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of Trucks

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# THE EFFECT OF GRADES UPON THE PERFORMANCE AND OPERATIONAL COSTS OF TRUCKS

Jim L. Pope

## INTRODUCTION

The transportation of logs from the woods to the mill has always been a major problem. In the past the railroad has been the most common means of moving logs. When timber stands were large and the yeild per acre great, the logging operators could afford to invest in expensive railroad equipment. When the timber stands became smaller and further apart some other means of transportation had to be found. The motor truck seemed to be just what was needed; initial cost was low, terrain was not a limiting factor, and drivers were easily secured. Many operators thought that the truck was the final solution to the transportation problem. Hence, the necessity of heavy investments in locomotives, railroad cars, steel rails, ties, grade and right-of-way maintenance, and special train crews would thus be eliminated. Only a comparatively few trucks would be necessary and they would cost only a fraction of what a single locomotive would cost, also some sort of a road would have to be built into the woods. With a reduction in the total investment the profit realized would increase. However, many of the loggers soon ran into serious difficulty. Because not enough was invested in road construction, usually only the cost of a bull-dozer to push the rocks out of the way so that some sort of alignment could be made delivery to the mill was slow and sporadic. Trucks could not make good time over the rough roads, and in rainy weather the movement of the logs almost ceased. Some of the operators tried to solve the problem by hiring contract carriers to deliver a stipulated number of logs to the mill within certain time limits; others went ahead and built better roads; but profits, instead of increasing, fell.

When trucks were first used in the woods the loads that they could carry were small; it took many trips to deliver the number of logs that would have arrived in a single train-load. The operators soon demanded larger trucks, and the automotive industry kept pace with the demands as best they could, but soon the requirements of the logger exceeded what even the largest type of commercial trucks would accomplish. The kind of truck that they wanted was not in common use, and the large manufacturers could not supply them. Consequently, the logger had special pilot models built by the smaller firms. The larger truck manufacturers said that trucks of this huge size would never prove economical. However, the logger proved that these trucks were economical, and that the loads carried were so large that the unit costs dropped considerably. The log operators were enthusiastic and had even larger trucks built - trucks that could carry more than the old type railroad car. In order to make these trucks, many necessary and expensive departures from conventional truck design had to be made. The logger was appalled, as truck costs had risen from a few thousand dollars to twenty or thirty thousand dollars. He was again having to invest heavily to get the logs out of the woods. Expensive equipment was re-employed in the logging operation, but the logger, in order to economize, cut road construction cost to a bare minimum. Some of the operators survived; others did not. Those that did survive soon realized that if the roads were improved, truck speeds could be increased and that even a delivery schedule could be kept. However, it was found that there is a balance between possible safe speeds and the cost of improved roads. The larger operators have discovered that this fundamental principle is sound and see only two ways of increasing the delivery to the mill: (1) to buy more trucks, or (2) to get larger trucks. The trend has been toward the use of the larger truck.

The present demands of the logger were stated at the Sixth Annual Intermountain Logging Conference (Missoula, Montana, March 30 - April 1, 1944) by Emmit Aston, who contended that the highways of the West were too light for post-war service, and that in the future they should be built to carry loads of 100,000 pounds and be wide enough to accommodate 10 foot bunks. Mr. Aston also stated that the ideal truck would be one that could carry a payload of 75,000 pounds and that to carry the load it must be equipped with 12.00 x 24 tires.[1] At a recent meeting of the Society of Automotive Engineers (Seattle, Washington, August 22-24, 1946), the desire for larger trucks was again voiced by James C. Sheasgreen, Superintendent of the Comax Logging and Railway Company, Ladysmith, B.C., who stated that vehicles with 300 horsepower engines would be needed.[2]

Those in the automotive industry are coming to hold the same opinion as the logger about the need for larger trucks. This opinion has been adequately expressed by F. R. Nail, Assistant to the Chief Engineer of the Mack-International Motor Truck Company, and Robert Cass who is Assistant to the President of the White Truck

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1....."Highway Log Transportation", Timberman, Vol. 65, No. 7, (May, 1944), p. 42.

2....."Sheasgreen Pleads for Larger, Higher Powered Trucks", Westcoast Lumberman, Vol. 70, No. 7, (September, 1946), p. 107.

Company.[3] Both of these men have expressed the belief that the 300 horsepower truck will soon come into use. Recent developments, the result of war demands, have been incorporated in new powerful models, which are now on the market. Other developments are in progress.[4] At the present time some industries have reached the 100,000 pound load, notably, strip-mining in the coal regions of Indiana and Illinois and iron mining in Minnesota. These industries are contemplating trucks of a still larger capacity; however the trucks used in these operations

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3.....F. R. Nail, "Power Requirements in Trucks of the Future", Commercial Car Journal, Vol. 71, No. 4, (June, 1946), p. 101 ff. and Robert Cass, "Trucks Five Years Hence", Commercial Car Journal, Vol. 70, No. 6, (February, 1946), p. 44 ff.

4.....For a more complete indication of the present trends of the automotive industry see any late issue of the Commercial Car Journal. The following articles are recommended: "White Super-Power Engines Feature Major Improvements", Commercial Car Journal, Vol. 72, No. 2, (October, 1946), p. 70 ff., "Heavy Duty Federal Develops 184 H.P.", Commercial Car Journal, Vol. 71, No. 4, (June, 1946), p. 130 ff. Though new models of the heavy-heavy classification (over 50,000 pounds gross vehicle weight) have been put on the market by White, Federal, International Harvester, and others there is still no vehicle capable of carrying a load of 75,000 pounds. There have been rumors that Mack has plans for a truck with a 115,000 pound gross vehicle weight, and that Kenworth has plans for a truck with a 106,000 pound gross vehicle weight; but at the present time the largest truck on the market is a Sterling, model HCS-339-H, with a gross weight of 80,000 pounds. Deducting the weight of the vehicle would mean a payload of about 65,000 pounds. Engines have reached as high as 220 horsepower, with displacements of 1300 cubic inches. To increase power output and still stay within a reasonable size creates a difficult engineering problem.

are of a specialized design for earth-moving and are not applicable to logging.[5]

When the investment in a single piece of equipment reaches the point that it has for these large trucks an operator has to realize the maximum profit; he has to know what he is buying and how to get the most out of his investment. The only way maximum efficiency can be realized for a truck is to know exactly how, where, and when the truck is to be used. Many loggers buy a truck regardless of the logging situation, and when hauling costs rise they blame the equipment rather than themselves for not planning for maximum operational efficiency. Each operation will call for a different plan. In some cases it may be best to buy the conventional type of truck; in others it may be better to invest in the larger vehicles. One situation might call for a good road, another, for a less expensive type of road. If it is decided that the less expensive road is to be built, can the larger trucks travel over it at a satisfactory rate of speed or would it be better to use smaller trucks? Questions like the above are always facing the logger, and the only answer has been experience.

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5.....Virgil Graves, "Euclid Trucks in Minnesota", Symposium on the Handling of Bulk Materials, pp. 15-19.

In mountainous country the presence of grades has always been an important problem. Grades increase the running time and the operating costs per trip, but whether it would pay to reduce them has never been accurately determined. More can be spent on grade reduction when large trucks are used and total operating costs are high, than when the smaller trucks are used, whose operating costs are less and their loads smaller. A balance exists between the amount that can be spent to reduce a grade and the benefits that will be derived from the reduction. It is the purpose of this paper to show how this balance may be found for each situation.

The actual conducting of tests to determine operating costs and time savings on various grades would require larger facilities, than are available. Therefore, in the main, this thesis consists of a compilation of the work, together with a record of the experimentation of others. However, the work seems to be in order as extended search has revealed no complete text by which the savings made possible by grade reduction can be analyzed.

It should be evident that the consideration of grades will be closely connected with the investigation of truck engines and their ability to meet the power requirements involved in operation. The first section of this paper will deal with the various resistances offered to the movement of any vehicle. These resistances will be discussed in the following order:

1. Internal friction, otherwise known as internal resistance or chassis friction.
2. Resistance to acceleration.
3. Tractive resistance, has been defined by Aggas, "....the hypothetical force whose line of action is parallel to the road surface and the longitudinal axis of the vehicle, and whose magintude is equal to the summation of the components in that line of all external forces acting on the vehicle when it is traveling on a level road surface".[6]
4. Grade resistance.

The following section will be devoted to the development of formulae by which the performance of a vehicle may be computed. Since performance depends upon overcoming the various resistances, it is well to have a complete understanding of the first section before proceeding to the second.

Basically there are two ways by which vehicle performance

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6.....Tractive Resistance of Automobiles and Coefficients of Friction, Iowa Engineering Experiment Station, Bulletin 88, p. 6.

may be computed: one method is based on the torque produced by a given engine, the other upon the horsepower. The figure following shows graphically the torque and horsepower output of an engine at various engine speeds. Orginally all of the calculations of performance were based upon torque; however, many of the manufacturers are beginning to realize the fallacy of this method and as a result are changing to the horsepower method.

To enable the engine to perform adequately power is produced. An engine's power, which is simply the ability to sustain a turning effort on a revolving shaft, has two components, torque and speed. Torque is measured in terms of pounds of effort at a one foot radius; speed is measured in revolutions of the crankshaft per minute. Taken together torque and speed produce power, or the ability to do work; either by itself is not power. Torque which is static, may be exerted on a stationary shaft, but no work can be done by static torque. Speed might be produced with zero output of torque. The shaft might be kept turning, but if enough torque were produced just to keep the shaft turning there could be no work. Any formula based upon torque is based upon the assumption of a static condition, an assumption which does not apply to vehicle operation. A needed dynamic formula can be developed by substituting the horsepower concept for the

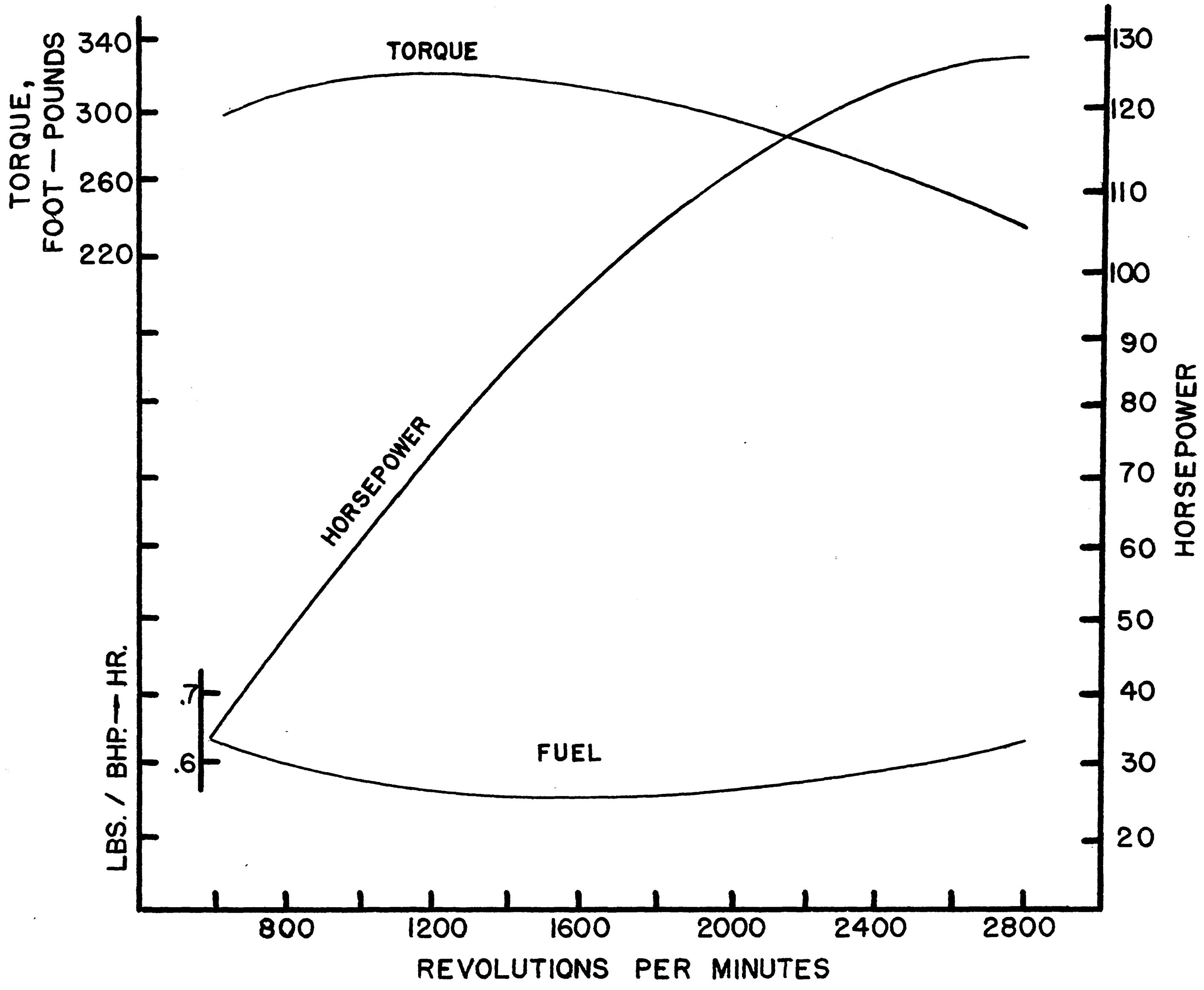


FIGURE 1 - HORSEPOWER, TORQUE AND FUEL CONSUMPTION CURVES FOR A CONTINENTAL ENGINE - MODEL B6427.

torque concept, since horsepower is simply the torque times the speed. The factors of performance are the same; namely, the tractive effort and the tractive resistance, but their values are expressed in terms of horsepower or foot-pounds per minute rather than static pounds.

The third section will deal with the savings that can be made when grades are reduced. The determination of these savings will be divided into two classes: (1) those savings possible because of a reduction in fuel consumption, and (2) those savings in hauling time due to an increase in speed.

The last section will be devoted to a sample problem in which it will be required to determine the correct type of truck for the situation; what type of road would be best suited for the operation; and what savings, if any, are possible from grade reductions.

# SECTION I

## OPERATIONAL RESISTANCES

### Internal Resistance.

Internal resistance consists of all those intermediary resistances encountered between the engine to the drive wheels. The majority of the resistance comes from the driveshaft, wheels, brake-drums, and the churning of oil in the main and auxilary transmissions. Generally all of these resistances are taken into account by multiplying the brake horsepower of the engine by a predetermined factor, and thus obtaining the power available at the wheels. In practice this figure is generally accepted as .85; in other words, 15 percent of the power of the engine is lost before it reaches the wheels. To assume that the internal friction is constant in all vehicles at all speeds is unsound.

Personal interviews with engineers of the General Motors Corporation, Federal Truck Company, and the Chevrolet Division of General Motors has proved that the majority of the manufacturers realize the fallacy of this constant percentage theory, but as yet none of them has done any work to find out exactly how much internal friction hinders truck performance.

Since this constant percentage theory involves considerable error, some other method must be devised by which frictional losses may be accurately determined.

In 1942 the Public Roads Administration undertook a series of tests to determine the "grade ability" of trucks.[7] In the course of the tests it was found necessary to determine the efficiency of the vehicles used. Because of the relatively large number of machines tested and the accuracy obtained, a complete explanation of the process will follow.[8]

The results of actual grade tests, together with the certified power, were used to provide efficiency factors for all the vehicles tested. The efficiency factors were obtained by applying the results of actual grade tests to a basic formula derived by equating the force produced at the driving wheels with the sum of the grade and tractive resistances.

The basic formula used to compute the grade ability of a vehicle is as follows:

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7....."Grade-ability" is an engineering term used to designate the grade climbing ability of a vehicle.

8.....Carl C. Saal, "Hill Climbing Ability of Motor Trucks", Public Roads, Vol. 23, No. 3, (May, 1942), pp. 44-46.

$$GVW = \frac{T \times GR \times R_e \times 12}{r(f + g)}$$

where

GVW is the gross vehicle weight in pounds,
T is the torque of a given engine speed in foot pounds,
GR is the total gear reduction,
$R_e$ is the efficiency factor,
r is the effective radius of the driving wheels in inches,
f is the coefficient of tractive resistance in pounds per pound of gross vehicle weight (See the tables following),
g is the grade rise in feet per foot, and
12 is the conversion factor for inches to feet.

The efficiency was then determined by solving the equation for $R_e$ as follows:

$$GVW = \frac{T \times GR \times R_e \times 12}{r(f + g)}$$

$$GVW(f + g) = T \times GR \times R_e \times 12$$

$$R_e = \frac{GVW(f + g)r}{T \times GR \times 12}$$

The numerator represents the torque actually produced at the driving wheels, and the denominator the torque that would have been produced at the same point if there had been no losses during the transmission of power.

The following is an example of the methods employed. A certain tractor-truck semitrailer maintained a speed of 25 miles per hour in fourth gear on a 4.5 percent concrete grade. The radius of the driving wheels for this weight and the coefficient of tractive resistance for the weight and speed involved were determined to be 16.9 inches and 0.015 pounds per pound of weight, respectively. The total gear reduction when the vehicle was operated in fourth gear was 7.15.

Charts that showed the certified power and torque at various engine speeds were used to ascertain the torque produced at the engine. In order to obtain the torque it was necessary to find the engine speed equivalent to a road speed of 25 miles per hour. The engine speed was computed in the following manner:

$$RPM = \frac{168 \times GR \times S}{r}$$

$$RPM = \frac{168 \times 7.15 \times 25}{16.9}$$

$$RPM = 1{,}780$$

where

RPM is the engine speed in revolutions per minute,
S is the road speed in miles per hour,
GR is the total gear reduction,
r is the effective radius of the driving wheels in inches, and
168 is the factor to convert units to revolutions per minute.

The torque produced at 1,780 revolutions per minute was 165 and 156 pound-feet, the manufacturers certified maximum and net torque respectively. The efficiency factors for the maximum and the net torque were then determined to be 90.5 percent and 94.4 percent by substituting the values previously found in the equation for efficiency.

1. For maximum torque:

$$R_e = \frac{12{,}500\ (0.015 + 0.045)\ 16.9}{165 \times 12 \times 7.15}$$

$$R_e = 90.5\%$$

2. For net torque:

$$R_e = \frac{12{,}500\ (0.015 + 0.045)\ 16.9}{156 \times 12 \times 7.15}$$

$$R_e = 94.4\%$$

The maximum torque is produced by an engine that is stripped of all its accessories except those that are necessary for its functioning. The net torque is that produced by an engine that has all the accessories operating, such as the fan, generator, exhaust pipe, muffler, tail pipe, and other equipment that is standard or regular equipment on the engine. The engines of the chassis tested in the field were removed and tested on a cradle dynamometer to determine the net torque and horsepower available at various engine speeds at full throttle. The results of these tests were compared with the net torque

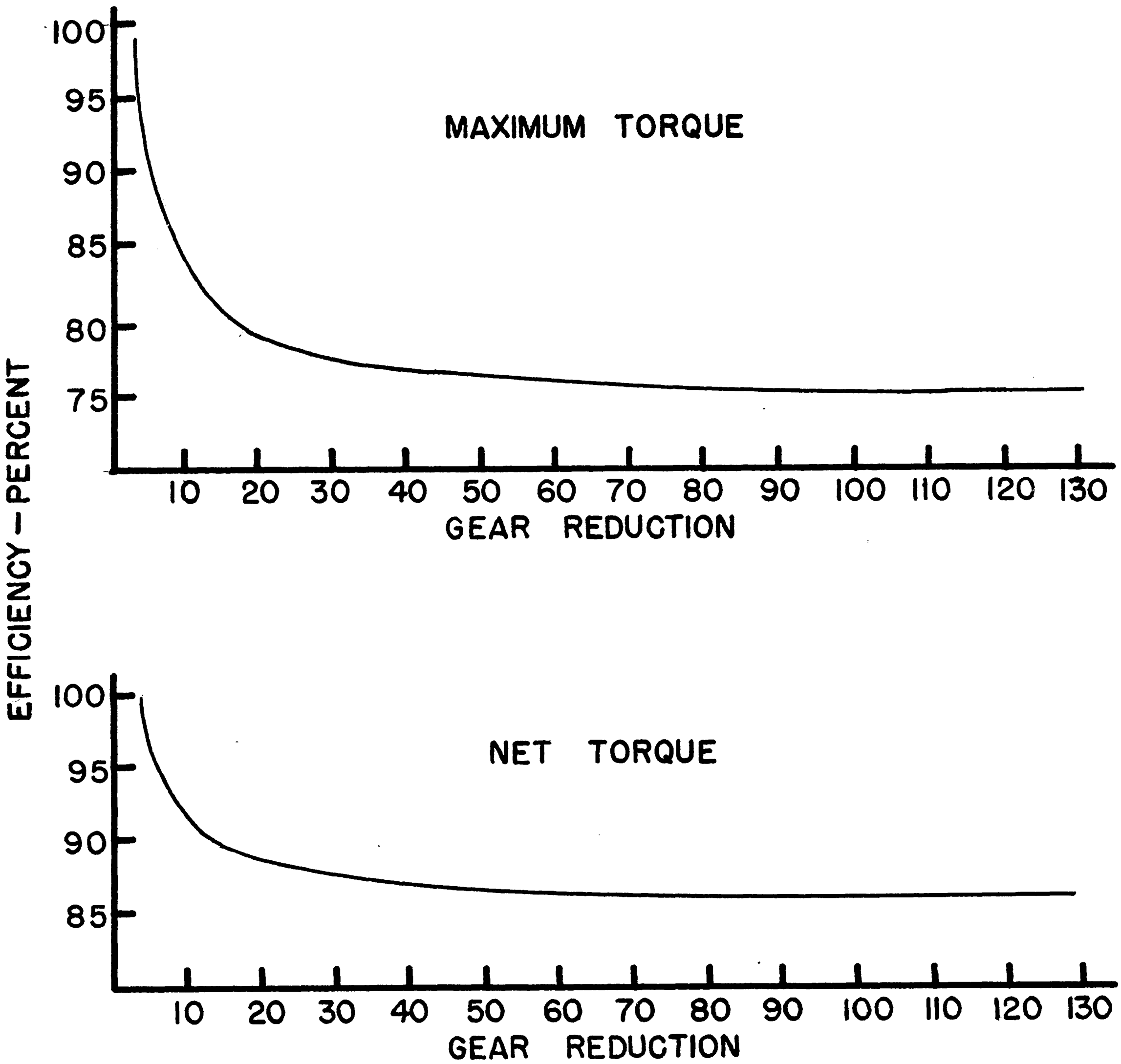


FIGURE 2 - VARIATION OF EFFICIENCY WITH GEAR REDUCTION FOR ALL TRUCKS AND TRACTOR-TRUCK SEMI TRAILERS.

and power values certified by the manufacturer and were found to be in close agreement in all except a few cases. In those cases where there was a marked difference that could not be explained, the efficiency factors were not computed.

After the efficiency factors were determined for the various weights, an average factor was determined for each individual vehicle tested and for each gear ratio used. From the figures obtained the curves shown on the previous page were drawn. The curves are hyperbolas, the equations of which were determined by the method of least squares. The hyperbola was found to fit the points and the conditions better than a straight line or parabola. The equations of the curves are:

1. For maximum torque;

$$R_e = 74.36 + \frac{99.69}{GR}$$

2. For net torque;

$$R_e = 85.64 + \frac{56.15}{GR}$$

The variation that occurs about the average efficiency is indicated by a standard deviation of 3.5 for the maximum torque and 3.1 for the net torque. In other words, 68 percent of the values lie within 3.5 percent of the efficiency shown by the curves.

It is evident that regardless of the gear ratio used this method will give greater accuracy than the old method of a straight percentage loss in the transmission of power. It is therefore important to select the correct factor with each different gear ratio.

Acceleration.

Acceleration, the rate at which speed increases, is variously expressed as feet per second per second (Ft./sec$^2$), miles per hour per second (MPH/sec), or in terms of acceleration due to gravity (32.2 ft./sec$^2$).

It is necessary that motor vehicles be powered sufficiently so that speed can be increased from zero (in addition to overcoming inertia) to a desirable driving speed in a reasonable period of time. The internal combustion engine, because of its peculiar characteristics, cannot accelerate a vehicle from zero speed if it is geared directly to the driving wheels. Some means must be provided for the gradual acceleration of the vehicle from the start without stalling the engine. This effect is accomplished by the clutch, which by slipping, permits the engine to run at a non-stalling speed while the vehicle is gradually started. (The hydromatic drive is a good application of this principle.) Thereafter, the rapidity of acceleration will depend upon the power developed by the engine at each particular speed. Since the horsepower of the motor will increase with the number of revolutions of the driveshaft, the introduction of reduction gears enables a greater acceleration of the vehicle at the lower speeds, this is why three or more forward speeds are used on motor vehicles. The basic law of physics for acceleration is:

$$R_a = \frac{W}{g} a$$

where

$R_a$ is the force in pounds required to accelerate the body,
$W$ is the weight of the body in pounds,
$g$ is the acceleration of gravity in feet per second per second, and
$a$ is the acceleration of the body in feet per second per second.

To convert the above formula to automotive use, and to determine the force required in horsepower, several changes are necessary. The horsepower required for acceleration is obtained by multiplying the force required by the distance the vehicle will travel in one second. Dividing the result by one horsepower, 550 foot-pounds per second, will keep the terms uniform. The new formula will then be:

$$H.P. = \frac{\frac{GVW}{32.2}\ a \times d}{550};$$

but since the distance traveled in one second is

$$H.P. = \frac{5280 \text{ feet per mile}}{3600 \text{ seconds per hour}} \times M.P.H.$$

the new formula becomes,

$$H.P. = \frac{\frac{GVW}{32.2}\ a \times \frac{5280}{3600}\ M.P.H.}{550}$$

factoring,

$$550\ H.P. = \frac{GVW}{32.2}\ a \times \frac{5280}{3600}\ M.P.H.$$

$$550\ H.P. = \frac{GVW}{32.2}\ a \times 1.466\ M.P.H.$$

$$(32.2)\ (550) H.P. = (GVW)\ (a)\ (1.466\ M.P.H.)$$

$$H.P. = \frac{(GVW)(a)(1.466\ M.P.H.)}{(32.2)(550)}$$

$$H.P. = \frac{(GVW)(a)(M.P.H.)}{12,000}$$

where

H.P. is the required horsepower for acceleration,
a is the acceleration in feet per second,

GVW is the gross vehicle weight in pounds,
M.P.H. is the vehicle speed in miles per hour, and
12,000 is a constant conversion factor.

The rate of acceleration of motor vehicles varies widely. For the heavier trucks and buses, it will be about one foot per second per second; for some of the high-powered passenger cars, it may be as high as four feet per second per second in third gear.

While all trucks, when loaded within their recommended capacities usually have adequate power to start, enough power should be available so that acceleration can be made in the higher gear ratios in order to maintain an adequate speed under all conditions.

The formula just developed may be used in several ways: (1) to determine the power necessary to accelerate from zero miles per hour to some given speed, and (2) to determine the power required to accelerate even more while the vehicle is in operation. Actually one is merely a variation of the other.

Example:

As an illustration of this first method, let it be assumed that it is desired to find the horsepower required to accelerate a 60,000 pound vehicle from zero miles per hour to 20 miles per hour in 20 seconds, which would be .975 feet per second per second, Substituting in the formula, the result would be as follows:

$$H.P. = \frac{(60,000)(.975)(20)}{12,000}$$

$$H.P. = (5)(.975)(20)$$

$$H.P. = 97.5$$

The second method is used to find the amount of accelerative ability left in an engine when the vehicle is actually in operation.

Assume the same vehicle was operating at 20 miles per hour, the horsepower capacity of the engine was 220 and that the vehicle required 180 horsepower for operation, 40 horsepower would be left for accelerative purposes. Therefore, what acceleration can be expected from the reserve power. Since,

$$H.P. = \frac{(GVW)(a)(MPH)}{12,000}$$

clearing the fraction:

$$12,000\ H.P. = (GVW)(a)(MPH)$$

therefore,

$$a = \frac{12,000\ H.P.}{(GVW)(MPH)}$$

substituting,

$$a = \frac{(12{,}000)(40)}{(60{,}000)(20)}$$

$$a = \frac{2}{5}$$

$a$ = .4 feet per second per second.

The acceleration of .4 of a foot per second per second is more than adequate for all general purposes.

It is safe to have some reserve power for passing, grades and emergencies. Economy suffers with reserve power. Since gasoline engine is most economical when operating closest to its maximum torque output, it is well when selecting a truck to consider the acceleration that will give optimum operation.

From the data presented it should be evident that acceleration depends on reserve power and that the lower the total reduction the greater the reserve power and, hence, the greater the acceleration. For logging trucks where huge loads are moved, acceleration is extremely important, this is indicated in the chart shown on the next page. Here are shown the five normal speeds found in a truck with a gross weight of 20,000 pounds; the speeds are plotted against the engine revolutions; power required is plotted against the available power. In the first speed the power available at the governed speed is 12 or

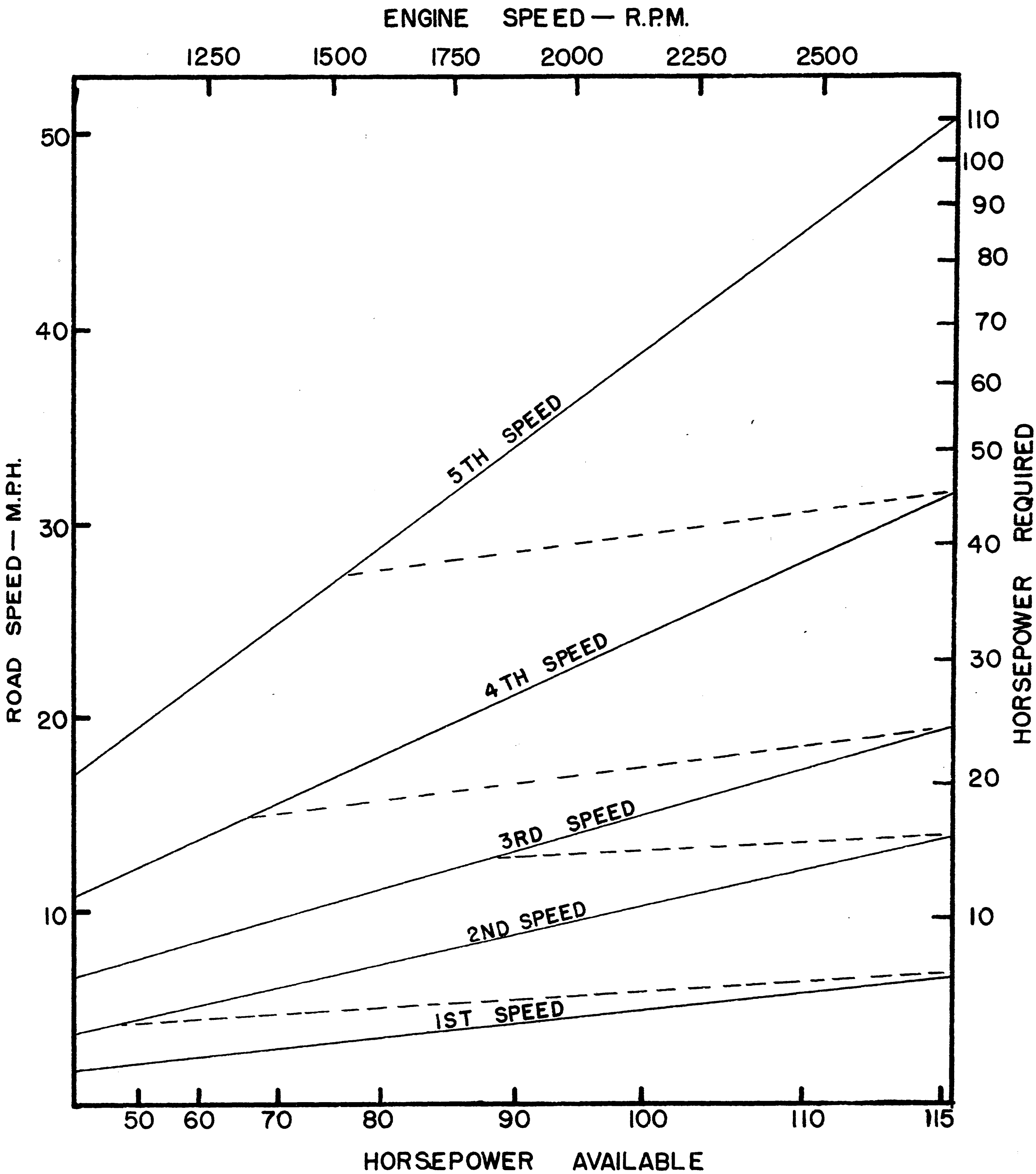


FIGURE 3 - RELATIONSHIP OF HORSEPOWER REQUIRED AND HORSEPOWER AVAILABLE AT VARIOUS SPEEDS.

13 times that required, the speed being 6.2 miles per hour. At this same speed in second; the engine is reduced to about 1100 revolution per minute, where it still has five or six times the required power, this means a high accelerative ability as indicated by the flat slope of the curve. Maximum speed in fourth, however, requires more than a third of the available horsepower. Fifth gear at the same speed drops the power down to only about half-again what is needed at the governed speed in fifth; the horsepower developed is little more than that required. It will be noted that the slope of the fifth speed curve is steeper than the others, a fact which shows that the acceleration is relatively limited.

Tractive Resistance.

Tractive resistance has been defined as the total of all external forces acting against the movement of a vehicle on a level road, these resistances are listed below.

I. Air resistance due to the retarding effect of the air when the car is in motion.

1. Density resistance is that part of air resistance due to turbulent whirls and eddies caused by the irregularities of the vehicle body.

2. Viscosity resistance is that part of air

resistance attributed to friction between the body of the vehicle and the surrounding air.

II. Rolling resistance is due to contact resistance between the vehicle and the road.

1. Road resistance is that part of rolling resistance that is due to friction between the tires and the surface of the road.

2. Impact resistance is that part of rolling resistance due to the retarding effect caused by the roughness of the road surface.

Although both air and rolling resistance are composed of component parts, as shown above, they are generally considered as two distinct items rather than being broken apart. This method is followed in practical use.

I. Air Resistance.

Air resistance which is often miscalled wind resistance, is simply the resistance to passage through still air offered by the form and frontal areas of the vehicle.

Air resistance, when the speed of a vehicle exceeds 60 miles per hour, becomes of the utmost importance. It has been estimated by Lay that when the speed exceeds 60 miles per hour, air resistance accounts for 60 percent of all the resistances.[9] Logging trucks will seldom reach this speed, but it is still an important factor because of the large frontal area presented by a loaded truck. Where large loads are carried even at medium speeds the effects of air resistance must be considered.

Air resistance computations are based upon three factors, namely, the frontal area of the car, the aerodynamic factor, and the velocity of the car.

Frontal area, expressed in square feet, is the total width of the vehicle times its total height, less openings such as those between wheels and rounded corners. As a rule, small subtractions of this kind are ignored because these small openings are responsible for slight increases in unit resistance due to a burbling effect. Air resistance, therefore will be directly proportional to frontal area.

The aerodynamic factor is the degree of fineness of the solid form of the body from an air resistance standpoint. In other words, to use a popular, if somewhat inaccurate phrase, the degree to which the body is streamlined. The aerodynamic factor is expressed as a constant,

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9....."Air Resistance to Motor Vehicles". Proceedings, Highway Research Board, Vol. 11, part I, pp. 36-55.

K, which has been determined by experiment in wind tunnels. However, K, has not been well established for trucks and may range from 0.0018 to 0.0025.[10] The constant will vary between an open rack body with a high head-board and tail-board, representing the highest resistance, to a stream-lined tank or van, representing the other extreme.

Density resistance, caused by turbulant whirls and eddies represents the dissipation of kinetic energy; it varies theoretically as the square of the speed.[11] According to Lay, density resistance constitutes 85 to 90 percent of the total air resistance, this percentage can probably be reduced with more efficient streamlining.[12] The air resistance remaining is attributed to viscosity resistance.

Viscosity or skin resistance, as it is more commonly called, occurs in the layers of air close to the body and other surfaces of the vehicle. Experiments indicate that this resistance can be taken as an exponent of the speed, about 1.4 or 1.5.[13]

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10.....Harry Tucker and Marc Leager, Highway Economics, p. 275.

