# FUEL CONSUMPTION RELATED TO VEHICLE TYPE AND ROAD CONDITIONS

John P. Zaniewski and Barry K. Moser, Texas Research and Development Foundation
Pedro José de Morais, Brazilian Road Research Institute
Russ L. Kaesehagen, Western Australia Main Roads Department

An investigation of the effect of road condition and vehicle type on fuel consumption was conducted in Brazil. A test fleet of nine vehicles ranging from a Volkswagen to an articulated truck was used to perform nine experiments. Roadway characteristics studied in the experiments include horizontal curvature, grade, surface type, and roughness. Vehicle operating modes studied were constant speed, acceleration, deceleration, and deceleration due to gravity. In addition, an experiment was performed to determine the effect of adding 20% alcohol to gasoline. Regression equations for predicting fuel consumption as a function of speed, and vehicle and roadway characteristics were developed for constant speed operation. It was found that curves of 72 m in radius did not cause a significant effect on fuel consumption. The inclusion of 20% alcohol in gasoline was found to result in approximately a 10% increase in fuel consumption.

The Government of Brazil and the United Nations Development Program are sponsoring a research project on the Interrelationships between Highway Construction, Maintenance and User Costs. Within this research, extensive measurements were made to establish relationships between fuel consumption and roadway characteristics. Experimental data were collected with a nine vehicle test fleet performing virtually every phase of vehicle operation over test sections with a select combination of roadway characteristics. A summary of the experimental program is presented herein followed by a detailed description of the methodology, equipment, and results of experiments on constant speed, road curvature, and using 20% alcohol in gasoline.

## Experimental Program

For these experiments the inference space, or the region for which the results apply, is established by the range of the independent variables and by the vehicles which are represented in the study. One or two vehicles were tested for each vehicle type and applications of the models must be made with this knowledge. Experiments were conducted to study fuel consumption in each phase of vehicle operation: constant speed, acceleration, deceleration and momentum. Additional experiments were performed to determine fuel consumption as the vehicles traversed horizontal curves and sag curves. The effect of vehicle tuning and using an alcohol-gasoline mixture was investigated by partially repeating the constant speed experiment. The latter experiment was performed and was included because a mixture containing 20% alcohol, by volume, is sold in Brazil. Finally, a calibration experiment was performed for validating the computer program for predicting fuel consumption (1). Thus, the experimental program consisted of nine individual experiments as summarized in Table 1.

## Roadway Parameters Studied

Roadway characteristics were used as independent variables in each of the experiments. After considering an extensive list of roadway parameters, the four thought to have the most significant effect on fuel consumption were selected: surface type, curvature, roughness, and grade. Two levels of surface type were tested, bituminous surfaces (asphalt concrete, and surface treatments), and unpaved roads. Lateritic gravels were studied for the unpaved roads due to their predominance in the study area. Except for the curvature and calibration experiments, sections with high speed alignment were used. A smooth and rough level of roughness was included for each of the surface types. Roughness measurements were made with a Maysmeter (2). Due to the importance of grade, up to seven levels were used in the experiments. The combinations of factors and levels selected for each of the experiments are shown in Table 1. All of the vehicles operated on all the sections except in the constant speed experiment, the light trucks and the bus did not operate on the 13% section and in the curvature experiment the light diesel truck was not included.

Measurements in the momentum experiment were started at the base of the grade and terminated when the vehicle reached steady state speed. Thus the length of the measurement area was variable. In the calibration experiment 10 km long test sections were used. For all other experiments sections 2 km long were sought to provide 500 meter transitions and 1000 meters for measurements. A minimum of 100 meters for the transitions and 600 meters for the measurements were accepted. The properties of the

Table 1. Summary of experimental program.

