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AVERAGE SPEED CONTROL AND ENERGY CONSERVATION ON LIMITED-ACCESS HIGHWAYS*

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ABSTRACT

A system for average speed control on limited-access highways for the purpose of conserving energy is presented. The system is particularly well-suited for toll roads where times of entry and exit can be recorded and used to determine the average speed maintained by a vehicle between the entry and exit locations. Estimates of the amount of fuel that can be saved by strict adherence to a given speed limit are determined by accounting for the aerodynamic drag and rolling resistance forces that act on a vehicle during constant speed motion. Using available data for average speeds and total mileage travelled on the New York State Thruway, it is estimated that between 12.7 million and 33.7 million gallons of fuel could be saved yearly by Thruway motorists if they all adhered to the national speed limit of 55 mph.

The paper concludes with a brief discussion of the safety benefits of a system of average speed control. It is anticipated that fewer vehicle accidents would occur due to the smoothing and slowing of the flow of traffic.

Introduction

The Emergency Highway Energy Conservation Act of 1974 was enacted as a temporary means of conserving fuel on the nation's highways by lowering the speed limit to 55 mph. On January 4, 1975, this speed limit was extended indefinitely by legislation signed by then President Gerald R. Ford [1]. Since enactment, the national 55 mph speed limit has been the subject of much controversy with its opponents arguing that the amount of fuel to be saved by

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the lower speed limit is not worth the inconvenience of longer trip times. Enforcement has also been a problem with speeders in some states often receiving no moving violations and maximum $5 fines until their speeds exceed the limits in effect before the 55 mph law [2]. The purpose of this paper is to present a relatively simple procedure for controlling the average speed of vehicles on limited-access highways and to estimate the amount of fuel that can be saved by strict adherence to a given speed limit.

Average Speed Control: A Proposed Method

One possible method for controlling the average speed of vehicles on limited-access highways is to record the times of entry and exit and then compute the average speed from the known distance travelled between the entry and exit locations. This would be a relatively simple procedure on toll roads, such as the New York State Thruway, where a card is issued to each entering motorist and is returned to an operator at the exit toll booth. Currently, the operator determines the toll to be paid from the distance travelled on the Thruway. It would be a simple matter to determine the toll from the distance travelled and the average speed maintained by the vehicle. Those observing the speed limit would pay only the distance toll whereas speeders would pay distance and speed tolls. It is noted that this proposed system of average speed control is not meant to replace current speed enforcement systems that detect speeds over a relatively short distance. Rather, it is meant to supplement these "spot checks" by providing an indication of the average speed maintained over a much greater distance.

A possible difficulty with this proposed system is the time spent by motorists at roadside rest areas. These times can be ignored or the times of entry and exit can be recorded on the toll card and eventually accounted for in the average speed determination at the exit toll booth.

Estimated Fuel Savings from Average Speed Control

The amount of fuel that can be saved by strict adherence to a given speed limit can be estimated by accounting for the forces that resist forward motion of a vehicle. That is, when a road vehicle travels at constant speed on a level highway the engine propels the vehicle forward by creating a thrust force on the wheels that balances the resistive forces due to aerodynamic drag and rolling resistance. The latter force is due to a number of factors such as the deformation of the tires as they roll over the road surface. Hoerner relates rolling resistance to vehicle speed and weight as well as to the tire inflation pressure according to [3],

$$D_R = W\left[0.005 + \frac{0.15}{P} + \frac{(0.000035)V^2}{P}\right], \tag{1}$$

where D_R is the drag force on the vehicle due to rolling resistance in pounds, W is the weight of the vehicle in pounds, V is the speed of the vehicle in miles per hour, and P is the tire inflation pressure in pounds per square inch. The aerodynamic drag force, D, on the vehicle can be determined from the standard relation,

$$D = \tfrac{1}{2}\rho A C_D V^2, \tag{2}$$

where ρ is the mass density of air and A, C_D and V refer to the frontal projected area, drag coefficient and speed of the vehicle, respectively.

Since the total thrust force to maintain constant speed is given by the sum of equations (1) and (2), the energy that must be delivered from the vehicle engine to the wheels for a trip distance, s, is given by

$$E = (D_R + D)\,s$$

Dividing this value by the efficiency of the engine, η, gives the total energy, E_f, that must be supplied to the engine by fuel in order to move the vehicle over the distance, s, at the speed, V. Thus,

$$E_f = \frac{(D_R + D)\,s}{\eta} \tag{3}$$

Equations (1)–(3) form the basis for estimating the amount of energy that can be saved by strict adherence to a given speed limit. There are, however, a number of parameters in equations (1)–(3) which must be estimated and values for these parameters have been determined as follows:

1. Reference [4] reports that about half of the automobile gasoline consumed in the United States is by automobiles that are four or more years old and reference [5] indicates that up to two-thirds of all travel is produced by vehicles from the most recent three or four model years. With this in mind the following automobile was selected as being representative of average vehicle size on today's highways [6]:

   1973 Chevrolet Monte Carlo
   Weight: 3,823 pounds
   Height: 52.7 inches
   Width: 77.6 inches

   With the latter two dimensions the frontal projected area, A, can be calculated according to Haase and Holden who recommend 0.8 times the product of height and width [7]. This yields a value of 22.7 square feet.

