Effect of Pavement Roughness on Vehicle Fuel Consumption

FREDERIC R. ROSS

Several published research reports have shown that vehicle fuel consumption increases as pavement roughness increases. The existence of such a relation is today of particular interest to state departments of transportation for use in cost-benefit analysis of potential highway improvement projects. For a variety of reasons, however, the results of the earlier studies are not readily usable in benefit calculations. Therefore, in 1980 the Wisconsin Department of Transportation conducted a local field study that sought to define, for practical application, the relation between automobile fuel consumption and pavement roughness. Three different automobiles traveled on five pavement sections that, collectively, represented a wide range of roughness. For these pavements, roughness was expressed in terms of serviceability index, as measured by Wisconsin's electronic road meter. Fuel consumption was measured by a specially designed fuel meter mounted in each test vehicle. To minimize the influence of variables other than pavement roughness on fuel consumption, test conditions and procedures were highly controlled. The collected data suggest that there is in fact a quantifiable, but very modest, increase in automobile fuel consumption as pavement roughness increases. Over the range of roughness typically associated with state trunk highways (serviceability values between 1.5 and 4.5), this increase was (a) about 1.5 percent, (b) linear, and (c) not related to vehicle size. For the entire range of roughness included in this study (serviceability values between 0.9 and 4.4), the increase in fuel consumption was about 3.0 percent, which suggests that the overall relation between fuel consumption and pavement roughness may be nonlinear.

Several research investigations in the past decade have indicated an apparent relation between vehicle fuel consumption and the roughness of the traveled pavement surface (1-3). Specifically, these investigations have shown that fuel consumption increases as pavement roughness increases. The existence of such a relation has aroused considerable national attention because of the increasing costs of motor fuel and the interest in conserving energy.

Two of these investigations, because of their thoroughness and their potential usefulness, are especially important. One was conducted in 1971 by Claffey under the auspices of the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) (1); the other was conducted in the late 1970s in Brazil by the Texas Research and Development Foundation (2). Unfortunately, there is substantial disagreement in the findings of these two studies. Using normalized data from the two sources, Zaniewski and others (4) have reported an indicated increase in fuel consumption between a broken asphalt pavement and a smooth surface of 30 percent for Claffey's results compared with only 10 percent for the Brazil results. Obviously, a difference of this magnitude creates serious problems for an agency interested in practical application of the findings.

Despite such disagreement, Claffey's results have formed the basis for a number of publications that seek to dramatize the effect of deteriorated pavements on fuel consumption. As an example, it has been reported that driving a car at 40 mph on a deteriorated paved surface can increase fuel consumption by 56 percent compared with driving on a pavement in good condition (5). Conceivably, this figure represents an extreme situation--some "worst possible" case. But there is good reason to believe it considerably overstates the effect of pavement roughness on fuel consumption for the expected range of roughness on state trunk pavements. Obviously, an abandoned, disintegrated pavement would be inappropriate for practical fuel consumption studies. There are other difficulties in applying Claffey's results. Only two levels of roughness were included in his study, and these were not defined by objective criteria that would allow systemwide extension of the findings. Finally, it is not certain that the automobile Claffey used--a 1964 sedan--responded to pavement roughness in the same way as do today's smaller automobiles.

Because of the apparent limitations in earlier investigations, the Wisconsin Department of Transportation (DOT) in 1980 contracted with Claffey to act as a consultant for an updated study that sought practical definition of the relation between fuel consumption and pavement roughness. This paper reports the results of that study.

FIELD STUDY

Test Pavements

Test pavements for the study had to be straight, level, lightly traveled, uniformly rough or smooth, all of one pavement type (in this case, bituminous concrete) and a minimum of 5000 ft in length (including a 4000-ft test segment and 500-ft approach segments at either end). Following extensive searching, five 2-lane bituminous concrete pavements were located that satisfied these requirements and, in addition, had suitably varied levels of roughness, as given below:

	Serviceability Index	
Test Site	Northbound/ Eastbound	Southbound/ Westbound
1	4.4	4.4
2	3.6	3.5
3	2.1	2.2
4	1.9	1.9
5	0.9	-

Rod and level measurements, taken at 200-ft intervals along the pavement surfaces, indicated that the selected sites were acceptably level. The maximum variation in any 200-ft interval at any site was slightly more than 1 ft, and the maximum variation over the 4000-ft test segment was 8 ft.