11.....R. G. Paustian, Tractive Resistance as Related to Roadway Surfaces and Motor Vehicle Operation. Iowa Engineering Experiment Station, Bulletin 119, p. 8.

12.....Op. cit. Proceedings, Vol. 12, Part I, pp. 66-75.

13.....R. G. Paustian, Op. cit., p. 9.

The total air resistance met by any vehicle is composed of two main resistances, one of which varies as the square of the speed, and the other as some power slightly less than the square. The aggregate of the two parts might be expressed as a single resistance that varies as some function of the speed, the exponent of this speed factor might be less than two.[14] Since having developed the component parts of air resistance, the following formula can be derived:

$$R_a = 0.0025FA(MPH^2)$$

where

$R_a$ is the air resistance in pounds,
FA is the frontal area in square feet,
MPH is the vehicle speed in miles per hour, and
0.0025 is the streamlining constant.

To convert the product to horsepower from pounds it is necessary to multiply by the speed in feet per minute to obtain foot-pounds per minute, then divide by 33,000 to get the horsepower equivalent. The formula will then become,

$$R_a = \frac{0.0025FA(MPH^2)(88 \times MPH)}{33{,}000},$$

14.....For a more complete analysis of air resistance see: Inid., pp. 8 ff. and J. C. Hunsaker, "Aeronautics". Mechanical Engineers Handbook, p. 1323.

which reduces to,

$$R_a = \frac{(FA)(MPH^3)}{15,000}$$

The above formula is applicable where the coefficient is 0.0025, as is the case for the larger trucks. Otherwise the general form of the formula, in which any value may be substituted, must be written as shown below:

$$R_a = \frac{(K)(FA)(MPH^3)}{375}$$

The following figure, prepared by the General Motors Corporation, is from a chart showing air resistances at different speeds with various cross-sectional areas. A value of 0.0025 was used for K, and an exponent of 2 was used in the basic formula, which is used to determine the air resistance in pounds.

Since the cross-sectional area presented to the air will change for every log load, where semi-trailers are used, and since the trucks seldom reach high speeds, the air resistance is of secondary importance only.

In data that will be given later, taken from data prepared by the Public Roads Administration, air resistance was not figured separately, but was included with the total tractive resistance. This method will eliminate the

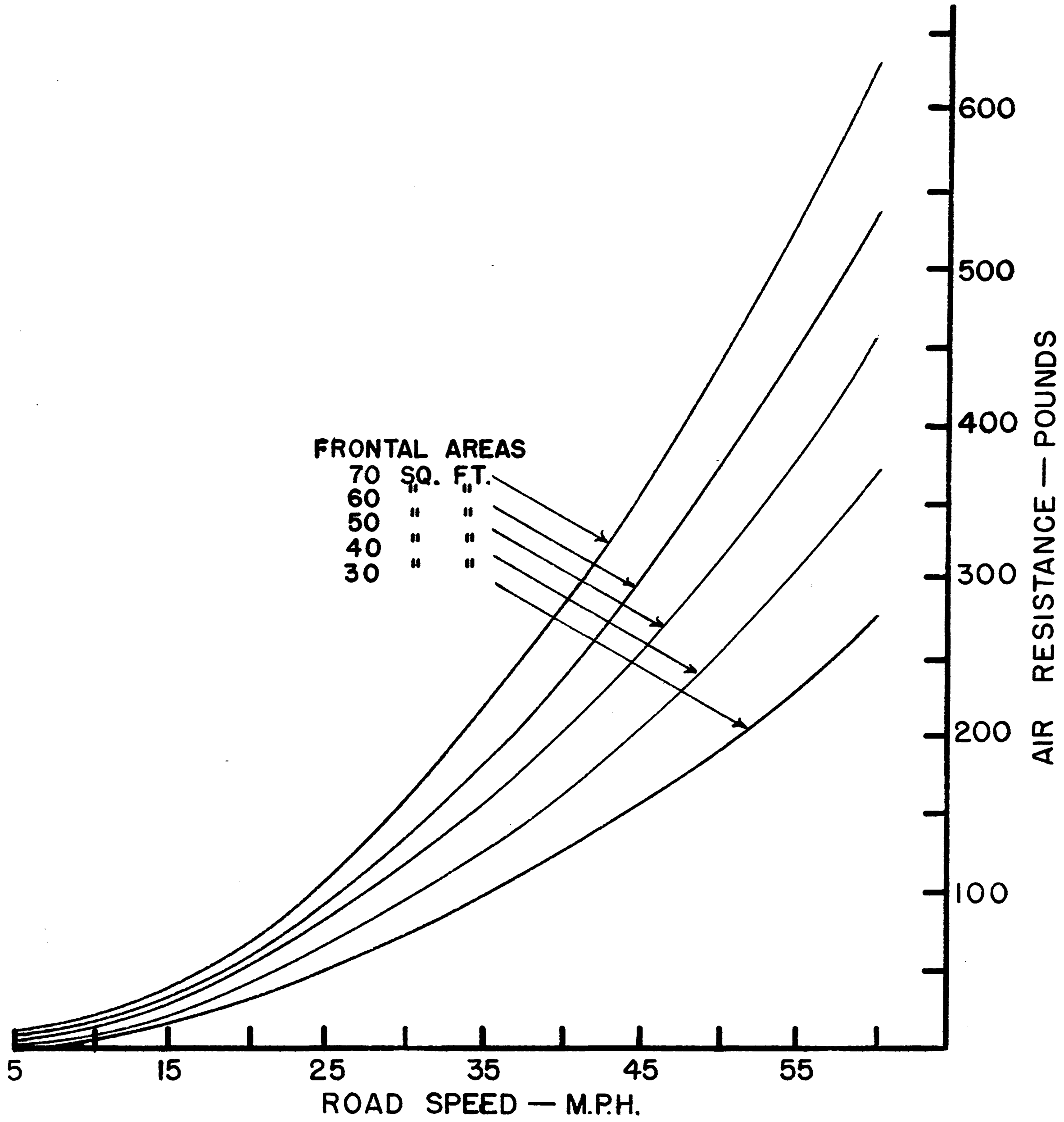


FIGURE 4 - AVERAGE AIR RESISTANCE FOR CERTAIN FRONTAL AREAS AND CERTAIN ROAD SPEEDS.

tedious process of figuring air resistance for each individual case.[15]

The following table may be used to determine the air resistance for a vehicle when the exact frontal area is unknown. Although the table was developed by General Motors it may be used for any vehicle. The smaller bodies should be used, as the larger sizes are for vans.

Table I[16]

Projected Frontal Areas Of Trucks in Square Feet.

| Models | Small Bodies | Large Bodies |
|---|---|---|
| Light Duty | 30 | 50 |
| Medium to Heavy Duty | 50 | 70 |

II. Rolling Resistance.

Rolling resistance has been divided into two phases:

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15.....The trucks used by the Public Roads Administration were equipped with low open rack bodies. In the case of the single unit trucks the height of the frontal area was only 18 inches. For the semi-trailers the height of the head and tail-boards was about 24 inches. The headboards are similar to those used on logging trucks, which have low side-boards or none when operating empty, and at which the highest speeds are reached and the air resistance is the greatest. When the trucks are loaded and the frontal area is maximum, the speed in most cases will not exceed 15 miles per hour; consequentaly air resistance will be at a minimum, and so can almost be eliminated from the calculation.

16....."General Motors Date Book", Performance Section. Detroit, Michigan, 1945.

friction between the road surface and running gear, and impact resistance, both of which are dependent upon the road surface. For general study however they can be taken together.

Rolling resistance can, perhaps, be best explained by considering Figure 5,[17] which shows a wheel about to pass over an obstacle. From this figure a formula can be devised.

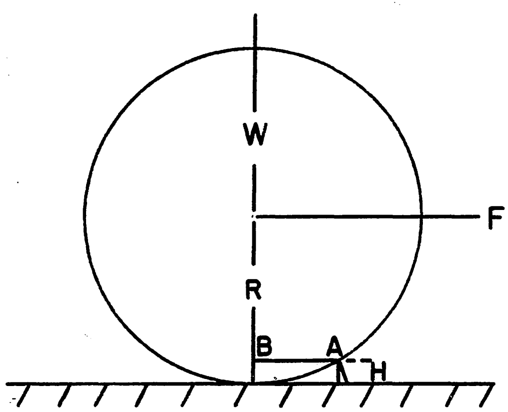


Figure 5 Rolling Resistance

$$F = \frac{GVW\sqrt{2rh-h^2}}{r-h}$$

where

F is the force required in pounds to overcome the obstacle,
GVW is gross vehicle weight on the wheel in pounds,
r is radius of the wheel in inches, and
h is the height of the obstacle in inches.

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17.....C. R. Townsend, The Motor Truck in Woods Operation, p. 63.

Several assumptions can now be made:

1. A balloon tire will require less force than a high pressure tire, due to the elasticity of tires and the lowered height of "h".

2. The force, F, required would be dependant upon the weight on the wheel.

3. The road surface would be of major importance. Any road surface, even the very finest type, is not perfectly smooth, but has many elevations and depressions which present obstacles to the wheels moving over them. On gravel and earth roads these obstacles may change with weather. When the road becomes soft and muddy it may sink under the load so that the wheel will be continually at the base of a small 'hill', thus "h" will be a comparatively large and constant value.

4. If the vehicle is moving at a high velocity over a rough road, the wheel may jump as a result and "h" may become "2h" or greater.

Tests made in proof of these assumptions have shown that resistance varies with the folliwing factors:

a. The type of road surface and its rigidity.

b. The gross vehicle weight.

c. The speed of the vehicle.

Other factors have been found so inconsequential compared with these factors that they are generally considered as component parts of the above.

Figures 6, 7 and 8 have been given to show the relative importance of the above factors. Figure 6 is given in proof of assumption a. Total resistances for four types of road surfaces have been plotted over speed. Total resistance of the rough dirt road is found to be seven times that of a good concrete road, proving that road surfaces must be considered. Figure 7 proves conclusion 'b'. Reading from the graph the total resistance at 8000 pounds is 68 pounds, while at 24,000 pounds the resistance is 206 pounds when the speed is constant at 4 miles per hour. Figure 8 proves the soundness of conclusion c. Total resistance is shown to increase with speed. Weight and road surface are constant. Technically then, it is not correct to speak of the rolling resistance without definitely indicating the speed of the vehicle, the type of road surface and the weight of the vehicle. One of the major fellacies in calculations made by manufacturers is that weight and speed have been entirely ignored and only road surface considered. With the tables given at the end of this section this error has been eliminated with the result that greater accuracy can be obtained. One of the major problems that cannot be solved, however,

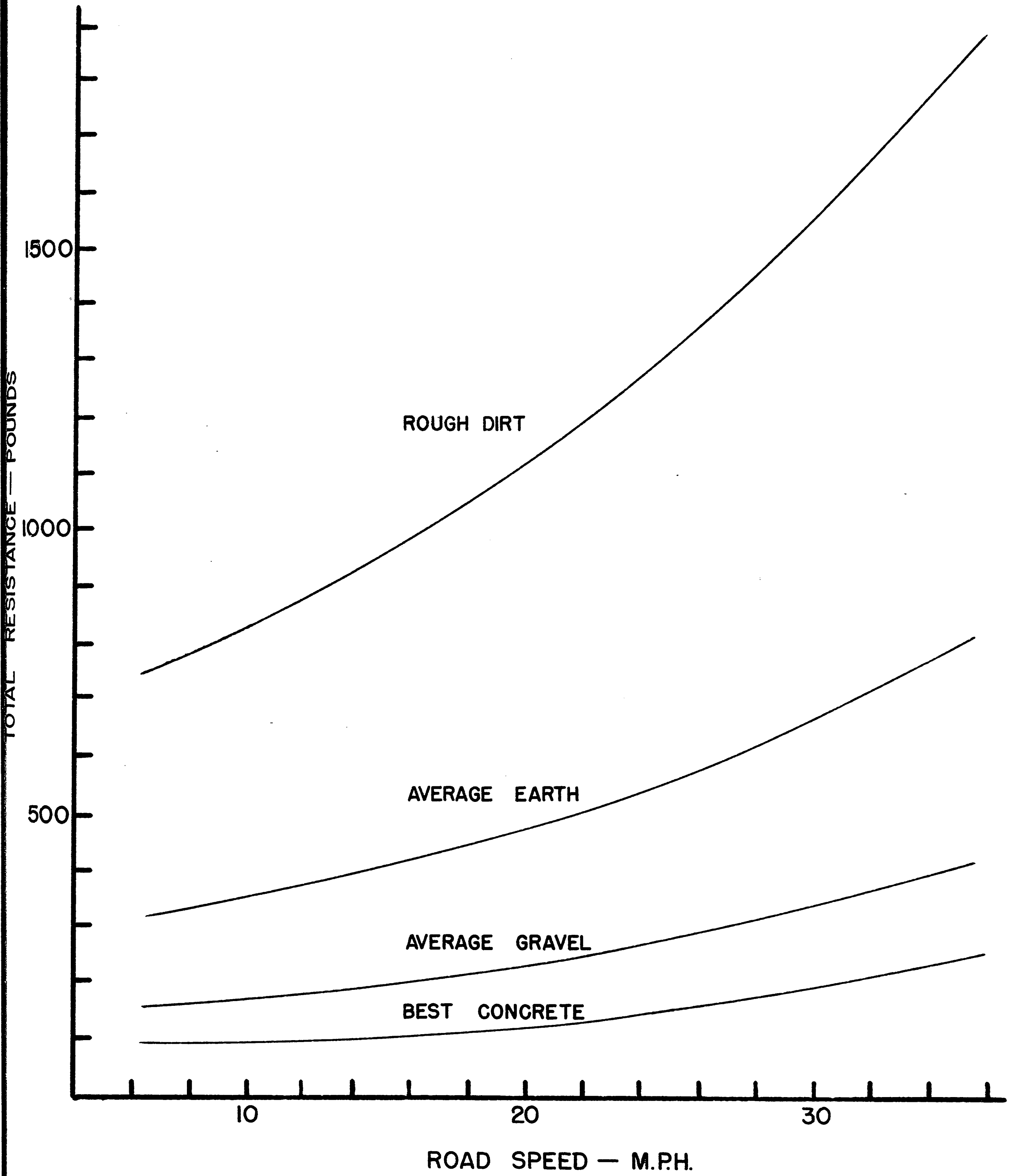


FIGURE 6 - AVERAGE TOTAL TRACTIVE RESISTANCE FOR A 10,000 POUND TRUCK AT VARIOUS SPEEDS ON 4 DIFFERENT ROAD TYPES.

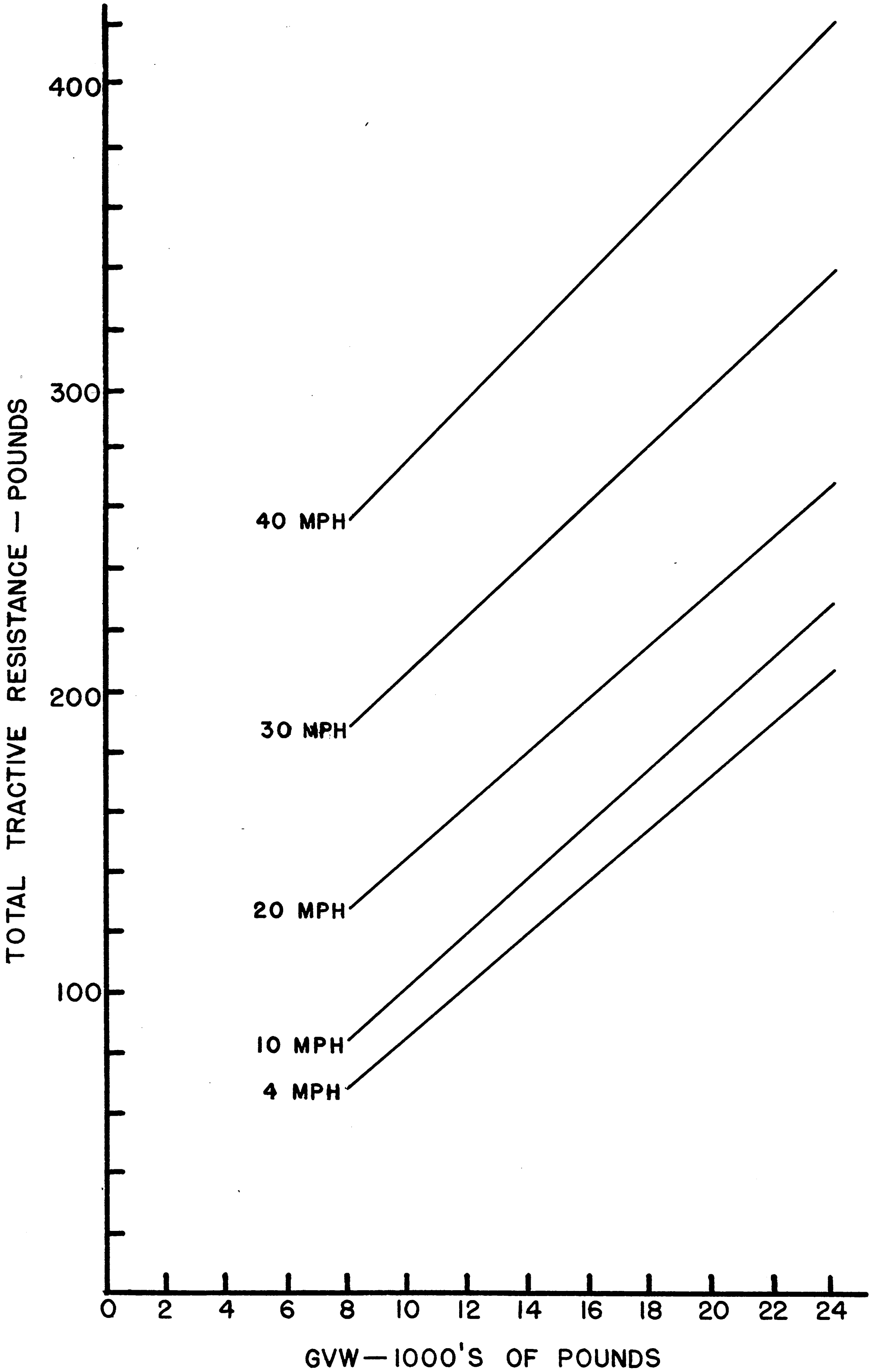


FIGURE 7 - AVERAGE TOTAL TRACTIVE RESISTANCE FOR SINGLE UNIT TRUCKS AT VARIOUS WEIGHTS AND AT FIVE DIFFERENT SPEEDS.

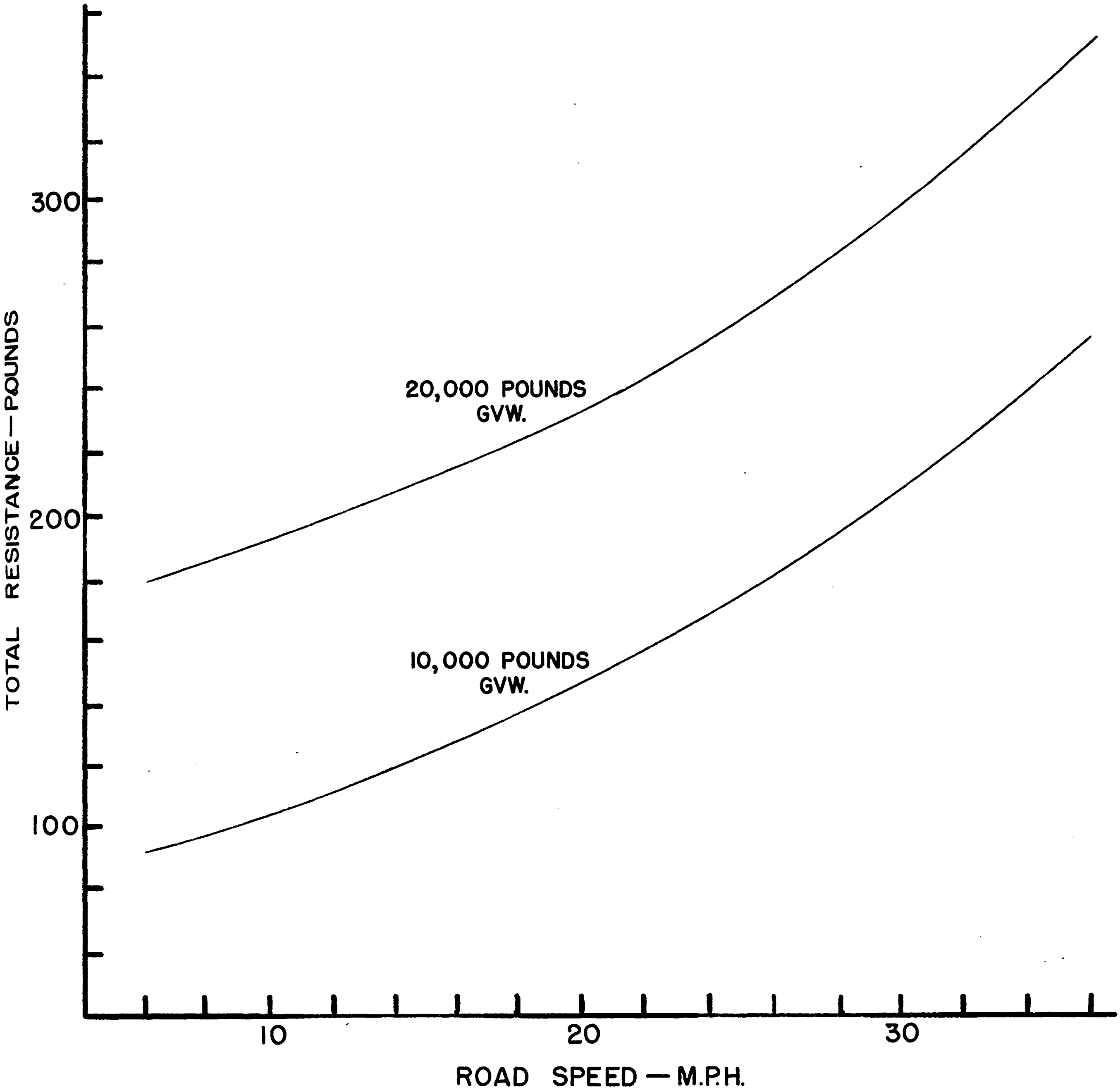


FIGURE 8 - AVERAGE TOTAL TRACTIVE RESISTANCE FOR A LIGHT TRUCK AT TWO DIFFERENT GROSS WEIGHTS.

is the inability to set definite ratios for road resistance as affected by different road surfaces. It would be difficult, in fact, to attempt such a task, except for the most rigid and uniform type of road surface. The best plan then, would be to establish resistance figures on a pavement such as concrete, and to use the figures as an index, and to develope conversion factors for other types of road surfaces. With such a wide variation of surface types as are found in this country these conversion factors will have an extremely wide range. With a little work any truck operator can find the correct conversion factor for his particular use. Since several methods have been developed to measure tractive resistance, it is well to describe them individually.

The towing method, as a means of measurement, is adequately illustrated by Lay in his Michigan tests.[18] The data given were the results of the first practical road tests made in the study of road resistances; however, since the equipment is now obsolete and the load weights were disregarded, the work is of historical value only. With this method the test vehicle is towed by another

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18....."Michigan State Highway Department Investigation of Truck Performance on Grades". In: <u>Proceedings of the Eighth Annual Conference on Highway Engineering held at the University of Michigan</u>. p. 31.

vehicle, the pull on the tow line being recorded by a dynamometer. Simple as this method appears, serious difficulties are involved. For instance consistent readings are hard to obtain, not only for small variations in the road surface, but for slight changes in speed as well. Another serious objection is that the towing vehicle disturbs the air so that it is impossible to determine air resistance.

The coasting method was used by the Oregon State Highway Commission for the determination of fuel consumption.[19] The requirements of this method of measurement are several uniform grades of sufficient length to allow a vehicle to reach a constant velocity for a considerable time. The propelling force with the vehicle in neutral is equal to the down grade component of the weight of the vehicle while the retarding force is a combination of the rolling and air resistances. At some speed for a given grade the force of the vehicle and the opposing resistances are in equilibrium, therefore if the weight of the vehicle is known, the component of this weight is parallel to the grade, and equal to the tractive resistance. Except for wind variability and possible unevenness of the road surface, this method gives an easy and accurate measure of the tractive resistance.

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19.....John Beckey, <u>The Effect of Highway Design on Vehicle Speed and Fuel Consumption</u>, Oregon State Highway Department Bulletin No. 5, pp. 11-14.

A method of direct measurement was developed by Paustin of the Iowa Engineering Experiment Station.[20] As far as can be determined he is the only one who has used this method successfully. The Oregon State Highway Commission tried, but found the apparatus too bulkly and unweildly, so discarded it for the coasting method.

Rather than find a grade long enough to allow a vehicle to coast to a suitable speed, a direct drive mechanism was developed to measure the power required to drive the vehicle. An electric motor was attached through the drive-shaft to the rear wheels of the car and the current needed to drive the electric motor was furnished by a generator, the armature of which was connected to the flywheel of the gasoline engine of the car. The engine drove the generator, which in turn supplied the electrical energy required to operate the motor which was connected to the rear wheels of the vehicle. The power in the form of electrical energy required to overcome tractive resistance was applied to the drive shaft thru the electric motor, and the energy used was a direct measure of the power required to drive the vehicle.[21]

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20.....Loc. cit., pp. 13-20

21.....Although the use of electrical energy was unique in this case, it is not the first time it has been used. See: N. A. Hall and I. M. Hargrave, "Energy Consumption of an Electric Truck on Different Street Surfaces". <u>Electric World</u>, Vol. 61, pp. 1040-41; A. E. Kennelly and

The fourth and last method to be described, that of deceleration, will be discussed in detail because it was used in the tractive resistance tests conducted by the Public Roads Administration. Since much of the material to be presented later will be taken from these tests, it would be well to understand the methods employed.[22] Where the majority of other investigations of tractive resistance and tractive ability were mainly restricted to automobiles the project of the Public Roads Administration was restricted to trucks with the aim of finding some method of eliminating traffic conjestion on hills by the development of a more satisfactory road speed for trucks. Over four years were spent testing 30 trucks which included all types used at the present time. It was the most complete test yet made to determine tractive resistance. The following conclusions have great significance when applied to log truck operation:

1) Grades should be reduced to 3% or less,
2) Engine power should be more than doubled,
3) Gross weights must be reduced.

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O. R. Schurig, "Tractive Resistance of a Motor Delivery Wagon on Different Roads at Different Speeds". Institute of Electrical Engineers, Transactions 35, pt. 2, pp. 925-53.; H. B. Shaw, "The North Carolina Road Test Truck". Highway Research Board, Proceedings 6, pp. 66-81.

22....Loc. cit., Carl C. Saal, pp. 40-44.

The deceleration method of measuring tractive resistance on a level grade consists of allowing the test vehicle to coast to a stop from a high speed to either a lower speed or a stop. During the time in which the vehicle coasts, records of elapsed time and distance are taken. As the name implies, the method depends upon the determination of deceleration.

The first step in the calculation of tractive resistance from the time-speed records is that of plotting a time-distance curve. Two successive differentiations of this curve will give, first, a curve which shows the deceleration at a given instant and, second, a curve which shows the actual velocity. The graphic method of differentiating these curves may be successfully used.

The deceleration of a vehicle when coasting on the level in neutral gear is proportional to the forces that oppose the motion of the vehicle. The following equation which expresses this relation is merely the acceleration formula given earlier.

$$R_a = \frac{GVW}{g} a$$

where

$R_a$ is the total tractive resistance in pounds, to deceleration (or acceleration),

GVW is the weight of the vehicle in pounds,
g is the acceleration of gravity in feet per second per second, and
a is the linear deceleration for acceleration in feet per second per second.

This equation, however, does not involve the energy that is stored in the rotating parts when the vehicle is accelerating or decelerating. The energy of these parts must be added to the energy of the linear motion expressed as 'a' above. The force equivalent to this energy is:

$$F = \frac{I}{r} a_a$$

where

F is the force equivalent to the energy of linear motion,
I is the moment of inertia of the rotating parts,
r is the effective radius of the rotating parts in inches; and
$a_a$ is the angular acceleration in radius per second per second.

When a vehicle is coasting in neutral, the only rotating parts decelerating are the wheels, brake drums, propeller shaft, and rear axle assembly. The moments of inertic of the propeller shaft and rear axle are so small in comparison with that of the wheels that it is practical to omit them from the consideration of stored energy. For the wheels and brake drums the angular acceleration is equal to $\frac{a}{r}$ where a is equal to the linear deceleration and, r is equal to the effective radius of the wheels. Substituting $\frac{a}{r}$ for $a_a$ and combining the equations for the energy of the rotating parts and of linear motion, the formula for determining tractive resistance is:

$$R_a = \frac{GVW}{g} a$$

adding F, $R_a$ becomes $R_t$

$$R_t = \frac{GVW}{g} + \frac{I}{r} \times r \; a$$

$$R_t = \frac{GVW}{g} + \frac{I}{r^2} a$$

$$R_t = (\frac{GVW}{g} + K_o) \; a$$

where

$R_t$ is total tractive resistance in pounds,
GVW is gross vehicle weight in pounds,
$a$ is linear deceleration of the vehicle in feet per second per second,
$K_o$ is the mass equivalent constant for neutral gear.

The mass equivalent constant can be determined experimentally if the deceleration is measured for a vehicle coasting on two different grades, one of which can be, and in this study was, level. As the total resistance on the grade is equal to the total resistance on the level for the same road speed and for the same load, the mass equivalent constant can be determined by solving the following equation for $K_o$.

$$GVW \sin A - a_g \left(\frac{GVW}{g} + K_o\right) = a_1 \left(\frac{GVW}{g} + K_o\right)$$

which by reduction becomes,

$$K_o = \frac{GVW \sin A - \frac{GVW}{g}(a_g + a_g)}{a_g + a_1}$$

where

$K_o$ is the mass equivalent constant for neutral gear,
GVW is the gross vehicle weight,
A is the angle in degrees that the grade line makes with the horizontal,
g is the acceleration of gravity in feet per second per second,
$a_g$ is linear acceleration on the grade in feet per second per second, and
$a_1$ is linear acceleration on the level in feet per second per second.

The mass equivalent constant can also be computed theoretically if the moments of inertia of the wheel assemblies are known. In most cases these data can be obtained from the manufacturer and used to compute a constant that could be used to check the experimental constant. The theoretical $K_o$ is obtained by adding the moments of inertia for the wheels and brake drums and dividing the total by the effective radius. This, however, is a tedious process and proves to be a slightly higher figure than that found in operation. Actual tests are therefore recommended.

A sample calculation will show the process very readily.

Data are first collected on rates of deceleration for a range of speeds, Table 2 illustrates a form suitable for this purpose.

Deceleration in Miles per Hour per Second for -

| Speed MPH | Run 27 N | Run 28 S | Run 29 N | Run 30 S | Run 31 N | Run 32 S | Run 33 N | Run 34 S | MPH/ sec. | Ft./ sec./ sec. |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | | | | | | | .145 | .141 | .142 | .210 |
| 4 | | | | | | | .154 | .141 | .148 | .217 |
| 6 | | | | | | | .162 | .141 | .152 | .223 |
| 8 | | | | | | | .173 | .151 | .162 | .238 |
| 10 | | | | | .172 | .163 | .184 | .158 | .169 | .248 |
| 12 | | | | | .182 | .177 | .197 | .181 | .184 | .270 |
| 14 | | | | | .194 | .181 | .215 | .210 | .200 | .293 |
| 16 | | | | | .213 | .197 | .241 | .244 | .224 | .329 |
| 18 | | | | | .237 | .218 | | | .228 | .334 |
| 20 | | | .234 | .241 | .270 | .246 | | | .248 | .364 |
| 22 | | | .257 | .253 | .306 | .291 | | | .277 | .406 |
| 24 | | | .271 | .271 | | | | | .271 | .397 |
| 26 | | | .299 | .299 | | | | | .296 | .434 |
| 28 | | | .332 | .322 | | | | | .327 | .480 |
| 30 | .359 | .320 | .378 | .348 | | | | | .351 | .515 |
| 32 | .374 | .341 | | | | | | | .358 | .525 |
| 34 | .393 | .371 | | | | | | | .382 | .560 |
| 36 | .414 | .404 | | | | | | | .409 | .600 |
| 38 | .444 | .456 | | | | | | | .450 | .660 |

Table 2. Values of Deceleration for a Tractor-Truck Semitrailer Coasting on a Zero Percent Grade With a Gross Vehicle Weight of 12,000 pounds.

(Note the wide range of speed used in this instance and that two test runs were made, one north and one south to compensate for wind resistance.) These time-speed records are the basis of all calculations and so should be kept as accurately as possible. The graph in Figure 9 is obtained from the time-speed record. The curve for the zero grade is taken from the column showing average deceleration in feet per second per second, and plotted over the appropriate speed. The curve for the 4.5 percent grade is obtained in the same manner. The time-speed record for this grade is not shown. From these two graphs the mass equivalent constant may be determined as shown below, by substituting in the formula (data for 36 miles per hour):

$$K_o = \frac{12000\ (.0451) - \frac{12000}{32.2}\ (0.790 + 0.600)}{(0.790 + 0.600)}$$

$$K_o = \frac{541 - 518}{1.4}$$

$$K_o = 16.4$$

Since $K_o$ should be determined more than once, the average is found to be about 16. Total tractive resistance can now be found by the use of the formula:

$$R_t = a\ (\frac{GVW}{g} + K_o)$$

which upon substitution becomes,

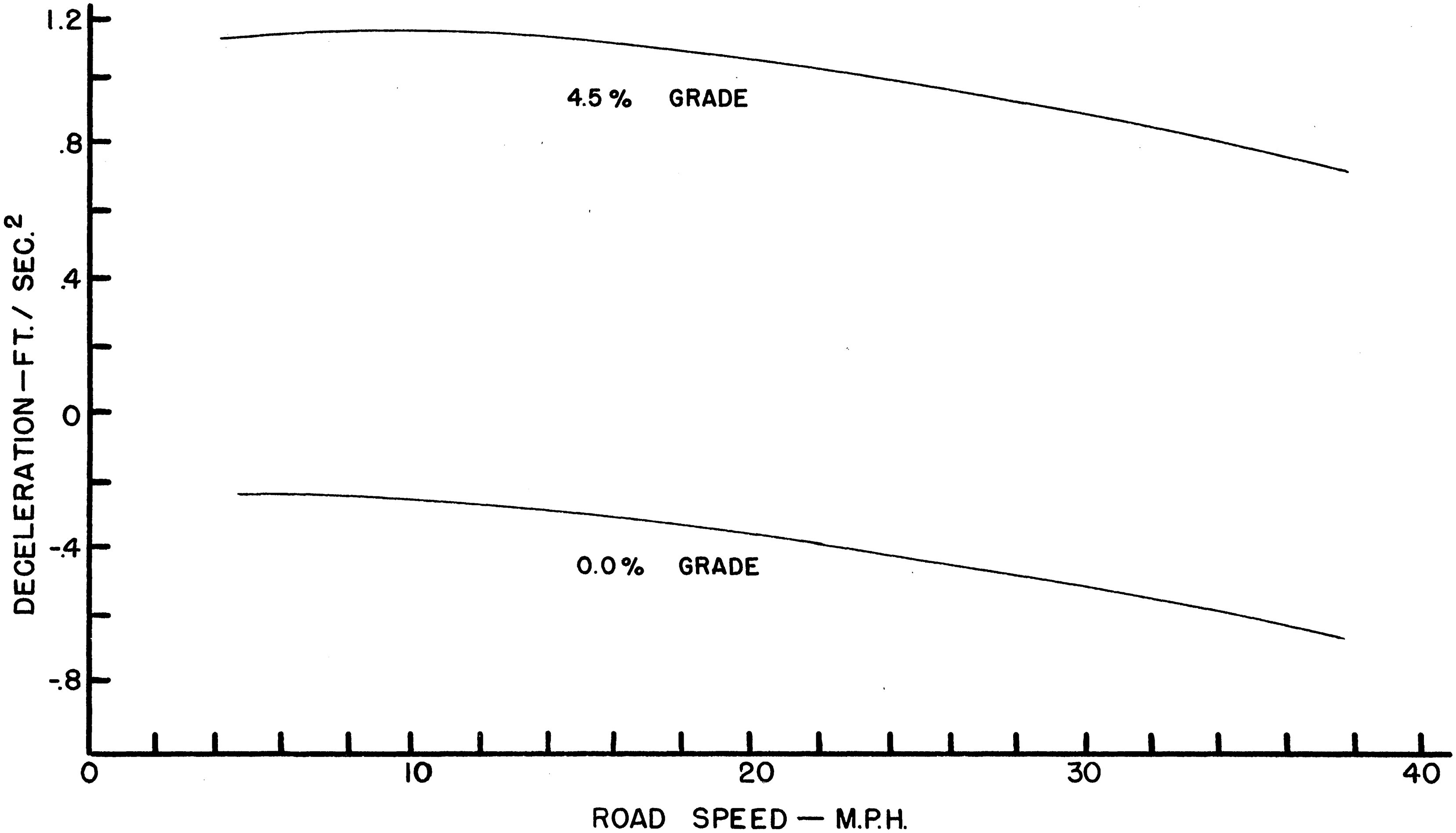



FIGURE 9 - ACCELERATION-SPEED CURVE FOR A TRACTOR TRACTOR SEMITRAILER COASTING ON A 0-PERCENT AND 4.5-PERCENT GRADE WITH A GROSS VEHICLE WEIGHT OF 12,000 POUNDS. (CONCRETE PAVEMENT.)

$$R_t = a\left(\frac{12{,}000}{32.2} + 16\right)$$

$$R_t = 389a$$

The accelerations being known, a table of resistances can be prepared as shown in Table 3.

| Speed | Deceleration | Total Tractive Resistance | Unit Tractive Resistance |
|---|---|---|---|
| MPH | Ft./sec.$^2$ | Pounds | Lb/1000 lb |
| 4 | .212 | 82.5 | 6.9 |
| 6 | .223 | 86.7 | 7.2 |
| 8 | .239 | 93.0 | 7.7 |
| 10 | .253 | 98.4 | 8.2 |
| 12 | .271 | 105.4 | 8.8 |
| 14 | .290 | 112.8 | 9.4 |
| 16 | .310 | 120.6 | 10.0 |
| 18 | .330 | 128.4 | 10.7 |
| 20 | .352 | 137.0 | 11.4 |
| 22 | .378 | 147.0 | 12.2 |
| 24 | .401 | 156.1 | 13.0 |
| 26 | .430 | 167.4 | 13.9 |
| 28 | .459 | 178.2 | 14.8 |
| 30 | .490 | 190.8 | 15.9 |
| 32 | .523 | 203.3 | 16.9 |
| 34 | .561 | 218.2 | 18.2 |
| 36 | .604 | 234.8 | 19.6 |
| 38 | .660 | 256.8 | 21.4 |
| 40 | .728 | 283.0 | 23.6 |

Table 3. Tractive Resistance for a Tractor-Truck Semi-trailer With a Gross Vehicle Weight of 12,000 Pounds.

