techniques to achieve improved gasoline mileage[8]. It was primarily based on actual driving tests, covering city driving, highway driving and cold weather operation. The document has the advantage of being written so that the average motorist could easily comprehend its meaning.

5.2 CLEAN AIR AND YOUR CAR

Issued by the U.S.E.P.A. in 1974, this publication was primarily concerned with vehicle emissions, air pollution, and different types of engine designs[9]. In this report, it was stated that fuel economy loss for 1973 model year vehicles over those with no emission controls ranged from 18 percent to 3 percent depending on vehicle weight. Several driving and vehicle maintenance recommendations were listed which would have enabled drivers to offset the loss due to emission control devices.

5.3 TIPS FOR THE MOTORIST

This brochure, currently available from the Federal Energy Administration, identifies 30 techniques which could lead to improved gasoline mileage[10]. Grouped under the major headings of (1) Improve Your Driving Skills; (2) Improve Your Trip Planning; (3) Maintenance and Car Care; and (4) Become Aware of Gas Usage; are numerous worthwhile suggestions. It is pointed out that if fuel consumption of the average car were reduced by only 15%, the nation's consumption of petroleum would decrease by over 28,000,000 gallons per day.

5.4 GAS MILEAGE GUIDE

To aid in the comparison of fuel economy among various types of new vehilces, the E.P.A. annually issues this summary of the results of its fuel economy tests[11]. Although this publication has received some criticism due to drivers not being able to achieve the estimated mileage ratings, the booklet is still valuable for assessing differences among vehicles under controlled test conditions. The booklet also contains a discussion of the factors that affect fuel economy, although this section is somewhat brief.

6. CONCLUSIONS

The response of the individual motorist to the energy supply problem does not appear to be favorable. Surveys conducted since 1973 have repeatedly indicated the majority of our citizens do not believe the energy problem to be a real crisis; but prefer to think of it as a contrived situation which does not merit the concern of the President.

6.1 PURCHASING HABITS

One indicator showing the lack of concern of the American motorist for our fuel supply is the type of vehicle and accessories which are being purchased. It is interesting that new car buyers have been attracted to the more economical, low cubic inch displacement imported cars so that such vehicles account for 14.8% of the U.S. sales market in 1976. Offsetting this trend, however, we find in 1976 almost 30% of domestic new cars were sold with larger sized optional V-8 engines, as opposed to the standard V-8 for the chosen model. Other accessories and their frequency of purchase on U.S. manufactured cars were: vinyl top (46%); automatic transmission (91%); power steering (90%); power windows (23%); power seats (16%); and stereo tape players (13%). On the positive side, 77% of new car buyers purchased steel-belted radial-ply tires. Another economy device, the automatic speed control, was less successful, being installed on only 26% of the vehicles sold(12).

6.2 DRIVING SPEEDS

Following the imposition of the 55 mph speed limit, highway speeds have gradually risen so that few vehicles are travelling under 60 mph on unpatrolled sections of open rural highway. Furthermore, it is common knowledge that many drivers have purchased citizen band ratios and frequently utilize them to evade law enforcement officers and speed measuring devices. Motorists have taken our national effort to preserve fuel so lightly that they are willing to invest \$50 to \$150 in order to save a few minutes on a trip and display their ability to avoid law enforcement officials.

6.3 HOW TO INFLUENCE THE MOTORIST

The problem of influencing motorists so they would more effectively utilize and preserve our ptetroleum supply is indeed complicated. For even those who acknowledge the existence of a critical problem, it is often thought by the individual that his contribution is too insignificant to be worth the bother. If society is to be responsive and responsible in their driving, then more drastic and innovative measures will have to be adopted. Perhaps, some of the following ought to be given more serious consideration: (1) major emphasis given to fuel economy in driver education courses; (2) publication of an easy to read and readily available fuel economy operator's guide; (3) more cooperation from automobile manufacturer's, their associations, and dealers in the marketing of fuel efficient vehicles and options; (4) rigid enforcement of traffic laws, including speeding, improper driving, and following too close; (5) adoption of driver's license examinations with questions concerning fuel economy; (6) identification of poor drivers and habitual violators with unique license plates carrying a motto such as "Speed Wastes Gas". While none, or even all of these enacted together would be adequate, these ideas, along with others, should be considered by responsible officials so that something may be done about our abuse of a valuable limited resource.