Pavement roughness was measured in terms of serviceability index (SI). Although there are more sophisticated measures of pavement profile, the advantage of SI is its universality. Furthermore, for a state such as Wisconsin, where periodic SI measurements are obtained on the entire system of state trunk highways, the existence of a relation between fuel consumption and SI would enable systemwide application of the results. For all five sites included in this study, serviceability measurements were made in each lane with Wisconsin's electronic road meter prior to fuel consumption testing. As the table above indicates, directional SI differences were minimal. As a check on these initial readings, repeat serviceability measurements were made midway through the study. In both instances, the assigned SI values were based on multiple readings. Values determined on the two dates were essentially the same for all sites.

Equipment

Three different sizes of automobiles were equipped with manual fuel meters constructed from schematic drawings prepared by Claffey. Details of the test vehicles are given in Table 1.

As Figure 1 shows, the fuel meters consisted of several buret tubes, an electric fuel pump, shut-off valves, and different lengths of rubber fuel-line hosing. This apparatus was mounted on 0.75-in plywood and attached to the automobile, as shown in Figure 2. Each test car was equipped with a tachometer and a vacuum gauge, mounted in the driver's line-of-sight for ease of reading (see Figure 3). Other essential equipment included a thermometer (suspended in one of the burets) for measuring fuel temperature and a stopwatch for recording driving time (i.e., average travel speed) over the test sections. An observation station, equipped with a thermometer and a recording anemometer, was established at each test site.

Table 1. Test vehicle data.

Item	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	Chevrolet	American Motors	Chevrolet
Model	Chevette	Concord	Impala
Body type	4-door sedan	4-door sedan	Station wagon
Year	1980	1980	1979
Engine size (in^3)	98	151	305
Number of engine cylinders	4	4	8
Rear-axle ratio	3.70	3.08	3.08
Normal fuel pressure (psi)	4	4.5	7
Tire type and size	13-in radial	14-in radial	15-in radial
Nominal vehicle test weight	2550	3240	4560
Speedometer reading			
Start of testing	5600	8890	16 200
End of testing	8450	11 700	19 400

Test Procedures

Operation of the fuel meter was quite simple. Well in advance of the test section, the driver stopped the automobile and the observer filled the two burets with gasoline from the automobile's fuel pump. After the level of gasoline in the test buret was noted and recorded, the auxiliary fuel pump was turned on, the hose from the automobile's fuel pump was shut off, and the three-way valve was adjusted to dispense gasoline from the reservoir buret. The driver started the car and accelerated to the 55-mph test speed before reaching the approach segment. The purpose of the approach segment was to stabilize vehicle performance at test conditions. On reaching the beginning of the test segment (plainly marked by traffic cones on both sides of the pavement), the observer quickly switched the three-way valve so that gasoline was dispensed from the test buret. At the end of the test segment, the valve was switched back to the reservoir buret. Finally, the driver brought the car to a stop, and the observer recorded the fuel remaining in the test buret. Fuel used over the 4000-ft test length was calculated by deducting the initial fuel reading from the final reading. The observer also recorded the temperature of the fuel and the elapsed time for each run. After these measurements, the driver turned the car around and the process was repeated in the opposite direction.

Numerous runs were made by each car at each site. As recommended by Claffey, testing continued until fuel consumption readings from at least six runs in each direction were clustered within several

Figure 1. Wisconsin-type fuel meter.