At the start the tests were based upon the old assumption that tractive resistance was a constant factor regardless of the weight. However, it was soon discovered that not only total resistance, but also the unit resistance in pounds per thousand pounds varied appreciably with weight. Thereafter, each vehicle was tested with three loads. The difference in total tractive resistance for any two gross weights proved to vary directly with the increase in weight; thus it was possible to determine the tractive resistance for any combination of weight and speed.

In the foregoing example the vehicle was tested again with gross vehicle weights of 21,000 and 30,000 pounds. The time-speed data are not given, but the unit resistances are shown in Figure 10 to indicate the variation with these three weights. If the variation is known, the resistance can be prorated and an average value determined as shown in Table 4. This is merely a sample problem; similiar results can be obtained for any vehicle.

Though expensive and very accurate equipment were used by the Public Road Administration equipment of this type would not be necessary for a private study. A stopwatch, a smooth level road surface of a known grade length, and a similar streach of logging road are all that would be required. Vehicle performance on the level road could be calculated and used as a basis for any road type resistance; this will take into consideration the truck characteristics. The data gathered will not be as accurate as the data given here, but will be suffice for practical purposes.

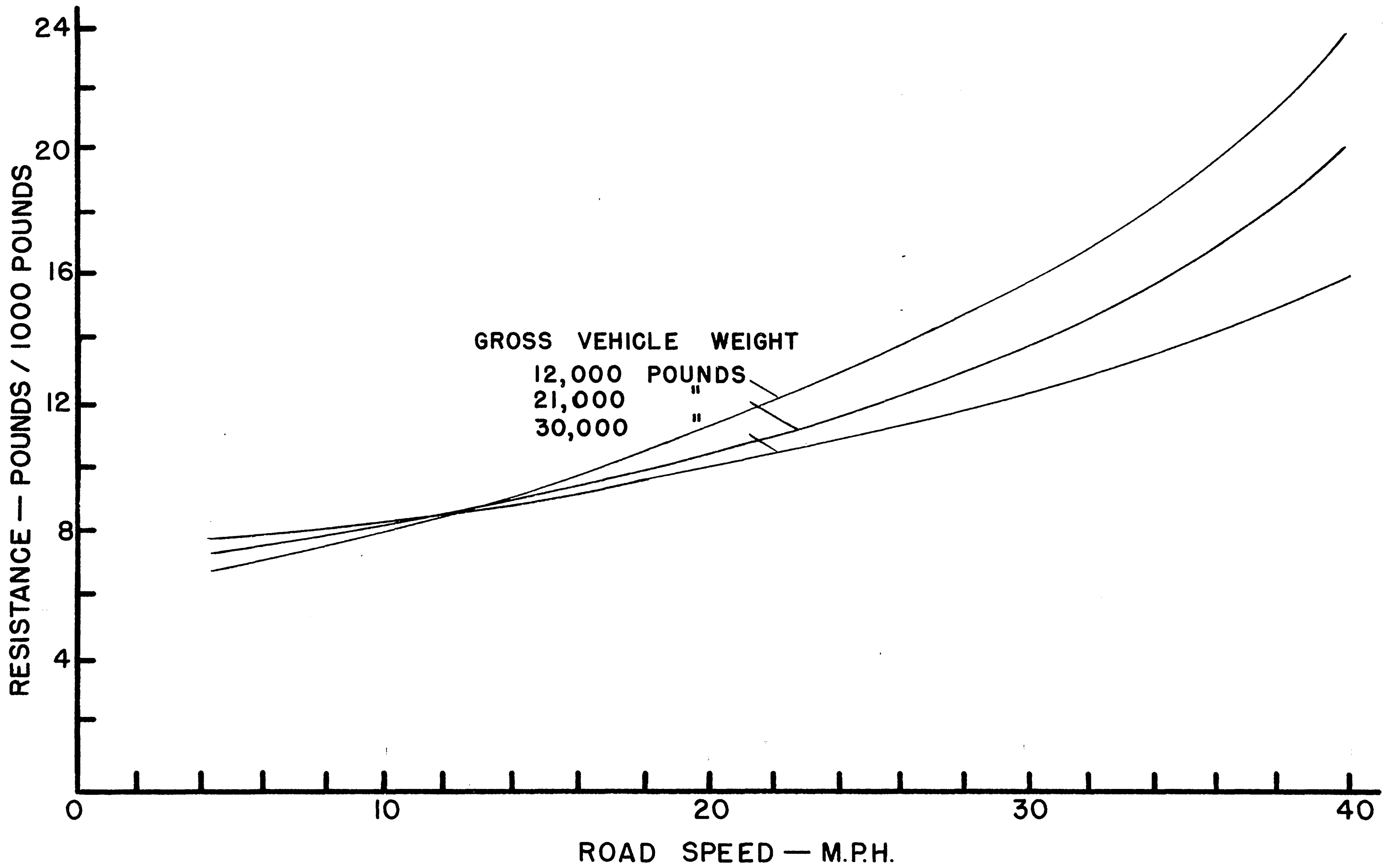



FIGURE 10 - VARIATION OF TRACTIVE RESISTANCE WITH SPEED AND WEIGHT FOR A TRACTOR TRUCK SEMITRAILER. (CONCRETE PAVEMENT.)

| | Total Tractive Resistance for Weights of - Thousands of Pounds | | | | | | | | | | | Increase from 12,000 to 21,000 lbs. | | Increase from 21,000 to 30,000 lbs. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12 lbs. | 14 lbs. | 16 lbs. | 18 lbs. | 20 lbs. | 21 lbs. | 23 lbs. | 25 lbs. | 27 lbs. | 29 lbs. | 30 lbs. | Total | Per 2000 lbs. | Total | Per 2000 lbs. |
| 6 | 86.7 | 101.4 | 116.1 | 130.8 | 145.5 | 153.0 | 170.8 | 186.6 | 206.4 | 224.2 | 233.1 | 66.3 | 14.7 | 80.1 | 17.8 |
| 8 | 93.0 | 108.7 | 124.4 | 140.1 | 155.8 | 163.8 | 181.2 | 198.6 | 216.0 | 223.4 | 242.0 | 70.8 | 15.7 | 78.2 | 17.4 |
| 10 | 98.4 | 115.0 | 131.6 | 148.2 | 164.8 | 173.0 | 190.3 | 207.6 | 224.6 | 242.2 | 251.3 | 74.6 | 16.6 | 78.3 | 17.4 |
| 12 | 105.4 | 122.5 | 139.6 | 156.7 | 173.8 | 182.3 | 199.5 | 216.7 | 233.9 | 251.1 | 259.9 | 76.9 | 17.1 | 77.6 | 17.2 |
| 14 | 112.8 | 130.4 | 148.0 | 165.6 | 183.2 | 192.2 | 209.6 | 227.0 | 244.4 | 261.8 | 270.4 | 79.4 | 17.6 | 78.2 | 17.4 |
| 16 | 120.6 | 138.2 | 155.8 | 173.4 | 191.0 | 199.7 | 218.0 | 236.3 | 254.6 | 272.9 | 282.2 | 79.1 | 17.6 | 82.5 | 18.3 |
| 18 | 128.4 | 145.9 | 163.4 | 180.9 | 198.4 | 207.0 | 226.1 | 245.2 | 264.3 | 283.4 | 292.9 | 78.6 | 17.5 | 85.9 | 19.1 |
| 20 | 137.0 | 155.0 | 173.0 | 19.0 | 209.0 | 217.9 | 237.0 | 256.1 | 275.2 | 294.5 | 304.0 | 80.9 | 18.0 | 86.1 | 19.1 |
| 22 | 147.0 | 164.8 | 182.6 | 200.4 | 218.2 | 227.0 | 246.9 | 266.8 | 286.7 | 306.6 | 316.5 | 80.0 | 17.8 | 89.5 | 19.9 |
| 24 | 156.1 | 174.7 | 193.3 | 211.9 | 230.5 | 239.9 | 260.4 | 280.9 | 301.4 | 321.9 | 332.0 | 83.8 | 18.6 | 92.1 | 20.5 |
| 26 | 167.4 | 186.0 | 204.6 | 223.2 | 241.8 | 251.0 | 271.5 | 292.0 | 312.5 | 333.0 | 343.4 | 83.6 | 18.6 | 92.4 | 20.5 |
| 28 | 178.2 | 197.9 | 217.6 | 237.3 | 257.0 | 267.1 | 287.2 | 307.3 | 327.4 | 347.5 | 357.5 | 88.9 | 19.7 | 90.4 | 20.1 |
| 30 | 190.8 | 211.5 | 232.2 | 252.9 | 273.6 | 284.0 | 303.5 | 323.0 | 342.5 | 362.0 | 372.0 | 93.2 | 20.7 | 88.0 | 19.5 |
| 32 | 203.3 | 225.7 | 248.1 | 270.5 | 292.9 | 304.0 | 323.1 | 342.2 | 361.3 | 380.4 | 390.0 | 100.7 | 22.4 | 86.0 | 19.1 |
| 34 | 218.2 | 242.4 | 266.6 | 290.8 | 315.0 | 327.0 | 345.4 | 365.8 | 382.2 | 400.6 | 409.9 | 108.8 | 24.2 | 82.9 | 18.4 |
| 36 | 234.8 | 261.4 | 288.0 | 314.6 | 341.2 | 354.9 | 371.1 | 387.3 | 403.5 | 419.7 | 428.0 | 120.1 | 26.7 | 73.1 | 16.2 |
| 38 | 256.8 | 285.8 | 314.8 | 343.8 | 372.8 | 387.1 | 402.2 | 417.3 | 432.4 | 447.5 | 455.0 | 130.3 | 29.0 | 67.9 | 15.1 |
| 40 | 283.0 | 313.6 | 344.2 | 374.9 | 405.4 | 421.0 | 434.6 | 448.2 | 461.8 | 475.4 | 482.0 | 138.0 | 30.6 | 61.0 | 13.6 |
| 42 | | | | | | 455.0 | 467.0 | 479.0 | 491.0 | 503.0 | 509.0 | | | 54.0 | 12.0 |

Unit Tractive Resistance, in Pounds per 1000 Pounds for Weights of -

Thousands of Pounds

| Speed MPH | 12 lbs. | 14 lbs. | 16 lbs. | 18 lbs. | 20 lbs. | 21 lbs. | 23 lbs. | 25 lbs. | 27 lbs. | 29 lbs. | 30 lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 7.2 | 7.2 | 7.3 | 7.3 | 7.3 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 |
| 8 | 7.7 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.9 | 8.0 | 8.0 | 8.0 | 8.1 |
| 10 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.3 | 8.3 | 8.3 | 8.4 | 8.4 |
| 12 | 8.8 | 8.8 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 |
| 14 | 9.4 | 9.3 | 9.2 | 9.2 | 9.2 | 9.2 | 9.1 | 9.1 | 9.1 | 9.0 | 9.0 |
| 16 | 10.0 | 9.9 | 9.7 | 9.6 | 9.6 | 9.5 | 9.5 | 9.5 | 9.4 | 9.4 | 9.4 |
| 18 | 10.7 | 10.4 | 10.2 | 10.1 | 9.9 | 9.9 | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 |
| 20 | 11.4 | 11.1 | 10.8 | 10.6 | 10.5 | 10.4 | 10.3 | 10.2 | 10.1 | 10.1 | 10.1 |
| 22 | 12.2 | 11.8 | 11.4 | 11.1 | 10.9 | 10.8 | 10.7 | 10.7 | 10.6 | 10.6 | 10.5 |
| 24 | 13.0 | 12.5 | 12.1 | 11.8 | 11.5 | 11.4 | 11.3 | 11.2 | 11.2 | 11.1 | 11.1 |
| 26 | 13.9 | 13.3 | 12.8 | 12.4 | 12.1 | 12.0 | 11.8 | 11.7 | 11.6 | 11.5 | 11.5 |
| 28 | 14.8 | 14.1 | 13.6 | 13.2 | 12.9 | 12.7 | 12.5 | 12.3 | 12.1 | 12.0 | 11.9 |
| 30 | 15.9 | 15.1 | 14.5 | 14.1 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.5 | 12.4 |
| 32 | 16.9 | 16.1 | 15.5 | 15.0 | 14.6 | 14.5 | 14.0 | 13.7 | 13.4 | 13.1 | 13.0 |
| 34 | 18.2 | 17.3 | 16.7 | 16.2 | 15.8 | 15.6 | 15.0 | 14.6 | 14.2 | 13.8 | 13.6 |
| 36 | 19.6 | 18.7 | 18.0 | 17.5 | 17.1 | 16.9 | 16.1 | 15.5 | 14.9 | 14.5 | 14.3 |
| 38 | 21.4 | 20.4 | 19.7 | 19.1 | 18.6 | 18.4 | 17.5 | 16.7 | 16.0 | 15.4 | 15.2 |
| 40 | 23.6 | 22.4 | 21.5 | 20.8 | 20.3 | 20.0 | 18.9 | 17.9 | 17.1 | 16.4 | 16.1 |
| 42 | | | | | | 21.6 | 20.3 | 19.2 | 18.2 | 17.3 | 17.0 |

Table 5. Unit Tractive Resistances for a Tractor-Truck Semi-trailer at Various Speeds and Gross Vehicle Weights. (Derived from Table 4.)

Admittedly it would be a long, tedious task to have to go through the procedure just given to determine the tractive resistance for a vehicle, and it is doubtful if any individual would do so for his own benefit. Therefore tables are given so that the tractive resistance for any type truck at any speed with any load may be determined. However, several explanations are in order.

First - total tractive resistance as given in these tables include: internal friction of the vehicle, air resistance, (for the headboard sizes as given previously) and rolling resistance. In other words, all resistances have been considered and separate deductions are unnecessary.

Secondly - the tables as originally composed are in pounds. (To obtain horsepower multiply by speed in feet per minute, this will give foot pounds per minute then divide by 33,000).

$$\text{H.P.} = \frac{\text{Unit Resistance (Lbs./1000 lbs)} \times 88 \times \text{MPH}}{33{,}000}$$

$$\text{H.P.} = \frac{\text{Unit Resistance (Lbs/1000 lbs)} \times \text{MPH}}{375}$$

To obtain total resistance multiply the answer by the gross vehicle weight in thousands of pounds.

Thirdly - the tables are based upon performance on concrete pavements. To obtain resistance for other road surfaces, the grade ability must be corrected with figures given in the conversion table. The table of conversion values that appears in Appendix A of this paper, compiled from data obtained from various manufacturers, is believed to be as near to the real values as possible. Parts of the table were taken from the Performance Section of the General Motors Data Book, the Timken Axle News, and a manual published by the Dodge Truck Division of the Chrysler Corporation. Although all of these publications are confidential, permission was granted to use only the resistance figures contained in them. Concrete is assumed to have a resistance of about 10 pounds per 1000 pounds of vehicle weight; with this figure as 1.00, other resistance relations can be derived.

Grade Resistance

Since, in this and subsequent sections, frequent reference will be made to grades, it is necessary to define several terms. By the "grade" of a highway is meant the deviation of the profile of the center line of the highway from a level line, it is generally expressed as a ratio known as the "rate of grade", which shows the number of feet rise in a horizontal distance of 100 feet.

If the rate of grade is multiplied by 100, the result is known as the "per cent of grade". Thus, a grade of 2% means a rise of 2 feet in 100 feet measured horizontally, and is equivalent to a rate of grade of 0.02.

The amount of a uniform rate of grade is obtained by dividing the difference in elevation between two termini by the horizontal distance between the termini. Thus, if the difference in elevation is 80 feet and the horizontal distance 2000 feet, the uniform rate of grade is 0.04 or a grade of 4 percent.

An "average grade" is the average of two or more grades used between two termini, due consideration being given to the length of each grade. The amount of an average grade may be obtained by finding the sum of the elevations attained by the "plus" grade and the decents made by the "minus" grades, and dividing that sum by the total length involved. A grade of + 3 percent with a length of 2000 feet followed by a - 6 percent grade for the next 500 feet would have a total rise of 60 feet, the total fall would be 30 feet, the total rise and fall being 90 feet. Dividing this total by 2500 feet will give an average rate of grade of 0.036 or a plus grade of 3.6 percent.

A "rolling grade" refers to a profile made up of alternating plus and minus grades. The term is usually restricted to grades of substantially the same length and magnitude.

An "adverse grade" is a grade whose sign is opposite that of the uniform grade that would be obtained between two termini.

When a vehicle is moving along the level at a uniform speed, the power of the engine is used only to overcome internal resistances and tractive resistance. Where a grade is encountered, additional power must be supplied by the engine if the same velocity of the vehicle is to be maintained. The resistance offered to movement of a vehicle up a grade, - known as "grade resistance", is expressed in pounds per vehicle, pounds per ton, or more generally pounds per 1000 pounds. In effect it is the force necessary to lift the vehicle through a height equal to that attained by the grade. This relationship can be expressed by the following formula

$$R_g = \frac{GVW\ (G)}{100}$$

where

$R_g$ is total resistance along the grade in pounds,
GVW is the weight of the vehicle in pounds,
G is grade rise in percent
100 is conversion factor

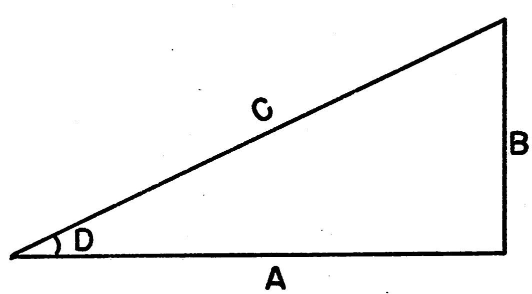
If GVW is taken as a 1000 pounds the formula will become,

$$R_g = 10\ G \times gvw$$

where

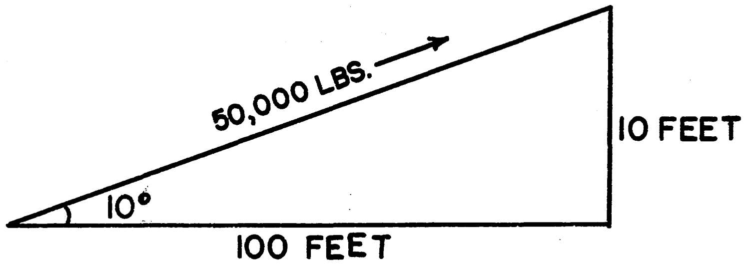
gvw = gross vehicle weight in thousands of pounds

It should be pointed out that the above formula is applicable for grades only under 20 percent as it is only an approximation. Since in the smaller grades the




distance traveled (C) is approximately equal to A the above formula may be used. Over 20 percent, however the "traveled" distance exceeds A; consequently the grade resistance can be expressed as the weight times the sine of D.

As an example a 50,000 pound truck moving up a 10% grade, will, by the formula $R_g = 10\ G$ encounter
10 x 10% = 100 x 50 (weight in 1000's of pounds) = 5000 foot pounds of resistance




Since the above is a right triangle,

$$C = \sqrt{A^2 + B^2}$$

$$C = \sqrt{100^2 + 10^2}$$

$$C = 100.49$$

$$\text{Resistance} = 50000 \times \frac{10}{100.49}$$

$$= 4975 \text{ foot-pounds}$$

Since the calculation is tedious and the difference so small, the formula $R_g = 10\ G$ is quite adequate for grade up to 20 percent; over twenty, however, the longer method is advised.

For the purpose of illustration resistance has been expressed as foot pounds. It is evident that the situation is static and should be converted to horse power. To do so the following formula is used:

$$H.P. = \frac{10 \times 88 \times M.P.H.}{33,000} \times gvw \times G$$

or

$$= \frac{MPH}{37.5} \times gvw \times G$$

where

H.P. is the required horsepower,
MPH is the speed in miles per hour,
gvw is the gross vehicle weight in thousands of pounds, and
G is the grade in percent.

It had not been intended that this section be devoted to the development of formulae for the computation of vehicle ability. However, in order to adequately develop the individual resistances and show their importance, it was found necessary to include some formulae. To develop the formulae will be the purpose of the following section.

If the fact has been realized that there are several types of resistance and that there are methods of calculating the resistances individually, the purpose of this section has been achieved.

# SECTION II

## VEHICLE PERFORMANCE

Performance of a truck or tractor-truck is usually expressed in terms of "Gradeability" or as a "Performance Factor". "Gradeability" or "Grade Climbing Ability" is the percent of grade that a vehicle will climb with a predetermined load. (In general this predetermined load will be considered as a capacity load, as experience has proved that it is not economical to operate with less than a maximum load; this is particularly true of logging vehicles.) "Performance Factor", or the measure of the relative ability of the unit to move a load, is expressed in pounds of tractive effort (often incorrectly termed rimpull) per thousand pounds of vehicle weight.

For a long time performance calculations have been (and still are in some cases) based upon a formula,

$$\text{Grade ability} = \frac{\text{Torque} \times \text{Gear Reduction} \times \text{Efficiency}}{\text{Tire rolling radius} \times \text{Gross Vehicle Weight}} - \text{Rolling Resistance}$$

or formulae similar to this except in details. This type of formula approaches the problem from the standpoint of statics - ignoring speed and considering that all the factors are practically constant at all speeds.

The theory is that with the engine everting a certain number of pound-feet of torque, this torque is multiplied by the total gear reduction, and reduced by internal friction losses to a certain percentage of that product to produce a given wheel torque. This wheel torque is then divided by the tire radius to produce tractive effort.

Dividing the total tractive effort by the gross vehicle weight, then, gives the tractive effort per unit of gross vehicle weight. Subtracting the rolling resistance per unit of gross vehicle weight will give the margin of tractive effort left, after fulfilling the requirements of level running, available for hill climbing.

If in the above formula the following expressions are used:

Torque in pound-inches,

Gear reduction in ratio of engine turns to driving wheel turns,

Efficiency in decimals of one,

Tire rolling radius in inches,

Gross Vehicle Weights in pounds, and

Rolling resistance in pounds per pound, gross vehicle weight,

then the result will be in terms of pounds per pound of gross vehicle weight. To convert this into percent grade, then, this result must be divided by 100, since grade resistance is 10 pounds per 1,000 pounds gross vehicle weight.

For greater convenience, therefore, it is customary to express gross vehicle weight in terms of 100 pounds and rolling resistance in terms of pounds per 100 pounds or else to multiply the dividend by 100 to secure the same result. Inasmuch as engine torque is commonly given in terms of pound-feet, instead of pound-inches, the dividend is often multiplied by 1200, so that the convenient form of this formula becomes:

$$G = \frac{1200 \times T \times GR \times E}{r \times GVW} - \frac{RR}{100}$$

where

G is the gradeability in percent,
T is the torque in pound-feet,
GR is the total gear reduction,
E is the efficiency factor,
r is the rolling radius of tires in inches,
GVW is the gross vehicle weight in pounds, and
RR is the rolling resistance in pounds.

The following four objections to this formula are evident:

1) It is static, being based on torque, whereas truck performance is dynamic.

2) Efficiency is considered as a constant, whereas it actually varies with gear reduction.

3) Rolling resistance is assumed to be a constant.

4) Air resistance is ignored.

As was explained earlier, torque, or the turning force exerted by an engine, is the product of the force times the distance from the center of rotation of the crank shaft, or the number of pounds applied to turn the crankshaft through a one-foot radius. Translating this force through the drive line and rear axle by means of the foregoing formula, results in a measure of the propelling force or ability of the truck to move the load at any particular instant, i.e., at a certain engine speed or at a certain road speed. It will be observed that the primary consideration here is applied force to perform work registered at any particular instant; hence, speed is only of relative importance.

Horsepower, on the other hand, is the time rate of doing work. In other words, it is the amount of torque exerted over a definite time. "Accumulated work", involving weight, distance, and time expresses torque exactly. The term, "horsepower", has been established as the rate of doing work equal to raising a 33,000 pound weight through a distance of one foot in one minute. Hence, horsepower is a measure of the amount of torque developed on a per minute basis. Horsepower may be found by multiplying the torque in foot-pounds by the circumference of the circle through which the torque force will act in one revolution times the number of revolutions per minute, divided by 33,000 foot-pounds per minute; expressed mathematically the formula is:

$$H.P. = \frac{T \times 2 \times 3.1416 \times 1 \times R.P.M.}{33,000}$$

or

$$H.P. = \frac{T \times R.P.M.}{5252.1}$$

where

H.P. is the horsepower,
T is the torque in foot-pounds, and
RPM is engine revolutions per minute at above torque.

Because horsepower involves the element of time, it increases approximately at the same rate as the speed increases, i.e; the faster the rotation, the greater the force accumulated in a given time. Hence, speed is the primary consideration, and for this reason, formulae for determining performance involving horsepower must also consider speed in miles per hour. Inasmuch as horsepower and speed are inseparable, their use indicate how fast a given load can be actually moved on the level or up grades continuously.

An example indicates the distinction between torque and horsepower. If the propelling ability of a truck to climb a 4 percent grade is desired, then performance formulae based on torque (force) should be used. On the other hand, if the actual calculated speed at which the truck will travel in propelling the load up the 4 percent grade is desired, then performance formulae based on horsepower (time rate of doing work) would be used.

Before any measure of performance can be ascertained, it is necessary to determine the tractive effort, or pounds of force exerted by the driving wheels at the point of contact with the road, tending to move the vehicle. This is readily obtained by the formula:

$$TE = \frac{T \times GR \times E \times 12}{r}$$

but since $T = \frac{5252 \times H.P.}{R.P.M.}$

$$TE = \frac{\frac{5252\ H.P.}{R.P.M.} \times GR \times E \times 12}{r}$$

or

$$TE = \frac{63025 \times HP \times GR \times E}{R.P.M. \times r}$$

where

TE is the tractive effort in pounds,

HP is the horsepower required or given,
RPM is the engine revolutions per minute for given horsepower,
GR is the total gear reduction,
E is the efficiency factor for the particular gear reduction, and
63025 is the conversion factor.

An important relationship exists between the tractive effort and miles per hour for any one model and engine size, which can be expressed as follows:

| Constant | Cause | Effect |
|---|---|---|
| For same tire size | Increased gear ratio (numerically) | Slower speed - Higher tractive effort |
| | Decreased gear ratio (numerically) | Faster speed - Lower tractive effort |
| For same gear ratio | Increased tire size | Faster speed - Lower rim pull |
| | Decreased tire size | Slower speed - Higher rim pull |

Theoretically speaking, speed varies inversely as the tractive effort, i.e., more speed is obtained at the sacrifice of pulling ability and vice versa. Although the tire size is more directly related to the vehicle capacity and is determined by the distribution of gross vehicle weight, the gear ratio is entirely related to performance; therefore the choice of the correct ratio should be guided by this rule - the ratio should be selected that will give the fastest speed possible and yet provides a tractive effort that gives equal or slightly more grade ability than is required. Maximum operating economy will then be assured.

Since the selection of the correct gear ratio is important, some means of determining the correct ratio to use at different speeds must be available. Since a vehicle will not use low gear at a road speed of 30 miles an hour, and since few can select the proper gear when ten or more ratios are available, the following formula is available:

$$R.P.M. = \frac{60 \times 5280 \times GR \times MPH \times 12}{3600 \times 2 \times 3.1416 \times r}$$

where

RPM is the engine speed in revolutions per hour,
60 is minutes per hour,
5280 is feet per mile,
GR is the total gear reduction,
MPH is the vehicle speed in miles per hour,
12 is inches per foot,
3600 is seconds per hour,
2 is the conversion factor to circle circumference,
3.14 is a constant, and
r is the radius of tires in inches

the formula then reduces to:

$$R.P.M. = \frac{168 \times GR \times MPH}{r}$$

and GR equals:

$$GR = \frac{RPM \times r}{168 \times MPH}$$

It should be remembered that since this is purely a theoretical value, it is to be used only to get an approximation of the gear ratio. The purpose of this determination will be shown after the development of the performance formulae.

Since the tractive effort required to move a vehicle at a certain speed up a certain grade is the effort required to overcome the internal, air, rolling and grade resistances, and since all these factors are contained in the previous tables, tractive effort may be expressed as follows:

$$TE = GVW\ (f + g)$$

where

TE is the tractive effort in pounds,
GVW is the gross vehicle weight in pounds,
f is the coefficient of tractive resistance in pounds per pound of gross vehicle weight, and
g is the grade rise in feet per foot.

It is extremely important that these values be used accurately because a difference of only .3 can cause a difference of 2 or 3 miles per hour. No more accuracy can be gained than is given in the tables, but extreme care is advised.

The coefficient of tractive resistance is the unit resistance for a given weight and speed divided by 1000 (or the total tractive resistance in pounds divided by the gross vehicle weight in pounds). Referring to the table for unit resistances of all tractor trucks, the unit resistance for 20 miles per hour for a gross vehicle weight of 30,000 pounds is 10.3 pounds. This value expressed as the coefficient of tractive resistance would be 10.3 divided by 1000 or .0103, it is readily seen that care must be taken in the computations.

If the sum of the resistances is known, vehicle ability for any given set of conditions, can be found by combining the following two formulae:

$$TE = \frac{63025 \times H.P. \times GR \times E}{RPM \times r}$$

and

$$TE = GVW\ (f + g)$$

which becomes,

$$GVW\ (f + g) = \frac{63025 \times H.P. \times GR \times E}{RPM \times r}$$

$$GVW\ (f) + GVW\ (g) = \frac{63025 \times H.P. \times GR \times E}{RPM \times r}$$

$$GVWf = \frac{63025 \times H.P. \times GR \times E}{RPM \times r} - GVW\ (g)$$

$$f = \frac{\frac{63025 \times H.P. \times GR \times E}{R.P.M. \times r} - GVW\ (g)}{GVW}$$

$$g = \frac{\frac{63025 \times H.P. \times GR \times E}{R.P.M. \times r} - GVW\ (f)}{GVW}$$

$$H.P. = \frac{GVW\ (f + g)\ RPM \times r}{63025 \times GR \times E}$$

$$GVW = \frac{63025 \times HP \times GR \times E}{RPM \times r \times (f + g)}$$

where

f is the coefficient of tractive resistance in pounds per pound of gross vehicle weight,
g is the grade rise in feet per foot,
HP is the given or required horsepower,
RPM is the engine speed in revolutions per minute for the above horsepower,
GR is the total gear reduction,
E is the efficiency factor for the above gear,
r is the radius of tires in inches,
GVW is the gross vehicle weight in pounds, and
63025 is a conversion factor.

The foregoing formulae are very specific and limited in their nature. Since gear ratio has been introduced care must be taken when speeds are determined. An example will clarify the situation.

Vehicle X

Gross Vehicle Weight (with trailer): 65,000#

Horsepower: 184 at 2600 r.p.m.

Axle Reduction: 6.53 low - 8.53 high

Transmission Reductions:

| | |
|---|---|
| 5th | .788 |
| 4th | 1.000 |
| 3rd | 1.738 |
| 2nd | 3.400 |
| 1st | 6.370 |

Tires: 11.00 x 24   r = 22.4 inches

What speed can be obtained for this vehicle, fully loaded, on a 3 percent concrete grade in second low gear? Solving for speed.

$$f = \frac{\frac{63025 \times 184 \times 29 \times .88}{2600 \times 22.4} - 65000\ (.03)}{65000}$$

$$f = \frac{4700 - 1900}{65000}$$

$$f = .0458$$

or, 45.8

Reference to the table shows that there is not any unit resistance of 45.8, the reason being that when the vehicle is operating at maximum engine speed power will be developed far in excess of that needed to climb a 3 percent grade. Two things can now be done: recalculate with a different gear ratio or compute the horsepower used to see if the correct gear ratio is being used. With the assumption that a speed of 20 miles per hour is attained and that the third low gear is selected, the following equation shows that the load cannot be moved in this gear at a reasonable speed.

$$H.P. = \frac{65000\ (0.0092 + 0.03)\ 2600 \times 22.4}{65000 \times 14.8 \times .88}$$

$$H.P. = 196$$

A horsepower requirement beyond the engine capacity means that the next lower gear ratio is to be used with partial engine power.

Since such computations are at times unwieldy and tiresome; and since they are specific in nature and limited in use, they are only to be used at times when exact performance in a given gear is desired.

In order to obtain a general formula which can be used for any speed, and not just maximum engine speed, gear reduction must be eliminated and miles per hour introduced; this can be accomplished by substituting road speed for engine speed.

$$GVW\ (f + g) = \frac{63025\ HP \times GR \times E}{RPM \times r}$$

substituting,

$$RPM = \frac{168 \times GR \times MPH}{r}$$

therefore,

$$GVW\ (f + g) = \frac{63025\ HP \times GR \times E}{\left(\frac{168GR \times MPH}{r}\right)\ r}$$

which will reduce.

$$GVW\ (f + g)\ \frac{168 \times GR \times MPH}{r} = \frac{63025\ HP \times E \times GR}{r}$$

$$GVW\ (f + g)\ \frac{168 \times GR \times MPH}{r} + \frac{r}{63025\ HP \times E \times GR}$$

$$GVW\ (f + g) \times MPH = 375 \times HP \times E$$

The efficiency factor "E", is necessary only when the gear reduction enters the calculation. Since the gear reduction has been eliminated from the above formula "E" may also be eliminated. The formula will then become:

$$HP = \frac{MPH \times GVW\ (f + g)}{375}$$

variations:

$$MPH = \frac{375 \times HP}{GVW\ (f + g)}$$

$$GVW = \frac{375 \times HP}{MPH\ (f + g)}$$

$$g = \frac{\frac{375 \times HP}{MPH} - GVW\ (f)}{GVW}$$

$$f = \frac{\frac{375 \times HP}{MPH} - GVW\ (g)}{GVW}$$

When solving for miles per hour or gross vehicle weight the will be two unknown quantities. Since "f" is dependent upon both speed and weight the formulae can be solved only by a "cut and try" method, that is; by first assuming a miles per hour (or gross vehicle weight) figure; and then determining the resistance for this assumed speed; if a descrepancy occurs in the solution, then it is necessary to repeat these steps with another assumed figure, and so on until the equation balances. This may seem a rather inadequate method of determining performance, but when two unknown values are involved, it is the only way possible. Experience will soon simplify the procedure.

