PASSENGER CAR FUEL CONSUMPTION AS AFFECTED BY ICE AND SNOW

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The effects of road surface ice, hard-packed snow, and various depths of newly fallen snow on the fuel consumption of a typical passenger car were examined during the winter of 1970-1971 on a straight, level test road near Ogdensburg, New York. Data on operation under various conditions of ice and snow were compared directly to data on dry road operation. The results given in this paper include the rate of fuel consumption of the typical passenger car in relation to speed for each of the ice and snow conditions involved in the study, the straight-line relationship between the fuel consumption of the typical passenger car and depth of newly fallen snow for three running speeds, and the factors to correct dry pavement fuel consumption rates for the different ice and snow conditions for the various speeds. The worst ice and snow condition as far as fuel consumption is concerned is snow depth. Fuel consumption will be 50 percent more on a road with a 2-in. snow depth than on a dry road. Information developed in this study and examples of applications in highway economy analyses are presented.

•THE DIFFICULTIES associated with ice and snow are widespread in the United States. Annual snowfalls of 40 in. or more are common in about 40 percent of the total area of the 48 conterminous states. Highways in 22 states, including the populous northeastern states, are subject to the effects of such snow accumulations each year. In many other states there are at least one and perhaps two or three traffic-disruptive snowstorms every winter.

State and local highway departments responsible for maintaining road service in the snow states must decide how frequently roads are to be plowed during and after snowstorms, the tolerable depth of snow on road surfaces for various traffic volumes, and when to use salts rather than sand to remove ice to give traction on surface ice. Because these decisions relate to the operating costs of highway users as well as to the levels of maintenance expenditure that are involved in snow clearing, adequate data on the effect ice and snow have on vehicle operating costs (especially fuel consumption) are needed in the snow states.

EFFECT OF SNOW ON VEHICLE OPERATION

Ice and snow conditions restrict vehicle movement in a variety of ways, depending on the actual condition of the ice or snow on the pavement. Both ice and snow, but particularly ice, cause excess fuel consumption by inducing slippage of the traction wheels, which in turn produces engine revolutions without corresponding vehicle movement. Both ice, when it freezes into shallow ruts, and snow, which packs down into a rough washboard-like surface, present an irregular running surface for vehicles. This wrinkled surface causes vehicles to consume extra fuel because they must continually climb over these irregularities to produce forward movement. Freshly fallen snow of 1 in. or more in depth also increases vehicle fuel consumption because of the effort needed

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to pack down the snow under the wheels as vehicles move along and the necessity to climb over and across ruts left by other vehicles. All ice and snow conditions involve considerable side throw of vehicles at speeds above 30 mph. This also adds to vehicle fuel consumption.

FUEL MEASURING TEST

The effect on fuel consumption of ice and snow on the roadway was determined by direct measurement of the fuel consumed by a typical passenger car operating on a level, straight section of good paved road for a variety of ice or snow surface conditions.

Test Road

The test road was the same section of highway that in previous years had been used for determining fuel consumption for optimum road geometrics in connection with the vehicle operating cost study conducted for the National Cooperative Highway Research Program (1). It is 4,000 ft long and has adequate approach sections and convenient places to turn around. There are no driveway entrances throughout the full distance between turn-around points, and traffic flow is negligible. The road is located in northern New York near Ogdensburg, where over 100 in. of snow fell during the 1970-1971 winter season.

Automobile

The test car was a 1964 Chevrolet sedan with a 283 cu in. V-8 engine and automatic transmission. It weighed 4,000 lb during test operations with all test personnel and equipment aboard. This vehicle was the principal passenger car used in the operating cost study reported by NCHRP (1). Engine performance was satisfactory. The engine consumed fuel under ideal test conditions at the time of the snow study (winter of 1970-1971) at about the same rate that it did during the 1964-1967 period when it was used for obtaining the data for the NCHRP study. Snow tires of a good grade that had previously been used for 5,000 miles of winter travel (typical wear of snow tires) were mounted on the traction wheels for this test program.

Fuelmeter

Fuel consumption was measured with the electronic fuelmeter that had been developed for the NCHRP study. It measures fuel consumption to the nearest 0.001 gal with dependable accuracy under all normal operating conditions.

Procedure

Test operations were carried out over the measured test section both for uniform running speeds of 20, 30, 40, 50, and 60 mph (when practicable) and for stop-and-go speed change cycles at running speeds of 30 and 50 mph. Uniform speed runs were made for each of the following ice or snow conditons:

1. Very slippery hard-packed snow and ice, with about 20 percent of the running track bare road;
2. Hard-packed snow on ice with irregular bumpy surface and wrinkles formed by many vehicles passing over snow left after close plowing;
3. One-half in. of new snow on hard-packed snow (about the depth left after passage of snowplow);
4. Three-quarter in. of new snow on hard-packed snow;
5. One in. of new snow on hard-packed snow;
6. One and one-half in. of new snow on hard-packed snow; and
7. Two in. of new snow on hard-packed snow.