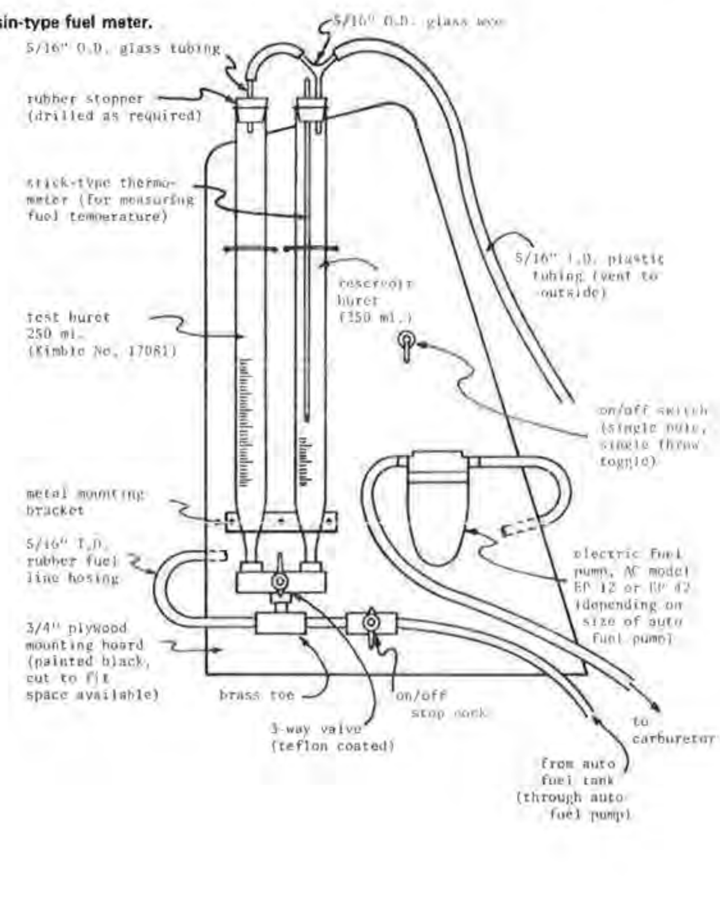


Figure 2. Fuel meter mounted in test vehicle.

Figure 3. Mounting of tachometer and vacuum gage in test vehicle.

milliliters of one another and within several milliliters of the observed readings in the opposite direction, or until variations due to wind or driver fatigue became excessive (in which case, testing was abandoned).

Field Testing

Actual field testing proved far more demanding than had originally been expected. Rigid controls were placed on test conditions and procedures to minimize or eliminate the effect of variables other than pavement roughness. The most rigorous controls were placed on wind velocity. Claffey initially suggested that testing be conducted only when winds were less than 3 mph, as measured by the recording anemometer and by cloth indicator flags posted at 200-ft intervals along the test sections. However, it soon became apparent that acceptable results (as gaged by apparent directional differences in fuel consumption) could only be obtained during near-zero winds. Since such conditions were a comparative rarity, testing extended over a six-week period.

Other variables measured and/or controlled during testing were fuel and air temperature, tire pressure, engine vacuum and speed, elapsed test time (vehicle speed), vehicle test weight, and engine operating condition. In the original design of the study, an allowable air-temperature range of 10°F was stipulated. But when it became apparent that this criterion and the wind criterion could not be met simultaneously, the temperature controls were eliminated. Instead, air temperatures were routinely recorded, along with fuel temperatures, on the presumption that they both could be statistically standardized after testing was completed. For the other variables mentioned, it was possible to meet the established controls. All testing was conducted at a nominal speed of 55 mph, as indicated by elapsed time. For the Impala, individual test runs in which the travel speed deviated from the mean speed for all runs by more than 1 mph were eliminated. For the other two cars, the allowable deviation was $\pm$0.5 mph. Constant monitoring of the tachometer and vacuum gage was required to ensure uniformity of travel speed and engine performance. Runs in which the engine vacuum varied by more than 1 in were eliminated. Tire pressure for all cars was maintained at 32 $\pm$ 0.5 psi, as determined by readings before, during, and after testing at each site. Fuel tanks were maintained above the one-half level. Unleaded fuel from a commercial source was used throughout the study. To the extent feasible, a single brand of fuel was used. The vehicle test weights given in Table 1 are nominal weights, as indicated. Actual test weight for each car varied from test to test and from run to run due to variations in the quantity of fuel in the gasoline tanks and, in several instances, to changes in crew personnel. However, efforts were made to keep these variations to a minimum, and in no case did they exceed 100 lb.