It must be remembered that the foregoing formulae are based upon performance on concrete roads and that performance on other road surfaces must be corrected accordingly.

Another formula which will save time is given below:

$$GVW_1\ (f_1 + g_1) = GVW_2\ (f_2 + g_2)$$

variations

$$GVW_2 = \frac{GVW_1\ (f_1 + g_1)}{(f_2 + g_2)}$$

$$g2 = \frac{GVW_1\ (f_1 + g_1) - GVW_2\ f_2}{GVW_2}$$

where

$GVW_1$ is the original gross vehicle weight,
$f_1$ is the original coeffecient of tractive resistance in pounds per pound of gross vehicle weight,
$g_1$ is the original grade rise in feet per foot,
$GVW_2$ is the new gross vehicle weight,
$f_2$ is the new coefficient of tractive resistance in pounds per pound of gross vehicle weight, and
$g_2$ is the new grade rise in feet per foot.

The above formula is based upon the assumption that a given vehicle will produce a tractive effort on one grade equal to that on another grade when operating in identical gears at like speeds. With this formula, grade and gross vehicle weight recalculations are eliminated; it is also extremely helpful when converting to other road surfaces from concrete.

With the formula just derived, speed, gradeability, and gross vehicle weight can be found for any condition. In previous computations it was necessary, first, to determine the effort available, then to use separate formulae for level roads, grades, slow, or fast speeds; now all situations can be handled with one formula and its variations. (For level road speed the "g" is merely dropped from the equation.)

Several illustrations will show the validity of this statement. Referring the vehicle used previously, what is the horsepower will be required to move the fully loaded vehicle up a 10 percent concrete grade at 8 miles per hour? Substituting the values in the correct formula:

$$HP = \frac{8 \times 65{,}000\ (.0079 + .100)}{375}$$

$$HP = \frac{8 \times 7000}{375}$$

$$HP = 149$$

What speed can be maintained on an 8 percent grade with a 65,000 gross vehicle weight?

$$MPH = \frac{375 \times 184}{65000\ (f + .08)}$$

$$MPH = \frac{69000}{65000\ f + 5200}$$

$$1 = \frac{69000}{MPH\ (65000\ f + 5200)}$$

Try 10 M.P.H.

$$1 = \frac{69,000}{10\quad 65000(.008)\ +\ 5200)}$$

$$1 = \frac{69000}{10\ (520 + 5200)}$$

$$1 \neq \frac{69000}{57200}$$

Try 15 M.P.H.

$$1 = \frac{69000}{15\quad 65000\ (.085 + 5200)}$$

$$1 = \frac{69000}{15\ (552 + 5200)}$$

$$1 \neq \frac{69000}{86400}$$

Try 12 M.P.H.

$$1 = \frac{69000}{12\quad 65000\ (.082 + 5200)}$$

$$1 = \frac{69000}{15\ (533 + 5200)}$$

$$1 = \frac{69000}{68700}$$

The speed will be slightly over 12 miles per hour.

What gross vehicle weight can this unit haul up a 10 percent grade at 20 miles per hour?

$$GVW = \frac{375 \times 184}{20\ (f + 0.1)}$$

Try 30,000 pounds

$$1 = \frac{69000}{30000 \quad 20\ (.0103 + .10)}$$

$$1 = \frac{69000}{30000\ (2.206)}$$

$$1 \neq \frac{69000}{66200}$$

Try 31,000 pounds

$$1 = \frac{69000}{31000 \quad 20\ (.0102 + .10)}$$

$$1 = \frac{69000}{31,000\ (2.204)}$$

$$1 = \frac{69000}{68500}$$

The vehicle can weigh slightly over 31,000 pounds and maintain a speed of 10 miles per hour.

What is the maximum grade at 6 miles per hour fully loaded?

$$g = \frac{\frac{375 \times 184}{6} - 65000\ (.0077)}{65{,}000}$$

$$g = \frac{10500 - 500}{65000}$$

$$g = .154$$

$$g = 15.4 \text{ percent}$$

Had the gradeability on a good haul road been desired, the conversion factor for this type of road is found in Appendix A. It is 3 percent. Subtracting 3 percent from 15.4 percent the result is 12.4 percent, the gradeability of this truck on a good haul road.

If the maximum grade is 15.4 percent for a 65,000 pound gross vehicle weight, what is the limiting grade for a 50,000 pound load? If both speeds are at 6 miles per hour; two methods may be used:

Number 1:

$$g = \frac{\frac{375 \times HP}{MPH} - GVW\ (f)}{GVW}$$

$$g = \frac{\frac{375 \times 184}{6} - 50000\ (.0077)}{50000}$$

$$g = \frac{10500 - 280}{50000}$$

$$g = 20.4\%$$

or, Number 2:

$$g_2 = \frac{GVW_1\ (f_1 + g_1) - GVW_2\ (f_2)}{GVW_2}$$

$$g = \frac{65000\ (.0077 + .154) - 50000\ (0077)}{50000}$$

$$g = \frac{10500 - 280}{50,000}$$

$$g = 20.4$$

This latter method is recommended, since only the total resistance of the original weight is generally known, the speed resistance of the new weight has to be found, whereas by the first method a whole new calculation has to be worked out. The second method will also apply to vehicle weight, thus eliminating the difficulty arising from the use of two unknowns: Speed in both cases must remain the same, or nearly so, or errors will result. For rapidity and ease of computation the use of a slide rule is suggested. With care in the reading of the scales a fair degree of accuracy can be realized. The saving in time more than compensates for small variations.

A word of caution is necessary. Performance calculated by formula, no matter what precautions are taken, are still theoretical, but should approximate actual performance if the engine is at maximum efficiency and other units such as transmission, axle, drive line, and bearings are in good condition and tires properly inflated. However, so many variables affect performance that it may be wise to be conservative when quoting figures. Air resistance can be figured fairly accurately, but wind has an equally important effect in retarding or accelerating the vehicle. Wind cannot be calculated with certainty, but a thirty mile head wind will reduce performance the same as air resistance at thirty miles per hour.

Density of traffic, requiring slow-downs and gear shifting, will change results. Frequent stops or blind intersections will do the same. These are but a few of the many unpredictable factors that affect performance, but of them all, the driver is the most variable factor. With drivers ranging from excellent to very poor, a certain percentage of the results will show unsatisfactory performance although the truck may be in perfect condition and show superlative ability in the hands of another driver.

Regardless of the fact that calculated performance many differ materially from actual, these figures provide an accurate means of comparison between two trucks. Under the same operating conditions and with equally efficient drivers, any two trucks will perform comparatively as shown by the formulae.

# SECTION III

## OPERATIONAL COSTS

In the two preceding sections consideration has been given to the power requirements for moving vehicles over different road surfaces and up grades, as well as to the gradeability of the vehicle itself. In the present section will be considered those factors that serve to create a differential in the cost of operating vehicles on the level and on grades. Much information is required to compute alternate locations of roads, and the use of the principles developed here will be illustrated in the subsequent section.

Before the reduction of costs can be considered some investigation must be made of the composition of the operating costs. In general these costs may be divided into two groups: (1) the mileage element group, sometimes called operating or variable costs, which embraces those functions of vehicular operating costs which vary with the mileage travelled, and (2) the time element or fixed cost group, which embraces all costs dependent upon the length of operation. The mileage element group must be further subdivided into the following sections:

1. Fuel.

2. Lubricants.

3. Tires and tubes.

4. Maintenance.

The determination of representive figures for the variable cost of operating motor vehicles is one of the most difficult undertakings in any study of highway economics. The difficulty exists not only because of the complexity of the variables involved, but also because of the rapidity with which improvements have been made in automotive design and construction. Extreme difficulty is also encountered in any attempt to obtain data that are truly representive and not changed by special conditions.

Detailed records of variable operating costs are kept by some concerns, but, in general, such records are not plentiful nor easily obtainable. The records that are available are usually scattered and many forms of accounting are used. An analysis of such data requires assembling and adjusting the various factors such as loads carried and speeds traveled, so that a comparison may be made. Special prices of equipment and supplies obtainable by large concerns and the factor of an extremely high annual mileage greatly influence the variable costs of the vehicles involved.

Reliable records of costs are practically impossible to obtain from private individuals as they are seldom kept and those that are unfortunately, in most cases, are biased by the individuals pride in the performance of his own vehicle. It is necessary, therefore, to use fleet operation costs since these are the best, even though the factors effecting cost values may vary widely between private and fleet ownership. Any analysis must be made with the above facts in mind.

A restatement of the various mileage cost items and a further discussion of the factors that influence the value of each will show still further the difficulty in determining accurately the variable operating costs of an average truck.

<u>Fuel</u>: Unit costs for fuel are directly proportional to the per gallon cost of such fuel and to the mileage obtained. The mileage obtainable, however, is influenced by many factors. Disregarding the inherent characteristics of the motor vehicle, mileage will be affected by speed of travel, road conditions, the use of which the vehicle is put, driving conditions, and the individual driving practices of the operators. The speed at which the light fleet vehicle is operated will probably be higher than that of the average passenger car of comparable weight. Road conditions encountered by the fleet-owned vehicle will, in many cases, be poorer because of the wider range of territory over which the vehicle is operated. The private car

operated solely for pleasure will undoubtedly remain on the improved highways since it is seldom necessary to travel roads that are not improved. Fuel consumption for the private car will not be as greatly affected by the use of poorer roads as that of the fleet owned vehicle. The business in which a company is engaged will determine whether its vehicles will be used in the city or in rural areas. City operation will increase fuel costs because of its intermittent character involving frequent starts and stops and because of the low daily mileage. Whether this will be offset by the increased fuel consumption which results from increased speed on rural trips is problematical. While the fleet-owned vehicle will normally be used for either city or rural purposes exclusively, the private vehicle is often used for both; which of the two it will be used for is dependent entirely upon the owner. The validity of the comparison of fuel costs of logging trucks and commercial trucks operating on fairly good roads is questionable. However, since records are not available for logging trucks exclusively, some correlation between log truck and commercial truck costs is required.

Lubricants: The variable cost for lubricants (considering only the oil used in the engine) will, for fleet-owned vehicles, be largely dependent upon the rules and maintenance practices of the company operating the fleet.

Changes of oil will be made at periodic intervals, and addition of oil will be dependent upon the inherent characteristics of the motor, including condition of repair and speed at which the vehicle is operated. The cost of the privately owned truck, on the other hand, will vary with each vehicle, because of the individual practices of the owner. Some private operators will change oil at periodic mileage intervals while others will wait. Oil additions (as in the case of the fleet owned truck), when needed, will depend upon the characteristics of the truck, its condition of repair and speed of operation. Other factors such as road conditions, car equipment and temperature will affect oil consumption. Dusty roads will contaminate oil by entering the engine through the crankcase ventilating system and air intake. Operation at high temperatures, often encountered in summer, will lead to a more rapid oxidation or sludging of the oil. Heat and dirt tend to shorten the service life of the oil and thus necessitate more frequent changes. Such equipment as air cleaners, oil filters, and oil cooling systems if used will, of course, counteract the above factors to a considerable extent.

Tires and Tubes: It is probably safe to say that tire and tube costs will depend upon speed of travel, type of road surfaces and individual driving practices.

Characteristics of the vehicle, such as the braking system, condition of repair, and wheel alignment will undoubtedly affect tire wear, which effect, in turn, is dependent upon the number of starts and stops made necessary by conditions of traffic, locale of operation, and driving practices of the individual. The additional wear on tires due to rapid acceleration and deceleration may be a large item today because of perfected braking systems and higher power of the modern motor vehicle. Tire wear, due to surface roughness, is obviously dependent upon the type of roads upon which the truck is operated. As in the case of fuel costs, the fleet-operated truck will in many instances show a greater tire cost because of its faster rate of travel and the necessity of serving localities that can only be reached over rough roadways. Under-inflation is also an item of importance and therefore it is likely that the fleet-operated vehicle will receive more attention in this respect. Because overloads reduce the service life of tires and tubes they are made with definite load ratings. commercial truck load limits are set by government regulations; however, since log trucks operating on private roads are not hindered by these restrictions, overloads are the rule rather than the exception. Consequently, tire failure, traceable to frequent overloading, is high.

Maintenance: Vehicular maintenance costs applicable to the average truck are the most difficult to determine because of the extreme spread in the variables involved in fleet operation, as compared to those in private operation. The term "vehicular maintenance" usually refers to all repairs necessary to chassis and body, also such items as washing and greasing. Those maintenance items which are strictly dependent on mileage are, in general, experienced alike by fleet and private operator. Such items as general deterioration of the body, accessories and finish, usually classed as mileage maintenance costs actually depend largely upon time and are usually escaped by the fleet owner because of higher annual mileage and shorter retirement periods. A factor that increases the fleet operator's maintenance costs over those of the private owner is that, since a breakdown on the road entails the loss of valuable time, the trucks of the fleet must of necessity be kept in better condition. Maintenance is affected by speed and roadway surfaces in the same manner as fuel consumption. Actual available data pertaining to the effect of roadway surfaces on vehicular maintenance are very meagre. Engine maintenance is probably dependent upon total revolutions or power output. Overall maintenance of chassis parts, on the other hand, will be affected by the roadway surface and speed. Dirt and grit present on the surface will find their way into chassis parts and thus increase wear.

Increased speed will undoubtedly cause higher maintenance through a greater disturbance of loose material and greater impact stresses. Recent improvements made in automotive design such as rigid bodies, rubber cushioning, stronger springs and sealed units, have to a certain extent reduced these costs. The fleet owner will be confronted in many instances with a greater maintenance cost than the private owner because of the necessity of his vehicles' covering areas not accessible by improved roads. The private operator that lives in such areas will also experience some of these higher maintenance costs.

The preceding paragraphs have presented those vehicular operating costs which are entirely dependent upon mileage. A comparison has been made between the relative costs that would be experienced by the contract carrier operating between the woods and a mill located on a public road, and the fleet carrier, which usually operates on private company roads. It is probably safe to say that the fleet-owned trucks will experience harder wear during its service life than the privately owned truck whether or not such factors as the higher annual mileage and the lower cost of replacement parts and repairs (obtainable by the fleet owner because of discounts, and operation of company repair shops) will compensate for this severe service, is hard to say.

Time element or fixed costs may be divided into the following groups:

1. Depreciation.
2. License and other fees.
3. Garage.
4. Interest.
5. Insurance.
6. Wages.

A discussion of the above list of costs, with the exception of depreciation, is quite unnecessary. These self-explanatory costs vary with each section of the country. Each operator therefore will have to determine his own fixed costs. Depreciation is another problem. Depreciation is a lessening in value of the motor vehicle due to its age and use. Some operators tend to depreciate a vehicle on the basis of its mileage, some prefer to base depreciation on time, and still others use a combination of the two. It is not the purpose here to weigh the advantages and disadvantages of each of these methods, but to state that the practice has been to depreciate logging trucks on a time basis.

Many forms have been developed for tabulating operational costs. One of the best, developed by the General Motors Corporation is given at the end of this section. The tabulation following was made by the Henderickson Truck

Company of Chicago, Illinois.

A cost analysis was made of two of the companies' trucks for a 375 mile haul. The costs are listed in the conventional manner for both the diesel and gasoline vehicle.

- Transportation Analysis: Chicago Area -

Conditions of Operation: This analysis was made for the purpose of finding the cost and possible profit involved by the transportation of milk into Chicago by truck.

Equipment - Analysis based on two different equipment combinations.

(1) Hendrickson Model AD-390-1 Diesel powered tractor-truck.
(2) Hendrickson Model A-240 Gasoline powered tractor-truck.

Both tractors to pull a 28 foot tandem axle, insulated trailer.

Distance - One way distance 375 miles, or about 150,000 miles yearly.

| | | |
|---|---|---|
| Cost of Equipment - | AD-390-1 Diesel tractor | $8000.00 |
| | A-240 Gasoline tractor | 4000.00 |
| | Insulated trailer | 3800.00 |

| Payload | Diesel | Gas |
|---|---|---|
| Chassis and Cab | 12,000 | 8,500 |
| Trailer | 12,000 | 12,000 |
| Total | 24,000 | 20,500 |
| Allowable Gross | 59,000 | 57,000 |
| Payload (Milk and Cans) | 35,000# | 36,500# |

Fixed Operating Cost - Total Per Year.

| | Diesel | Gasoline | Trailer |
|---|---|---|---|
| Interest on Investment (less tires) 6% per year | $ 223.80 | $ 103.80 | $ 92.40 |
| Depreciation: 33 1/3% per yr. | 2487.67 | 1153.34 | 1202.67 |
| Garage rent: $12 per mo. | 144.00 | 144.00 | 144.00 |
| License: Illinois | 150.00 | 150.00 | 200.00 |
| Chicago | 24.00 | 24.00 | ------- |
| Insurance: Fire | 40.00 | 10.60 | 10.60 |
| Theft | 6.40 | 3.20 | 3.20 |
| P.L.-P.D. 50/100,000 | 150.00 | 150.00 | 100.00 |
| $250.00 Dedt. Coll. | 216.00 | 216.00 | 199.00 |
| Taxes: 2% as investment | 149.20 | 69.20 | 61.60 |
| Total per year | 3591.07 | 2024.14 | 2013.47 |
| Cost per mile | .0239 | .0135 | .0134 |

Variable Operating Cost

| | Cost Per Mile | | |
|---|---|---|---|
| | Diesel | Gasoline | Trailer |
| Tires - Truck (45,000 miles per set) | .012 | .012 | |
| Trailer (62,000 miles per set) | | | .012 |
| Repairs - Average over 3 years | .0125 | .015 | .003 |
| Fuel - Diesel (6.5 miles per gallon) at 12¢ | .018 | | |
| Gasoline (4 miles per gallon) at 14.5¢ | | .038 | |
| Lubrication | .004 | .004 | .001 |
| Painting and General Upkeep | .0005 | .0005 | .0005 |
| Supervision | .0015 | .0015 | .0015 |
| Drivers' Wages: $1.30 per hour | .0462 | .0462 | |
| Social security | .0005 | .0005 | |
| Compensation Insurance | .0016 | .0016 | |
| Cost per mile | .0968 | .1193 | .0180 |

Summary -

Diesel:

| | |
|---|---|
| Fixed | - .0239 |
| Variable | - .0968 |
| | .1207 |

Gasoline:

| | |
|---|---|
| Fixed | - .0135 |
| Variable | - .1193 |
| | .1328 |

Trailer:

| | |
|---|---|
| Fixed - | .0134 |
| Variable - | .0180 |
| | .0314 |

Total:

| | | | |
|---|---|---|---|
| Diesel | .1207 | Gasoline | .1328 |
| Trailer | .0314 | Trailer | .0314 |
| | .1521 | | .1642 |

Difference per Mile

| | |
|---|---|
| Gasoline | 0.1642 |
| Diesel | 0.1521 |
| | 0.0121 |

Difference per Year

150,000 x 0.0121 = $1,815 saved by Diesel

Total operating cost may also be calculated by means of an hourly machine rate. The machine rate method is the most applicable of the two forms of depreciation for truck logging. The following example was prepared by Prof. D. M. Matthews of the School of Forestry and Conservation at the University of Michigan. The following tabulation is much the same as the previous illustration but is based on time rather than mileage.

Lake States Region

Machine Rate for One and One-Half Ton Truck.
(Based on 2000 Hour Year and Three Year Life.)

| | | | |
|---|---|---|---|
| **Fixed Cost Per Hour** | | | |
| License and Insurance (Michigan data): | | | |
| Registration | $55.00 | | |
| Public Liability: $50,000/$100,000 plus $25,000 | | | |
| Property Damage | 52.20 | | |
| Collision ($50 Deductible) | 40.00 | | |
| Fire and Theft | 32.00 | | |
| | $179.20 | ÷ 2000 hrs = | 0.090 |
| Depreciation: | | | |
| Original cost | $1,800.00 | | |
| Less tires | 300.00 | | |
| | $1,500.00 | | |
| Wrecking value | 200.00 | | |
| | $1,300.00 | ÷ 2000 hrs = | 0.216 |
| Labor (Michigan data) | | | |
| Drivers' wages (plus 10% overtime) | | | 0.880 |
| Helpers' wages (plus 10% overtime) | | | 0.770 |
| Social security, workmen's compensation, etc., at 21% | | | 0.347 |
| Total fixed Cost per Hour | | | $2.303 |
| **Operating Cost Per Hour** | | | |
| Oil at $0.30 per qt. 10 qts. every 50 hrs. | 0.06 | | |
| Repairs - average of $400 per year | 0.20 | | |
| Greasing and General Maintenance | 0.04 | | |
| Fuel (average) | 0.40 | | |
| Tires - $300.00 ÷ 1000 hrs. | 0.30 | | |
| Total Operating Cost per Hour | | | 1.00 |
| Hauling Cost per Hour | | | $3.30 |

With the various operating costs itemized, it now remains to be seen how grades will affect these costs. The savings to motor vehicle operation that are reflected in a reduction of gradients are two-fold. One is a direct monetary benefit resulting from a saving in operating costs; the other includes items of time saving, and certain somewhat intangible benefits such as ease of driving and increased safety.

Examining the various items of the operating cost a question at once arises. Where will the saving take place and how can it be evaluated? Referring to the previous discussions, it becomes quite obvious that the savings can be calculated only for the fuel. The other items of expense, viz., tires, tubes, oil and maintenance are of minor importance when compared to fuel consumption and so may be eliminated. The following statement taken from page 31 of the Oregon State Highway Department Technical Bulletin No. 5, upholds the previous statement: "Any determination of savings resulting from grade reductions can best be made from the standpoint of relative <u>fuel consumption</u> since one of the most important differences in the cost of operation comes from this source. <u>Speed</u>, and consequent time reductions are important with heavy equipment but not a determining factor with passenger cars. <u>Oil consumption</u> is definitely a function of engine speed, and, regardless of whether a vehicle is operated on the level or on grades, the engine speed at constant gear ratios will be the same for identical road speeds. Due to the slight difference in distance between grade and level operation (approximately 20 feet per mile for a six percent grade), a difference in tire wear might be considered over a long period of operation, but such an effect would be extremely small. Since the operating costs are the only ones materially affected by road gradients, a consideration of grade reduction is logical from a gasoline consumption standpoint."

The calculation of savings brought about by a grade reduction will then fall into two classes: (1) the reduction of fuel consumption, and (2) reduction in total operating time per trip. Each type of saving will be explained seperately, and at the end of the section both methods will be used to determine the savings possible in a sample grade reduction problem. Since the subject of fuel consumption is more detailed than that of time it will be explained first.

A study of engineering literature discloses that several methods have been proposed for determining the increase in fuel consumption that takes place when a vehicle moves up a grade. Of these several methods only two will be considered, one of which is based upon actual fuel measurements, the other upon what engineers call the "straight-line" relation between brake horsepower and fuel consumption.

Naturally any data based upon actual vehicle operation would be most desirable, but the only tests of actual fuel consumption that can be found on record were made in 1937 by the Oregon State Highway Commission.

In the Oregon tests actual data were gathered for the fuel consumption of different vehicles on grades ranging from zero to six percent. These tests were not limited to passenger cars alone, but included commercial trucks as well. Although the tests did not include grades over six percent, it was thought that the data available could be extrapolated so as to be applicable to logging operations; however, this method was found impracticable.

The data gathered by the Oregon Commission are extremely valuable as they stand alone; no other organization has attempted fuel consumption tests on such a large scale. Therefore, the majority of the material following is based upon the conclusions drawn from these tests.

In order to obtain data that would be truly representative of operating conditions, all tests were made either when the vehicles were in use for their various commercial purposes or on special test runs with a regular company driver.

The equipment used to determine fuel consumption and speed consisted of a positive displacement meter having an accuracy of 0.001 gallon, an alcohol bulb type thermometer to determine fuel temperature, and an accurate speedometer. The speedometer was of the magnetic type, driven directly from the front wheel of the vehicle by means of the regulation housed flexible cable.

Tests were conducted on Oregon Highway No. 50 between Portland and Maupin, a distance of 79 miles, and probably the most difficult trucking route in the state. On this route there are many grades, some over a mile in length, ranging between level and 6.2 percent. An important reason for selecting this route was that nearly all types of diesel and gasoline powered trucks from the smallest to the largest operate over it.

A heavy vehicle has, within certain limits, one speed suitable for each percent increase in grade. The necessary modification of this statement comes from the fact that trucks are provided with gear reductions, from 3 to about 12. Thus, a single reduction will have to be used, with a slight change in engine speed, over a small range of grades. However, a given vehicle operating on a given grade, will have a fairly definite characteristic speed.

Graphs were prepared to show the fuel consumption and speed of six heavy vehicles, ranging in gross weight from 9,180 to 52,900 pounds and operating on the positive and negative grades of the test route referred to above. An examination of the speed curves showed that, within limits to be expected, there was in all cases a fairly definite characteristic speed on each percent grade for a particular vehicle. The trend of the speed curves was especially definite on the positive grades. By combining the average speed on the similar positive and negative grade a composite speed curve was obtained. This composite curve can be used to calculate time savings due to grade reduction.

Examination of the fuel consumption curves for the six vehicles showed a marked similarity in all cases. The grouping of the points on each curve was consistent in the positive grade region and rather scattered in the negative grade region. The extreme variability in down-grade operation depends upon alignment, traffic, weather and time of day.

Fuel consumption on each positive grade was combined with fuel consumption on the similar negative grade to obtain a composite fuel mileage point for a composite grade. A rather interesting and somewhat significant point was brought out from these composite fuel consumption curves. In practically every case the composite fuel mileage did not drop off appreciably until the vehicle was operated on a grade exceeding three percent.

In 1934 the Federal Coordinator of Transportation published a report showing the fuel consumption of gasoline driven automobiles to be definitely a function of the weight. From a survey of 400,000 vehicles he concluded that the fuel consumption, in gallons per mile, was equal to $0.031\ GVW^{0.675}$, in which GVW is the gross vehicle weight in pounds. Inasmuch as this relation was determined from average operating conditions such as highway trips, starting, stopping, and driving in traffic, the equation has no specific application other than to give the parabolic relation between gasoline consumption and gross weight.

If such a relation could hold for a general sampling of vehicles it was thought by the Oregon State Highway Commission that a similar relation might hold for heavy vehicles operating on various grades. Accordingly, the composite fuel consumption data gathered from the test on the six trucks were plotted on logarithmic coordinates, as shown in Figure 11. If it is realized the small number of vehicles tested, the correlation between fuel consumption and gross weight is seen to be surprisingly good. The sharp upward trend of the curves is evident.

The following is taken from the Oregon Highway Bulletin No. 5, "Some explanation of the method used to locate the curves in figure 53 (Figure 11 in this text) is necessary to make clear the irregular spacing. The zero and six percent grade curves were first located as the best averages through the observed data. The fine intermediate curves were then located by making the following calculations. The spread, or difference in fuel consumption between a zero grade and a six percent grade was taken as 100 percent in the case

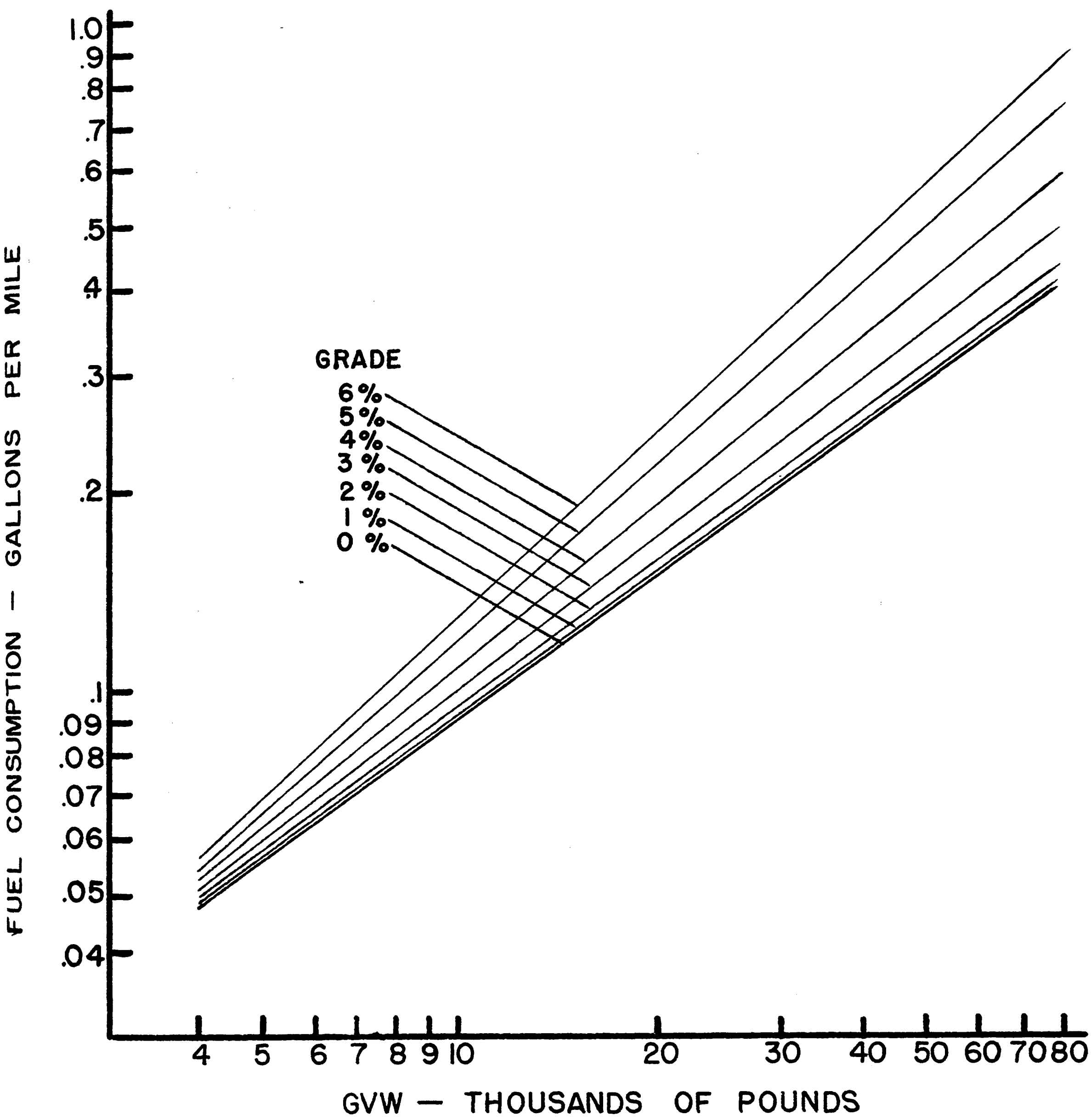



FIGURE 11 - GASOLINE CONSUMPTION ON COMPOSITE GRADES IN RELATION TO GROSS VEHICLE WEIGHT.

of each vehicle of different gross weight. The difference in fuel consumption between each even grade was then tabulated from the test results of each vehicle. Following this, the percent difference in fuel consumption was determined in each case. The curves were then located through points which represented the average of the percent difference from all vehicles.

It will be seen from the figure that the zero and one percent grade curves lie quite close together. This, of course, follows from the fact that for each vehicle tested the difference in fuel consumption between a zero and a one percent grade was slight."

Equations have been determined for these curves and are listed below, GVW being the gross vehicle weight in pounds.

For a 0 percent grade, gallons per mile = $0.0001283GVW^{G.712}$
For a 1 percent grade, gallons per mile = $0.0001179GVW^{0.723}$
For a 2 percent grade, gallons per mile = $0.0000954GVW^{0.750}$
For a 3 percent grade, gallons per mile = $0.0000731GVW^{0.785}$
For a 4 percent grade, gallons per mile = $0.0000542GVW^{0.825}$
For a 5 percent grade, gallons per mile = $0.0000373GVW^{0.876}$
For a 6 percent grade, gallons per mile = $0.0000260GVW^{0.928}$

The solution of these equations will provide a reasonable determination of fuel consumption of any grade for any gross weight. The formulae are adequate to cover any load limit as the gross vehicle weight is arbitrary; however, the range of grades is extremely limited. Grades on logging roads often exceed 6 percent; an increase in elevation of

20 feet per 100 feet is not uncommon. Therefore, in order to satisfy all situations the fuel consumption formulae must be extrapolated.

Examination of Figure 11 shows that the fuel consumption curves for, 2, 3, 4, 5 and 6 percent are spaced, more or less, at even intervals. It was hoped that when the constants and exponents of the equations just given, were plotted over the percent grade, a definite pattern would be revealed. A glance at Figure 12 will show that with only seven points, it was impossible to guess what shape the curves would take. However, the points were also plotted on logarithmic and semi-logarithmic coordinates, on which the curve of the exponents made a steady rise, but the curve of the constants plotted almost straight down. Some liberty was taken in Figure 12 in order to keep the curve above the horizontal axis. Averages were taken of the different curves and the following equations developed.

For a 7 percent grade, gallons per mile = $0.0000175 GVW^{0.978}$
For an 8 percent grade, gallons per mile = $0.0000116 GVW^{1.035}$
For a 9 percent grade, gallons per mile = $0.0000077 GVW^{1.095}$
For a 10 percent grade, gallons per mile = $0.0000059 GVW^{1.160}$
For an 11 percent grade, gallons per mile = $0.0000044 GVW^{1.239}$
For a 12 percent grade, gallons per mile = $0.0000037 GVW^{1.310}$
For a 13 percent grade, gallons per mile = $0.0000031 GVW^{1.385}$
For a 14 percent grade, gallons per mile = $0.0000028 GVW^{1.475}$
For a 15 percent grade, gallons per mile = $0.0000025 GVW^{1.571}$

Calculations were carried out to check the derived equations. The following tabulation was made for a 40,000 pound

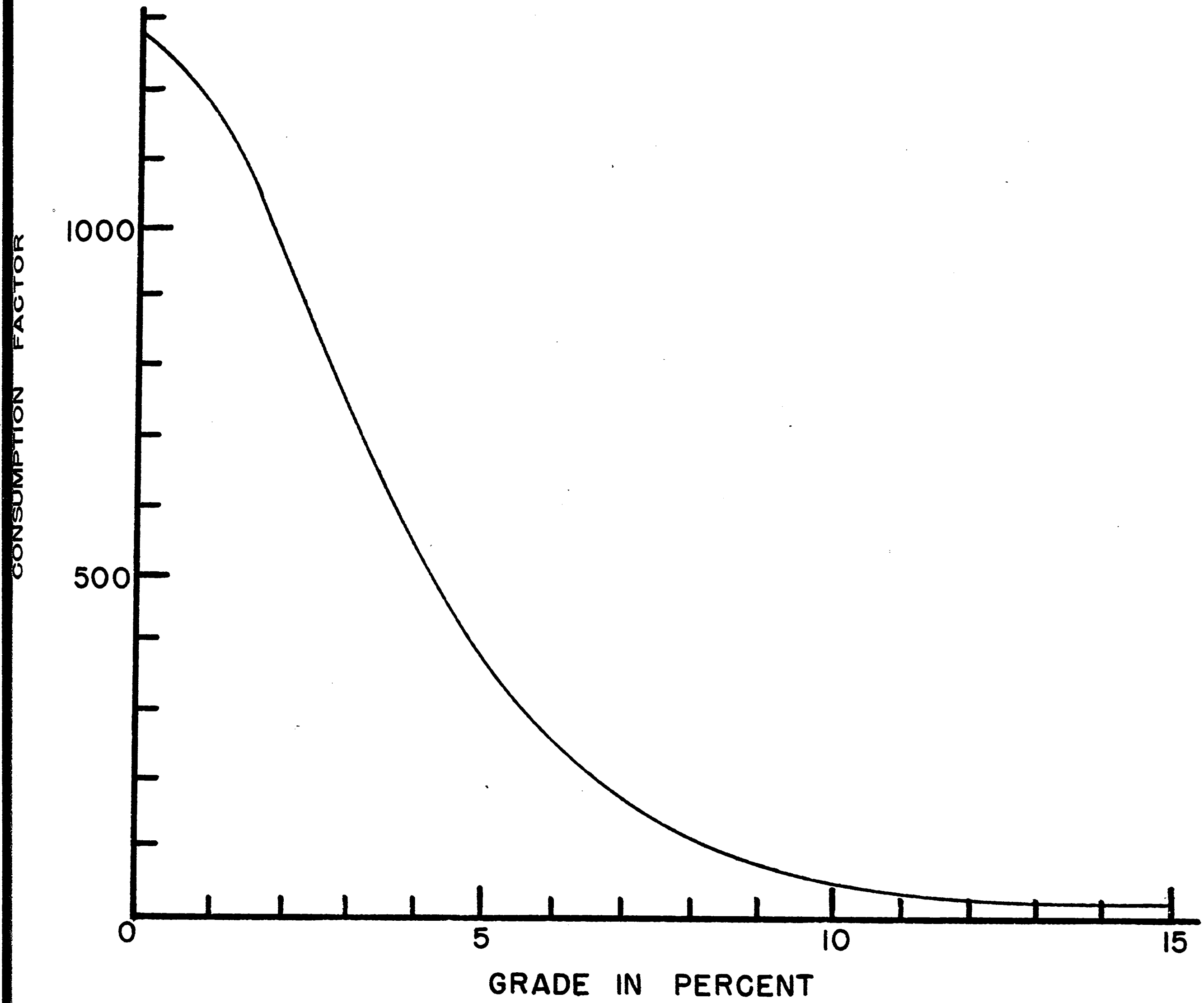



FIGURE 12 - EXTRAPOLATION OF FUEL CONSUMPTION FACTOR.