Data were obtained for operations under conditions 3, 4, 5, 6, and 7 during the same snowstorm so that all factors affecting results were identical except the snow depth.

Stop-and-go speed change cycles were made only on very slippery hard-packed snow and ice (condition 1). All test runs were made at air temperatures between 25 and 30 F and only during periods of calm wind conditions.

Fuel consumption was also measured for test runs on dry pavement during late fall of 1970 and early spring of 1971. This was done for the following reasons: (a) to provide comparison data for analysis of the increase in fuel consumption due to ice and snow conditions and (b) to serve as a check on the accuracy of the fuelmeter and the constancy of the basic fuel consumption characteristics of the test car's engine. Because the air temperature during the dry road test runs (40 F) was necessarily somewhat higher than that during the ice and snow test runs (25 to 30 F), a correction factor from NCHRP Rept. 111 (1, p. 63) was applied to adjust dry road fuel consumption data for the lower temperature.

Results

The relationship between fuel consumption rates and vehicle speeds for passenger car operation on roads with the various ice and snow conditions is shown in Figure 1. Curve A shows the fuel consumption for the test vehicle operating on dry pavement. Data for this curve were obtained by operation at ambient temperatures higher than those encountered during the ice and snow test operations (40 F compared to 25 to 30 F). However, before plotting curve A, these data were corrected to what they would have been at 25 to 30 F by using temperature curves mentioned earlier (1, p. 65). Test operations were carried out at speeds up to 60 mph on bare pavement, on ice-covered roads, and for snow depths up to ½ in. However, for snow depths greater than ½ in., maximum test speeds were limited to 50 mph largely because of the severe side throw drivers encountered in deeper snow when traveling at high speeds.

The excess fuel consumed for stop-and-go cycles on very slippery, hard-packed snow and ice (condition 1) was found to be 0.008 and 0.017 gal per stop for 30- and 50-mph running speeds respectively. These values are close to those observed for stop-and-go cycles on dry pavement, 0.010 and 0.017 gal per stop. However, the excess time consumed for stop cycles at 30 and 50 mph is approximately 50 percent greater on ice- and snow-covered pavement than on dry pavement. Apparently any extra fuel consumption due to slipping on the ice during the acceleration portion of the stop cycle is compensated for by reduced consumption due to lower acceleration on ice.

The curves of Figure 1 show that the ice and snow condition having the most severe effect on passenger car fuel consumption is newly fallen snow. Even as little as ½ in. of snow (curve 3) will induce fuel consumption rates greater than either a very slippery, hard-packed snow surface (curve 1) or a less slippery, but bumpy, wrinkled surface (curve 2). Curves 3, 4, 5, 6, and 7 give the fuel consumption rates for road conditions that are identical except for snow depths, which are ½, ¾, 1, 1½, and 2 in. respectively. It is evident from Figure 1, however, that all roads with ice or snow or both, whether principally slippery, rough, or snow-covered, produce a substantial increase in passenger car fuel consumption compared to operation on dry pavement.

The curves of snow depth versus passenger car fuel consumption for 30-, 40-, and 50-mph running speeds are shown in Figure 2. These curves show that the effect of snow depth on fuel consumption increases with increases in speed. The principal reasons for this increase are the side throw and rough handling experienced by drivers traveling at high speed over the ruts left in a fresh snowfall by other vehicles.

Table 1 gives correction factors to adjust passenger car fuel consumption rates on dry pavement for operation when the road surface is covered with ice and snow. If the dry surface fuel consumption rate of a particular type of automobile (or of passenger cars in general) is known for travel on a road having given geometrics, the fuel consumption when the road is covered with any of a variety of snow or ice conditions may be found by multiplying by the appropriate correction factor from Table 1. Dry pavement fuel consumption rates should be corrected for temperature before applying correction factors for snow conditions.

igure 1. Fuel consumption rates of a passenger car for arious ice and snow conditions.