As originally planned, a specific driver and observer were assigned to each car. Extensive training was conducted to minimize possible idiosyncratic variations and to standardize procedures. Particular emphasis was placed on standardizing driving techniques. Drivers were warned against even the slightest acceleration or deceleration in the test sections and were instructed to monitor engine performance gages constantly. For a variety of reasons, several crew changes were necessary during the course of testing. However, these changes were exclusively transfers from one car to another; in no case were untrained technicians used. In the final tally, a total of 18 tests were considered acceptable (as used here, a "test" refers to the complete series of test runs by one car at one site on one date); the originally assigned crews were responsible for 14 of these.

The engines of all test cars were precisely tuned before any testing started, and no adjustments were made thereafter. No record testing was conducted until the engines were warmed up by driving at least 20 miles at highway travel speed. As an additional precaution against cold engines, and to ensure that test procedures were stable before the start of record runs, the initial runs of every test were eliminated.

Testing Considerations

There were eight separate test dates, as indicated in Table 2. Note that in several instances multiple tests were made by a particular car at a particular site. Although it was not completely intentional, it is apparent that the three cars and five sites are distributed quite randomly over these dates. Thus, it is improbable that time produced a systematic variation in the results. Testing was attempted on several other days, but these eight were the only ones for which wind conditions were judged acceptably calm.

The study plan called for testing to be conducted in both directions at each site. Because the se-

Table 2. Test dates and test conditions.

Test Date	Time (a.m.)	Wind (mph)	Air Temperature (°F)	Chevette	Concord	Impala
Oct. 9	7:00-9:00	0-3	34-46		Site 2	Site 2
Oct. 20	6:00-7:30	0-1	47-51	Site 1		
Oct. 21	6:30-8:00	0	32-42	Site 4	Site 4	
Oct. 22	6:30-10:00	0-1	18-38	Site 2/Site 5	Site 1	Site 3/Site 4
Oct. 29	6:00-7:30	0-1	12-21	Site 3	Site 5	
Nov. 5	6:00-8:30	0-1	18-32		Site 1	Site 1
Nov. 11	6:00-8:00	0-2	20-28		Site 3	Site 5
Nov. 18	6:00-9:30	0	10-25	Site 1/Site 5		

lected sites were all level and the winds at time of testing virtually calm, it was felt that systematic grade or wind variations would be minimal. Moreover, averaging directional results would tend to neutralize any variation produced by these sources. On four of the five sites, it proved to be possible to test in both directions. On the fifth site, because of an intersecting highway near the eastern terminus, it was possible to test only in the eastbound direction.

The test burets indicated fuel levels to the nearest milliliter, and it was possible, with practice, to read the burets this precisely. The three-way valves proved effective in abruptly starting and stopping the flow of fuel from the burets. Presumably, since the valves were manually operated, some variation was introduced in the readings due to variations in the observer's response time, but these would tend to be neutralized by averaging the multiple runs at each site.

In the operation of the fuel meter, the electric pump delivered fuel from the burets to the carburetor in surges. Therefore, a particular reading could theoretically vary according to the size of the surge. But these surges were small (measured less than 2 mL), and, again, the effect of multiple runs would be to neutralize the variation.

Elimination of Unacceptable Runs

In the final tally, the number of directional runs for any test ranged from 9 to 15, depending on the variables cited previously (wind speed, consistency of results, time available, etc.). When testing was completed, the raw data were examined and unacceptable runs were eliminated as noted above. Specifically, this process resulted in the elimination of

1. All runs labeled "abort" at the time of testing (such as for deer in the road or for trucks passing),
2. All first runs in both directions (these were considered "warm-up" runs),
3. All runs in which a fluctuation in engine vacuum greater than 1 in was noted,
4. All runs in which driving time varied from the mean time for each car by $\pm$0.5 mph ($\pm$1 mph for the Impala), and
5. All "deviant" runs (deviancy here is defined as any lone high or lone low fuel consumption reading that varied from the next highest or lowest reading by more than 1 mL).

After this process, 257 of the original 355 individual runs remained: 100 of 122 for the Chevette, 86 of 133 for the Concord, and 71 of 197 for the Impala. The number of directional runs for any test ranged from 4 to 13.