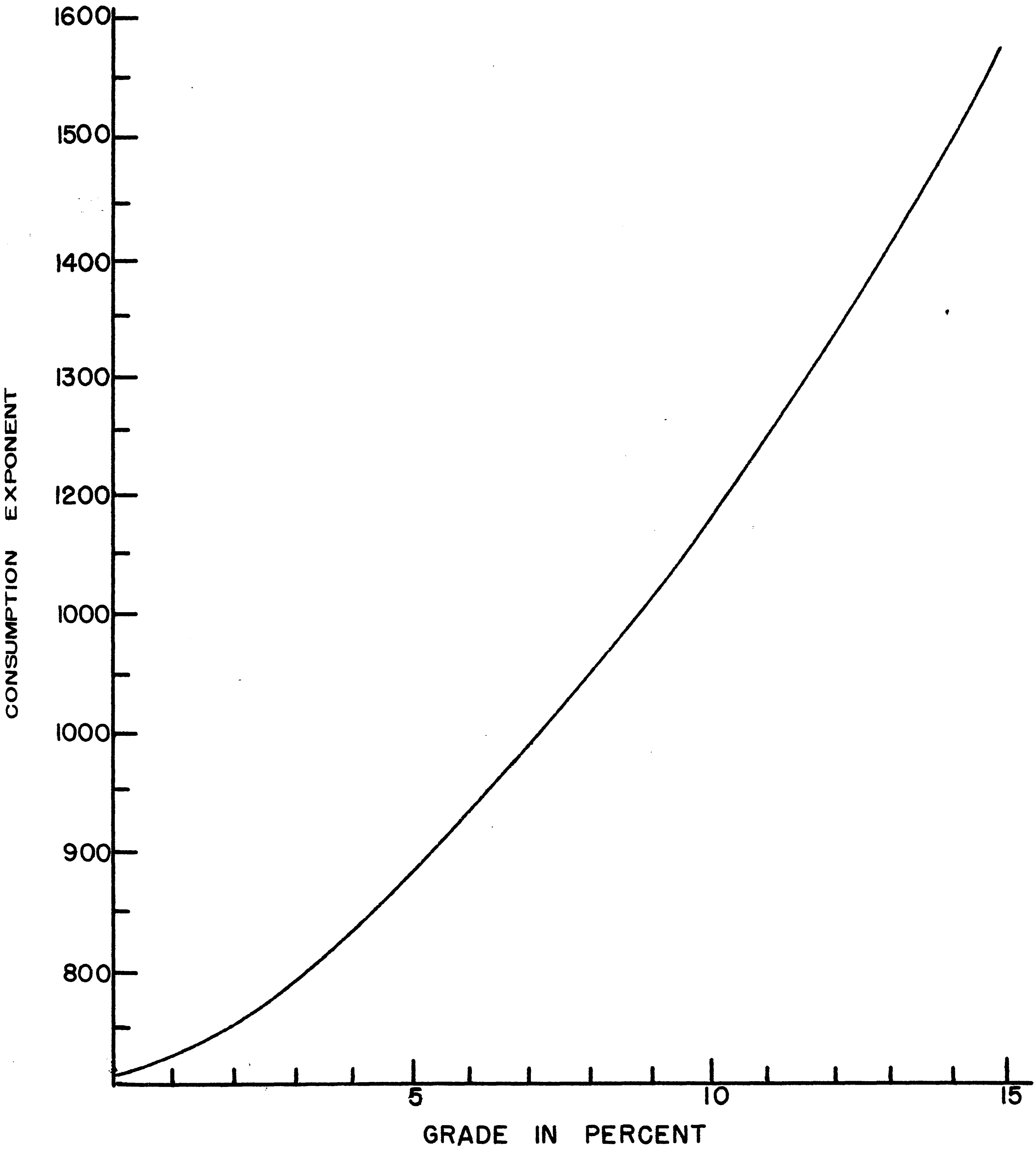



FIGURE 13 - EXTRAPOLATION OF FUEL CONSUMPTION EXPONENT.

truck on all grades for which an equation is given.

Log of 40,000 = 4.602

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4.602x0.712 = 3.28 | which | is | 1,905x0.0001283 = | 0.245 | gallons | per | mile |
| " x0.723 = 3.33 | " | " | 2,140x0.0001179 = | 0.252 | " | " | " |
| " x0.750 = 3.46 | " | " | 2,880x0.0000954 = | 0.275 | " | " | " |
| " x0.785 = 3.62 | " | " | 4,170x0.0000731 = | 0.305 | " | " | " |
| " x0.825 = 3.80 | " | " | 6,310x0.0000542 = | 0.343 | " | " | " |
| " x0.876 = 4.04 | " | " | 10,980x0.0000373 = | 0.409 | " | " | " |
| " x0.928 = 4.27 | " | " | 18,600x0.0000260 = | 0.484 | " | " | " |
| " x0.978 = 4.50 | " | " | 31,600x0.0000175 = | 0.553 | " | " | " |
| " x1.035 = 4.77 | " | " | 58,900x0.0000116 = | 0.684 | " | " | " |
| " x1.095 = 5.05 | " | " | 112,000x0.0000077 = | 0.864 | " | " | " |
| " x1.600 = 5.35 | " | " | 224,000x0.0000059 = | 1.325 | " | " | " |
| " x1.239 = 5.61 | " | " | 407,000x0.0000044 = | 1.791 | " | " | " |
| " x1.310 = 6.04 | " | " | 1,098,000x0.0000037 = | 3.962 | " | " | " |
| " x1.385 = 6.38 | " | " | 2,400,000x0.0000031 = | 7.440 | " | " | " |
| " x1.475 = 6.80 | " | " | 6,300,000x0.0000028 = | 17.640 | " | " | " |
| " x1.571 = 7.24 | " | " | 17,380,000x0.0000025 = | 44.380 | " | " | " |

When these data are plotted, the curve has a sharp upswing, as shown in Figure 14. Logarithmic coordinates were used in order to place all the points on one graph. The theoretical expansion of the experimental formulae seems to break down when a 9 percent grade is exceeded; and to assume that a vehicle would consume 44 gallons of gasoline per mile on a 15 percent grade would involve gross error. Therefore, if these formulae are to be used to determine fuel consumption, the grades must be limited to nine percent or under, and even then the results derived should be used for comparative purposes only. It must be remembered that when a formula is based upon variable factors it can be only as strong as its weakest

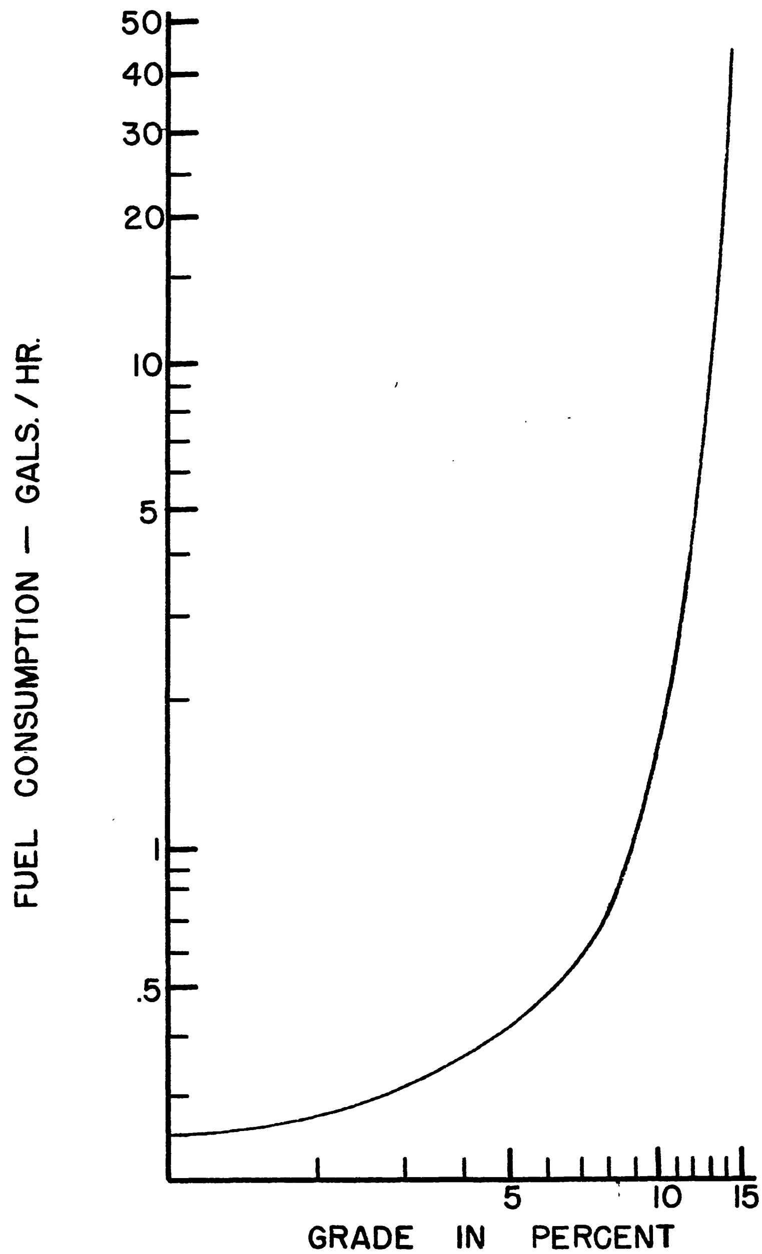



FIGURE 14 - FUEL CONSUMPTION FOR A 40,000 POUND TRUCK ON VARIOUS GRADES.

component. It is not possible that the formulae developed in this paper be absolute; they are intended only as a means of comparison.

Fortunately another means of estimating fuel consumption is available that is limited only by the vehicles' ability to negotiate a given grade, this method is based upon the assumption that fuel consumption is a function of vehicle horsepower.

A method in which analyses are made of fuel consumption on composite grades, and using the straight-line characteristic of fuel consumption and brake horsepower for the internal combustion engine has been developed by Professor H. B. Shaw of the North Carolina State College.[23] Highway engineers have known for many years that fuel consumption on grades up to 4 percent was not much, if any, in excess of consumption on the level. Professor Shaw seems to have been the first to point out the reason for this constant fuel consumption, and to furnish the experimental proof. From the results of numerous road tests in which the amounts of fuel consumed on grades were measured, he proved that, for the lower grades and for movement both up and down grade, little, more fuel was consumed than for an equal distance on the level. If the speed be held constant,

23.....H. B. Shaw, "Highway Grades and Motor Vehicle Costs", Bulletin No. 7, Engineering Experiment Station, North Carolina State College.

he showed that, theoretically, no more fuel will be used on the grades than on the level, provided the grades do not exceed a maximum. This maximum grade is the "floating grade", or the decending grade on which no power from the engine is required to maintain the speed.

The proof of Professor Shaw's conclusions lies in the fact that for a constant speed the fuel consumption of an internal combustion engine varies directly as the brake horsepower.

Although Figure 15 a purely hypothetical case, it serves to illustrate the above statement.

With the formula:

$$H.P. = \frac{M.P.H. \times GVW\ (f + g)}{375},$$

horsepower requirements for a speed of 40 miles per hour and a gross vehicle weight of 12,000 pounds, on all grades ranging from 0 to 7 percent, were found. With a performance curve for a Continental engine, model B-6427, serial number 1174, the fuel consumption in pounds per brake horsepower-hour for the corresponding engine speed was calculated using the following formula:

$$\text{No. of gals./hr} = \frac{\text{lbs. fuel/hr.} \times BHP}{6.25}$$

where 6.25 is the weight in pounds of a gallon of gasoline,

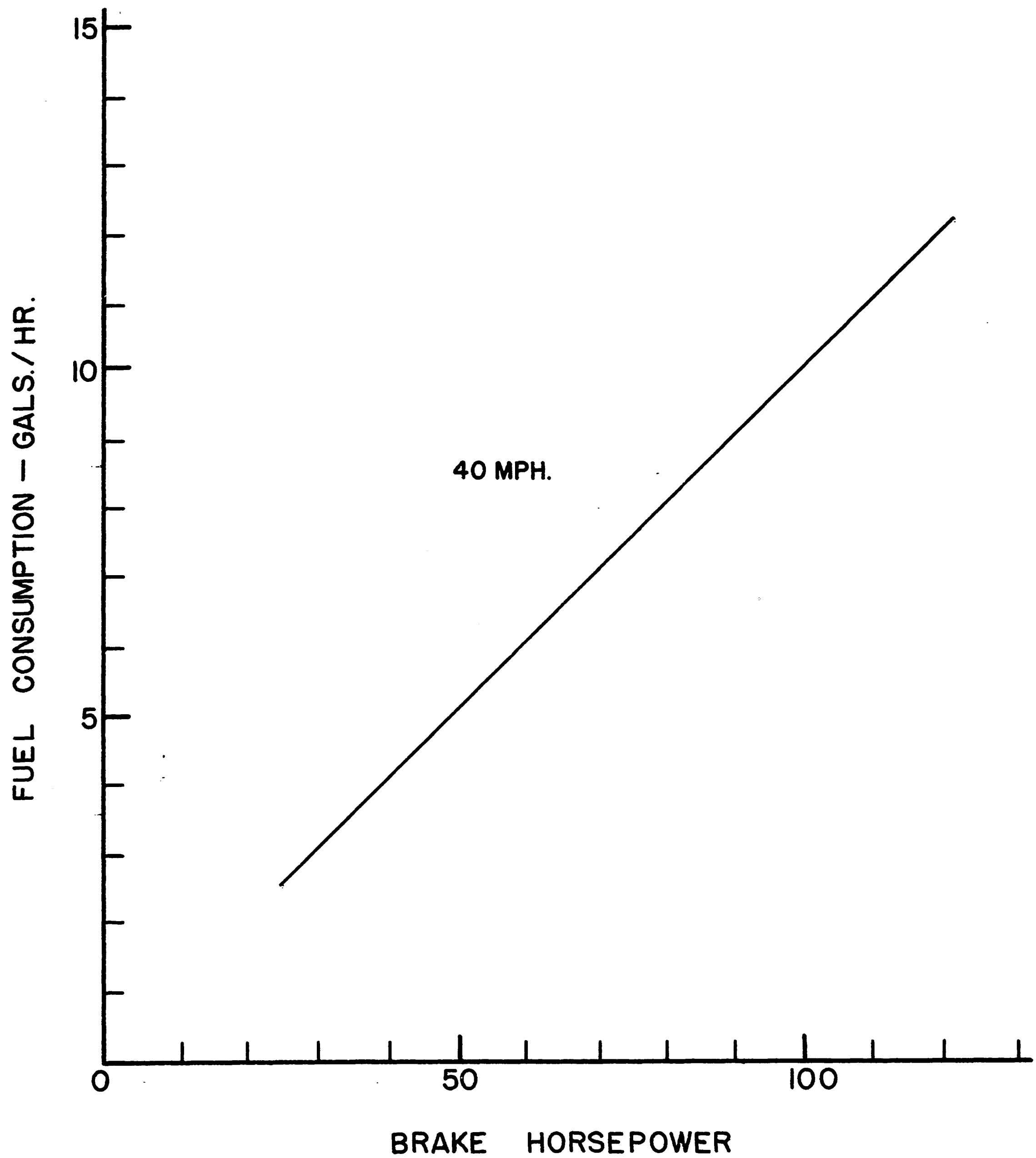



FIGURE 15 - STRAIGHT LINE RELATIONSHIP OF FUEL CONSUMPTION AND HORSEPOWER.

the fuel consumption corresponding to each horsepower requirement was computed. Similar tests on other engines indicate that, for constant fuel mixtures and engine temperatures, the straight-line relation holds. If, then, a vehicle is driven over a highway at a constant speed, the fuel consumption will be proportional to the horsepower output of the engine. The horsepower output will, in turn, be proportional to the tractive resistance. For example, if a vehicle that is moving at a constant speed encounters a grade of 4 percent for a distance of 1000 feet, the additional horsepower required will be proportional to the grade resistance. If, at the same speed, the vehicle decends a 4 percent grade that is 1000 feet long, the total horsepower required will be decreased because of negative grade resistance. The power requirements while the vehicle is going up and down the grade may be summarized as follows:

> Total horsepower required <u>up</u> the grade = Horsepower to overcome tractive resistance <u>plus</u> horsepower to overcome grade resistance.
>
> Total horsepower required <u>down</u> the grade = Horsepower to overcome tractive resistance <u>minus</u> horsepower due to negative grade resistance.

If, for example, the horsepower <u>up</u> a grade is utilized for 1000 feet, and the horsepower <u>down</u> can be reduced without reducing the road speed, the resultant fuel consumption, which is proportional to the horsepower, for moving both up and down the grade will be the same as for moving a vehicle 2000 feet on the level. Compensating grades of this type are usually called floating grades.

Some engineers have objected to the use of the straight-line principle for determining fuel consumption on the basis that a variation in the air-fuel ratio will change the power requirements.

Constant air-fuel ratio as an indication of constant combustion efficiency is a necessary requirement to obtain the straight-line relation. The air-fuel ratio can be controlled in laboratory work, but under road conditions the fuel mixture is varied by the carburetor. Even if such a variation does exist the method can still be used to aid in the determination of fuel consumption. As long as all comparisons are made on the same basis any error would have a counter-balancing effect.

On every properly prepared engine performance curve there should appear a curve labeled "Fuel-pounds per brake horsepower-hour". If the governed speed of an engine should be 2600 revolutions per minute, the horsepower and pounds of fuel consumption for this engine speed can be located. In this case the horsepower was found to be 120 and the fuel consumption .6 of a pound per brake horsepower-hour. With the following formula fuel consumption can be determined:

$$\text{Gallons per hour} = \frac{\text{Lbs of fuel/hour x BHP}}{\text{Weight of a pound of fuel}}$$[24]

$$= \frac{.6 \times 120}{6.2}$$

$$= 11.6$$

Therefore, if this vehicle were traveling at 25 miles per hour, it would use 0.465 gallons of gasoline per mile. With this relation established the fuel used on any grade can be determined for any load.

This method is especially applicable to heavily loaded trucks since the engine will be operating at full governed speed the major part of the time. Fuel consumption on grades can therefore be expressed as a function of the time required to travel up the grade.

The discussion so far has been limited to the consideration of trucks powered with gasoline engines; however,

---

24.....Fuel weights:

| | | |
|---|---|---|
| 1. Diesel fuel (Slow speed - Industrial) = | 7.48 | lbs./gal. |
| 2. Diesel fuel (High speed - Bus and Truck) | 7.12 | " " |
| 3. Tractor fuel | 6.95 | " " |
| 4. Volatile tractor fuel | 6.50 | " " |
| 5. Third grade gasoline | 6.20 | " " |
| 6. Regular and Premium gasoline | 6.15 | " " |
| 7. Aviation gasoline | 6.00 | " " |

since diesel powered trucks have become increasingly more important in the field of transportation, some mention must be made of their fuel consumption characteristics.

Data on diesel fuel consumption, due to the relative newness of this type of engine in trucks, is even more meagre than data on gasoline consumption. Again, the only actual tests made have been conducted by the Oregon State Highway Commission. The following passage, taken from page three of the Oregon State Highway Department Technical Bulletin No. 5, present the conclusions derived from these tests. "Results from a survey comprising 100 vehicles in actual service show diesel fuel consumption, expressed in gallons per mile, to be 40 percent less than gasoline in relatively level country and 45 percent less in mountainous country".

The second savings, that of time, is also a function of speed, but not in the same sense as fuel consumption. Speed is affected by many factors, a few of which are listed below.

1. Improvement of road surfaces.
2. Reduction of rise and fall in elevation.
3. Improvement of gradients.
4. Improved alignment.
5. Increased shoulder widths.
6. Elimination of congestion.

7. Elimination of intersections and railroad crossings.

All of the above factors are important in relation to speed, but space limits this discussion to gradients. A reduction of rise and fall, which is closely related to the reduction of gradient, is almost impossible in logging operations. In public highway location, rise and fall may be reduced to a minimum; but for a logging operation in rough terrain, routes are frequently limited by topography; consequently rise and fall is fixed. The gradient, however, can be changed in most cases.

A 40,000 pound truck traveling over a mile of 3 percent grade will use 0.2996 gallons of fuel. The same truck traveling on an alternate route, but so divided that one half of the distance is on the level and the other half of the distance is on a 6 percent grade, will use 0.3637 gallons of gasoline. The rise and fall has remained the same in both cases, 168 feet, but the reduction of the rate of grade, or gradient, has reduced fuel consumption 0.0641 gallons per mile. In this situation it was assumed that the rise and fall was restricted, as is the case, for the logger. If this situation had existed in the location of a public highway and it had been possible to reduce the total rise and fall to 106 feet with no increase in distance the following computations would be made:

Route 1

Distance: One mile.
Rise and fall: 168 feet
Sections: Continuous at 3%

$$\text{Fuel} = 0.0000731\ (40{,}000^{0.785})$$
$$= 0.2996 \text{ miles per gallon.}$$

Route #2

Distance: One mile.
Rise and fall: 168 feet
Sections: $\frac{1}{2}$ mile at 0 percent grade
$\frac{1}{2}$ mile at 6 percent grade

$$\text{Fuel} = 0.0001283\ (40{,}000^{0.712})$$
$$= .2426 \times .5 \text{ mile} = 0.1213$$
$$\text{Fuel} = 0.0000260\ (40{,}000^{0.928})$$
$$= .4849 \times .5 \text{ mile} = 0.2424$$

Total fuel = 0.3637 miles per gallon

Route #3

Distance: One mile
Rise and fall: 106 feet
Sections: Continuous at 2%

$$\text{Fuel} = 0.0000954\ (40{,}000^{0.750})$$
$$= .2698 \text{ miles per gallon}$$

The above principle, that total rise and fall in logging road cannot be reduced, will hold true for time savings as well. Since time savings are a function of speed, formulae have been developed by which speed for commercial vehicle operating on public roads can be determined. The following have been used by the Oregon State Highway Commission.

Composite grades -

$$\text{Speed (mph)} = 60 - 0.5\ gvw - 1.5\ G^{1.47}$$

Ascending grades only -

$$\text{Speed (mph)} = 60 - 0.5\ gvw - 4.33\ G$$

where

gvw is the gross vehicle weight in thousands of pounds, and
G is the grade in percent.

The following formula is more applicable to log trucks.

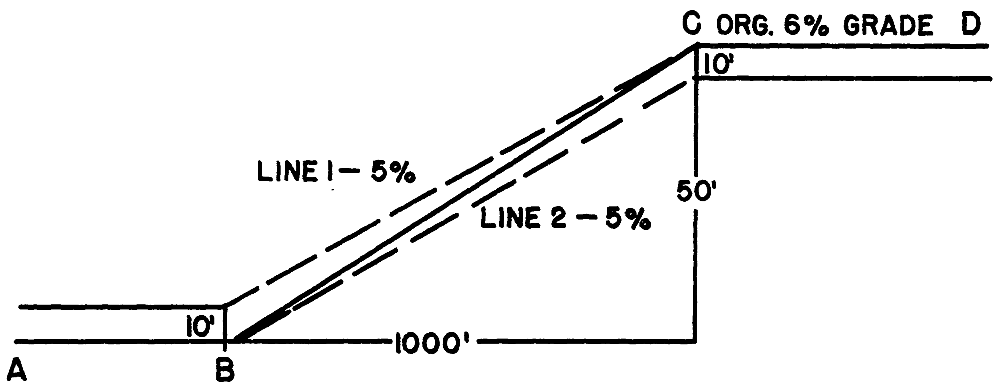
$$M.P.H. = \frac{375\ H.P.}{GVW\ (f + g)}$$

For any truck of a specified gross weight, the difference in speeds corresponding to two grades can be found by means of the above formula. However, it is the loss of time, rather than the difference in speed that is usually required. It then becomes necessary to change the speed corresponding to each grade to "time in hours to travel one mile". The difference in these times will then give the time lost in traveling one mile on one grade rather than the other. The following table may be found useful, though generally the time difference can be calculated quite readily for the particular case in which loss of time is a factor. Time required to travel one mile can be found by dividing one hour by the speed in mile per hour.

Table 6 - Time in Hours to Travel One Mile

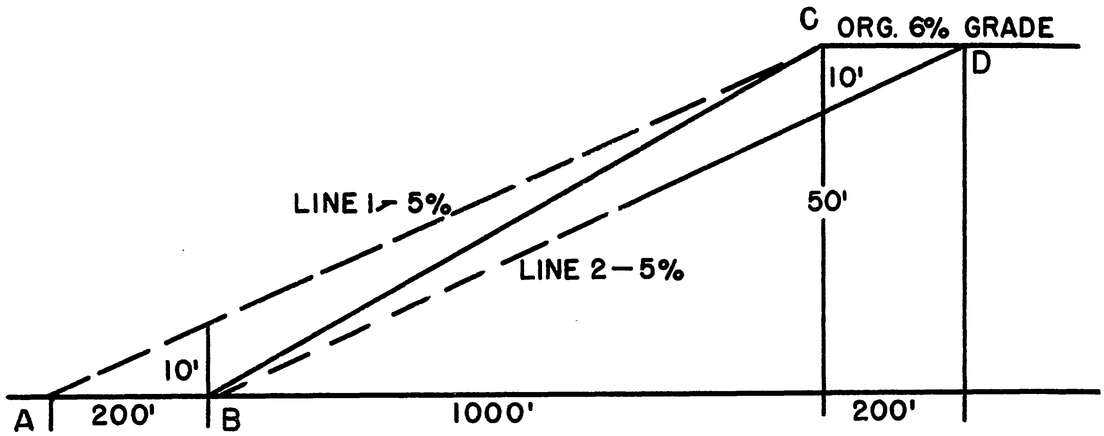
| Speed MPH | Time for One Mile | Speed MPH | Time for One Mile | Speed MPH | Time for One Mile | Speed MPH | Time for One Mile |
|---|---|---|---|---|---|---|---|
| 1 | 1.000 | 11 | 0.0910 | 21 | 0.4760 | 31 | 0.0323 |
| 2 | 0.5000 | 12 | 0.0833 | 22 | 0.4540 | 32 | 0.0325 |
| 3 | 0.3333 | 13 | 0.0769 | 23 | 0.4345 | 33 | 0.0303 |
| 4 | 0.2500 | 14 | 0.0714 | 24 | 0.4165 | 34 | 0.0294 |
| 5 | 0.2000 | 15 | 0.0667 | 25 | 0.0400 | 35 | 0.0286 |
| 6 | 0.1666 | 16 | 0.0625 | 26 | 0.0384 | 36 | 0.0279 |
| 7 | 0.1430 | 17 | 0.0588 | 27 | 0.0370 | 37 | 0.02705 |
| 8 | 0.1250 | 18 | 0.0556 | 28 | 0.0357 | 38 | 0.0263 |
| 9 | 0.1112 | 19 | 0.0526 | 29 | 0.0345 | 39 | 0.0256 |
| 10 | 0.1000 | 20 | 0.0500 | 30 | 0.0333 | 40 | 0.0250 |

The actual mechanical reduction of a grade can be accomplished in several ways. One method is by the reduction in total rise and fall as shown below:




In the example the original grade is 6 percent. A fill of 10 feet between points A and B reduces the grade to 50 feet, the result being a 5 percent grade with the original distance of 1000 feet. A cut of 10 feet between points C and D will give the same result.

The other method of grade reduction requires an increase in the length of the grade, but expensive earth moving operations are not involved, as is the case if the first method were used and the total height of the grade reduced.

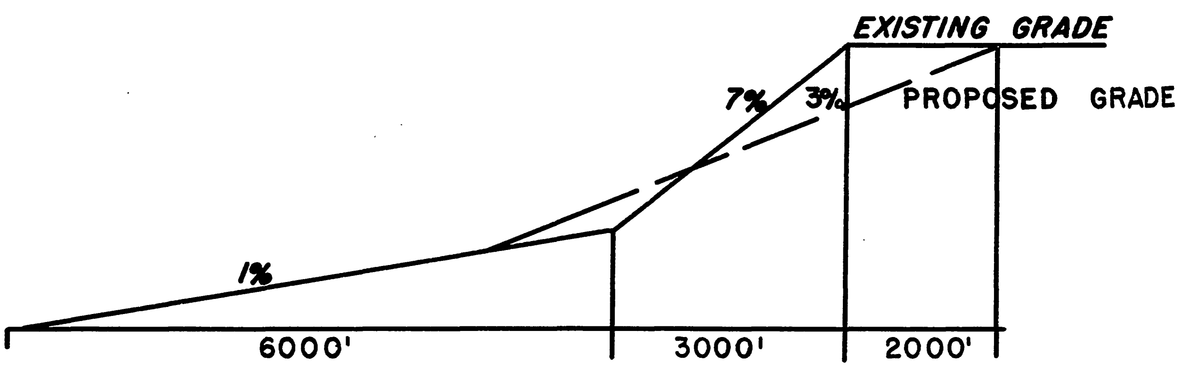



In this case the elevation B can be increased 10 feet and the 5 percent grade can be continued to A; the length of the grade is thus increased from 1000 to 1200 feet. Or, the grade at C can be reduced 10 feet and the 5 percent grade continued to D, the length of the grade likewise being increased to 1200 feet. A third way, and usually the most economical one, consists in raising the grade at B five feet and lowering the grade at C by 5 feet. An additional length of 100 feet would be necessary between A and B, and another 100 feet would be necessary between C and D, so that the total length of the grade would again be 1200 feet.

Now that both methods of calculating savings due to grade reductions have been explained and formulae presented by which these savings can be determined, the sample problem following may be used as a guide to show the steps involved in determining the savings possible by any grade reduction.

Example.

On a certain operation the main line logging road crosses a saddle between two ranges of mountains. The grade approaching the saddle is 6000 feet in length with a constant rise of about 1 percent. The last 3000 feet rises 210 feet, or has a grade of 7 percent. What saving can be made if the last 3000 feet are reduced to a 3 percent grade? Traffic over the road is 25 trucks per day with an average load of 100,000 pounds. The road is type 4, a good haul road with a resistance of about 2 percent. Variable hauling cost is $2.00; fixed operating cost is $5.00. Safe speed is limited to 20 MPH.



Rise in height of 7% grade = 3000' x 7% = 210'

Length necessary for 3% grade to reach 210' = 210' ÷ 3% = 7000'

Length of 3% grade 7000'

Length of 7% grade 3000'

Comparative Grade Sections -

| Existing Grade: | | Proposed Grade: | |
|---|---|---|---|
| (a) | 6000 feet at 1% | ($a_1$) | 4000 feet at 1% |
| (b) | 3000 feet at 7% | ($b_1$) | 7000 feet at 3% |
| (c) | 2000 feet at 0% | | |
| | 11,000 feet | | 11,000 feet. |

Note: Since the resistance of the road surface is equal to a 2 percent grade (approximately 20 pounds per 1000 pounds) this figure must be added to the gradients in order to solve for the true possible savings, i.e., fuel consumption and hauling time on the 7 percent grade will actually be equivalent to those for a 9 percent grade.

Time Savings -

Determine the speed using this formula:

$$\text{M.P.H.} = \frac{375\ \text{H.P.}}{\text{GVW}\ (f + g)}$$

(d) Speed on existing 1% grade (Figured as 3% grade.)

Assume: 19 m.p.h.

$$\text{M.P.H.} = \frac{375 \times 200}{100,000\ (.0087 + .03)}$$

$$= \frac{75000}{3870}$$

$$= 19.4$$

Time on this grade = 1 hr. ÷ 19.4 mph $\left(\frac{6000}{5280}\right)$ = 0.0586 hrs.

(b) Speed on the existing 7% grade (Figured as 9% grade.)

Assume: 8 m.p.h.

$$\text{M.P.H.} = \frac{375 \times 200}{100,000\ (.0077 + .09)}$$

$$= \frac{75000}{9770}$$

$$= 7.7$$

Time on this grade = 1 hr. ÷ 7.7 mph $\left(\frac{3000}{5280}\right)$ = 0.0740 hrs.

(c) Speed on existing level section (Figured as 2% grade.)

Assume: 26 m.p.h.

$$\text{M.P.H.} = \frac{375 \times 200}{100,000\ (.0093 + .02)}$$

$$= \frac{75000}{2930}$$

$= 25.6$

Time on this grade = 1 hr ÷ 20 mph (safe speed) $(\frac{2000}{5280})$ = 0.0190 hrs.

($a_1$) Speed on the remainder of the 1% grade after new grade is cut. This calculation will be the same as in (a) except the distances are different.

Time on this grade = 1 hr. ÷ 19.4 mph $(\frac{4000}{5280})$ = 0.0391

($b_1$) Speed on the 3% grade. (Figured as 5% grade.)

Assume: 13 m.p.h.

$$\text{M.P.H.} = \frac{375 \times 200}{100{,}000\ (.008 + .05)}$$

$$= \frac{75000}{5800}$$

$$= 13 \text{ m.p.h.}$$

Time on this grade = 1 hr. ÷ 13 mph $(\frac{7000}{5280})$ = 0.1020

Total time -

| Existing grade | | Proposed grade | |
|---|---|---|---|
| 1% grade = | 0.0586 | 1% grade = | 0.0391 |
| 7% grade = | 0.0740 | 3% grade = | 0.1020 |
| 0% grade = | 0.0190 | | |
| | 0.1516 | | 0.1411 |

Time savings

| | | |
|---|---|---|
| Total time on existing grade | = 0.1516 | hrs |
| Total time on proposed grade | = 0.1411 | hrs |
| Savings in hours | 0.0105 | hrs |
| Trucks per day | 25 | |
| Savings per day | 0.2625 | hrs |
| Working days per year | 300 | |
| Saving per year | 78.7500 | |
| Fixed operating cost | $ 5.00 | |
| Saving per year | $ 393.75 | |

Engine - Waukesha, model 6-WAL

Net horsepower 200 at 1800 r.p.m.