2. Reference [8] reports a range of 0.4 to 0.6 for the aerodynamic drag coefficient, C_D, of passenger cars. A value of 0.5 was selected for use in equation (2).
3. Reference [9] reports data on tire inflation pressures and a value of 25 pounds per square inch was selected for use in equation (1).
4. Reference [10] reports a range of 17 to 23 per cent for the brake thermal efficiency of automobile internal combustion engines. A value of 20 per cent was selected for use in equation (3).
5. For use in equation (2), the density of air was calculated to be 0.00237 slugs per cubic foot from the ideal gas law for assumed atmospheric conditions of 14.7 pounds per square inch and 60°F for pressure and temperature, respectively.

Summarizing, the values of the parameters selected for use in equations (1)–(3) are:

$$\begin{aligned} W &= 3{,}823 \text{ pounds} \\ A &= 22.7 \text{ square feet} \\ C_D &= 0.5 \\ P &= 25 \text{ pounds per square inch} \\ \eta &= 0.20 \\ \rho &= 0.00237 \text{ slugs per cubic foot} \end{aligned}$$

It is noted that these values will yield units of British Thermal Units (Btu) for E_f in equation (3) when the conversion factor, 778 foot·pounds per Btu, is employed. A more convenient unit of energy for this discussion is the number of gallons of fuel required to supply this amount of energy to the engine. This can be determined from,

$$E_f \text{ (gals.)} = \frac{E_f \text{ (Btu)}}{Q_c \ \gamma_f} \tag{4}$$

where Q_c and γ_f are the heat of combustion and weight density of the fuel, respectively. For motor gasoline, reference (10, p. 9-124) reports the following values for these parameters which are adopted for use in equation (4):

$$\begin{aligned} Q_c &= 21{,}050 \text{ Btu per pound} \\ \gamma_f &= 6.17 \text{ pounds per gallon} \end{aligned}$$

Equations (1)–(4) form the basis for estimating the amount of fuel, in gallons, that can be saved by strict adherence to a given speed limit. This will now be illustrated for a specific limited-access highway system, the New York State Thruway.

Estimated Fuel Savings on the New York State Thruway via Average Speed Control

The New York State Thruway is a limited-access, toll highway system consisting of 559 miles of multilane roadways. During 1976, the total miles travelled on this highway system was 4,182,892,022 miles [11]. This data plus information on average highway speeds provides the means for estimating the amount of fuel to be saved if all these miles were travelled at 55 mph.

The following sources were adopted as being indicative of average highway speeds in the United States in recent years:

1. Reference [12] reports a mean speed of 58 mph for passenger cars on rural interstate highways in 1974 and in 1975.
2. An average speed of 58.6 mph was reported by Tofany [13] from data taken at twenty-four interstate stations in a number of different states.
3. The average speed of passenger cars on the New York State Thruway was reported to be 60.0 mph in reference [14]. It was further reported that 88 per cent of the passenger cars exceeded 55 mph, 56 per cent exceeded 60 mph and 21 per cent exceeded 65 mph. Trucks generally travelled slower than passenger cars but buses went significantly faster (e.g., 42 per cent exceeded 65 mph).
4. Reference [15] reports 85 per cent of the motorists on the Long Island Expressway averaged 64 mph during a test. If the remaining 15 per cent averaged 55 mph this would produce an overall average of 62.65 mph.

With these average speeds and the total mileage on the New York State Thruway for 1976, equations (1)–(4) can be used to determine the fuel savings, in gallons, if all Thruway motorists adhere to the present speed limit of 55 mph. These results are tabulated in Table 1 where the savings range from 12.7 million gallons per year to 33.7 million gallons per year at average speeds of 58.0 mph and 62.65 mph, respectively. It is noted that these savings apply only to the New York State Thruway and if a system of average speed control were employed on all limited-access highways in the United States the savings would, perhaps, approach one billion gallons of fuel per year.

Although the emphasis here has been on energy conservation there are other benefits of controlled lower speeds that are worthy of mention such as reduced highway fatalities. The National Safety Council [16] reports that more than 27,000 lives were saved during the first three years of the national 55 mph speed limit. Moreover in 1976 the annual motor vehicle death rate, the number of people killed per 100 million miles of travel, dropped to its lowest level since 1923 [16]. Tofany [13, p. 101] indicates that the lower speed limit also produces a smoother flow of traffic and this helps to

Table 1. Estimated Fuel Savings per Year on the New York State Thruway in Millions of Gallons for Various Average Speeds and a Speed Limit of 55 MPH

Average Speed (MPH)	*58.0*	*58.6*	*60.0*	*62.65*
Fuel Savings (millions of gallons)	12.7	15.3	21.5	33.7

reduce the chance of an accident. Thus, a system of average speed control would conceivably further reduce the number of traffic fatalities by smoothing and slowing the flow of traffic.

Discussion

The results of this study clearly indicate that a system of average speed control on limited-access highways can result in substantial fuel savings as well as providing opportunities for safer travel. Current toll roads, such as the New York State Thruway, provide unique opportunities for implementing such a system at least on a trial basis. It is hoped that state and/or federal officials will react favorably to such proposals for average speed control on our nation's highways with the goal being a reasonable fuel-conscious speed limit that is observed by all motorists.

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