Standardization for Differences in Fuel and Air Temperatures

The processed data were submitted to the University of Wisconsin-Madison Statistical Laboratory for analysis. The first step was to adjust the observed fuel consumption readings to some standard fuel and/or air temperature, since analysis clearly indicated the existence of a statistically significant relation between these variables. Two methods were considered: (a) adjusting for fuel temperature via volumetric corrections developed by the Society of Automotive Engineers and then adjusting statistically for air temperature and (b) adjusting statistically for fuel and air temperatures simultaneously. These methods were attempted for the three cars individually and for the three cars collectively. The method finally selected is one that simultaneously adjusts for fuel and air temperatures for the three cars collectively and standardizes all readings to the average fuel and air temperature. The mathematical model is as follows:

$$f_s = f_o + 0.109\,63\,(t_f - 71.4) + 0.067\,44\,(t_a - 28.4) \quad (1)$$

where

f_s = standardized fuel consumption for any run,
f_o = observed fuel consumption for any run,
t_f = observed fuel temperature for any run, and
t_a = observed air temperature for any run.

The average fuel and air temperatures are 71.4°F and 28.4°F, respectively.

This method generally yielded a high degree of consistency among the readings. Credit for this consistency properly goes to the equipment and the field operations, however, since the temperature adjustments were proportionately small. For all 257 readings, the average adjustment was 1.14 mL and the standard deviation was 0.67.

Directional Difference in Fuel Consumption

Despite efforts to eliminate systematic variations in the readings, as described earlier, examination of the data revealed systematic directional differences in average standardized fuel consumption. These differences are summarized below ("difference" is taken as the average standardized fuel consumption for the eastbound or northbound direction minus the standardized fuel consumption for the westbound or southbound direction; * = statistical significance at the 0.05 level):

	Directional Differences (mL/4000 ft)		
Site	Chevette	Concord	Impala
1	-0.36	+0.25	-2.71*
2	+2.43*	-1.64	-2.95*
3	+0.49	-0.02	+2.43*
4	+0.26	-0.25	-4.43*

Because of the difference in sign, these variations cannot be ascribed to directional variations in the road (e.g., in roughness or gradient). Conceivably, they are related to prevailing wind, although winds were virtually nonexistent during

Figure 4. Comparison of fuel consumption versus SI for three test vehicles.

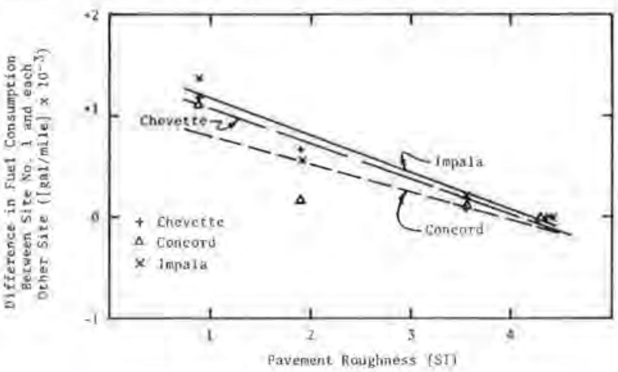
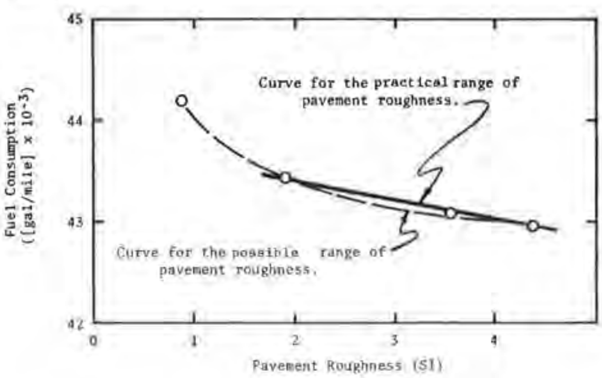


Figure 5. Standardized fuel consumption versus pavement roughness for car traveling at 55 mph on Wisconsin state trunk highways.



record testing. But in fact these variations posed no major difficulties in treating the data, since, in accordance with Claffey's recommendation, the directional averages were themselves averaged to produce a single figure for each site.