Lbs. fuel/bhp-hr at 1800 r.p.m. = .570 (70-octane gasoline)

Gallons per pound of 70-octane gasoline = 6.20

$$\text{Gallons per hour} = \frac{.570 \times 200}{6.20}$$

$$= 18.4$$

(a) Fuel consumption on existing 1% grade.

18.4 gallons x 0.0586 hrs = 1.078 gallons.

(b) Fuel consumption on existing 7% grade.

18.4 gallons x 0.0740 = 1.362 gallons

(c) Fuel consumption on the existing level grade.

18.4 gallons x 0.0190 = 0.350 gallons

($a_1$) Fuel consumption on the remainder of the 1% grade.

18.4 gallons x 0.0391 = 0.719

($b_1$) Fuel consumption on the 3% grade.

18.4 gallons x 0.1020 = 1.877 gallons

Total fuel

Existing grade:

| | | | |
|---|---|---|---|
| 1% grade | = | 1.078 | gals. |
| 7% " | = | 1.362 | " |
| 0% " | = | 1.350 | " |
| | | 3.790 | |

Proposed grade:

| | | |
|---|---|---|
| 1% grade | = | 0.719 |
| 3% grade | = | 1.877 |
| | | 2.596 |

Fuel Savings

| | | |
|---|---|---|
| Existing grade = | 3.790 | gallons |
| Proposed grade = | 2.596 | " |
| Gallons saved per trip | 1.194 | " |
| Trucks per day | 25 | |
| Gallons saved per day | 29.85 | |
| Workingdays per year | 300 | |
| Gallons saved per year | 8955 | |
| Cost per gallon | .20 | |
| Dollars saved per year | $1791.00 | |

| | |
|---|---|
| Saving in time = | $ 393.75 |
| Saving in fuel = | 1791.00 |
| Total saved per year = | $ 2184.75 |

Now that the total saving per year is known the amount that can be spent to effect the grade reduction must be determined. Naturally any money that is invested must be figured at some rate of interest, regardless of whether it is borrowed or not. If the investment is to be recovered in 15 years, and 5 percent interest must be made, the following compound interest formula will be used.

$$Co = \frac{a\,(1.0\,p^n - 1)}{0.0\,p \times 1.0\,p^n}$$

where

Co is the amount that can be spent,
a is the annual saving,
p is the rate of interest, and
n is the number of years.

Substituting the correct values in the given formula:

$$Co = \frac{\$2185.00\ (1.05^{15} - 1)}{0.05 \times 1.05^{15}}$$

$$= \frac{2185.00\ (2.079-1)}{0.05 \times 2.079}$$

$$= \$2185.00\ (10.3797)$$

$$= \$22{,}620.00$$

The use of five percent in the foregoing problem for captalizing the savings in operating cost may be questioned. If money can be borrowed at five percent, and the annual savings amounts to only five percent on the investment, it is doubtful whether the investment should be made. For a private enterprise, some additional return above the bare interest should be obtainable in order to justify the expenditure. (See the following calculation.) Some economists have suggested that a rate of interest that is double the prevailing rate should be used in capitalizing the savings.

Some engineers have followed the practice of capitalizing the savings as continuing forever. Following this practice, and assuming the logging situation just used was to be placed on sustained yield and that an interest rate of six percent was required, the amount that could be spent for grade reduction would be determined as follows:

$$= \frac{3431.25}{0.06}$$

$$= \$57{,}187.50$$

The above procedure is based upon an illogical assumption; viz., that a road will last forever. Therefore, it is suggested that the amount to be spent be figured only for a fixed period. This period can be determined only by experience; better roads will last longer than poor, and should be capitalized accordingly.

Close examination of the preceding problem will make another fact evident, viz., that improvements in road surfacing may be treated as grade reductions.

In the table of conversion factors, given at the end of the first section, road resistances were evaluated as rates of grade. These conversion factors were based upon the assumption that the average resistance on concrete is 10 pounds, which is equal to the resistance encountered in moving 1000 pounds up a 1 percent grade. Therefore, if a road is so improved that the resistance drops 10 pounds per 1000 pounds, it is the same as reducing the grade 1 percent.

In the previous problem it is quite obvious that if the grade reduction had been made it would not be economical to improve the remaining 4000 foot length of 1 percent grade, as maximum safe speed has been attained. However, the operator in this instance decided that if the 7000 foot 3 percent grade were graded, limed and watered daily, tractive resistance could be reduced 10 pounds per 1000. The cost of this work has been found through experience to cost about $500.00 per mile per year. Would it be economical to improve the surface of the road?

Assume: 16 mph

$$M.P.H. = \frac{375 \times 200}{100,000\ (.0083 + .04)}$$

$$= \frac{75000}{4830}$$

$$= 15.6$$

Time on this grade = 1 hr. ÷ 15.6 $\left(\frac{7000}{5280}\right)$ = 0.0855 hrs.

Fuel consumption

18.4 gallons x 0.0855 hrs = 1.57 gals.

Comparative savings -

| Time: | | | Fuel: | | |
|---|---|---|---|---|---|
| Unimproved | 0.1020 | hrs | Unimproved | 1.877 | gallons |
| Improved | 0.0855 | " | Improved | 1.570 | " |
| | .0165 | hrs | | 0.307 | " |
| Trucks per day | 25 | | | 25 | |
| Savings per day | .4125 | hrs | | 7.675 | " |
| Days per year | 300 | | | 300 | |
| Saving per year | 123.75 | hrs | | 2202.50 | " |
| Operating costs | 5.00 | per hr. | Cost of fuel | 20¢ | per gal. |
| | $618.75 | | | $440.50 | |

| | |
|---|---|
| Time Savings | $ 618.75 |
| Fuel Savings | 440.50 |
| Savings per yr | $1059.25 |

Since the cost of improvement is $500.00 $\left(\frac{7000}{5280}\right)$ = $665.00 the improvement should be made.

To find the amount that can be spent use the compound interest formula that has been given.

Substituting:

$$Co = \frac{\$1059.00\ (1.05^{15} - 1)}{0.05 \times 1.05^{15}}$$

$$= \frac{\$1059.00\ (2.079 - 1)}{0.05 \times 2.079}$$

$$= \$1059.00\ (10.3797)$$

$$= \$11,000.00$$

Of the factors affecting speed it is now possible to determine saving due to:

1. Improved road surfaces.
2. Reduction of rise and fall.
3. Reduced gradients.

# SECTION IV

# SAMPLE PROBLEM

## Sample Problem

In order to demonstrate the practical application of the principles that have been set forth, a situation has been assumed in which it is necessary to select the correct type of hauling equipment, giving due consideration to possible road locations and road surfaces.

The costs which are used in this illustration are not meant to apply to any particular operation, they are merely an average of what might be expected.

The tract of timber to be logged is composed of several townships lying adjacent to one another. The area has been cruised and the volume found to be 2,300,000,000 board feet. Since an annual cut of 130,000,000 board feet is needed to supply the mill the operation is expected to last about 20 years. The interior logging roads have been planned and all that remains is to locate the main haul road and select the hauling equipment. For this purpose the following data has been collected:

Possible Main Line Roads -

Route I.

| | | |
|---|---|---|
| Section | 1. | 7.85 mi. at + 1%. |
| " | 2. | 1.30 mi. at + 3%. |
| " | 3. | 3.00 mi. at 0%. |
| " | 4. | 4.95 mi. at - 2.34% |

Route II.

| | | |
|---|---|---|
| Section | 1. | 0.41 mi. at 0% |
| " | 2. | 1.70 mi. at + 8% |
| " | 3. | 1.60 mi. at - 5% |

| | | |
|---|---|---|
| Section 4. | 1.86 mi. at - 3% | |
| " 5. | 3.84 mi. at + 2% | |
| " 6. | 0.50 mi. at - 15.4% | |

Note: Plus grades are considered adverse when the trucks must negotiate the grade when loaded.

Possible Road Surfaces -

Type II. Good Macadam.
Resistance - 1.5% (or 15 lbs. per 1000 lbs.)
Construction Cost per Mile:

| | | |
|---|---|---|
| Route I | Light Trucks | $ 10,000 |
| | Medium " | 11,000 |
| | Heavy " | 13,000 |
| Route II | Light " | 12,000 |
| | Medium " | 13,000 |
| | Heavy " | 15,000 |

Maintenance Cost per Mile per Year:

| | | |
|---|---|---|
| Route I | Light Trucks | $ 300 |
| | Medium " | 400 |
| | Heavy " | 500 |
| Route II | Light " | 400 |
| | Medium " | 500 |
| | Heavy " | 600 |

Type III. Hard Clay-Bound Gravel, Rolled, and Watered Daily.
Resistance - 2.5% (or 25 lbs. per 1000 lbs.)
Construction Cost per Mile:

| | | |
|---|---|---|
| Route I | Light Trucks | $4,000 |
| | Medium " | 5,000 |
| | Heavy " | 7,000 |
| Route II | Light " | 5,000 |
| | Medium " | 6,000 |
| | Heavy " | 8,000 |

Maintenance Cost per Mile:

| | | |
|---|---|---|
| Route I | Light Trucks | $ 400 |

| | | |
|---|---|---|
| | Medium Trucks | $ 500 |
| | Heavy " | 600 |
| Route II | Light " | 500 |
| | Medium " | 600 |
| | Heavy " | 700 |

Type IV. Good Haul Road. Hard-Packed Natural Soil, Stabilized Subgrade, Watered Daily.
Resistance - 4.0% (or 40 lbs. per 1000 lbs.)
Construction Cost per Mile:

| | | |
|---|---|---|
| Route I | Light Trucks | $ 2,500 |
| | Medium " | 3,500 |
| | Heavy " | 5,500 |
| Route II | Light " | 3,500 |
| | Medium " | 4,500 |
| | Heavy " | 6,500 |

Maintenance Cost per Mile per Year:

| | | |
|---|---|---|
| Route I | Light Trucks | $ 475 |
| | Medium " | 575 |
| | Heavy " | 675 |
| Route II | Light " | 575 |
| | Medium " | 675 |
| | Heavy " | 775 |

Type V. Fair Haul Road. Partially Packed to Flexible Under Medium and Heavy Loads.
Resistance -5% (or 50 lbs. per 1000 lbs.)
Construction Cost per Mile:

| | | |
|---|---|---|
| Route I | Light Trucks | $ 1,250 |
| | Medium " | 2,250 |
| | Heavy " | 4,250 |
| Route II | Light " | 1,500 |
| | Medium " | 2,500 |
| | Heavy " | 4,500 |

Maintenance Cost per Mile per Year:

| | | |
|---|---|---|
| Route I | Light Trucks | $ 550 |

| | | |
|---|---|---|
| | Medium Trucks | $ 650 |
| | Heavy " | 750 |
| Route II | Light " | 650 |
| | Medium " | 750 |
| | Heavy " | 850 |

Possible Truck Types -

Light Trucks:

Engine.

| | |
|---|---|
| Displacement | 245 cubic inches. |
| Maximum torque | 191 ft.-lbs at 1000 rpm. |
| Maximum horsepower | 89 hp. at 3100 rpm. |
| Fuel consumption | 0.67 lbs. per bhp-hr at 3100 rpm. |
| | 0.59 lbs. per bhp-hr at 500 rpm. |

Weights.

| | |
|---|---|
| Payload | 35,375 lbs (or about 7M) |
| G.V.W. | 43,800 lbs. |
| Empty | 8,425 lbs. |
| Machine rate | $3.50 per hr. |

Medium Trucks:

Engine.

| | |
|---|---|
| Displacement | 501 cubic inches. |
| Maximum torque | 384 ft.-lbs at 1200 rpm. |
| Maximum horsepower | 148 hp at 2400 rpm. |
| Fuel consumption | 0.62 lbs per bhp-hr at 2400 rpm. |
| | 0.64 lbs per bhp-hr at 600 rpm. |

Weights.

| | |
|---|---|
| Payload | 65,195 lbs. (or about 9M) |
| G.V.W. | 81,500 lbs. |
| Empty | 15,305 lbs. |
| Machine rate | $6.50 per hr. |

Heavy Trucks:

Engine.

| | |
|---|---|
| Displacement | 1090 cubic inches. |
| Maximum torque | 940 ft.-lbs at 1300 rpm. |
| Maximum horsepower | 295 hp. at 2000 rpm. |
| Fuel consumption | 0.56 lbs. per bhp-hr at 2000 rpm. |
| | 0.54 lbs. per bhp-hr at 800 rpm. |

Weights.

| | |
|---|---|
| Payload | 324,100 lbs. (or about 43M) |
| G.V.W. | 358,600 lbs. |
| Empty | 34,500 lbs. |
| Machine rate | $14.00 per hr. |

Note 1. Resistance on the loaded trip will be calculated as a normal tractor-truck semi-trailer, but since it is the practice to load the trailer on the tractor for the return trip the resistance will therefore be calculated as a single unit truck. An exception to this will be the heavy truck. The heavy truck is equipped with an extra three axle trailer which cannot be loaded. Consequently, the return trip for the heavy truck will be calculated as a semi-trailer.

Note 2. When the required horsepower drops below the output at idling speed (as shown in the fuel consumption data) fuel consumption will be figured on the fuel that would be used at idling speed multiplied by the required horsepower, the product of which is divided by 6.2 pounds, the weight of 1 gallon of gasoline. Since it is the practice of truck drivers to put the vehicle into gear and come down steep grades under compression rather than using their brakes, fuel consumption will be determined in the same manner as is done for a positive horsepower output.

Note 4. All costs will be determined for a round-trip mile.

Note 5. Average speed is calculated by the following formula:

$$M.P.H. = \frac{2\,HL}{HL}$$

where

H is the high speed, and
L is the low speed.

Note 6. Hauling cost per M for a round-trip mile will be calculated by the following formula:

$$H.C. = \frac{2 \times M.R.}{M.P.H. \times Ld}$$

where

M.R. is the hourly machine rate,
M.P.H. is the average round-trip speed, and
Ld is the load in thousands of board feet (M).

Selection of the correct route and road type for LIGHT TRUCKS.

**Loaded**

Type II. Assume: 29 mph.

$$MPH = \frac{375 \times 89}{44000\ (.015 + .00113)}$$

$$= \frac{33375}{1159}$$

$$= 28.8$$

Over a safe loaded speed of 20 mph. Calculate the horsepower required for 20 mph.

$$20 = \frac{375\ H.P.}{44000\ (.015 + .0097)}$$

$$20 = \frac{375\ H.P.}{1088}$$

$$H.P. = \frac{21760}{.375}$$

$$H.P. = 58$$

**Empty**

Type II. Determine the horsepower as it is quite obvious that a safe empty speed of 40 mph will be exceeded.

$$40 = \frac{375\ H.P.}{8000\ (.015 + .035)}$$

$$40 = \frac{375\ H.P.}{400}$$

$$H.P. = \frac{16000}{375}$$

$$H.P. = 43$$

Fuel used at 43 hp.:

$$= \frac{.52 \times 43}{6.2}$$

$$= 3.60 \text{ gals. per hr.}$$

Loaded

Fuel used at 58 hp.:

$$= \frac{.52 \times 56}{6.2}$$

= 4.86 gals. per hr.

1 hr. ÷ 20 mph = 0.05 hr per mi.
0.05 hr. per mi. x 4.86 gals. per hr. = 0.243 gal. per mi. x 20¢ per gal. = 4.86¢ per mi.

Empty

1 hr. ÷ 40 mph. = 0.025 hr. per mi.
0.025 hr. per mi. x 3.60 gals. per hr. = 0.0900 gal. per mi. x 20¢ per gal. = 1.80 ¢ per mi.

---

Type III. Assume: 22 mph.

$$MPH = \frac{375 \times 89}{44000\ (.025 + .0099)}$$

$$= \frac{33375}{1535}$$

= 21.7 (safe enough)

1 hr. ÷ 20 mph = 0.05 hr per mi.
0.05 hr. per mi. x 9.52 gals. per hr. = 0.476 gal. per mi. x 20¢ per gal. = 9.50¢ per mi.

Type II. Calculate horsepower.

$$40 = \frac{375\ H.P.}{8000\ (.025 + .035)}$$

$$40 = \frac{375\ H.P.}{480}$$

$$H.P. = \frac{19200}{375}$$

H.P. = 51

Fuel used at 51 hp.:

$$= \frac{.52 \times 51}{6.2}$$

= 4.28 gals. per hr.

1 hr. ÷ 40 mph = 0.025 hr. per mi.
0.025 hr. per mi. x 4.28 gals.

| Loaded | Empty |
| --- | --- |
| | per hr. = 0.107 gal. per mi. x 20¢ per gal. = 2.14¢ per mi. |

---

**Type IV. Assume: 15 mph.**

$$MPH = \frac{375 \times 89}{44000\ (.04 + .0088)}$$

$$= \frac{33375}{2145}$$

$$= 15.5$$

1 hr. ÷ 15.5 mph = 0.0645 hr per mi.
0.0645 hr. per mi. x 9.52 gals. per hr. = 0.614 gal. per mi. x 20¢ per gal. = 12.30¢ per mi.

**Type IV. Calculate horsepower.**

$$40 = \frac{375\ H.P.}{8000\ (.04 + .035)}$$

$$40 = \frac{375\ H.P.}{600}$$

$$H.P. = \frac{24000}{375}$$

$$H.P. = 64$$

Fuel used at 64 hp.:

$$= \frac{.52 \times 64}{6.2}$$

= 5.37 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi.
0.025 hr. per mi. x 5.37 gals. per hr. = 0.1345 gal. per mi. x 20¢ per gal. = 2.69¢ per mi.

---

**Type V. Assume: 13 mph.**

$$MPH = \frac{375 \times 89}{44000\ (.05 + .0084)}$$

$$= \frac{33375}{2570}$$

**Type V. Calculate horsepower.**

$$40 = \frac{375\ H.P.}{8000\ (.05 + .035)}$$

$$40 = \frac{375\ H.P.}{680}$$

**Loaded**

= 13

1 hr. ÷ 13 mph. = 0.0770 hr. per mi.
0.0770 hr. per mi. x 9.52 gals. per hr. = 0.734 gal. per mi. x 20¢ per gal. = 14.7¢ per mi.

**Empty**

$$H.P. = \frac{27200}{680}$$

H.P. = 73

Fuel used at 73 hp.:

$$= \frac{.53 \times 73}{6.2}$$

= 6.24 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi.
0.025 hr. per mi. x 6.24 gals. per hr. = 0.1560 gal. per mi. x 20¢ per gal. = 3.12¢ per mi.

---

Round-trip calculations:

Type II.

Round-trip speed.

$$\frac{2(40)(20)}{40 + 20}$$

= 26.7 mph.

Fuel per M per mi.

4.86¢
1.80
6.66¢ ÷ 5M = 1.333¢

Type III.

Round-trip speed.

$$\frac{2(40)(20)}{40 + 20}$$

= 26.7 mph.

Fuel per M per mi.

$$\begin{array}{r} 9.50¢ \\ 2.14 \\ \hline 11.64¢ \end{array} \div 5M = 2.328¢$$

Type IV.

Round-trip speed.

$$\frac{2(40)(15.5)}{40 + 15.5}$$

$$= 22.3 \text{ mph.}$$

Fuel per M per mi.

$$\begin{array}{r} 12.30¢ \\ 2.69 \\ \hline 14.99¢ \end{array} \div 5M = 2.998¢$$

Type V.

Round-trip speed.

$$\frac{2(40)(13)}{40 + 13}$$

$$= 19.6 \text{ mph.}$$

Fuel per M per mi.

$$\begin{array}{r} 14.74¢ \\ 3.12 \\ \hline 17.86¢ \end{array} \div 5M = 3.572¢$$

Summary of Costs for Route I

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi | Const. per mi. Rt. I | Const. per M per mi. | Maint. per yr. Rt. I | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 26.7 | 5.25¢ | 1.333¢ | $10000 | 0.435¢ | $300 | 0.230¢ | 7.248¢ |
| III | 26.7 | 5.25¢ | 2.328¢ | 4000 | 0.174¢ | 400 | 0.308¢ | 8.060¢ |
| IV | 22.3 | 6.28¢ | 2.998¢ | 2500 | 0.109¢ | 475 | 0.366¢ | 9.753¢ |
| V | 19.6 | 7.14¢ | 3.572¢ | 1250 | 0.054¢ | 550 | 0.423¢ | 11.209¢ |

Summary of Costs for Route II

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 26.7 | 5.25¢ | 1.333¢ | $12000 | 0.521¢ | $400 | 0.308¢ | 7.412¢ |
| III | 26.7 | 5.25¢ | 2.328¢ | 5000 | 0.217¢ | 500 | 0.385¢ | 8.180¢ |
| IV | 22.3 | 6.28¢ | 2.998¢ | 3000 | 0.152¢ | 575 | 0.442¢ | 9.872¢ |
| V | 19.6 | 7.14¢ | 3.572¢ | 1500 | 0.065¢ | 650 | 0.500¢ | 11.277¢ |

Based on level performance the cost of transportating 1000 board feet can now be found for light trucks.

| | | | |
|---|---|---|---|
| Route I | 17.1 mi. x 7.248¢ | = | $1.24 |
| Route II | 9.9 mi. x 7.412¢ | = | .73 |
| Savings on Rt. II | | | $0.51 |

This calculation is based on level road performance, but can be used to determine the best road type, in both cases it would be Type II where total costs are lowest, and the most economical road location. For actual hauling costs similar calculations must be made for each individual section of the adopted road type and route.

Determinate of Actual Hauling Costs for Light Trucks on Route I

Type II Road

| Loaded | Empty |
|---|---|
| Section 1. | |
| Assume: 22 mph. | Calculate horsepower |
| $MPH = \frac{375 \times 89}{44000\ (.015 + .01 + .0099)}$ | $40 = \frac{375\ H.P.}{8000\ (.015 + .035 + -.01)}$ |
| $= \frac{33375}{1535}$ | $40 = \frac{375\ H.P.}{320}$ |
| $= 21.7$ mph (safe enough) | $H.P. = \frac{12800}{375}$ |

**Loaded**

1 hr. ÷ 20 mph = 0.05 hr. per mi. 0.05 hr. per mi. x 7.85 mi. = 0.392 hr. 0.392 hr. x 9.52 gals. per hr. = 3.74 gals. x 20¢ per gal. = 74.60¢

**Empty**

H.P. = 34

Fuel used at 34 hp.:

$$\frac{.52 \times 34}{6.2}$$

= 2.85 gals. per hr.

1 hr. ÷ 40 mph = 0.025 hr. per mi. 0.025 hr. per mi. x 7.85 mi. = 0.1965 hr. 0.1965 hr. x 2.85 gals. per hr. = 0.560 gal. x 20¢ per gal. = 11.20¢

---

## Section 2.

Assume: 14 mph.

$$MPH = \frac{375 \times 89}{44000(.015 + .03 + .0087)}$$

$$= \frac{33375}{2360}$$

$$= 14.1$$

1 hr. ÷ 14.1 mph. = 0.071 hr. per mi. 0.071 hr. per mi. x 1.3 mi. = 0.0925 hr. 0.0925 hr x 9.52 gals per hr. = 0.88 gal. x 20¢ per gal. = 17.60¢

Calculate horsepower

$$40 = \frac{375 \text{ H.P.}}{8000(.015 + .035 + -.03)}$$

$$40 = \frac{375 \text{ H.P.}}{160}$$

$$\text{H.P.} = \frac{6400}{375}$$

H.P. = 17

Fuel used at 17 hp.:

$$\frac{.55 \times 17}{6.2}$$

= 1.51 gals. per hr.

1 hr. ÷ 40 mph = 0.025 hr. per mi. 0.025 hr. per mi.

| Loaded | Empty |
| --- | --- |
| | x 1.3 mi. = 0.0325 hr. 0.0325 hr x 1.51 gals. per hr. = 0.049 gal. x 20¢ per gal. = 1.00¢ |

---

Section 3

**Loaded**

In the calculations necessary to determine road type it was found that a loaded truck could attain 20 mph on the level with a horsepower output of 58. Fuel consumption was also determined, and found to be 4.86 gals. per hr.

1 hr ÷ 20 mph. = 0.050 hr. per mi. 0.050 hr. per mi. x 3 mi. = 0.15 hr. 0.15 hr. x 4.86 gals. per hr. = 0.729 gal. x 20¢ per gal. = 14.60¢

**Empty**

In the calculations necessary to determine road type it was found that an empty truck could attain the speed of 20 mph. on the level with an output of 43 horsepower. Fuel consumption was also determined, and found to be 3.60 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 3 mi. = 0.075 hr. 0.075 hr. x 3.60 gals. per hr. = 0.270 gal. x 20¢ per gal. = 5.40¢

---

Section 4

**Loaded**

Calculate horsepower.

$$20 = \frac{375\ H.P.}{44000(.015+0097+\ -.0234)}$$

$$20 = \frac{375\ H.P.}{57}$$

$$H.P. = \frac{1144}{375}$$

$$H.P. = 3$$

Fuel used at 3 hp.:

**Empty**

Calculate horsepower.

$$40 = \frac{375\ H.P.}{8000(.015+.035+.0234)}$$

$$40 = \frac{375\ H.P.}{588}$$

$$H.P. = \frac{23450}{588}$$

$$H.P. = 63$$

Fuel used at 63 hp.:

| Loaded | Empty |
|---|---|
| $= \frac{.59 \times 3}{6.2}$ | $= \frac{.52 \times 63}{6.2}$ |
| = .315 gal. per hr. | = 5.25 gals. per hr. |
| 1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 4.95 mi. = 0.248 hr. 0.248 hr. x 0.315 gal. per hr. = 0.078 gal. 0.078 gal. x 20¢ per gal. = 1.56¢ | 1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 4.95 mi. = 0.124 hr. 0.124 hr. x 5.25 gals. per hr. = 0.651 gals. x 20¢ per gal. = 13.04¢ |

---

Calculation of the Actual Cost of Hauling over Route I

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| Section 1 | 0.3920 hr. | 74.60¢ | 0.1965 hr. | 11.20¢ |
| " 2 | 0.0925 | 17.60 | 0.0325 | 1.00 |
| " 3 | 0.1500 | 14.60 | 0.0750 | 5.40 |
| " 4 | 0.2480 | 1.56 | 0.1240 | 13.04 |
| Total | 0.8825 hr. | 108.36¢ | 0.4280 hr. | 30.64¢ |

Round-trip speed and fuel cost.

Loaded speed. 17.1 mi. ÷ 0.8825 hr = 19.4 mph.
Empty speed. 17.1 mi. ÷ 0.4280 hr = 40.0 mph.

$$\text{Round-trip speed} = \frac{2\,(40)(19.4)}{40 + 19.4}$$

$$= 26.2 \text{ mph.}$$

Fuel per M per mi.

| | |
|---|---|
| Loaded | 108.36 |
| Empty | 30.64 |
| | 139.00¢ ÷ 17.1 mi = 8.13¢ ÷ 5M = 1.625¢ |

Summary of Actual Costs for Route I.

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt I | Const. per M per mi. | Maint. per yr. Rt. I | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 26.2 | 5.34¢ | 1.625¢ | $10000 | 0.435¢ | $300 | 0.230¢ | 7.630¢ |

Actual Hauling Cost per M - Woods to Mill.

17.1 mi. x 7.63¢ = $1.30

Determination of Actual Hauling Costs for Light Trucks on Route II

Type II Road

**Loaded**

Section 1

Loaded speed on the level has been found to be 20 mph. at a power output of 58 horsepower. Fuel consumption for this speed is 4.86 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .41 mi. = 0.0205 hr. 0.0205 hr. x 4.86 gals. per hr. = 0.100 gal. x 20¢ per gal. = 2.00¢

**Empty**

Empty speed on the level has been found to be 40 mph. at a power output of 43 horsepower. Fuel consumption for this speed is 3.60 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x .41 mi. = 0.0103 hr. 0.0103 hr. x 3.60 gals. per hr. = 0.0370 gal. x 20¢ per gal. = 0.74¢

Section 2

Assume: 7 mph.

$$MPH = \frac{375 \times 89}{44000(.015 + .08 + .0081)}$$

Calculate horsepower

$$40 = \frac{375 \text{ H.P.}}{8000(.015 + .035 + -.08)}$$

**Loaded**

$$= \frac{33375}{4520}$$

$$= 7.4$$

1 hr. ÷ 7.4 mph. = 0.135 hr. per mi. 0.135 hr. per mi. x 1.7 mi. = 0.200 hr. 0.200 hr. x 9.52 gals. per hr. = 1.905 gals. x 20¢ = 38.05¢

**Empty**

$$40 \quad \frac{375 \text{ HP}}{-240}$$

$$\text{H.P.} = \frac{-9600}{375}$$

$$\text{H.P.} = -25.6$$

Fuel is computed as if the engine were developing 25.6 hp. as the driver would put the engine in compression rather than use brakes.

$$\frac{.54 \times 25.6}{6.2}$$

$$= 2.23 \text{ gals. per hr.}$$

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.7 mi. = 0.0425 hr. 0.0425 hr. x 2.23 gals. per hr. = 0.0947 gal. x 20¢ per gal. = 1.90¢

---

## Section 3

Calculate horsepower.

$$20 = \frac{375 \text{ H.P.}}{44000(.015 + .0097 + -.05)}$$

$$20 = \frac{375 \text{ H.P.}}{-1088}$$

$$\text{H.P.} = \frac{-21760}{375}$$

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{8000(.015 + .05 + .035)}$$

$$40 = \frac{375 \text{ H.P.}}{800}$$

$$\text{H.P.} = \frac{32000}{375}$$

**Loaded**

H.P. = - 58

Fuel used at 58 hp.:

$$\frac{.52 \times 58}{6.2}$$

= 4.87 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.6 mi. = 0.08 hr. 0.08 hr x 4.87 gals. per hr. = 0.390 gal. x 20¢ per gal. = 7.80¢

**Empty**

H.P. = 85

Fuel used at 85 hp.:

$$\frac{.59 \times 85}{6.2}$$

= 7.95 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. x 1.6 mi. = 0.04 hr. 0.04 hr. x 7.95 gals. per hr. = 0.318 gal. x 20¢ per gal. = 6.36¢

---

Section 4

**Loaded**

Calculate horsepower.

$$20 = \frac{375 \text{ H.P.}}{44000(.015+.0097+ -.03)}$$

$$20 = \frac{375 \text{ H.P.}}{-235}$$

$$\text{H.P.} = \frac{-4700}{375}$$

H.P. = -12.5

Fuel used at 12.5 hp.:

$$\frac{.59 \times 12.5}{6.2}$$

= 1.19 gals per hr.

**Empty**

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{8000(.015+.035+.03)}$$

$$40 = \frac{375 \text{ H.P.}}{640}$$

$$\text{H.P.} = \frac{25600}{375}$$

H.P. = 68

Fuel used at 68 hp.:

$$\frac{.52 \times 68}{6.2}$$

= 5.70 gals. per hr.

**Loaded**

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.86 mi. = 0.094 hr. 0.094 hr. x 1.19 gals. per hr. = 0.112 gal. x 20¢ per gal. = 2.24¢

**Empty**

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.86 mi. = 0.047 hr. 0.047 hr. x 5.70 gals. per hr. = 0.268 gal. x 20¢ per gal. = 5.36¢

---

## Section 5

Assume: 17 mph.

$$MPH = \frac{375 \times 89}{44000(.015+.02+.0093)}$$

$$= \frac{33375}{1940}$$

$$= 17.2$$

1 hr. ÷ 17.2 mph. = 0.0561 hr. per mi. 0.0561 hr. per mi. x 3.84 mi = 0.223 hr. 0.273 hr. x 9.52 gals. per hr. = 2.2 gals. x 20¢ per gal. = 42.40¢

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{8000(.015+.035+ -.02)}$$

$$40 = \frac{375 \text{ H.P.}}{240}$$

$$\text{H.P.} = \frac{9600}{375}$$

$$\text{H.P.} = 25.6$$

Fuel used at 25.6 hp.:

$$\frac{.54 \times 25.6}{6.2}$$

$$= 2.23 \text{ gals. per hr.}$$

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 3.84 mi. = 0.096 hr. 0.096 hr. x 2.23 gals. per hr. = 0.214 gal. x 20¢ per gal. = 4.23¢

---

## Section 6

### Loaded

Calculate horsepower.

$$20 = \frac{375\ H.P.}{44000(.015+.0097+-.154)}$$

$$20 = \frac{375\ H.P.}{-5830}$$

$$H.P. = \frac{-116600}{375}$$

$$H.P. = -311$$

Fuel calculated at the maximum.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .5 mi. = 0.025 hr. 0.025 hr. x 9.52 gals. per hr. = 0.238 gal. x 20¢ per gal. = 4.76¢

### Empty

Assume: 22 mph.

$$MPH = \frac{375 \times 89}{8000(.015+.154+.0174)}$$

$$= \frac{33375}{1490}$$

$$= 22.3$$

1 hr. ÷ 22.3 mph. = 0.045 hr. per mi. 0.045 hr. per mi. x .5 mi. = 0.0225 hr. 0.0225 hr. x 9.52 gals. per hr. = 0.214 gal. x 20¢ per gal. = 4.28¢

---

Calculation of the Actual Cost of Hauling over Route II.

| | Loaded Time | Loaded Fuel | Empty Time | Empty Fuel |
|---|---|---|---|---|
| Section 1 | 0.0205 hr. | 2.00¢ | 0.0103 | 0.74¢ |
| Section 2 | 0.2000 | 38.05 | 0.0425 | 1.90 |
| " 3 | 0.0800 | 7.80 | 0.0400 | 6.36 |
| " 4 | 0.0940 | 2.24 | 0.0465 | 5.36 |
| " 5 | 0.2230 | 42.40 | 0.0960 | 4.23 |
| " 6 | 0.0250 | 4.76 | 0.0225 | 4.28 |
| Total | 0.6425 hr. | 97.25¢ | 0.2578 | 22.87¢ |

Round-trip speed and fuel cost.

Loaded speed. 9.9 mi. ÷ 0.6425 hr. = 15.4 mph.
Empty Speed. 9.9 mi. ÷ 0.6425 hr. = 38.5 mph.

$$\text{Round-trip speed} - \frac{2(38.5)(15.4)}{38.5 + 15.4}$$

$$= 22 \text{ mph.}$$

Fuel per M per mi.

| | |
|---|---|
| Loaded | 97.25 |
| Empty | 22.87 |
| | 120.12 ÷ 9.9 mi. = 12.15¢ ÷ 5M = 2.42¢ |

Summary of Actual Costs for Route II

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 22 | 6.36¢ | 2.42¢ | $12000 | 0.522¢ | $400 | 0.308¢ | 9.61¢ |

Actual Hauling Cost per M - Woods to Mill.

9.9 mi. x 9.61¢ = $0.952

Selection of the correct route and road type for MEDIUM TRUCKS.

---

## Loaded

Type II. Calculate horsepower

$$20 = \frac{375\ H.P.}{82000\ (.015 + .009)}$$

$$20 = \frac{375\ H.P.}{1970}$$

$$H.P. = \frac{39400}{375}$$

H.P. = 105

Fuel used at 105 hp.:

$$= \frac{.57 \times 105}{6.2}$$

= 9.65 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 9.65 gals. per hr. = 0.482 gal. per mi. x 20¢ per gal. = 9.65¢ per mi.

## Empty

Type II. Calculate horsepower.

$$40 = \frac{375\ H.P.}{16000\ (.015 + .023)}$$

$$40 = \frac{375\ H.P.}{6070}$$

$$H.P. = \frac{24280}{375}$$

H.P. = 65

Fuel used at 65 hp.:

$$= \frac{.60 \times 65}{6.2}$$

= 6.28 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 6.28 gals. per hr. = 0.1570 gal. per mi. x 20¢ per gal. = 3.14¢ per mi.

---

## Loaded

Type III. Assume: 20 mph.

$$MPH = \frac{375 \times 148}{82000\ (.025 + .009)}$$

$$= \frac{55500}{2790}$$

## Empty

Type III. Calculate horsepower

$$40 = \frac{375\ H.P.}{16000\ (.025 + .023)}$$

$$40 = \frac{375\ H.P.}{767}$$

**Loaded**

$= 19.9$

1 hr. ÷ 19.9 mph. = 0.0503 hr. per mi. 0.0503 hr. per mi. x 14.8 gals. per hr. = 0.745 gal. per mi. x 20¢ per gal. = 14.90¢

**Empty**

$$H.P. = \frac{30650}{375}$$

H.P. = 82

Fuel used at 82 hp.:

$$= \frac{.58 \text{ x } 82}{6.2}$$

= 7.17 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 7.17 gals. per hr. = 0.1796 gal. per mi. x 20¢ per gal. = 3.59¢ per mi.