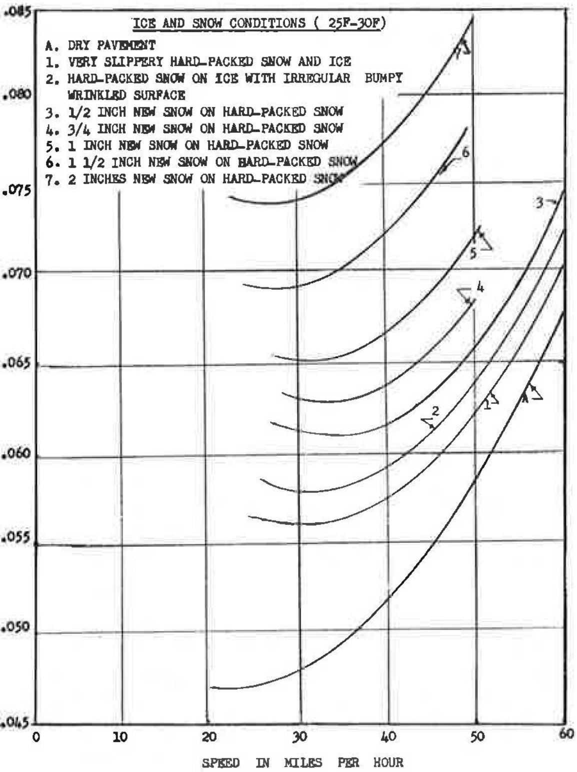
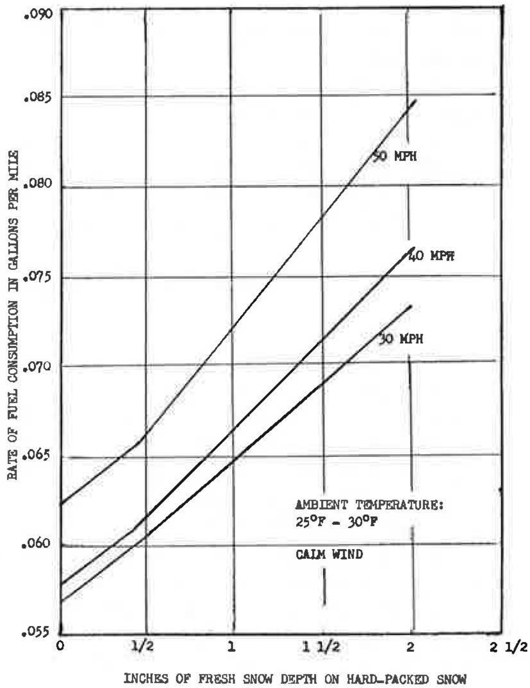


Figure 2. Relationship between snow depth and rate of fuel consumption of passenger cars.



able 1. Correction factors to adjust passenger car fuel consumption for ice and now conditions.

peed (mph)	Dry Pavement	Very Slippery Hard-Packed Snow	Hard-Packed Snow on Ice With Bumpy Surface	New Snow on Hard-Packed Snow (in.)				
				½	¾	1	1½	2
0	1.00	1.23	1.30	1.36	1.43	1.47	1.51	1.60
0	1.00	1.16	1.20	1.28	1.32	1.35	1.45	1.54
0	1.00	1.11	1.14	1.20	1.23	1.28	1.40	1.48
0	1.00	1.06	1.10	1.12	1.18	1.24	1.34	1.45
0	1.00	1.04	1.08	1.10	—	—	—	—

ote: Correction factors are designed to be applied to values in Table 6 of NCHRP Report 111. They may, however, so be applied to any valid passenger car fuel consumption rates for operation on dry pavement.

APPLICATION OF RESULTS

The results of this research have many applications in highway engineering economy analysis, including the following:

1. Evaluation of the extra cost to road users of operating on ice or snow in order to justify the cost of accelerated ice and snow removal;
2. Comparison of total passenger car fuel consumption costs over alternate routes where one is subject to substantial ice and snow cover and the other is free of snow problems;
3. Determination of spacing of gasoline service plazas along limited-access roads subject to ice and snow;
4. Prediction of fleet fuel consumption costs when operations are in regions where roads are snow-covered for part of the year; and
5. Selection of geometric design details for roads in snow areas to compensate road users for the extra operating costs incurred because of snow conditions.

SAMPLE PROBLEM 1—JUSTIFICATION OF SNOW REMOVAL PROGRAM

Problem

A nearly level, two-lane, two-way, high type of asphalt road interconnects two small cities 6 miles apart. During the normal workday rush period (4:00 to 7:00 p.m.) an average of 3,000 passenger cars move from one city to the other over this road. On a particular winter day a heavy snowfall occurring between 3:00 and 8:00 p.m. is able to maintain a 2-in. depth of new snow on a layer of traffic-packed snow. Assuming that gasoline costs $0.40/gal and that vehicles maintain an average speed of 50 mph, determine the total fuel cost of the 3,000 cars using the road during the snowstorm (a) if no attempt is made to remove the snow, (b) if plowing is continuous during the peak hours, thus maintaining a hard-packed snow surface, and (c) if only limited plowing is provided so that 50 percent of the cars encounter a hard-packed snow surface while the other 50 percent encounter an average of only 1 in. of new snow on a hard-packed snow base.

Solution

Compute the fuel consumption of 3,000 passenger cars operating at 50 mph on a level high type of pavement for a distance of 6 miles for each of the given ice and snow conditions [the fuel consumption rate on level, dry pavement is 0.052 gallon per mile (gpm)].