Fuel Consumption Versus SI Readings

Average standardized fuel consumption readings were converted from milliliters per 4000 ft, as given in the table above, to the more common units of gallons per mile. To compare the results from the three cars directly, the difference in fuel consumption between site 1 (the smoothest surface) and each of the four other sites is given below:

Car	Difference in Fuel Consumption [(gal/mile) x 10^{-3}]			
	Site 2	Site 3	Site 4	Site 5
Chevette	+0.077	-0.056	+0.673	+1.189
Concord	+0.098	-0.188	+0.154	+1.099
Impala	+0.206	-0.293	+0.548	+1.395

Note that positive signs in this table indicate that fuel consumption for the particular site and car was greater than for the smoothest surface; negative signs indicate lesser fuel consumption than for the smoothest surface.

It is evident at once that a similar pattern exists for the three cars, the principal features of which are the following:

1. Substantially more fuel was consumed on site 5 (the roughest pavement) than on the other sites.
2. Less fuel was consumed on site 3 than on any other site.
3. For sites 1, 2, 4, and 5 (i.e., from the smoothest to the roughest pavement), there is a progressive (although irregular) increase in fuel consumption.

Site 3 presents analytical problems. For all three cars it runs counter to the pattern of fuel consumption indicated by the other sites, and it differs markedly from site 4, although measured roughness levels at the two locations are quite close. In seeking an explanation for the apparently anomalous readings at this site, one could look at (a) the assigned SI value, (b) the recorded air or fuel temperature, (c) the calculated temperature adjustment factors, (d) the possibility of peculiarities in the pavement surface, or (e) the fuel consumption measurements themselves. Since there are difficulties with all these explanations, it seems wisest simply to recognize the site as anomalous, to omit it from further analysis, and not to attempt a rationalization at this time.

The data given in the table above for sites 1, 2, 4, and 5 are plotted versus SI in Figure 4. Linear regression analysis using the plotted points indicates slopes of -0.000 347 2, -0.000 269 3, and -0.000 368 7 for the Chevette, Concord, and Impala, respectively. Undoubtedly, better fit could be obtained with some nonlinear expression, but the straight-line model is immediately useful for comparing the results of the three cars.

The consistently negative signs of the slopes and the general agreement in their size are significant; that is, fuel consumption for each car increased as roughness increased (or as SI decreased), and the individual increases are of the same order. Clearly, there are differences in the pattern of data points from car to car that cannot be explained by differences in vehicle size, since the lowest indicated slope is for the middle-sized car (Concord). Thus, for the three cars included in this study, the effect of pavement roughness was not an apparent function of vehicle size.

When the three data points at each of the four sites are averaged, the results are as plotted in Figure 5. The dashed curve represents the indicated relation between SI and fuel consumption for automobiles at 55 mph over the range of pavement roughness included in this study. The data in this curve support the findings in earlier studies that fuel consumption increases as pavement roughness increases. For SI levels above about 2.0, this increase appears quite modest; at lower levels it is more significant. Between the smoothest and roughest surfaces (SIs of 4.4 and 0.9, respectively), the indicated increase is about 3 percent. As a practical matter, however, SI levels below 1.5 are rarely encountered for project-length segments of the Wisconsin state trunk system. Thus, it would seem that the solid line, which closely approximates the dashed curve over the SI range of 1.5 to 4.5, reasonably depicts the apparent practical relation between fuel consumption (F_S) and pavement roughness (SI). The regression model for this line is as follows:

$$F_s = 0.043\,771 - 0.000\,187\,9 \times SI \qquad (2)$$

where F_S is in gallons per mile.

Using this relation gives an indicated increase in fuel consumption of about 1.5 percent between SIs of 4.5 and 1.5, under the conditions of this study. For practical application, it appears that the slope of this line, 0.000 187 9, is appropriate for translating differences in pavement roughness into differences in automobile fuel consumption.

It should be noted that, even if one allows normalizing results from different sources, the increase in fuel consumption on rough pavements reported here is considerably less than the increases reported in some earlier studies. But since the curve in Figure 5 is distinctly nonlinear over the possible range of roughness, comparisons such as this may be misleading. For example, assignment of an improper objective roughness level to Claffey's "badly broken and patched" surface could be of major consequence. Differences in objective roughness scales, as between SI and Zaniewski's quality index, could also be of major consequence. Therefore, comparisons of reported relations between fuel consumption and pavement roughness require great care.