| Experiment | Description | Levels of Roadway Factors | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Surface Typed | | Curvature | | Roughness | | Grade (%) | | | | | | |
| | | Bituminous | Gravel | Tangent | Curved | Smooth | Rough | 0 | 2 | 4 | 6 | 7[a] | 8[b] | 13[b] |
| Constant Speed | Constant speed operation on positive and negative grades | x | x | x | | x | x | x | x | x | x | x | x | x |
| Acceleration | Vehicles accelerate from zero to maximum speed on positive and negative grades | x | x | x | | x | x | x | x | x | x | x | x | x |
| Deceleration | Vehicles decelerate from maximum speed to zero on positive and negative grades | x | x | x | | x | | x | | | x | | | |
| Momentum | Vehicles decelerate from high entry speed to crawl speed on positive grades using full power | x | | x | | x | | | | x | | x | | |
| Curvature | Partially repeat a constant speed experiment on one section with extreme curvature | | x | | x | x | x | | | | | | x | |
| Sag Curves | Vehicles use full power to traverse sag curves on two sections | x | | x | | x | | | | | | | | |
| Untuned | Partially repeat constant speed experiment with vehicles deregulated | x | x | x | covariate | | | x | | | x | | | |
| Alcohol | Partially repeat constant speed experiment with gasoline vehicles using a mixture of 20% alcohol and 80% gasoline | x | x | x | covariate | | | x | | x | x | | | |
| Calibration | Operate test vehicles over longer sections using normal driving procedures | x | x | | x | x | | high/low | | | | | | |

a) paved only

b) unpaved only

test sections used in the constant speed, curvature and alcohol experiment are given in Table 2.

### Other Independent Variables Measured

In addition to the specific roadway characteristics studied, several variables were measured that describe the environment and roadway conditions. Environmental variables included temperature, wind speed and direction, and rainfall. Roadway covariates measured were rut depth of all sections, and looseness, moisture content, and spacing of corrugations of gravel test sections.

## Equipment

### Vehicle Fleet Characteristics

The test vehicles were selected to be representative of those operating on rural roads in Brazil. The fleet included seven different vehicle types and two replicate vehicles to obtain a measure of replicate vehicle variance. The test fleet consists of one car, two utilities, a light gasoline truck, a light diesel truck, two medium diesel trucks, an articulated diesel truck and a rural diesel bus. The properties of these vehicles are shown in Table 3. All vehicles were purchased new and maintained in good mechanical condition.

All trucks were fitted with flat beds for ease in loading. Concrete blocks weighing 665 kg were fabricated with an exposed loop of reinforcing steel for use as loads. One of the trucks was fitted with a hydraulic crane for loading and unloading the trucks. Concrete cylinders of 13.4 kg were used for loading the other vehicles.

Fuel measurements were made with the vehicles empty, and fully loaded to the manufacture's specifications. The medium diesel trucks with a full load was an exception. It weighed more when full than the rated gross vehicle weight because in calculating the loads to apply to these trucks, the weight of the trucks bed was not included in the tare weight for the vehicle as given by the manufacture. In addition, as time permitted, test were made at half load and with a 10% overload.

In order to maintain comparable weights, two of the vehicles carried some load in the "empty" condition. One medium diesel always carried a load approximately equal to the weight of the hydraulic crane mounted in the other medium diesel. In the case of the light trucks, the gasoline truck always carried a load equal to the difference weight of the two motors.

All fuel used was obtained from the normal stock of local suppliers. The standard gasoline prior to August 1978 in Brazil was 73 octane. After this date 20% alcohol, by volume, was added to the gasoline in the study area. Therefore, an experiment to determine the effect of 20% alcohol in gasoline was performed.

### Fuel Meters

The fuel meters used were based on the designs

Table 2. Test section properties.