REFERENCES

1. Energy Statistics, A Supplement to the Summary of National Transportation Statistics, Department of Transportation; Washington, D.C., August 1974.

2. Energy, The Economy, and Mass Transit, Office of Technology Assessment; Washington, D.C., December 1975.

3. Highway Statistics, Department of Transportation; Washington, D.C., Annual.

4. Owen, Wilfred, "The Metropolitan Transportation Problems," Brookings Institution, 1966.

5. Hearings Before the Committee on Commerce, United States Senate, Ninety-Third Congress First Session on S.1055 and S.1903, U.S. Government Printing Office; Washington, D.C., 1973.

6. Chang, M., L. Evans, R.Herman, and P. Wasielewski, "Gasoline Consumption in Urban Traffic," Transportation Research Record 599, Transportation Research Board; Washington, D.C., 1976.

7. Factors Affecting Automotive Fuel Economy, Environmental Protection Agency; Washington, D.C., October 1976.

8. Fuel Economy Through Planned Driving, Plymouth Division, Chrysler Corporation; Detroit, Michigan, 1949.

9. Clean Air and Your Car, Environmental Protection Agency; Washington, D.C., March 1974.

10. Tips for the Motorist, Federal Energy Administration, Washington, D.C., 1977.

11. 1977 Gas Mileage Guide, Environmental Protection Agency; Washington, D.C., January 1977.

12. Motor Vehicle Facts and Figures '77, Motor Vehicle Manufacturers Association; Detroit, Michigan, 1977.

BIOGRAPHIES

Charles E. Dare is an Associate Professor in Civil Engineering at the University of Missouri-Rolla. He received his Ph.D. from the University of Iowa in 1968 and is a registered Professional Engineer in the State of Illinois. His teaching and research interests are in the areas of traffic and transportation engineering, pollution control, and transportation systems analysis.

Dr. Frank Gerig, Jr. is Professor of Civil Engineering and Director, UMR Transportation Institute. He has degrees from the U.S. Military Academy at West Point, N.Y., California Institute of Technology, and Texas A&M University.

He received the Highway Research Board Award for the Outstanding Paper presented at the 47th Annual Meeting. He has been active in Highway, Rail, Water and Air Transportation Studies and Research for needed facilities. His current work focuses on Systems Engineering.

Table 1. Annual Petroleum Consumption by Major Sector in the U.S., 1950-73 (in Trillions of Btu)

Year	Household and Commercial	Industrial	Transportation	Electrical Generation
1950	3,038	2,666	6,785	662
1960	4,923	3,682	10,372	564
1970	6,453	5,267	15,592	2,087
1973	7,024	6,043	17,927	3,435

Source: U.S.D.O.T. Energy Statistics

Table 2. Fuel Consumed for Highway Purposes, in the U.S., by Vehicle Type, 1950-76 (in Millions of Gallons)

Year	Passenger Cars and Motorcycles	Buses	Trucks	Total
1950	24,305	732	10,566	35,603
1960	41,169	827	15,832	57,878
1965	50,275	894	19,935	71,104
1970	65,784	944	25,600	92,328
1973	78,011	847	31,615	110,473
1974	74,217	858	31,226	106,301
1975	76,457	895	31,632	108,984
1976	(Preliminary Estimate)			115,174

Source: U.S. Federal Highway Administration, Highway Statistics, Annual

Table 3. Fuel Consumption of Typical Full Sized Sedan

Speed, mph	15	25	35	45	55	65	75
Miles per gallon	19.1	20.3	19.7	18.5	16.7	13.9	9.8

Table 4. Suburban Driving Test

Driving Instruction	Miles per Gallon	Average Trip Time (in Seconds)	Overall Travel Speed (in miles per hour)
1	11.64	2405.7	25.15
2	10.59	2079.0	29.10
3	9.92	2149.2	28.14
4	13.00	2419.2	25.00
6	12.31	2440.8	24.78
7	12.51	2592.0	23.33

Table 5. Effect of Poor Maintenance on Fuel Economy

Maintenance Item	Miles per Gallon Loss (Percent)
One Sparkplug Misfiring 50% of the Time	7
Tires Under inflated by 35%	7
Front Wheels 1/4 inch out of Alignment	2