CONCLUSIONS

Based on an analysis of data collected in this study, and within the limits implied or expressed, the following conclusions are made:

1. The effect of pavement roughness on automobile fuel consumption, because it is proportionately small, can be overwhelmed by the effect of more significant variables--e.g., travel speed, road gradient, driving habits, and wind velocity. In particular, wind can pose great difficulties in conducting field tests on fuel consumption. For this study, reliable data were obtained only during virtual dead-calm conditions.
2. To detect the relatively small variations in fuel consumption produced by pavement roughness, equipment capable of very accurate measurement is essential. The manual fuel meter developed for this study and described in this paper proved capable of measuring fuel consumption accurately to 1 mL, which for the 4000-ft test segments used here is considered minimum acceptable accuracy.
3. The collected data indicate that automobile fuel consumption increases as pavement roughness increases, where roughness is measured in terms of SI. Between the smoothest and roughest pavement included in this study (SIs of 4.4 and 0.9, respectively), the indicated increase was about 3 percent, which appears to be considerably less than has been reported by other investigators. However, since the relation between fuel consumption and pavement roughness determined in this study is distinctly nonlinear, comparison with results from other studies must be done with great caution.
4. Although the relation between fuel consumption and pavement roughness appears nonlinear over the range of roughness included in this study, for the pavements normally encountered on Wisconsin state trunk highways (SIs ranging from 4.5 to 1.5), the relation can be approximated by a straight line that has a slope of 0.000 187 9 gal/mile/SI. This study indicates that, for the conditions described here, an automobile traveling on a paved surface that has an SI of 1.5 consumes about 1.5 percent more fuel than it would consume traveling on a paved surface that has an SI of 4.5.
5. For the three automobiles used in this study, the relation between fuel consumption and pavement roughness was not an apparent function of vehicle size.

REFERENCES

1. P.J. Claffey. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP, Rept. 111, 1971.
2. J.P. Zaniewski and others. Fuel Consumption Related to Vehicle Type and Road Conditions. TRB, Transportation Research Record 702, 1979, pp. 328-334.
3. S.W. Abaynayaka. Some Techniques for Measuring Vehicle Operating Costs and Deterioration Parameters with Particular Reference to Developing Countries. Transportation and Road Research Laboratory, Crowthorne, Berkshire, England, Supplementary Rept. 193 UC, 1976.
4. J.P. Zaniewski and others. Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors. Texas Research and Development Foundation, Austin, June 1980.
5. Conserving Energy Through Improved Highways. AASHTO/Associated General Contractors of America/American Road and Transportation Builders Assn. Joint Committee, Washington, DC, 1980.

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Rational Seasonal Load Restrictions and Overload Permits

BILLY CONNOR

Seasonal load restrictions have been enforced in Alaska since the first paved road in 1950. The time frame and level of such restrictions have historically been based on the experience and judgment of maintenance personnel. This results in a lack of continuity from region to region. A rational load-restriction policy has been developed based on the load-damage relations on a pavement structure. Deflection data are used to monitor the strength of the embankment and thus to provide the information on which to base the time frame and level of restrictions. A policy on overweight-vehicle permits is presented based on the ability of the roadway system to carry the load and the load-damage relations. The policy uses the philosophy that the user pays for any damage in excess of that which would be incurred by legal loading.

The relation between vehicle weights and the performance of the pavement structure has been recognized for many years. Because of the large decrease in pavement life due to heavy vehicle weights and the rapid rise in maintenance costs, strict control of excessive truck weights has become imperative.

The problem of controlling excessive truck weights becomes crucial when the stress in the asphalt layer exceeds the tensile strength of the material. When this occurs, failure is immediate. Failure due to high tensile stress is not likely to happen under normal conditions. However, for highways in cold climates, this may well be the case if the pavement structure is weakened during the spring-thaw period. To protect these highways during the thaw-weakened period, a decision must be made concerning the level and duration of spring load restrictions.

In Alaska, as in most other states, such decisions have typically been made by maintenance engi-