| Section No. | Surface[1] Type | Grade[2] (%) | Roughness (QI) | Curves | |
|---|---|---|---|---|---|
| | | | | Number | Radius (meters) |
| 503 | DST | - 6.1 | 30-39 | 1 | 1011 |
| 507 | DST | ± 6.0 | 25-31 | 1 | 700 |
| 508 | AC | ± 4.0 | 55-59 | | |
| 510 | AC | ± 5.8 | 24-33 | 1 | 1146 |
| 511 | DST | - 2.0 | 23-39 | | |
| 512 | DST | + 1.9 | 23-39 | | |
| 513 | GV | ± 2.0 | 42-88 | | |
| 514 | DST | ± 0.2 | 25-30 | 1 | 2929 |
| 516 | GV | ± 8.0 | 43-100 | 1 | 650 |
| 517 | GV | ± 8.0 | 26-100 | 2 | 72-101 |
| 519 | AC | + 3.8 | 23-26 | | |
| 520 | GV | ± 4.0 | 57-98,<br>151-230 | | |
| 521 | GV | ± 0.1 | 38-97 | 1 | 702 |
| 522 | DST | ± 7.0 | 24-31 | 4 | 400-550 |
| 523 | GV | ± 6.0 | 48-99,<br>146-154 | 1 | 1011 |
| 528 | AC | ± 4.0 | 25-32 | | |
| 531 | DST | ± 1.8 | 107-147 | 1 | 603 |
| 532 | DST | ± 2.3 | 103-158 | 2 | 510-702 |
| 533 | DST | ± 3.6 | 88-125 | 1 | 674 |
| 535 | DST | ± 0.3 | 140-229 | 2 | 603-996 |
| 536 | DST | ± 5.8 | 80-129 | | |
| 537 | GV | ± 1.0 | 76-137 | | |
| 538 | GV | ± 6.1 | 141-293 | 4 | 287-350 |
| 555 | GV | ±13.0 | 141-155 | 7 | 84-500 |

1. AC = asphalt concrete
   DST= double surface treatment
   GV = gravel

2. The sign indicates the direction used during the test. On two sections; tests were run in only the positive direction; two sections were used only in the negative direction; on all other sections tests were run in both directions.

by Abaynayaka (3) and Sawhill and Firey (4). To ensure that the meters were zeroed at the start of a run, a syphon was incorporated into the design. Since the accuracy of this type of fuel meter is a function of its size, tests were performed to determine the minimum size fuel meter which could be used with each vehicle. Thus, the size of the fuel meters varied from 250 ml to two liters.

Due to the size differential, two designs were adopted. The smaller fuel meter consisted of a 250 ml graduated cylinder with appropriate tubes and valves for installation. The larger fuel meters had a two cylinder reservoir. A tube scaled in 10 ml increments was put between the cylinders so the fuel could be accurately read on grades and cross slopes. Fuel readings were interpolated to the closest 5 ml with the large fuel meters and to the closest 2 ml with the 250 ml meters.

### Other Equipment

Measurements of looseness and rut depth were performed in accordance with the procedures described by Visser (2). Wind speed was measured with an Airguide Model 918 Windial and the direction was estimated with respect to the axis of the test section.

Each vehicle was equipped with a Numetrics electronic distance measuring instrument (DMI) and either two normal stopwatches or a split second hand stopwatch.

## Methodology

A common methodology was used for the constant speed, curvature, and alcohol experiments to simplify crew training and minimize equipment development. The procedure required the observer to zero the fuel meter, stopwatch, and the DMI while the test vehicle was stopped prior to the start of the transition. The driver then accelerated the vehicle to the desired speed by the start of the transition section and then maintained constant speed. As the vehicle passed the start marker of the transition section, the observer switched on the DMI. When the reading on the DMI was equal to the length of the transition section, the observer simultaneously started the stopwatch and the fuel meter. When the DMI showed that the distance travelled was equal to the length of the transition section plus one half the length of the measurement section, one of the stopwatches, or split second hand on that type of watch was stopped. When the vehicle reached the end of the section, the stopwatch was stopped and the fuel meter switched off. The vehicle was then stopped and the measurements were recorded on the data forms. These forms were designed for direct keypunching to eliminate transcribing errors.

Test runs were made in 10 kph increments for all possible speed gear and loading combinations. At least three repeat runs were made for each combination of speed gear and loading condition. In some cases maximum possible speeds could not be realized for safety reasons.