---

Type IV. Assume: 14 mph.

$$MPH = \frac{375 \text{ x } 148}{82000\ (.040 + .0083)}$$

$$= \frac{55500}{3960}$$

$= 14$

1 hr. ÷ 14 mph. = 0.0714 hr. per mi. 0.0714 hr. per mi. x 14.8 gals. per hr. = 1.058 gals. per mi. x 20¢ per gal. = 21.10¢ per mi.

Type IV. Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{16000\ (.04 + .023)}$$

$$40 = \frac{375 \text{ H.P.}}{1010}$$

$$H.P. = \frac{40400}{375}$$

H.P. = 108

Fuel used at 108 hp.:

$$= \frac{.57 \text{ x } 108}{6.2}$$

Loaded | Empty

**Empty (continued):**

= 9.95 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 9.95 gals. per hr. = 0.249 gal. per mi. x 20¢ per gal. = 4.97¢ per mi.

---

**Loaded:**

Type V. Assume: 12 mph.

$$\text{MPH} = \frac{375 \times 148}{82000\ (.05 + .0081)}$$

$$= \frac{55500}{4760}$$

$$= 11.6$$

1 hr. ÷ 11.6 mph. = 0.0863 hr. per mi. 0.0863 hr. per mi. x 14.8 gals. per hr. = 1.276 gals. per mi. x 20¢ per gal. = 25.5¢ per mi.

**Empty:**

Type V. Calculate horsepower.

$$40 = \frac{375\ \text{H.P.}}{16000\ (.05 + .023)}$$

$$40 = \frac{375\ \text{H.P.}}{1170}$$

$$\text{H.P.} = \frac{46700}{375}$$

$$\text{H.P.} = 125$$

Fuel used at 125 hp.:

$$= \frac{.58 \times 125}{6.2}$$

= 11.7 gals. per hr.

1 hr. ÷ 40 mph = 0.025 hr. per mi. 0.025 hr. per mi. x 11.7 gals. per hr. = 0.293 gal. per mi. x 20¢ per gal. = 5.85¢ per mi.

---

Round-trip calculations:

Type II

Round-trip speed. $\frac{2(40)(20)}{40 + 20}$

$= 26.7$ mph.

Fuel per M per mi.

$$\begin{array}{r} 9.65¢ \\ \underline{3.14} \\ 12.79¢ \div 5M = 1.421¢ \end{array}$$

Type III

Round-trip speed $\frac{2(40)(19.9)}{40 + 19.9}$

$= 26.6$ mph.

Fuel per M per mi.

$$\begin{array}{r} 14.90¢ \\ \underline{3.59} \\ 18.49¢ \div 9M = 2.05¢ \end{array}$$

Type IV

Round-trip speed. $\frac{2(40)(14)}{40 + 14}$

$= 20.7$ mph.

Fuel per M per mi.

$$\begin{array}{r} 21.10¢ \\ \underline{4.97} \\ 26.07¢ \div 9M = 2.89¢ \end{array}$$

Type V

Round-trip speed. $\frac{2(40)(11.6)}{40 + 11.6}$

$= 18$ mph.

Fuel per M per mi. 25.50¢
5.85
31.35 ÷ 9M = 3.49¢

Summary of Costs of Route I

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. I | Const. per M per mi. | Maint. per yr. Rt. I | Maint. per M per yr. | Total Costs |
|---|---|---|---|---|---|---|---|---|
| II | 26.7 | 5.41¢ | 1.421¢ | $11000 | 0.478¢ | $400 | 0.308¢ | 7.617¢ |
| III | 26.6 | 5.44¢ | 2.054¢ | 5000 | 0.217¢ | 500 | 0.385¢ | 8.096¢ |
| IV | 20.7 | 6.99¢ | 2.890¢ | 3500 | 0.152¢ | 575 | 0.442¢ | 10.474¢ |
| V | 18.0 | 8.03¢ | 3.490¢ | 2250 | 0.098¢ | 650 | 0.500¢ | 12.118¢ |

Summary of Costs for Route II

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. I | Const. per M per mi. | Maint. per yr. Rt. I | Maint. per M per yr. | Total Costs |
|---|---|---|---|---|---|---|---|---|
| II | 26.7 | 5.41¢ | 1.421¢ | $13000 | 0.565¢ | $500 | 0.385¢ | 7.781¢ |
| III | 26.6 | 5.44¢ | 2.054¢ | 6000 | 0.261¢ | 600 | 0.461¢ | 8.216¢ |
| IV | 20.7 | 6.99¢ | 2.890¢ | 4500 | 0.195¢ | 675 | 0.519¢ | 10.594¢ |
| V | 18.0 | 8.03¢ | 3.490¢ | 2500 | 0.109¢ | 750 | 0.576¢ | 12.205¢ |

Based on level performance the cost of transportating 1000 board feet can now be found for medium trucks.

Route I 17.1 mi. x 7.617¢ = $1.30
Route II 9.9 mi. x 7.781¢ = .77
Savings on Rt. II $0.53

For the determination of actual costs, as affected by grades, the following calculations are necessary:

Determination of Actual Hauling Costs for Medium Trucks on Route I

Type II Road

---

| Loaded | Empty |
|---|---|

Section 1

Assume: 20 mph.

$$MPH = \frac{375 \times 148}{82000(.015+.01+.009)}$$

$$= \frac{55500}{2785}$$

$$= 19.9$$

1 hr. ÷ 19.9 mph. = 0.0502 hr. per mi. x 7.85 mi. = 0.394 hr. 0.394 hr. x 14.80 gals. per hr. = 5.84 gals. x 20¢ = 116.70¢

Calculate horsepower

$$40 = \frac{375 \text{ H.P.}}{16000(.015+.023+ -.01)}$$

$$40 = \frac{375 \text{ H.P.}}{448}$$

$$\text{H.P.} = \frac{17910}{375}$$

H.P. = 47

Fuel used at 47 hp.:

$$\frac{.62 \times 47}{6.2}$$

= 4.7 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 7.85 mi. = 0.1965 hr. x 4.7 gals. per hr. = 0.919 gal. x 20¢ per gal. = 18.40¢

---

Section 2

Assume: 13 mph.

Calculate horsepower

### Loaded

$$MPH = \frac{375 \times 148}{82000(.015 + .03 + .0082)}$$

$$= \frac{55500}{4370}$$

$$= 12.7$$

1 hr. ÷ 12.7 mph. = 0.079 hr per mi. 0.079 hr. per mi. x 1.3 mi. = 0.1023 hr. 0.1023 hr. x 14.8 gal. per hr. = 1.515 gals. x 20¢ per gal. = 30.30¢

### Empty

$$40 = \frac{375 \text{ H.P.}}{16000(.015 + .023 + -.03)}$$

$$40 = \frac{375 \text{ H.P.}}{128}$$

$$\text{H.P.} = \frac{5120}{375}$$

$$\text{H.P.} = 14$$

Fuel used at 14 hp.:

$$= \frac{.64 \times 14}{6.2}$$

$$= 1.44 \text{ gals. per hr.}$$

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.3 mi. = 0.0325 hr. 0.0325 hr. x 1.44 gals. per hr. = 0.047 gal. x 20¢ per gal. = 0.94¢

---

## Section 3

In the calculations necessary to determine road type it was found that a loaded vehicle could attain 20 mph. on the level with an output of 105 horsepower. Fuel consumption was also determined, and found to be 9.65 gals. per hr.

1 hr. ÷ 20 mph. = 0.050 hr. per mi. 0.050 hr. per mi. x

In the calculations necessary to determine road type it was found that an empty vehicle could attain 40 mph. on the level with an output of 65 horsepower. Fuel consumption was also determined, and found to be 6.28 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x

**Loaded**

3 mi. = 0.15 hr. 0.15 hr. x 9.65 gals. per hr. = 1.45 gals. x 20¢ per gal. = 29.00¢

**Empty**

3 mi. = 0.075 hr. 0.075 hr. x 6.28 gals. per hr. = 0.470 gal. x 20¢ per gal. = 9.40¢

---

## Section 4

Calculate horsepower.

$$20 = \frac{375\ H.P.}{82000(.015 + .009 + -.0234}$$

$$20 = \frac{375\ H.P.}{49}$$

$$H.P. = \frac{980}{375}$$

H.P. = 2.5

Fuel used at 2.5 hp.:

$$= \frac{.64 \times 2.5}{6.2}$$

= .25 gal. per hr.

1 hr. ÷ 20 mph. = 0.050 hr. per mi. 0.050 hr. per mi. x 4.95 mi. x 0.248 hr. 0.248 hr. x 0.25 gals. per hr. = 0.06 gal. x 20¢ per gal. = 1.20¢

Calculate horsepower.

$$40 = \frac{375\ H.P.}{16000(.015 + .023 + .0234)}$$

$$40 = \frac{375\ H.P.}{984}$$

$$H.P. = \frac{39350}{375}$$

H.P. = 105

Fuel used at 105 hp. has been found to be 9.65 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 4.95 mi. = 0.124 hr. 0.124 hr. x 9.62 gals. per hr. = 1.193 gals. x 20¢ per gal. = 23.82¢

---

Calculation of the Actual Cost of Hauling over Route I

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| Section 1 | 0.3940 hr. | 116.70¢ | 0.1965 hr. | 18.40¢ |
| " 2 | 0.1023 | 30.30 | 0.0325 | .94 |
| " 3 | 0.1500 | 29.00 | 0.0750 | 9.40 |
| " 4 | 0.2480 | 1.20 | 0.1240 | 23.82 |
| Total | 0.8943 hr. | 177.20¢ | 0.4280 hr. | 52.36¢ |

Round-trip speed and fuel cost.

Loaded speed. 17.1 mi. $\div$ 0.8940 = 19.1 mph.
Empty speed. 17.1 mi. $\div$ 0.4280 = 40.0 mph.

Round-trip speed. $\frac{2(40)(19.1)}{40 + 19.1}$

= 25.8 mph.

Fuel per M per mi.

Loaded 177.20¢
Empty 52.36
229.56¢ $\div$ 17.1 mi. = 13.40¢ $\div$ 9M = 1.489¢

Summary of Actual Costs for Route I

| oad ype | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. I | Const. per M per mi. | Maint. per yr. Rt. I | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| I | 25.8 | 5.60¢ | 1.489¢ | $11000 | 0.478¢ | $400 | 0.308¢ | 7.875¢ |

Actual Hauling Cost per M - Woods to Mill.

17.1 mi. x 7.875¢ = $1.35

Determination of Actual Hauling Cost for Medium Trucks on Route II

Type II Road

---

Loaded | Empty

Section 1

**Loaded**

Loaded speed on the level has been found to be 20 mph. at a power output of 105 horsepower. Fuel consumption for this speed is 9.65 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .41 mi. = 0.0205 hr. 0.0205 hr. x 9.65 gals. per hr. = 0.198 gal. x 20¢ per gal. = 3.96¢

**Empty**

Empty speed on the level has been found to be 40 mph. at a power output of 65 horsepower. Fuel consumption for this speed is 6.28 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x .41 mi. = 0.0102 hr. 0.0102 hr. x 6.28 gals. per hr. = 0.0640 gal. x 20¢ per gal. = 1.28¢

---

Section 2

**Loaded**

Assume: 7 mph.

$$MPH = \frac{375 \times 148}{82000(.015+.08+.0077)}$$

$$= \frac{55500}{8435}$$

$$= 6.6$$

1 hr. ÷ 6.6 mph. = 0.152 hr. per mi. 0.152 hr. per mi. x 1.7 mi. = 0.304 hr. 0.304 hr. x 14.8 gals. per hr. = 4.5 gals. x 20¢ per gal. = 90.00¢

**Empty**

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{16000(.015+.023+ -.08)}$$

$$40 = \frac{375 \text{ H.P.}}{-672}$$

$$\text{H.P.} = \frac{-26880}{375}$$

$$\text{H.P.} = -71.7$$

Fuel used at 71.7 hp.:

$$\frac{.59 \times 71.7}{6.2}$$

**Loaded** | **Empty**

*Empty:*

= 6.81 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.7 mi. = 0.0425 hr. 0.0425 hr. x 6.81 gals. per hr. = 0.289 gal. x 20¢ per gal. = 5.77¢

---

## Section 3

*Loaded:*

Calculate horsepower.

$$20 = \frac{375 \text{ H.P.}}{82000(.015 + .009 + -.05)}$$

$$20 = \frac{375 \text{ H.P.}}{-2130}$$

$$\text{H.P.} = \frac{-42600}{375}$$

H.P. = -113.5

Fuel used at 113.5 hp.:

$$\frac{.57 \times 113.5}{6.2}$$

= 10.43 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.6 mi. = 0.08 hr. 0.08 hr x 10.43 gals. per hr. = 0.835 gal. x 20¢ per gal. = 16.70¢

*Empty:*

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{16000(.015 + .023 + .05)}$$

$$40 = \frac{375 \text{ H.P.}}{1410}$$

$$\text{H.P.} = \frac{56400}{375}$$

H.P. = 150 (148 maximum)

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.6 mi. = 0.04 hr. 0.04 hr. x 14.8 gals. per hr. = 0.591 gal. x 20¢ per gal. = 11.81¢

---

## Section 4

**Loaded**

Calculate horsepower.

$$20 = \frac{375 \text{ H.P.}}{82000(.015 + .009 + -.03)}$$

$$20 = \frac{375 \text{ H.P.}}{-142}$$

$$\text{H.P.} = \frac{-2840}{375}$$

$$\text{H.P.} = -7.5$$

Fuel used at 7.5 hp.:

$$\frac{.64 \times 7.5}{6.2}$$

$$= .78 \text{ gal. per hr.}$$

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.86 mi. = 0.093 hr. 0.093 hr. x .78 gal. per hr. = 0.072 gal. x 20¢ per gal. = 1.40¢

**Empty**

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{16000(.015 + .023 + .03)}$$

$$40 = \frac{375 \text{ H.P.}}{1088}$$

$$\text{H.P.} = \frac{43520}{375}$$

$$\text{H.P.} = 116$$

Fuel used at 116 hp.:

$$\frac{.57 \times 116}{6.2}$$

$$= 10.7 \text{ gals. per hr.}$$

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.86 mi. = 0.0465. 0.0465 hr x 10.7 gals. per hr. = 0.498 gal. x 20¢ per gal. = 9.96¢

---

## Section 5

**Loaded**

Assume: 15 mph.

$$\text{MPH} = \frac{375 \times 148}{82000(.015 + 02 + 0084)}$$

**Empty**

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{16000(.015 + .023 + -.02)}$$

**Loaded**

$$= \frac{55500}{3560}$$

$$= 15.6$$

1 hr. ÷ 15.6 mph. = 0.064 hr per mi. 0.064 hr. per mi. x 3.84 mi. = 0.248 hr. 0.248 hr. x 14.8 gals. per hr. = 3.64 gals. x 20¢ per gal. = 72.80¢

**Empty**

$$40 = \frac{375 \text{ H.P.}}{288}$$

$$\text{H.P.} = \frac{11520}{375}$$

H.P. = 30.6

Fuel used at 30.6 hp.:

$$\frac{.66 \times 30.6}{6.2}$$

= 3.36 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 3.84 mi. = 0.096 hr. 0.096 hr. x 3.36 gals. per hr. = 0.322 gal. x 20¢ per gal. = 6.44¢

---

## Section 6

Calculate horsepower

$$20 = \frac{375 \text{ H.P.}}{82000(.015+009+ -.154)}$$

$$20 = \frac{375 \text{ H.P.}}{-10650}$$

$$\text{H.P.} = \frac{-213000}{375}$$

H.P. = -568

Assume: 19 mph.

$$\text{MPH} = \frac{375 \times 148}{16000(.015+.154+.0121)}$$

$$= \frac{55500}{375}$$

$$= 19.2$$

1 hr. ÷ 19.2 mph. = 0.0541 hr. per mi. 0.0541 hr. per mi. x

| Loaded | Empty |
|---|---|
| Fuel consumption at maximum. 1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .5 mi. = 0.025 hr. 0.025 hr. x 14.8 gals. per hr. = 0.370 gal. x 20¢ per gal. = 7.40¢ | .5 mi. = 0.0272 hr. 0.0272 hr. x 14.8 gals. per hr. = 0.403 gal. x 20¢ per gal. = 8.06¢ |

Calculation of the Actual Cost of Hauling over Route II

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| Section 1 | 0.021 hr. | 3.96¢ | 0.0102 hr. | 1.28¢ |
| " 2 | 0.304 | 90.00 | 0.0425 | 5.77 |
| " 3 | 0.080 | 16.70 | 0.0400 | 11.81 |
| " 4 | 0.093 | 1.40 | 0.0465 | 9.96 |
| " 5 | 0.248 | 72.80 | 0.0960 | 6.44 |
| " 6 | 0.025 | 7.40 | 0.0272 | 8.06 |
| Total | 0.771 hr. | 192.26¢ | 0.2624 hr. | 43.32¢ |

Round-trip speed and fuel cost.

Loaded speed. 9.9 mi. ÷ 0.771 hr. = 12.8 mph.
Empty speed. 9.9 mi. ÷ 0.2624 hr.= 37.8 mph.

Round-trip speed. $\frac{2(37.8)(12.8)}{37.8 + 12.8}$

= 18.8 mph.

Fuel per M per mi.

| | |
|---|---|
| Loaded | 192.26¢ |
| Empty | 43.32 |
| | 235.58¢ ÷ 9.9 mi. = 23.8¢ ÷ 9M = 2.64¢ |

Summary of Actual Costs for Route II

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per M Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 18.8 | 7.68¢ | 2.64¢ | $13000 | 0.565¢ | $500 | 0.385¢ | 11.27¢ |

Actual Hauling Cost per M - Woods to Mill.

9.9 mi. x 11.27¢ = $1.115

Selection of the correct route and road type for HEAVY TRUCKS.

---

### Loaded

Type II. Assume: 13 mph.

$$MPH = \frac{375 \times 295}{360000(.015 + .0082)}$$

$$= \frac{110625}{8342}$$

$$= 13.3 \text{ mph.}$$

1 hr. ÷ 13.3 mph. = 0.0752 hr. per mi. 0.0752 hr. per mi. x 26.68 gals. per hr. = 2.01 gals. per mi. x 20¢ per gal. = 40.20¢

### Empty

Type II. Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{34000(.015 + .016)}$$

$$40 = \frac{375 \text{ H.P.}}{1055}$$

$$\text{H.P.} = \frac{42400}{375}$$

$$\text{H.P.} = 113$$

Fuel used at 113 hp.:

$$= \frac{.54 \times 113}{6.2}$$

$$= 9.84 \text{ gals. per hr.}$$

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 9.84 gals. per hr. = 0.246 gals. per mi. x 20¢ per gal. = 4.82¢

---

### Loaded

Type III. Assume: 9 mph.

$$MPH = \frac{375 \times 295}{360000(.025 + .00798)}$$

$$= \frac{110625}{1185}$$

### Empty

Type III. Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{34000(.025 + .016)}$$

$$40 = \frac{375 \text{ H.P.}}{1392}$$

**Loaded**

= 9.4

1 hr. ÷ 9.4 mph. = 0.1063 hr. per mi. 0.1063 hr. per mi. x 26.68 gals. per hr. = 2.84 gals. per mi. x 20¢ per gal. = 56.80¢ per mi.

**Empty**

$$H.P. = \frac{55680}{375}$$

H.P. = 147

Fuel used at 147 hp.:

$$= \frac{.54 \times 147}{6.2}$$

= 12.92 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 12.92 gals. per hr. = 0.323 gal. per mi. x 20¢ per gal. = 6.46¢ per mi.

---

Type IV. Assume: 6 mph.

$$MPH = \frac{375 \times 295}{360000(.04+.00775)}$$

$$= \frac{110625}{1720}$$

= 6.4

1 hr. ÷ 6.4 mph. = 0.156 hr. per mi. 0.156 hr. per mi. x 26.68 gals. per hr. = 4.18 gals. per mi. x 20¢ per gal. = 83.60¢ per mi.

Type IV. Calculate horsepower.

$$40 = \frac{375\ H.P.}{34000(.04+.016)}$$

$$40 = \frac{375\ H.P.}{1905}$$

$$H.P. = \frac{76200}{375}$$

H.P. = 203

Fuel used at 203 hp.:

$$= \frac{.52 \times 203}{6.2}$$

| Loaded | Empty |
|---|---|
| | = 17.05 gals. per hr. |
| | 1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 17.05 gals. per hr. = 0.426 gal. per mi. x 20¢ per gal. = 8.52¢ per mi. |

---

| | |
|---|---|
| Type V. Assume: 5 mph. | Type V. Calculate horsepower. |
| $MPH = \frac{375 \times 295}{360000(.05 + .00752)}$ | $40 = \frac{375\ H.P.}{34000(.05 + .016)}$ |
| $= \frac{110625}{2075}$ | $40 = \frac{375\ H.P.}{2225}$ |
| $= 5.3$ | $H.P. = \frac{88000}{375}$ |
| 1 hr. ÷ 5.3 mph. = 0.1887 hr per mi. 0.1887 hr. per mi. x 26.68 gals. per hr. = 5.04 gals. per mi. x 20¢ per gal. = 100.80¢ | H.P. = 234 |
| | Fuel used at 234 hp.: |
| | $= \frac{.52 \times 234}{6.2}$ |
| | = 19.65 gals. per hr. |
| | 1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 19.65 gals. per hr. = 0.492 gal. per mi. x 20¢ per gal. = 9.84¢ per mi. |

---

Round-trip calculations:

Type II

Round-trip speed. $\frac{2(40)(13.3)}{40 + 13.3}$

$= 20$ mph.

Fuel per M per mi.

$$\begin{array}{r} 40.20¢ \\ \underline{4.82} \\ 45.02¢ \end{array} \div 46M = 0.979¢$$

Type III.

Round-trip speed. $\frac{2(40)(9.4)}{40 + 9.4}$

$= 15.2$ mph.

Fuel per M per mi.

$$\begin{array}{r} 56.80¢ \\ \underline{6.46} \\ 63.26¢ \end{array} \div 46M = 1.375¢$$

Type IV.

Round-trip speed. $\frac{2(40)(6.4)}{40 + 6.4}$

$= 11$ mph.

Fuel per M per mi.

$$\begin{array}{r} 83.60¢ \\ \underline{8.52} \\ 92.15¢ \end{array} \div 46M = 2.001¢$$

Type V.

Round-trip speed. $\frac{2(40)(5.3)}{40 + 5.3}$

$= 9.4$ mph.

Fuel per M per mi.

$$\begin{array}{r} 100.80 \\ \underline{9.84} \\ 110.64 \end{array} \div 46M = 2.402¢$$

Summary of Costs for Route I

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. I | Const. per M per mi. | Maint. per yr. Rt. I | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 20.0 | 3.04¢ | 0.979¢ | $13000 | 0.565¢ | $500 | 0.385¢ | 4.969¢ |
| III | 15.2 | 4.00¢ | 1.375¢ | 7000 | 0.304¢ | 600 | 0.461¢ | 6.140¢ |
| IV | 11.0 | 5.52¢ | 2.001¢ | 5500 | 0.239¢ | 675 | 0.519¢ | 8.278¢ |
| V | 9.4 | 6.47¢ | 2.402¢ | 4250 | 0.185¢ | 750 | 0.576¢ | 9.633¢ |

Summary of Costs for Route II

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. I | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 20.0 | 3.04¢ | 0.979¢ | $15000 | 0.652¢ | $600 | 0.461¢ | 5.132¢ |
| III | 15.2 | 4.00¢ | 1.375¢ | 8000 | 0.348¢ | 700 | 0.539¢ | 6.262¢ |
| IV | 11.0 | 5.52¢ | 2.001¢ | 6500 | 0.282¢ | 775 | 0.596¢ | 8.399¢ |
| V | 9.4 | 6.47¢ | 2.402¢ | 4500 | 0.195¢ | 850 | 0.654¢ | 9.721¢ |

Based on level performance the cost of transportation 1000 board feet may now be found for heavy trucks.

| | | |
|---|---|---|
| Route I | 17.1 mi. x 4.969¢ = | $0.85 |
| Route II | 9.9 mi. x 5.132¢ = | .51 |
| Savings on Rt. II | | $0.34 |

As pointed out in the light and medium trucks the above figures represent only a comparison, however they enable the operator to select the most economical route and road surface. For actual hauling costs the following procedure must be followed:

Determination of Actual Hauling Costs for Heavy Trucks on Route I

Type II Road

| Loaded | Empty |
|---|---|

## Section 1

**Loaded**

Assume: 9 mph.

$$MPH = \frac{375 \times 295}{360000(.015 + .01 + .00788)}$$

$$= \frac{110625}{11850}$$

$$= 9.4$$

1 hr. ÷ 9.4 mph. = 0.1063 hr per mi. 0.1063 hr. per mi. x 7.85 mi. = 0.836 hr. 0.836 hr. x 26.68 gals. per hr. = 22.35 gals. x 20¢ per gal. = 447.00¢

**Empty**

Calculate horsepower

$$40 = \frac{375\ HP}{34000(.015 + .016 + -.01)}$$

$$= \frac{375\ H.P.}{715}$$

$$H.P. = \frac{28600}{375}$$

H.P. = 76

Fuel used at 76 hp.:

$$= \frac{.54 \times 76}{6.2}$$

= 6.61 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 7.85 mi. = 0.196 hr. 0.196 hr. x 6.61 gals. per hr. = 0.123 gal. x 20¢ per gal. = 2.46¢

---

## Section 2

**Loaded**

Assume: 6 mph.

$$MPH = \frac{375 \times 295}{360000(.015 + .03 + .00775)}$$

**Empty**

Calculate horsepower.

$$40 = \frac{375\ H.P.}{34000(.015 + .016 + -.03)}$$

**Loaded**

$$= \frac{110625}{19000}$$

$$= 5.8$$

1 hr. ÷ 5.8 mph. = 0.1725 hr per mi. 0.1725 hr. per mi. x 1.3 mi. = 0.224 hr. 0.224 hr. x 26.68 gals. per hr. = 6.00 gals. x 20¢ per gal. = 120.00¢

**Empty**

$$40 = \frac{375 \text{ H.P.}}{34}$$

$$\text{H.P.} = \frac{1360}{375}$$

H.P. = 3.63

Fuel used at 3.63 hp.:

$$= \frac{.54 \times 3.63}{6.2}$$

= 3.18 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.3 mi. = 0.0325 hr. 0.0325 hr. x 3.18 gals. per hr. = 0.1025 gal. x 20¢ per gal. = 2.05¢

---

## Section 3

In the calculations necessary to determine road type it was found that a loaded truck could maintain a speed of 13.3 mph. Fuel consumption at the maximum.

1 hr. ÷ 13.3 mph. = 0.0752 hr per mi. 0.0752 hr. per mi. x 3 mi. = 0.2256 hr. 0.2256 hr. x 26.68 gals. per hr. = 6.01 gal. x 20¢ per gal. = 120.20¢

In the calculations necessary to determine road type it was found that an empty truck could maintain a speed of 40 mph. on the level with a power output of 113 horsepower. Fuel consumption was also determined, and found to be 9.84 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 gal. per hr. 0.025 gal. per hr. x 3 mi. = 0.075 hr. 0.075 hr. x 9.84 gals. per hr. = 0.738 gal. x 20¢ per gal. = 14.76¢

---

Loaded / Empty

Section 4

**Loaded**

Calculate horsepower.

$$20 = \frac{375 \text{ H.P.}}{360000(.015 + .0085 + -.0234)}$$

$$20 = \frac{375 \text{ H.P.}}{36}$$

$$\text{H.P.} = \frac{1440}{375}$$

H.P. = 3.84

Fuel used at 3.84 hp.:

$$= \frac{.54 \times 3.84}{6.2}$$

= .331 gal. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 4.95 mi. = 0.2475 hr. 0.2475 hr. x .331 gal. per hr. = 0.082 gal. x 20¢ per gal. = 1.64¢

**Empty**

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{34000(.015 + .016 + .0234)}$$

$$40 = \frac{375 \text{ H.P.}}{1850}$$

$$\text{H.P.} = \frac{74000}{375}$$

H.P. = 197.5

Fuel used at 197.5 hp.:

$$= \frac{.52 \times 197.5}{6.2}$$

= 16.57 gal. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 4.95 mi. = 0.1239 hr. 0.1239 hr. x 16.57 gal. per hr. = 2.05 gal. x 20¢ per gal. = 41.00¢

---

Calculation of the Actual Cost of Hauling over Route I.

| | Loaded Time | Loaded Fuel | Empty Time | Empty Fuel |
|---|---|---|---|---|
| Section 1 | 0.8360 hr. | 447.00¢ | 0.1960 hr. | 2.46¢ |
| " 2 | 0.2240 | 120.00 | 0.0325 | 2.05¢ |
| " 3 | 0.2256 | 120.20 | 0.0750 | 14.76 |
| " 4 | 0.2475 | 1.64 | 0.1239 | 41.00 |
| Total | 1.5331 hr. | 688.84¢ | 0.4274 hr. | 60.27¢ |

Round-trip speed and fuel cost.

Loaded speed. 17.1 mi. ÷ 1.5331 hr. = 11.1 mph.
Empty speed. 17.1 mi. ÷ 0.4274 hr. = 40.0 mph.

Round-trip speed $\frac{2(40)(11.1)}{40 + 11.1}$

= 17.2 mph.

Fuel per M per mi.

Loaded 688.84¢
Empty 60.27
749.11¢ ÷ 17.1 mi. = 43.80¢ ÷ 46M = 0.95¢

Summary of Actual Costs for Route I

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. I | Const. per M per mi. | Maint. per yr. Rt. I | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 17.2 | 3.54¢ | 0.950¢ | $13000 | 0.565¢ | $500 | 0.385¢ | 5.440 |

Actual Hauling Cost per M - Woods to Mill

17.1 mi. x 5.44¢ = $0.93

Determination of Actual Hauling Costs for Heavy Trucks on Route II

Type II Road

---

**Loaded** / **Empty**

### Section 1

**Loaded**

Loaded speed on the level has been found to be 13.3 mph. at maximum horsepower output.

1 hr. ÷ 13.3 mph. = 0.0752 hr. per mi. 0.0752 hr. per mi. x .41 mi. = 0.0308 hr. 0.0308 hr. x 26.68 gals. per hr. = 0.823 gal. x 20¢ per gal. = 16.46¢

**Empty**

Empty speed on the level has been found to be 40 mph. at a power output of 113 horsepower. Fuel consumption for this speed is 9.84 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x .41 mi. = 0.0102 hr. 0.0102 hr. x 9.84 gals. per hr. = 0.101 gal. x 20¢ per gal. = 2.02¢

---

### Section 2

**Loaded**

Assume: 3 mph.

$$MPH = \frac{375 \times 295}{360000(.015+.08+.00753)}$$

$$= \frac{110625}{36900}$$

$$= 3$$

1 hr. ÷ 3 mph. = 0.333 hr. per mi. 0.333 hr. per mi. x 1.7 mi. = 0.567 hr. 0.567 hr. x 26.68 gals. per hr. = 15.15 gals. x 20¢ per gal. = 303.00¢

**Empty**

Calculate horsepower

$$40 = \frac{375\ H.P.}{34000(.015+.016+ -.08\ )}$$

$$40 = \frac{375\ H.P.}{-1670}$$

$$H.P. = \frac{-66800}{375}$$

$$H.P. = -178$$

Fuel used at 178 hp.:

**Loaded**

**Empty**

$$\frac{.52 \times 178}{6.2}$$

= 14.9 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.7 mi. = 0.0425 hr. 0.0425 hr. x 14.9 gals. per hr. = 12.68¢

---

Section 3

**Loaded**

Calculate horsepower.

$$20 = \frac{375\ H.P.}{360000(.015 + .00851 + -.05)}$$

$$20 = \frac{375\ H.P.}{-9950}$$

$$H.P. = \frac{191000}{-375}$$

H.P. = -510

Engine in full compression plus brakes.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.6 mi. = 0.08 hr. 0.08 hr x 26.68 gals. per hr. = 2.138 gals. x 20¢ per gal. = 42.80¢

**Empty**

Calculate horsepower

$$40 = \frac{375\ H.P.}{34000(.015 + .016 + .05)}$$

$$40 = \frac{375\ H.P.}{2755}$$

$$H.P. = \frac{110200}{375}$$

H.P. = 287

Fuel used at 287 hp.:

$$\frac{.52 \times 287}{6.2}$$

= 24.00 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.6 mi. = 0.04 hr. 0.04 hr. x 24.00 gals. per hr. = 0.96 gal. x 20¢ per gal. = 19.20¢

---

Loaded | Empty

## Section 4

**Loaded**

Calculate horsepower.

$$20 = \frac{375 \text{ H.P.}}{360000(.015+.0085+ -.037)}$$

$$20 = \frac{375 \text{ H.P.}}{-2338}$$

$$\text{H.P.} = \frac{-46760}{375}$$

H.P. = -125

Fuel used at 125 hp.:

$$\frac{.54 \times 125}{6.2}$$

= 10.90 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.86 mi. = 0.093 hr. 0.093 hr. x 10.90 gals. per hr. = 1.025 gal. x 20¢ per gal. = 20.50¢

**Empty**

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{34000(.015+.016+.03)}$$

$$40 = \frac{375 \text{ H.P.}}{2075}$$

$$\text{H.P.} = \frac{63000}{375}$$

H.P. = 168

Fuel used at 168 hp.:

$$\frac{.53 \times 168}{6.2}$$

= 14.36 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.86 mi. = 0.0465 hr. 0.0465 hr. x 14.36 gals. per hr. = 0.667 gal. x 20¢ per gal. = 13.34¢

---

## Section 5

**Loaded**

Assume: 7 mph.

$$\text{MPH} = \frac{375 \times 295}{360000(.015+.02+.0077)}$$

$$= \frac{110625}{15380}$$

**Empty**

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{34000(.015+016+ -.02)}$$

$$40 = \frac{375 \text{ H.P.}}{374}$$

**Loaded**

= 7.2

1 hr. ÷ 7.2 mph. = 0.139 hr. per mi. 0.139 hr. per mi. x 3.84 mi. = 0.534 hr. 0.534 hr. x 26.68 gals. per hr. = 14.25 gals. x 20¢ per gal. = 285.00¢

**Empty**

$$H.P. = \frac{15960}{375}$$

H.P. = 42.5

Fuel used at 42.5 hp.:

$$\frac{.54 \times 42.5}{6.2}$$

= 3.70 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 3.84 mi. = 0.096 hr. 0.096 hr. x 3.70 gals. per hr. = 0.355 gal. x 20¢ per gal. = 7.10¢

---

## Section 6

Calculate horsepower.

$$20 = \frac{375\ H.P.}{3600000(.015 + .00851 + -.154)}$$

$$20 = \frac{375\ H.P.}{-47000}$$

$$H.P. = \frac{-940000}{375}$$

H.P. = -2500

Calculate fuel consumption at the maximum.

Assume: 18 mph.

$$MPH = \frac{375 \times 295}{34000(.015 + .154 + .0109)}$$

$$= \frac{110625}{6070}$$

= 18.2

1 hr. ÷ 18.2 mph. = 0.055 hr. per mi. 0.055 hr. per mi. x .5 mi. = 0.0275 hr. 0.0275 hr. x 26.68 gals. per hr. = 0.735 gal. x 20¢ per gal. = 14.70¢

| Loaded | Empty |
|---|---|
| 1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .5 mi. = 0.025 hr. 0.025 hr. x 26.68 gals. per hr. = 0.667 gals. x 20¢ per gal. = 13.34¢ | |

---

Calculation of the Actual Cost of Hauling over Route II

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| Section 1 | 0.0308 hr. | 16.46¢ | 0.0102 hr. | 2.02¢ |
| " 2 | 0.5670 | 303.00 | 0.0425 | 12.68 |
| " 3 | 0.0800 | 42.80 | 0.0400 | 19.20 |
| " 4 | 0.0930 | 20.50 | 0.0465 | 13.34 |
| " 5 | 0.5340 | 285.00 | 0.0960 | 7.10 |
| " 6 | 0.0250 | 13.34 | 0.0270 | 14.70 |
| | 1.3298 hr. | 681.10¢ | 0.2627 hr. | 69.04¢ |

Round trip speed and fuel cost.