If the surface is covered with a 2-in. layer of fresh snow lying on hard-packed snow (no plowing), the correction factor for this condition (Table 1) is 1.45. The fuel consumption rate for this snow condition (0.052 gpm × 1.45) is 0.075 gpm. Total fuel consumption (0.075 gpm × 3,000 cars × 6 miles) is 1,350 gal. The total fuel consumption cost (1,350 gal × $0.40/gal) is $540.00.

If the surface is maintained as hard-packed snow by complete plowing, then the correction factor for this condition is 1.10. The fuel consumption rate (0.052 gpm × 1.10) is 0.057 gpm. Total fuel consumption (0.057 gpm × 3,000 cars × 6 miles) is 1,026 gal. The total fuel consumption cost (1,026 gal × $0.40/gal) is $410.40.

If 50 percent of traffic travels on a hard-packed snow surface and 50 percent on a 1-in. thickness of fresh snow (limited plowing), two correction factors are used: hard-packed snow surface, 1.10; 1 in. of snow on hard-packed snow, 1.24. The fuel consumption rates are 0.057 gpm (0.052 gpm × 1.10) for hard-packed snow surface and 0.064 gpm (0.052 gpm × 1.24) for 1 in. of snow on hard-packed snow. Total fuel consumption is 513 gal (0.057 gpm × 1,500 cars × 6 miles) for hard-packed snow surface plus 576 gal (0.064 gpm × 1,500 cars × 6 miles) for 1 in. of snow on hard-packed snow, which equals 1,089 gal. The total fuel consumption cost (1,089 gal × $0.40/gal) is $435.60.

Summary

1. User fuel cost with no plowing is $540.00.
2. User fuel cost with full plowing is $410.40.
3. User fuel cost with limited plowing is $435.60.

The user fuel saving with full plowing ($540.00 - $410.40) is $129.60. User fuel saving with limited plowing ($540.00 - $435.60) is $104.40. The cost to have a snowplow drive back and forth between the two cities continually during the rush hours is amply justified by the fuel cost savings experienced by the users.

SAMPLE PROBLEM 2—USER COST COMPARISON FOR ALTERNATE ROUTES

Problem

Two through routes connect cities A and B. Each is a level, two-lane, two-way, high type of asphalt road. One route is 500 miles long but runs along a lakeshore where heavy snowfall is frequent during the winter. The alternate route is 600 miles long but by swinging southward escapes serious snowfall. A driver contemplating a trip between these cities is advised that the lakeshore route is covered by 2 in. of fresh snow for the entire length and will not be plowed before his trip is made. The longer route, however, is free of all snow. The trip on the lakeshore route would be made at an average speed of 50 mph whereas speed on the alternate route would be 60 mph (trip time is 10 hours in each case). On which route would fuel consumption cost be least (assuming a fuel cost of $0.40/gal)?

Solution

Compute the fuel consumption cost to operate the passenger car on each of the alternate routes.

1. On the lakeshore route: The fuel consumption on dry pavement at 50 mph (1, p. 17) is 0.052 gpm. The correction factor for 2 in. of snow is 1.45. The fuel consumption rate on the lakeshore route (0.052 x 1.45) is 0.075 gpm. Fuel consumption for the entire trip (0.075 gpm x 500 miles) is 37.5 gal. Fuel cost for the trip (37.5 gal x $0.40/gal) is $15.00.
2. On the southern route: Fuel consumption on dry pavement at 60 mph is 0.058 gpm. Fuel consumption for the entire trip (0.058 gpm x 600 miles) is 34.8 gal. Fuel cost for the trip (34.8 gal x $0.40/gal) is $13.92.

Summary

The southern route is the least costly route for the trip. Fuel cost on the lakeshore route would exceed that on the southern route by $1.08 ($15.00 - $13.92).

CONCLUSION

Ice and snow conditions have a direct impact on passenger car fuel consumption. Slipperiness, as such, does not add substantially to fuel consumption because drivers tend to use extra care to control speed on ice and to hold wheel slippage to a minimum. However, road ice is usually frozen into an irregular surface as a result of the frequent passage of vehicles during the freezing process. This roughness induces substantial extra fuel consumption.

The most severe increase in passenger car fuel consumption due to ice and snow conditions arises when new-fallen snow depths of more than ½ in. are allowed to accumulate. In this situation vehicles need extra fuel not only to pack down snow beneath the wheels but also to propel vehicles across and over surface irregularities due to rutting by previous vehicles. A 2-in. layer of snow on a section of road may add 50 percent to the dry surface fuel consumption of passenger cars.

Ice and snow conditions are unavoidable during the winter season on many highways. Road users and those responsible for maintenance on these roads should be aware of the effects, often severe, that ice and snow can have on vehicle fuel consumption.

REFERENCE

1. Claffey, P. J. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP Rept. 111, 1971, 97 pp.