## Analysis and Results

### Data Processing

Following field data collection, the data forms were manually checked in the office for completeness, keypunched, verified and then edited for logic and limits using a computer. The original data forms were retained in the event of errors being established during the data processing and analysis phases. Due to the magnitude of the experiments, all data were stored on magnetic computer tapes. Space mean speeds for each half and whole run were computed. Fuel consumption was computed in milliliters per second and a summary computer print out of the speed and fuel consumption produced. This output was reviewed for inconsistencies and replicate runs were performed to resolve questionable data.

### Tests for Significance

Replicate vehicle and replicate run variances were calculated for the utility and medium truck types. The replicate run variance was one tenth of the replicate vehicle variance for the utilities and one sixth for the medium trucks. Thus, the mean fuel consumption in milliliters per second across replicate runs was used as the dependent variable for all vehicle types (5).

The replicate vehicle variance for the utilities was significantly smaller than for the medium trucks. Since these variances were not homogeneous separate regression equations were developed for each vehicle type in the constant speed experiment.

The replicate vehicle variance was used to test the significance of the independent variables in the analysis of variance for the utility and medium truck types. The pooled variance of the four factor and higher interactions was used to test the independent variables for the other vehicle types. In the case of the utility and medium truck types, using pooled variance would have resulted in conservative tests since the pooled variance was smaller than the replicate vehicle variance. It is therefore expected that the tests for the significant factors for the

Table 3. Properties of the test vehicles.

| Type | Car | Utility | Bus | Light Truck | Light Truck | Medium Truck | Medium Truck | Articulated Truck | |
|---|---|---|---|---|---|---|---|---|---|
| Make | Volkswagen | Volkswagen | Mercedes Benz | Ford | Ford | Mercedes Benz | Mercedes Benz | Scania | Rodoviaria |
| Model | 1300 | Kombi | 0-362 Bus | F-400 | F-4000 | 1113 | 1113 with Monk | 110-39 | trailer (3 axles) |
| BODY (m) | | | | | | | | | |
| ground clearance | 0.152 | 0.200 | 0.273 | 0.200 | 0.200 | 0.279 | 0.279 | 0.300 | |
| total height | 1.500 | 1.912 | 2.945 | 1.890 | 1.890 | 2.454 | 2.454 | 2.013 | |
| width | 1.540 | 1.746 | 2.500 | 2.030 | 2.030 | 2.350 | 2.350 | 2.403 | |
| distance between axles | 2.400 | 2.400 | 5.500 | 4.030 | 4.030 | 4.200 | 4.200 | 3.800 | 8.750 |
| front overhang | 0.760 | 1.130 | 2.310 | 0.750 | 0.750 | 1.100 | 1.100 | 1.480 | 0.90 |
| rear overhang | 0.910 | 0.867 | 2.800 | 2.200 | 2.200 | 3.850 | 4.600 | - | 2.600 |
| total length | 4.070 | 4.397 | 10.660 | 6.980 | 6.980 | 9.150 | 9.900 | 16.630* | 12.250 |
| WEIGHT (kg) | | | | | | | | | |
| tare | 780 | 1,195 | 7,500 | 2,227 | 2,444 | 8,065 | 9,735 | 5,583 | 14,000 |
| GVW | 1,160 | 2,155 | 11,500 | 6,060 | 6,060 | 18,500 | 18,500 | 45,000* | |
| load level 1 | 920 | 1,335 | 7,640 | 2,567 | 2,584 | 9,935 | 9,875 | 19,723* | |
| load level 2 | 1,050 | 1,615 | 8,650 | 4,147 | 4,124 | 14,190 | 14,265 | 33,323* | |
| load level 3 | 1,200 | 1,885 | 9,890 | 5,952 | 5,909 | 20,175 | 20,250 | 46,923* | |
| load level 4 | - | - | - | 6,410 | 6,427 | 23,378 | 23,383 | 48,983* | |
| MOTOR | | | | | | | | | |
| fuel | GAS | GAS | DIESEL | GAS | DIESEL | DIESEL | DIESEL | DIESEL | |
| type | Horiz.Opp. | Horiz.Opp. | in line | V | in line | in line | in line | in line | |
| cylinders | 4 | 4 | 6 | 8 | 4 | 6 | 6 | 6 | |
| bore (mm) | 77 | 83 | 97 | 92 | 105 | 97 | 97 | 127 | |
| stroke (mm) | 69 | 69 | 128 | 84 | 120 | 128 | 128 | 145 | |
| displacement (cc) | 1,285 | 1,493 | 5,675 | 4,457 | 4,163 | 5,675 | 5,675 | 11,000 | |
| compression | 6.6 | 6.6 | 17.0 | 7.3 | 17.8 | 17.0 | 17.0 | 16.0 | |
| torque/ RPM (m.kgf) | 9.1/ 2600 | 10.3/ 2600 | 37.0/ 2000 | 33.5/ 2200 | 29.2/ 1600 | 37.0/ 2000 | 37.0/ 2000 | 79/ 1200 | |
| horse power/ RPM (SAE) | 48/ 4600 | 60/ 4600 | 147/ 2800 | 169/ 4400 | 102/ 3000 | 147/ 2800 | 147/ 2800 | 285/ 2200 | |
| DRIVE TRAIN | | | | | | | | | |
| Gear 1 | 3.80 | 3.80 | 8.02 | 6.40 | 5.90 | 8.02 | 8.02 | 13.51 | |
| 2 | 2.06 | 2.06 | 4.77 | 3.09 | 2.85 | 4.77 | 4.77 | 10.07 | |
| 3 | 1.32 | 1.32 | 2.75 | 1.69 | 1.56 | 2.75 | 2.75 | 7.55 | |
| 4 | 0.89 | 0.89 | 1.66 | 1.00 | 1.00 | 1.66 | 1.66 | 5.66 | |
| 5 | | | | | | 1.00 | 1.00 | 4.24 | |
| 6 | | | | | | | | 3.19 | |
| 7 | | | | | | | | 2.38 | |
| 8 | | | | | | | | 1.78 | |
| 9 | | | | | | | | 1.34 | |
| 10 | | | | | | | | 1.00 | |
| Differencial | 4.375 | 4.375 | 4.875 | 5.140 | 4.630 | 4.875 | 4.875 | 4.710 | |
| Tire diameter (m) | 0.650 | 0.654 | 1.016 | 0.808 | 0.808 | 1.016 | 1.016 | 1.080 | 1.080 |

