

EFFECT OF PAVEMENT SURFACE TYPE ON FUEL CONSUMPTION

by Dr. John P. Zaniewski, P.E.*

Data from a comprehensive study of vehicle operating costs show that the type of road surface can significantly affect fuel economy. Tests were conducted with both cars and trucks traveling on a variety of pavement types. For cars, fuel consumption was not influenced by pavement surface type but trucks consumed less fuel on concrete pavements than on asphalt pavements. Such savings could have a profound impact on highway life-cycle costs—the method transportation agencies use to assess the total cost of a highway over its useful life.

Studies of Vehicle Operating Costs

Highway transportation costs can be broadly divided into two categories: costs borne by the highway agencies to construct and maintain the facilities and costs borne directly by highway users. In the United States, highway agencies are funded by the highway users through taxes on fuels, tires, parts, and so forth, and through vehicle registration fees. The objective of a highway system should be to minimize total highway transportation costs.

Highway agency costs include design, construction, and maintenance of the highways. Direct user costs include all of the cost of operating a vehicle over the roadway: the costs of buying the vehicle, registration and licensing fees, insurance, depreciation, fuel, tires, maintenance, and so forth. The direct costs of operating a vehicle, that are sensitive to roadway design features (fuel, tires, maintenance, and use-related depreciation) are approximately one-half of the total user cost. When vehicle operating costs are compared to highway agency costs, by far the largest component of highway transportation costs are borne directly by the user. Frequently, vehicle operating costs will exceed highway agency costs by a factor of 10 or more, especially on high-volume roads.

Including user costs in a life-cycle cost analysis requires establishing a relationship between highway design and condition factors and vehicle operating costs. These relationships have been studied for 50 years by several inves-

tigators such as Moyer, Sawhill, Claffey, and Winfrey.

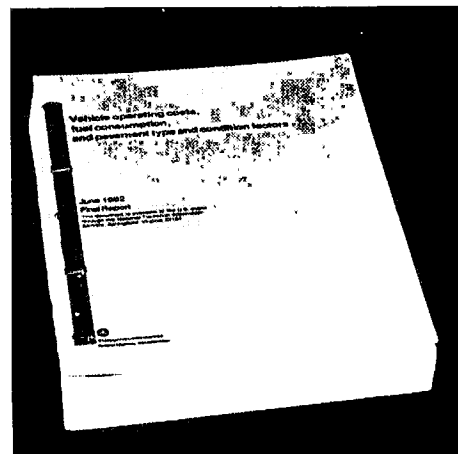
In recent years, the World Bank has studied the life-cycle costs of highways for evaluating investment decisions in several developing countries. The largest of these studies was a \$15-million project sponsored jointly by the World Bank and the Brazilian government from 1975 to 1980. Texas Research and Development Foundation (TRDF) was hired to provide international support to the project. This project demonstrated that vehicle operating costs increased on rough roads.

The TRDF project used the data gathered during the World Bank-Brazil study to the greatest extent possible. However, due to the importance of fuel consumption and the differences between vehicle design in Brazil and the United States, TRDF was hired by the Federal Highway Administration (FHWA) to revise the vehicle operating costs tables used to generate reports to Congress on the condition of highways in the United States.

The new study was also intended to update previous findings in light of significant changes in vehicle technology such as unleaded fuel, radial tires, better aerodynamics, and more efficient motors.

The TRDF research for the FHWA was a comprehensive study of the relationship between highway design and vehicle operating costs. The results of the TRDF project are reported in *Vehicle Operating Costs, Fuel Consumption and Pavement Type and Condition Factors* by Zaniewski et. al., Report No. FHWA/PL/82/001, published by the FHWA in June 1982. Vehicle operating costs were separated into several components:

- Fuel consumption
- Accidents
- Oil consumption
- Emissions
- Tire Wear
- Operating speeds
- Maintenance and repair
- Use-related depreciation



Major emphasis in the study was placed on fuel consumption due to its importance as a major component of vehicle operating costs and as an important factor in the energy posture of the United States. This brief report describes only the fuel consumption portion of the comprehensive TRDF project.

The Experiments on Fuel Consumption

Fuel consumption data were collected for a range of vehicle types, roadway design, pavement type and condition factors, and grade and curvature of roadway.

A total of 12 highway sections were tested during the experiments. These included pavement surfaces of asphaltic concrete (AC), portland cement concrete (PC), asphalt surface treatment (ST), and gravel (G). Although rough pavements were included in the overall study, this brief report concentrated on asphalt and concrete pavements with intermediate to smooth riding qualities (serviceability index, SI, in the range of 3.2 to 4.4) that would be typical of most major highway pavements in the United States. Vehicles were driven on these test sections at constant speeds of 10, 20, 30, 40, 50, 60, and 70 mph while fuel consumption, speed, and other factors were accurately measured with special instrumentation.