* Total for tractor-trailer unit.

other vehicle types are also conservative.

## Constant Speed Experiment

The significant effects identified in the analysis of variance were entered into a model of the form:

$$FUEL = a_0 e^{(a_1 x_1 + a_2 x_2 + \ldots)} + \varepsilon \qquad (1)$$

The non-linear regression program in the SAS library (6) was used to estimate the coefficients. The equations, their mean square error, $S^2_e$, and the $R^2$ value are presented in Table 4. The equation for the articulated truck varies from the form of equation 1 in that $a_0$ is divided by the absolute value of negative grades.

Figures 1 to 5 illustrate the form of the equations and the magnitude of the main effects. Figure 1 shows the predicted fuel consumption for each vehicle type. There is a general trend of increasing fuel consumption with vehicle weight. This can be clearly seen in comparing the fuel consumption of the bus and medium trucks. Even though these vehicles have identical drive-trains, the bus comsumes much less fuel than the trucks at half load, due mainly to the 5,500 kg difference in the weights used in this comparison.

One exception to the trend of increasing fuel consumption with weight, is the comparison of gasoline and diesel trucks. The light gasoline truck actually consumes more fuel than the medium weight diesel trucks at speeds less than 45 kph. The fuel consumption of the gasoline truck is always greater than the equivalent diesel truck as shown in Figures 1 and 2. Figure 2 demonstrates that the gasoline truck empty consumes 50 to 100 percent more than the diesel vehicle consumes full. Figure 2 also shows the effect of gears on fuel consumption for the empty gasoline truck.

The effect of load on fuel consumption for the articulated diesel truck is shown in Figure 3. The significance of the load-speed interaction is clearly illustrated as the curve for the loaded vehicle has a greater slope than the empty vehicle. In fact, at 10 kph the fuel consumption is about the same for all three load conditions, but at 70 kph, the vehicle consumes approximately 50% more when loaded.

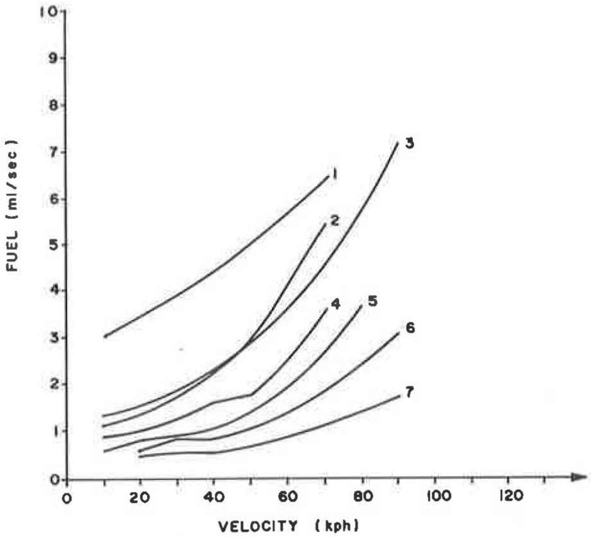
The effect of surface type was tested indepen-

Table 4. Fuel consumption equations (ml/seg).

| Vehicle | $S_e^2$ | $R^2$ | |
|---|---|---|---|
| Car | .037 | .91 | $FUEL=.142e^{.02287S+.000855(S)GR+.03782\,P(GR+3)+.2695(5-GEAR)+.0001024(QI)(GR+14)}$ |
| Utility | .060 | .93 | $FUEL=.197e^{.02579S+.001062(S)GR+.02932\,P\,(GR+3)+.2485(5-GEAR)+.0000785(QI)(GR+14)}$ |
| Light Gas Truck | .41 | .94 | $FUEL=.906e^{(.0127+.00063P+.00699(5-GEAR)+.0000215(QI))S+.01234GR(P)GEAR}$ |
| Light Diesel Truck | .14 | .90 | $FUEL=.1826e^{.0325S+.00208(GR)S+.0254P(GR+1)+.2333(5-GEAR)+.001405QI}$ |
| Medium Truck | .19 | .93 | $FUEL=.583e^{(.02356+.000491(P)(GR+1))S+(.00594P+.01224GR)(6-GEAR)+.00057QI}$ |
| Heavy Truck | .41 | .96 | $FUEL = (2.76/\sqrt{1+G})e^{(.00404+.0002169(P)(GR+1)+.0000282QI)\ S}$ |
| Bus | .17 | .92 | $FUEL=.195e^{.0359S+.0044(GR)S+.0075(P)(GR+1)+.2781(6-GEAR)+.0002088(P)QI}$ |

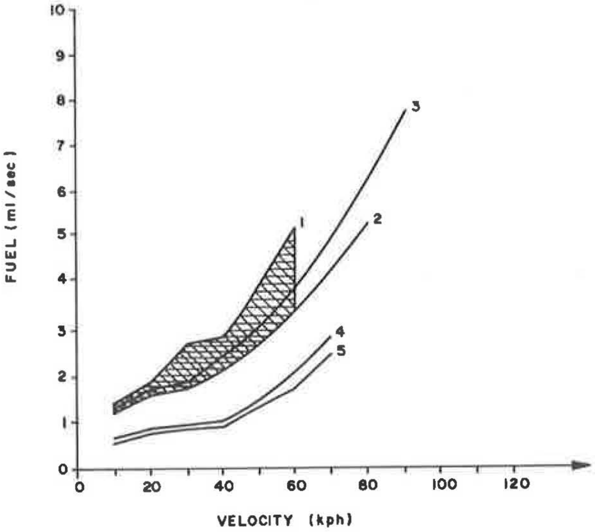
S = Speed (kph)
GR = Grade (%)
G = |GR| for negative grades,
0 otherwise
P = Weight of vehicle (metric tons)
QI = roughness

Figure 1. Fuel prediction for each vehicle type (load level 2, see Table 3, highest gear at each speed, zero grade, roughness 30 QI).