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Table 1 present the characteristics of the vehicles used in the fuel consumption experiments.

Influence of Surface Type on Fuel Consumption

The test for the effect of pavement type on fuel consumption was extremely interesting. Statistical analyses were not meaningful for the whole set of data, which includes a broad mix of cars and trucks, speeds, pavement conditions, and other variables. The data clearly show the fuel consumption of automobiles is not affected by type of surface. For automobiles, the fuel consumption rate is sometimes better on the asphalt surface and sometimes better on the concrete surface.

However, in reviewing the truck data, the average fuel consumption on concrete pavements was less than the fuel consumption on asphalt pavements. The balance of this report presumes the trends in the data reflect the true performance.

Plots of the data for trucks are shown in Fig. 1. In every test at speeds of 20 mph or greater, fuel consumption on asphalt was greater than fuel consumption on portland cement concrete. The difference in fuel consumption between the two pavement surfaces, for comparable roughness, can be as much as two miles per gallon. For the semitrailer truck, the fuel consumption on portland cement concrete pavement was consistently one mile per gallon better than on the asphalt surface. Since the semitrailer truck tested in this experiment had a fuel economy of 4.5 to 5.5 miles per gallon, the difference in fuel consumption between the two pavement types was approximately 20%. Logic supports this conclusion since trucks cause more deflection on flexible pavements than on rigid pavements; deflecting the pavement absorbs part of the vehicle energy that would otherwise be available to propel the vehicle. Thus the hypothesis

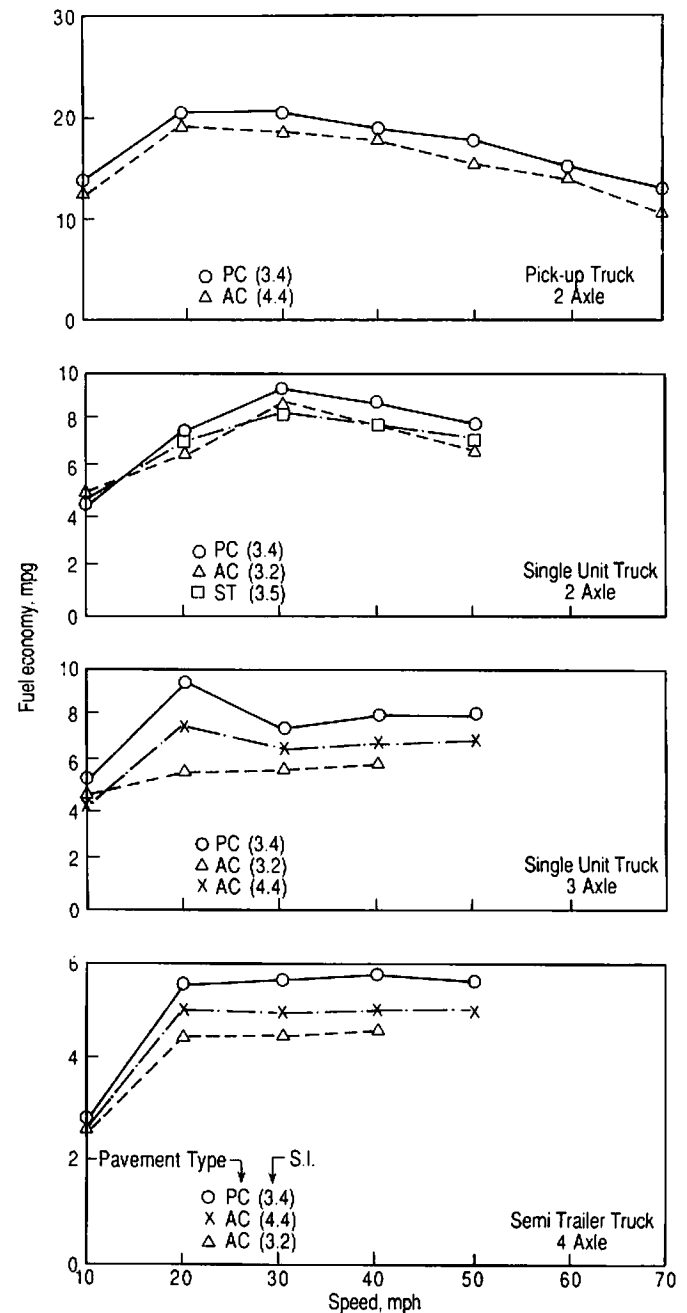


Fig. 1. Fuel economy data on different pavements surfaces.