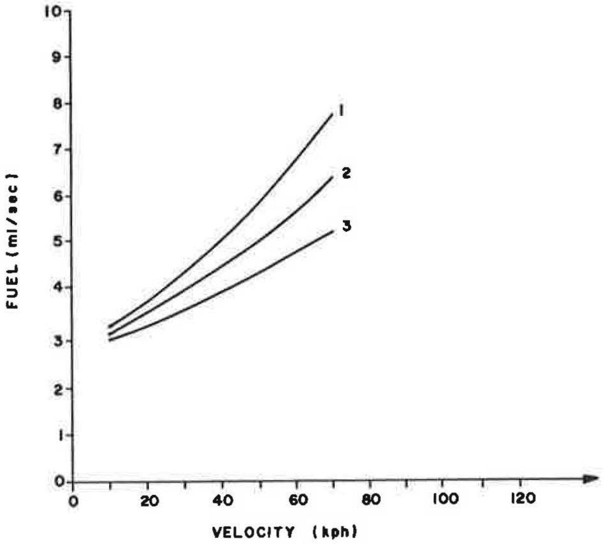
1. Articulated truck
2. Medium truck
3. Light gasoline truck
4. Bus
5. Light diesel truck
6. Utility vehicle
7. Car

Figure 2. Fuel prediction for light gasoline and diesel trucks (zero grade, roughness 30 QI). Shaded area shows the effect of gears.



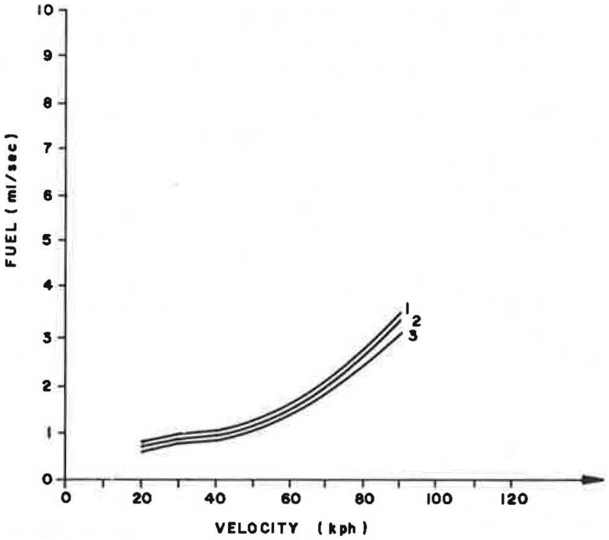
1. Light gasoline truck, load level 1, lowest gear for each speed
2. Light gasoline truck, load level 1, highest gear for each speed
3. Light gasoline truck, load level 3, highest gear for each speed
4. Light diesel truck, load level 3, highest gear for each speed
5. Light diesel truck, load level 1, highest gear for each speed

Figure 3. Fuel predictions for articulated truck (zero grade, roughness 30 QI).



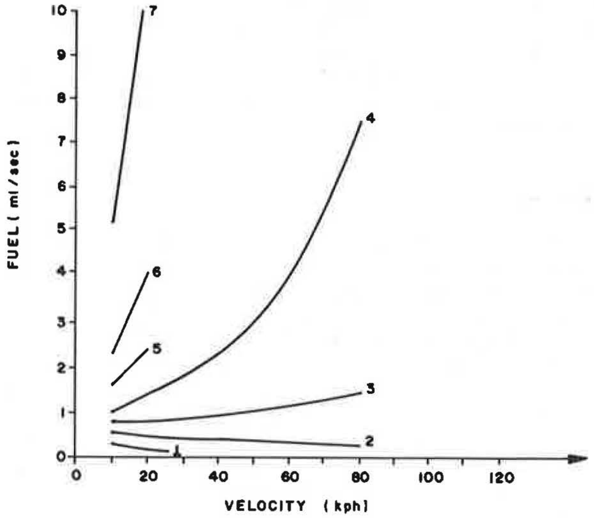
1. Load level 3
2. Load level 2
3. Load level 1

Figure 4. Fuel predictions for utility vehicles at three roughness levels (load level 2, highest gear for each speed, zero grade).