Table 1. Test Fleet Characteristics

Vehicle Category	Model and body style	Road weight, lb	Load material
Small car	Ford Escort, stationwagon	2,412	N.A.
Medium car	Ford Fairmont, sedan	3,006	N.A.
Medium car	Ford Fairmont, sedan	3,006	N.A.
Large Car	Oldsmobile Delta 88, sedan	4,350	N.A.
Pickup truck	1980 Ford, box	3,678	N.A.
2 axle, single unit truck	GMC, van	17,120	Scrap iron
3 axle, single unit truck	GMC Brigadier, dump	35,870	Sand
Semitrailer truck, 2-S2	Freightliner, flat bed	56,000	Brick

can be made that more energy and therefore more fuel is required to drive on flexible pavements.

Implications for Highway Pavements in the United States

The most meaningful data regarding fuel consumption is for trucks traveling at typical road speeds on pavements in a condition representative of major highways in the United States. For these conditions, speeds of 30 to 70 mph, and pavement conditions of Serviceability Index (SI) of 3.2 to 4.4, differences in fuel consumption on asphalt and concrete were computed in terms of fuel savings per 1000 miles traveled. Fig. 2 shows a plot of this fuel savings versus the gross weights of the trucks. Here the trend for increased fuel savings for heavier trucks is apparent.

Implications of the study are particularly significant to the trucking industry. Truck mileage and fuel consumption in the United States are 440 billion miles and 51 billion gallons (1985 values according to the 1987 *Highway Fact Book* of Highway Users' Federation and the 1987 *National Transportation Statistics Annual Report* of the U.S. Department of Transportation).

Concerning road costs, highway agencies are beginning to adopt the practice of including user cost along with agency costs in their life cycle cost analysis. Since fuel use is a major portion of user cost, the consistent trend for heavy vehicles to use less fuel on concrete pavements raises the question of the economic impact of constructing asphalt and concrete pavements. To demonstrate the potential impact, an example of the fuel savings on a 10-mile section of concrete pavement is shown in Table 2. The savings in fuel costs would accumulate in several years to a value equal to the highway agency's cost for the concrete surface. For example, if future fuel costs average \$1.00/gal and today's bid price is \$16.00/sq yd for concrete in

Table 2. Fuel Savings on a 10-Mile Section of Concrete Highway
(four-lane rural Interstate, average daily traffic = 25,000)

Vehicle	Percent of Traffic	Vehicle-miles per year (1000)	Estimated Fuel Savings, gal/year
autos	70	63,880	0
pickups, panels	12	10,950	60,230
2 axle SU trucks	3	2,740	41,100
3 axle SU trucks	1	910	31,850
combinations*	14	12,770	<u>510,800</u>
Total			643,980

*Tractor-semitrailers and truck-trailer combinations.

place, the fuel savings would pay for the concrete in seven years; computed as follows:

$$\begin{aligned}
 \text{savings on fuel} &= 643,980 \text{ gal} \times \$1.00 \times 7 \text{ years;} \\
 &= \$4,506,000 \\
 \text{concrete cost} &= 10 \text{ miles} \times 28,160 \text{ sq yd} \times \$16.00 \\
 &= \$4,506,000
 \end{aligned}$$

The results of this study show that the fuel consumption differential can be a dominant element in the total cost analysis of highway pavements.

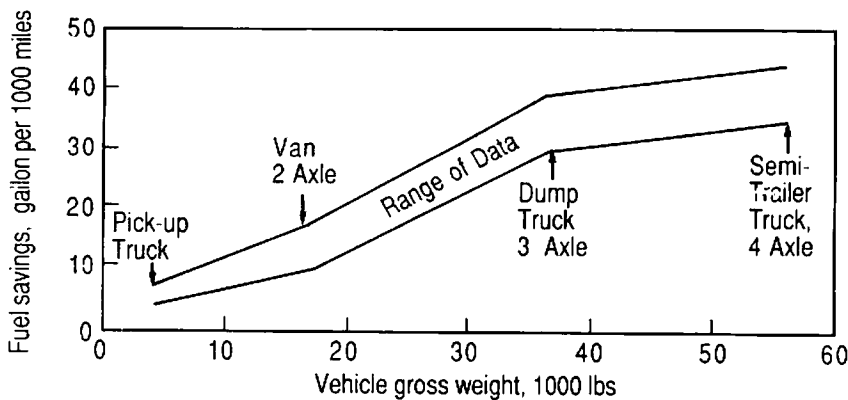


Fig. 2. Fuel savings computed for different truck types.

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