1. 150 QI
2. 100 QI
3. 30 QI

Figure 5. Fuel predictions for medium diesel trucks at various grade levels (load level 2, highest gear for each speed, roughness 30 QI).



1. - 13%
2. - 6%
3. - 3%
4. 0%
5. + 3%
6. + 6%
7. + 13%

dent of roughness for a range of QI from 90-110 where QI values of rough paved roads overlap those of smooth gravel roads. The data from the medium diesel trucks were used to test the surface type effect and it was found to be not significant for $\alpha=0.1$. Because QI values of less than 90 and greater than 110 usually represent paved and gravel roads respectively, and the surface type was nonsignificant from 90 to 110, the roughness variable explains the combined effect of surface type and roughness. Roughness was found to be significant for all vehicle types. Figure 4 shows the influence of roughness on fuel consumption for the utility vehicles.

Finally, Figure 5 shows the effect of grade on fuel consumption for the medium weight trucks. As expected, grades have a major influence on fuel consumption, and the grade-speed interactions is very significant. On steep negative grades, the fuel consumption is almost independent of speed, but for the 6% positive grade, increasing speed from 10 to 20 kph results in an increase in fuel consumption of more than 80%.

## Horizontal Curvature Experiment

Two gravel sections with 8% grade were used to test the effect of horizontal curvature. Measurements made on a tangent section were compared to those from a section with a 72 m and a 101 m radius curve. For all vehicle types the effect of curvature was found to be nonsignificant at the $\alpha=0.1$ level. A maximum increase of 3% on the negative curved section was observed with the utility vehicles.

## Effect of Alcohol on Fuel Consumption

The data set analyzed for this experiment consisted of fuel consumption measurements of the four gasoline vehicles in the fleet operating on paved and unpaved test sections of 0,4, and 6% grade in the positive and negative direction. Data for the light gasoline truck on the 0% unpaved section was not collected because of weather conditions. Data were collected with 20% alcohol in the gasoline starting in August of 1978 when this fuel mixture became available to the public. These data were compared to data collected earlier during the constant speed experiment. Thus, results from this experiment may be confounded by vehicle age.

For all three gasoline vehicle types the mean consumption of fuel with 20% alcohol was significantly greater at $\alpha = .01$ than the consumption of pure gasoline. The amount of increase in all cases dependend on the speed-gear combination used and therefore is probably dependent on the revolutions per minute of the vehicle motor.

For the utility vehicle the increase was significantly different in the positive and negative directions.

The average increase for the car on paved sections was 6% for the combinations of speeds and gears tested. This value varied from 1% for 30 kph in third gear to 14% for 40 kph in second gear. The mean increase for the utility vehicle was 11% for the speed-gear combinations tested. A maximum value of 14% for 40 kph in third gear and a minimum of 2% for 20 kph in second gear were found. On positive grades the mean increase was 12% and on negative grades 7%. The light gasoline truck had a mean increase of 4%. The differences between the consumption of the two types of fuel was constant for the two surface types.

## Summary and Conclusions

A major experimental program investigating the relationship between fuel consumption and roadway characteristics was described. The data collection effort is complete, and three experiments have been analyzed. These experiments demonstrate that at constant speed, vehicle type, weight, gear, grade, roughness, and mixing alcohol in gasoline, all have a significant effect on fuel consumption. Horizontal curvature was not found to be significant in a limited experiment. Surface type did not produce significantly different fuels for a fixed roughness and since roughness and surface type were highly correlated the continuous scale of roughness was used to explain the overall effect.

Regression equations are presented for calculating fuel consumption during constant speed operation. These equations, one for each vehicle type, show that fuel consumption is exponentially related to speed, weight, gear, grade, and roughness.

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