Loaded speed. 9.9 mi. ÷ 1.3298 hr. = 7.5 mph.
Empty Speed. 9.9 mi. ÷ 0.2627 hr. = 37.6 mph.

Round-trip speed. $\frac{2(37.6)(7.5)}{37.6 + 7.5}$

= 12.5 mph.

Fuel per M per mi.

| | |
|---|---|
| Loaded | 681.10¢ |
| Empty | 69.04 |
| | 750.14 ÷ 9.9 mi. = 75.90¢ ÷ 46M = 1.65¢ |

Summary of Actual Costs for Route II

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 12.5 | 4.87¢ | 1.65¢ | $15000 | 0.652¢ | $600 | 0.461¢ | 7.633¢ |

Actual Hauling Cost per M - Woods to Mill.

9.9 mi. x 7.633¢ = $0.755

Road Type Analysis - Route I

(based on level road performance)

| ad pe | Truck Type | Round-Trip Speed | Hauling Cost per M | Fuel per M per mi. | Const. per mi. | Const. per M per mi. | Maint. per yr. | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|---|
| I | Light | 26.7 | 5.25¢ | 1.333¢ | $10000 | 0.435¢ | $ 300 | 0.230¢ | 7.248¢ |
| | Medium | 26.7 | 5.41 | 1.421 | 11000 | 0.478 | 400 | 0.308 | 7.617 |
| | Heavy | 20.0 | 3.04 | 0.979 | 13000 | 0.565 | 500 | 0.385 | 4.969 |
| I | Light | 26.7 | 5.25 | 2.328 | 4000 | 0.174¢ | 400 | 0.308 | 8.060 |
| | Medium | 26.6 | 5.44 | 2.054 | 5000 | 0.217 | 500 | 0.385 | 8.096 |
| | Heavy | 15.2 | 4.00 | 1.375 | 7000 | 0.304 | 600 | 0.461 | 6.140 |
| | Light | 22.3 | 6.28 | 2.998 | 2500 | 0.109¢ | 475 | 0.366 | 9.753 |
| | Medium | 20.7 | 6.99 | 2.890 | 3500 | 0.152 | 575 | 0.442 | 10.474 |
| | Heavy | 11.0 | 5.52 | 2.001 | 5500 | 0.239 | 675 | 0.519 | 8.278 |
| | Light | 19.6 | 7.14 | 3.572 | 1200 | 0.054¢ | 550 | 0.423 | 11.209 |
| | Medium | 18.0 | 8.03 | 3.490 | 2250 | 0.098 | 650 | 0.500 | 12.118 |
| | Heavy | 9.4 | 6.47 | 2.402 | 4250 | 0.185 | 750 | 0.576 | 9.633 |

Road Type Analysis - Route II

(based on level road performance)

| ad pe | Truck Type | Round-Trip Speed | Hauling Cost per M | Fuel per M per mi. | Const. per mi. | Const. per M per mi. | Maint. per yr. | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|---|
| | Light | 26.7 | 5.25¢ | 1.333¢ | $12000 | 0.521¢ | $ 400 | 0.308¢ | 7.412¢ |
| | Medium | 26.7 | 5.41 | 1.421 | 13000 | 0.565 | 500 | 0.385 | 7.781 |
| | Heavy | 20.0 | 3.04 | 0.979 | 15000 | 0.652 | 600 | 0.461 | 5.132 |
| I | Light | 26.7 | 5.25 | 2.328 | 5000 | 0.217 | 500 | 0.385 | 8.180 |
| | Medium | 26.6 | 5.44 | 2.054 | 6000 | 0.261 | 600 | 0.461 | 8.216 |
| | Heavy | 15.2 | 4.00 | 1.375 | 8000 | 0.348 | 700 | 0.539 | 6.262 |
| | Light | 22.3 | 6.28 | 2.998 | 3500 | 0.152 | 575 | 0.442 | 9.872 |
| | Medium | 20.7 | 6.99 | 2.890 | 4500 | 0.195 | 675 | 0.519 | 10.594 |
| | Heavy | 11.0 | 5.52 | 2.001 | 6500 | 0.282 | 775 | 0.596 | 8.399 |
| | Light | 19.6 | 7.14 | 3.572 | 1500 | 0.065 | 650 | 0.500 | 11.277 |
| | Medium | 18.0 | 8.03 | 3.490 | 2500 | 0.109 | 750 | 0.576 | 12.205 |
| | Heavy | 9.4 | 6.47 | 2.402 | 4500 | 0.195 | 850 | 0.654 | 9.721 |

Conclusion: Route I, Type II Road, Heavy Trucks.
4.969¢ x 17.1 mi. = $0.850
Route II, Type II Road, Heavy Trucks.
5.132¢ x 9.9 mi. = $0.507
Savings by use of Route II $0.243

## Actual Cost Analysis - Route I

### Type II Road

| ck pe | Round-Trip Speed | Hauling Cost per M | Fuel per M per mi. | Const. per mi. | Const. per M per mi. | Maint. per yr. | Maint. per M per yr. | Actual Total | Trip Total |
|---|---|---|---|---|---|---|---|---|---|
| ght | 26.2 | 5.34¢ | 1.625¢ | $10000 | 0.435¢ | $ 300 | 0.230¢ | 7.630¢ | $1.300 |
| ium | 25.8 | 5.60 | 1.489 | 11000 | 0.478 | 400 | 0.308 | 7.875 | $1.350 |
| vy | 17.2 | 3.54 | 0.950 | 13000 | 0.565 | 500 | 0.385 | 5.440 | $0.930 |

## Actual Cost Analysis - Route II

### Type II Road

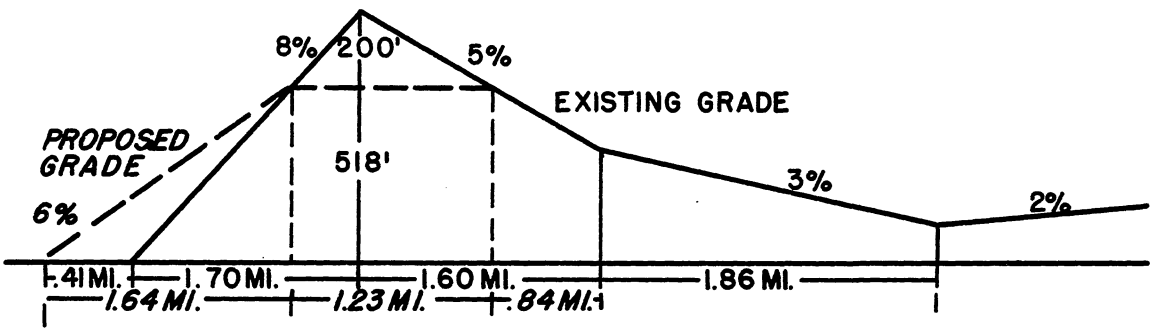
| ck e | Round-Trip Speed | Hauling Cost per M | Fuel per M per mi. | Const. per mi. | Const. per M per mi. | Maint. per yr. | Maint. per M per yr. | Actual Total | Trip Total |
|---|---|---|---|---|---|---|---|---|---|
| ht | 22.0 | 6.36¢ | 2.75¢ | $12000 | 0.522¢ | $ 400 | 0.308¢ | 9.94¢ | $0.984 |
| ium | 18.8 | 7.68 | 2.64 | 13000 | 0.565 | 500 | 0.385 | 11.27 | $1.115 |
| vy | 12.5 | 4.87 | 1.65 | 15000 | 0.652 | 600 | 0.461 | 7.63 | $0.755 |

Conclusion: Based on level road performance Route II, Type II Roads and Heavy Trucks were found most economical.
Theoretical cost was $0.51.
Proof of this choice is made in the above table, but due to grade the cost is actually $0.76.

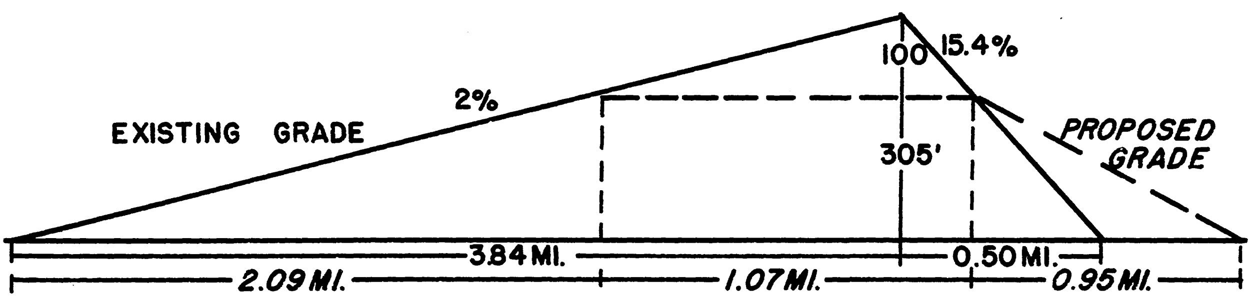
Grade Reductions

Determine the economic possibilities of grade reductions on Route II for all types of trucks.

Possible Grade Reduction 1 - Road Sections 1, 2, and 3.




Possible Grade Reduction 2 - Road Sections 5 and 6.




New length if this grade is reduced - 10.35 mi.

## Light Trucks

### Reduction of Road Sections 1, 2 and 3

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**Loaded**

6% Section

Assume: 9 mph.

$$MPH = \frac{375 \times 89}{44000(.015 + .06 + .008)}$$

$$= \frac{33375}{3650}$$

$$= 9.2$$

1 hr. ÷ 9.2 mph. = 0.108 hr. per mi. 0.108 hr. per mi. x 1.64 mi. = 0.177 hr. 0.177 hr. x 9.52 gals. per hr. = 1.69 gals. x 20¢ per gal. = 33.80¢

**Empty**

Calculate horsepower.

$$40 = \frac{375\ H.P.}{8000\ (.015 + .035 + -.06\ )}$$

$$40 = \frac{375\ H.P.}{-80}$$

$$H.P. = \frac{-3200}{375}$$

$$H.P. = -8.5$$

Fuel used at 8.5 hp.:

$$\frac{.59 \times 8.5}{6.2}$$

$$= .81 \text{ gal. per hr.}$$

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.64 mi. = 0.041 hr. 0.041 hr. x .81 gal. per hr. = 0.0332 gal. x 20¢ per gal. = 0.66¢

---

0% Section

Loaded speed on the level

Empty speed on the level has

| Loaded | Empty |
|---|---|
| has been found to be 20 mph. at 58 horsepower. Fuel consumption at this speed is 4.86 gals. per hr. | been found to be 40 mph. at 43 horsepower. Fuel consumption at this speed is 3.60 gals. per hr. |
| 1 hr. ÷ 20 mph = 0.05 hr. per mi. 0.05 hr. per mi. x 1.23 mi. = 0.0615 hr. 0.0615 hr. x 4.86 gals. per hr. = 0.298 gal. x 20¢ per gal. = 5.98¢ | 1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.23 mi. = 0.0307 hr. 0.0307 hr. x 3.60 gals. per hr. = 0.111 gal. x 20¢ per gal. = 2.22¢ |

---

Remainder of 5% Section

| | |
|---|---|
| Speed downgrade has been found to be 20 mph. at -58 horsepower. Fuel consumption is 4.87 gals. per hr. | Speed upgrade has been found to be 40 mph. at 85 horsepower. Fuel consumption is 7.95 gals. per hr. |
| 1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .84 mi. = 0.042 hr. 0.042 hr. x 4.87 gals. per hr. = 0.203 gal. x 20¢ per gal = 4.06¢ | 1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 84 mi. = 0.021 hr. 0.021 hr. x 7.95 gals. per hr. = 0.167 gal. x 20¢ per gal. = 3.34¢ |

---

Calculation of New Hauling Costs

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| 6% Section | 0.1770 hr. | 33.80¢ | 0.0410 | 0.66 |
| 0% Section | 0.0615 | 5.98 | 0.0301 | 2.22 |
| 5% " | 0.0420 | 4.06 | 0.0210 | 3.34 |
| Section 4 | 0.0940 | 3.32 | 0.0465 | 5.32 |
| " 5 | 0.2230 | 42.40 | 0.0960 | 4.23 |
| " 6 | 0.0250 | 0.89 | 0.0225 | 4.28 |
| Total | 0.6225 hr. | 90.45¢ | 0.2577 hr. | 20.05¢ |

Round-trip speed and fuel cost.

Loaded speed. 9.9 mi. ÷ 0.6225 hr. = 15.9 mph.
Empty speed. 9.9 mi. ÷ 0.2577 hr. = 38.5 mph.

Round-trip speed $\frac{2(38.5)(15.9)}{38.5 + 15.9}$

= 22.5 mph.

Fuel per M per mi.

Loaded 90.45¢
Empty 20.05¢
110.50 ÷ 9.9 mi. = 11.18¢ ÷ 5M = 2.24¢

Summary of New Hauling Costs

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 22.5 | 6.22¢ | 2.24¢ | $12000 | 0.522¢ | $ 400 | 0.308¢ | 9.29¢ |

New Hauling Cost per M - Woods to Mill

9.9 mi. x 9.29¢ = $0.920
Original Hauling Cost per M 0.952
Reduction saving $0.032

Annual Savings $0.032 x 130,000M = $4160.00

Reduction of Road Sections 5 and 6

| Loaded | Empty |
|---|---|
| Remainder of 2% Section | |
| Speed up the 2% grade has previously been found to be 17.2 mph. Fuel consumption | Speed down the 2% grade has previously been found to be 40 mph. at 25.6 horsepower. |

**Loaded**

at the maximum.

1 hr. ÷ 17.2 mph. = 0.0561 hr. per mi. 0.0561 hr. per mi. x 2.9 mi. = 0.163 hr. 0.163 hr. x 9.52 gals. per hr. = 1.55 gals. x 20¢ per gal. = 31.00¢

**Empty**

Fuel consumption is 2.23 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. 2.9 mi. = 0.0725 hr. 0.0725 hr. x 2.23 gals. per hr. = 0.1615 gal. x 20¢ per gal. = 3.23¢

---

## 0% Section

Loaded speed on the level has been found to be 20 mph. at 58 horsepower. Fuel consumption is 4.86 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.07 mi. = 0.0535 hr. 0.0535 hr. x 4.86 gals. per hr. = 0.26 gal. x 20¢ per gal. = 5.20¢

Empty speed on the level has been found to be 40 mph at 43 horsepower. Fuel consumption is 3.60 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.07 mi. = 0.0267 hr. 0.0267 hr. x 3.60 gals. per hr. = 0.0961 gal. x 20¢ per gal. = 1.93¢

---

## 6% Section

Calculate horsepower.

$$20 = \frac{375 \text{ H.P.}}{44000(.015+.0097+ -.06)}$$

$$20 = \frac{375 \text{ H.P.}}{-1551}$$

$$\text{H.P.} = \frac{-31000}{375}$$

Assume: 39 mph.

$$\text{MPH} = \frac{375 \times 89}{8000(.015+.032+.06)}$$

$$= \frac{33375}{865}$$

$$= 38.7$$

Loaded

H.P. = -82.7

Fuel used at 82.7 hp.:

$$\frac{.55 \times 82.7}{6.2}$$

= 7.32 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .95 mi. = 0.0475 hr. 0.0475 hr. x 7.32 gals. per hr. = 0.348 gal. x 20¢ per gal. = 6.96¢

Empty

1 hr. ÷ 38.7 mph. = 0.0258 hr. per mi. 0.0258 hr. per mi. x .95 mi. = 0.0246 hr. 0.0246 hr. x 9.52 gals. per hr. 0.234 gal. x 20¢ per gal. = 4.68¢

---

Hauling Costs if Both Grades are Reduced.

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| 6% Section | 0.1770 hr. | 33.80¢ | 0.0410 hr. | 0.66¢ |
| 0% " | 0.0615 | 5.98 | 0.0307 | 2.22 |
| 5% " | 0.0420 | 4.06 | 0.0210 | 3.34 |
| Section 4 | 0.0940 | 3.32 | 0.0465 | 5.32 |
| 2% Section | 0.1630 | 31.00 | 0.0725 | 3.23 |
| 0% Section | 0.0535 | 5.20 | 0.0267 | 1.93 |
| 6% " | 0.0475 | 6.96 | 0.0246 | 4.68 |
| Total | 0.6385 hr. | 90.32¢ | 0.2630 hr. | 21.38¢ |

Round-trip speed and fuel cost.

Loaded speed. 10.35 mi. ÷ 0.6385 hr. = 16.2 mph.
Empty speed. 10.35 mi. ÷ 0.2630 hr. = 39.3 mph.

Round-trip speed $\frac{2(39.3)(16.2)}{39.3 + 16.2}$

= 23 mph.

Fuel per M per mi.

Loaded 90.32¢
Empty 21.38
111.70¢ ÷ 10.35 mi. = 10.78¢ ÷ 5M = 2.16¢

Summary of Hauling Costs - Both Grades Reduced.

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 23.0 | 6.08¢ | 2.16¢ | $12000 | 0.522¢ | $ 400 | 0.308¢ | 9.07¢ |

Hauling Cost if Both Grades Reduced - Woods to Mill

10.35 mi. x 9.07¢ = $0.94

Hauling Cost if Grade in Sections 1, 2 and 3 is reduced $0.92.

Since the hauling cost per trip is increased (due to additional length of fill) the second grade should not be reduced.

Amount that can be spent to reduce the grade in Sections 1, 2 and 3, if interest is at 6% and the investment is to be returned at the end of the operation.

| | |
|---|---|
| Original cost per trip | $0.952 |
| Reduced " " " | .920 |
| Saving per M per trip | $0.032 |

| | |
|---|---|
| Annual cut | 130,000M |
| Saving per M | $ 0.032 |
| Annual saving | $4160.00 |

$$Co = \frac{\$4160.00(1.06^{20}-1)}{0.06 \times 1.06^{20}}$$

$$= \frac{4160.00\ (2.207)}{0.06 \times 3.207}$$

$$= \$4160.00\ (11.47$$

$= \$47,700.00$ to reduce the grade in Sections 1, 2 and 3.

## Medium Trucks

### Reduction of Road Sections 1, 2 and 3

---

**Loaded** | **Empty**

### 6% Section

**Loaded**

Assume: 8 mph.

$$MPH = \frac{375 \times 148}{82000(.015 + .06 + .0078)}$$

$$= \frac{55500}{6785}$$

$$= 8.2$$

1 hr. ÷ 8.2 mph. = 0.122 hr. per mi. 0.122 hr. per mi. x 1.64 mi. = 0.200 hr. 0.200 hr. x 14.8 gals. per hr. = 2.955 gals. x 20¢ per gal. = 59.10¢

**Empty**

Calculate horsepower.

$$40 = \frac{375 \text{ H.P.}}{16000(.015 + .023 + -.06)}$$

$$40 = \frac{375 \text{ H.P.}}{-352}$$

$$\text{H.P.} = \frac{-14080}{375}$$

$$\text{H.P.} = -37.5$$

Fuel used at 37.5 hp.:

$$\frac{.64 \times 37.5}{6.2}$$

$$= 3.88 \text{ gals. per hr.}$$

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.64 mi. = 0.041 hr. 0.041 hr. x 3.88 gals. per hr. = 0.159 gal. x 20¢ per gal. = 3.08¢

---

### 0% Section

Loaded speed on the level has been found to be 20 mph.

Empty speed on the level has been found to be 40 mph. at

**Loaded**

at 105 horsepower. Fuel consumption at this speed is 9.65 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.23 mi. = 0.0615 hr. 0.0615 hr. x 9.65 gals. per hr. = 0.593 gal. x 20¢ per gal. = 11.86¢

**Empty**

65 horsepower. Fuel consumption at this speed is 6.28 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.23 mi. = 0.0307 hr. 0.0307 hr. x 6.28 gals. per hr. = 0.1926 gal. x 20¢ per gal. = 3.86¢

---

## Remainder of 5% Section

Speed downgrade has been found to be 20 mph. at -113.5 horsepower. Fuel consumption is 10.43 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .84 mi. = 0.042 hr. 0.042 hr. x 10.43 gals. per hr. = 0.439 gal. x 20¢ per gal. = 8.78¢

Speed topgrade has been found to be 40 mph. at maximum horsepower. Fuel consumption is 14.8 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x .84 mi. = 0.021 hr. 0.021 hr. x 14.8 gals. per hr. = 0.311 gal. x 20¢ per gal. = 6.22¢

---

## Calculation of New Hauling Costs.

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| 6% Section | 0.2000 hr. | 59.10¢ | 0.0410 | 3.08 |
| 0% Section | 0.0615 | 11.86 | 0.0307 | 3.86 |
| 5% " | 0.0420 | 8.78 | 0.0210 | 6.22 |
| Section 4 | 0.0930 | 6.82 | 0.0465 | 9.96 |
| " 5 | 0.2480 | 72.80 | 0.0960 | 6.64 |
| " 6 | 0.0250 | 1.84 | 0.0272 | 8.06 |
| Total | 0.6695 hr. | 161.20¢ | 0.2624 hr | 37.64¢ |

Round-trip speed and fuel cost.

Loaded speed. 9.9 mi. ÷ 0.6695 hr. = 14.8 mph.
Empty speed. 9.9 mi. ÷ 0.2624 hr. = 37.8 mph.

Round-trip speed. $\frac{2(37.8)(14.8)}{37.8 + 14.8}$

= 21.2 mph.

Fuel per M per mi.

Loaded 161.20¢
Empty 37.64
198.84¢ ÷ 9.9 mi. = 20.15¢ ÷ 9M = 2.23¢

Summary of New Hauling Costs

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 21.2 | 6.82¢ | 2.23¢ | $13000 | 0.565¢ | $ 500 | 0.385¢ | 10.00¢ |

New Hauling Cost per M - Woods to Mill

9.9 mi. x 10.00¢ = $0.99
Original Hauling Cost per M = $1.12
Reduction saving $0.13

Annual Savings $0.13 x 130,000M = $16,900

Reduction of Road Sections 5 and 6

| Loaded | Empty |
|---|---|
| Remainder of 2% Section | |
| Speed up the 2% grade has previously been found to be | Speed down the 2% grade has previously been found to be |

**Loaded**

15.6 mph. Fuel consumption at the maximum.

1 hr. ÷ 15.6 mph. = 0.0641 hr. per mi. 0.0641 hr. per mi. x 2.9 mi. = 0.186 hr. 0.186 hr. x 14.8 gal. per hr. = 2.755 gal. x 20¢ per gal. = 55.15¢

**Empty**

40 mph. at 30.6 horsepower. Fuel consumption is 3.36 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 2.9 mi. = 0.0725 hr. 0.0725 hr. x 3.36 gal. per hr. = 0.244 gal. x 20¢ per gal. = 4.88¢

---

## 0% Section

Loaded speed on the level has been found to be 20 mph. at 105 horsepower. Fuel consumption is 9.65 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x 1.07 mi. = 0.0535 hr. 0.0535 hr. x 9.65 gals. per hr. = 0.516 gal. x 20¢ per gal. = 10.32¢

Empty speed on the level has been found to be 40 mph. at 65 horsepower. Fuel consumption is 6.28 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.07 mi. = 0.0267 hr. 0.0267 hr. x 6.28 gals. per hr. = 0.1675 gals. x 20¢ per gal. = 3.35¢

---

## 6% Section

Calculate horsepower

$$20 = \frac{375 \text{ H.P.}}{82000(.015 + .009 + -.06)}$$

$$20 = \frac{375 \text{ H.P.}}{-2235}$$

$$\text{H.P.} = \frac{-44700}{375}$$

Assume: 37 mph.

$$\text{MPH} = \frac{375 \times 148}{16000(.015 + .06 + .0204)}$$

$$= \frac{55500}{1525}$$

$$= 36.4$$

| Loaded | Empty |
|---|---|
| H.P. = -119 | 1 hr. ÷ 36.4 mph. = 0.0275 hr. per mi. 0.0275 hr. per mi. x .95 mi. = 0.0262 hr. 0.0262 hr. x 14.8 gals. per hr. = 0.3865 gal. x 20¢ per gal. = 7.64¢ |

Fuel used at 119 hp.:

$$\frac{.57 \times 119}{6.2}$$

= 10.95 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .95 mi. = 0.0475 hr. 0.0475 hr. x 10.95 gals. per hr. = 0.521 gal. x 20¢ per gal. = 10.42¢

---

Hauling Costs if Both Grades are Reduced.

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| 6% Section | 0.2000 hr. | 59.10¢ | 0.0410 hr. | 3.08¢ |
| 0% " | 0.0615 | 11.86 | 0.0307 | 3.86 |
| 5% " | 0.0420 | 8.78 | 0.0210 | 6.22 |
| Section 4 | 0.930 | 6.82 | 0.0465 | 9.96 |
| 2% Section | 0.1860 | 55.15 | 0.0725 | 4.88 |
| 0% " | 0.0535 | 10.32 | 0.0267 | 3.35 |
| 6% " | 0.0475 | 10.42 | 0.0262 | 7.64 |
| Total | 0.6835 hr. | 162.45¢ | 0.2646 hr. | 38.99¢ |

Round-trip speed and fuel cost.

Loaded speed. 10.35 mi ÷ 0.6835 hr. = 15.2 mph.
Empty speed. 10.35 mi ÷ 0.2646 hr. = 39.1 mph.

Round-trip speed $\frac{2(39.1)(15.2)}{39.1 + 15.2}$

= 21.9 mph.

Fuel per M per mi.

| | |
|---|---|
| Loaded | 162.45¢ |
| Empty | 38.99 |
| | 201.44¢ ÷ 10.35 mi. = 19.45¢ ÷ 9M = 2.16¢ |

Summary of Costs - Both Grades Reduced.

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 21.9 | 6.60¢ | 2.16¢ | $13000 | 0.565 | $ 500 | 0.385¢ | 9.71¢ |

Hauling Cost if Both Grades are Reduced - Woods to Mill.

10.35 mi. x 9.71¢ = $1.00

Hauling Cost if Grade in Sections 1, 2 and 3 is Reduced. $0.99

Since the hauling cost per trip is increased (due to the increased length of the route) the second grade should not be reduced.

Amount that can be spent to reduce the grade in Sections 1, 2 and 3, if interest is at 6% and the investment is to be returned at the end of the operation.

| | |
|---|---|
| Original cost per trip | $1.12 |
| Reduced " " " | .99 |
| Saving per M " " | $0.13 |

| | |
|---|---|
| Annual cut | 130,000M |
| Saving per M | $0.13 |
| Annual saving | $16,900.00 |

$$Co = \frac{\$16,900.00\ (1.06^{20}-1)}{0.06 \times 1.06^{20}}$$

$$= \frac{\$16,900.00\ (2.207)}{0.06 \times 3.207}$$

$$= \$16,900.00\ (11.47)$$

= $193,700.00 to reduce the grade in Sections 1, 2 and 3

Heavy Trucks

Reduction of Sections 1, 2 and 3

---

6% Section

**Loaded**

Assume: 4 mph.

$$MPH = \frac{375 \times 295}{360000(.015 + .06 + .0076)}$$

$$= \frac{110625}{29750}$$

$$= 3.7$$

1 hr. ÷ 3.7 mph. = 0.270 hr. per mi. 0.270 hr. per mi. x 1.64 mi. = 0.443 hr. 0.443 hr. x 26.68 gals. per hr. = 11.82 gals. x 20¢ per gal. = 236.40¢

**Empty**

Calculate horsepower

$$40 = \frac{375\ H.P.}{34000(.015 + .016 + -.06\ )}$$

$$40 = \frac{375\ H.P.}{-1658}$$

$$H.P. = \frac{-66320}{375}$$

$$H.P. = -177$$

Fuel used at 177 hp.:

$$\frac{.53 \times 177}{6.2}$$

$$= 15.11 \text{ gals. per hr.}$$

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.64 mi. = 0.041 hr. 0.041 hr. x 15.11 gals. per hr. = 0.62 gals. x 20¢ per gal. = 12.40¢

---

| Loaded | Empty |
|---|---|

## 0% Section

Loaded speed on the level has been found to be 13.3 mph. at maximum horsepower. Fuel consumption at maximum output is 26.68 gals. per hr.

1 hr. ÷ 13.3 mph. = 0.0752 hr. per mi. 0.0752 hr. per mi. x 1.23 mi. = 0.0926 hr. 0.0926 hr. x 26.68 gals per hr. = 2.475 gals. x 20¢ per gal. = 49.50¢

Empty speed on the level has been found to be 40 mph. at 113 horsepower. Fuel consumption at this speed is 9.84 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.23 mi. = 0.0308 hr. 0.0308 hr. x 9.84 gals. per hr. = 0.302 gal. x 20¢ per gal. = 6.40¢

---

## Remainder of 5% Section

Speed downgrade has been found to be 20 mph. at -510 horsepower. Fuel consumption at maximum, 26.68 gals. per hr.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .84 mi. = 0.042 hr. 0.042 hr. x 26.68 gals. per hr. = 1.122 gals. x 20¢ per gal. = 22.44¢

Speed upgrade has been found to be 40 mph. at 287 horsepower. Fuel consumption at 24.00 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x .84 mi. = 0.021 hr. 0.021 hr. x 24.00 gals. per hr. = 0.505 gals. x 20¢ per gal. = 10.10¢

---

## Calculation of New Hauling Costs.

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| 6% Section | 0.4430 hr. | 236.40¢ | 0.0410 hr. | 12.40¢ |
| 0% " | 0.0926 | 49.50 | 0.0308 | 6.40 |
| 5% " | 0.0420 | 22.44 | 0.0210 | 10.10 |
| Section 4 | 0.0930 | 20.50 | 0.0465 | 13.34 |
| " 5 | 0.5340 | 285.00 | 0.0960 | 7.10 |
| " 6 | 0.0250 | 13.34 | 0.0270 | 14.70 |
| Total | 1.2296 hr. | 627.18¢ | 0.2623 hr. | 64.04¢ |

Round-trip speed and fuel cost.

Loaded speed. 9.9 mi. ÷ 1.2296 hr. = 8.1 mph.
Empty speed. 9.9 mi. ÷ 0.2623 hr. =37.6 mph.

Round-trip speed. $$\frac{2(37.6)(8.1)}{37.6 + 8.1}$$

$$= 13.3 \text{ mph.}$$

Fuel per M per mi.

| | |
|---|---|
| Loaded | 627.18¢ |
| Empty | 64.04 |
| | 691.22 ÷ 9.9 mi. = 69.85¢ ÷ 46M = 1.52¢ |

Summary of New Hauling Costs

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per mi. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 13.3 | 4.58¢ | 1.52¢ | $15000 | 0.652¢ | $ 600 | 0.461¢ | 7.213¢ |

New Hauling Cost per M - Woods to Mill

| | |
|---|---|
| 9.9 mi. x 7.213¢ = | $0.72 |
| Original Hauling Cost per M = | $0.76 |
| Reduction saving | $0.04 |

Annual Savings $0.04 x 130,000M = $5200.

Reduction of Road Sections 5 and 6.

Loaded | Empty

Remainder of 2% Section

Speed up the 2% grade has | Speed down the grade has

**Loaded**

previously been found to be 7.2 mph. Fuel consumption at the maximum.

1 hr. ÷ 7.2 mph. = 0.139 hr. per mi. 0.139 hr. per mi. x 2.9 mi. = 0.403 hr. 0.403 hr. x 26.68 gals. per hr. = 10.75 gals. x 20¢ per gal. = 215.00¢

**Empty**

previously been found to be 40 mph. at 42.5 horsepower. Fuel consumption is 3.70 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 2.9 mi. = 0.0725 hr. 0.0725 hr. x 3.70 gals. per hr. = 0.268 gal. x 20¢ per gal. = 5.36¢

---

## 0% Section

Loaded speed on the level has been found to be 13.3 mph. at maximum horsepower. Fuel consumption also at the maximum.

1 hr. ÷ 13.3 mph. = 0.0752 hr. per mi. 0.0752 hr. per mi. x 1.07 mi. = 0.0805 hr 0.0805 hr. x 26.68 gals. per hr. = 2.15 gals. x 20¢ per gal. = 43.00¢

Empty speed on the level has been found to be 40 mph at 113 horsepower. Fuel consumption is 9.84 gals. per hr.

1 hr. ÷ 40 mph. = 0.025 hr. per mi. 0.025 hr. per mi. x 1.07 mi. = 0.0268 hr. 0.0268 hr. x 9.84 gals. per hr. = 0.252 gals. x 20¢ per gal. = 5.04¢

---

## 6% Section

Calculate horsepower.

$$20 = \frac{375 \text{ H.P.}}{360000(.015+.00851+ -.06)}$$

$$20 = \frac{375 \text{ H.P.}}{-13150}$$

$$\text{H.P.} = \frac{263000}{375}$$

Assume: 36 mph.

$$\text{MPH} = \frac{375 \times 295}{34000(.015+.06+014)}$$

$$= \frac{110625}{3060}$$

$$= 36.2$$

**Loaded**

H.P. = -700

Calculate fuel at the maximum.

1 hr. ÷ 20 mph. = 0.05 hr. per mi. 0.05 hr. per mi. x .95 mi. = 0.0475 hr. 0.0475 hr. x 26.68 gals. per hr. = 1.27 gals. x 20¢ per gal. = 25.40¢

**Empty**

1 hr. ÷ 36.2 mph. = 0.0276 hr. per mi. 0.0276 hr. per mi. x .95 mi. = 0.0262 hr. 0.0262 hr. x 26.68 gals. per hr. = 0.70 gal. x 20¢ per gal. = 14.00¢

---

## Hauling Costs if Both Grades are Reduced

| | Loaded | | Empty | |
|---|---|---|---|---|
| | Time | Fuel | Time | Fuel |
| 6% Section | 0.4430 hr. | 236.40¢ | 0.0410 hr. | 12.40¢ |
| 0% " | 0.0926 | 49.50 | 0.0308 | 6.40 |
| 5% " | 0.0420 | 22.44 | 0.0210 | 10.10 |
| Section 4 | 0.0930 | 22.50 | 0.0465 | 13.34 |
| 2% Section | 0.4030 | 215.00 | 0.0725 | 5.36 |
| 0% " | 0.0805 | 43.00 | 0.0268 | 5.04 |
| 6% " | 0.0475 | 25.40 | 0.0262 | 14.00 |
| Total | 1.2016 hr. | 612.24¢ | 0.2648 hr. | 56.64¢ |

Round-trip speed and fuel cost.

Loaded speed. 10.35 mi. ÷ 1.2016 hr. = 8.6 mph.
Empty speed. 10.35 mi. ÷ 0.2648 hr. =38.1 mph.

Round-trip speed. $\frac{2(38.1)(8.6)}{38.1 + 8.6}$

$= 14.4$ mph

Fuel per M per mi.

| | |
|---|---|
| Loaded | 612.24¢ |
| Empty | 56.64 |
| | 668.88¢ ÷ 10.35 mi. = 64.6¢ ÷ 46M = 1.406¢ |

Summary of Hauling Costs - Both Grades Reduced.

| Road Type | Round-Trip Speed | Hauling Cost | Fuel per M per mi. | Const. per mi. Rt. II | Const. per M per mi. | Maint. per yr. Rt. II | Maint. per M per yr. | Total Cost |
|---|---|---|---|---|---|---|---|---|
| II | 14.4 | 4.23 | 1.406 | $15000 | 0.652 | $ 600 | 0.461 | 6.749¢ |

Hauling Cost if Both grades are Reduced - Woods to Mill

10.35 mi. x 6.749¢ = $0.70

Hauling Cost if Grade in Section 1, 2 and 3 is reduced = $0.72

Since there is a saving both grades should be reduced.

Amount that can be spent to reduce the grade in Sections 1, 2 and 3, if interest is at 6% and the investment is to be returned at the end of the operation.

| | |
|---|---|
| Original cost per trip | $0.76 |
| Cost if Grade 1 is reduced | .72 |
| Saving per M per trip | $0.04 |

| | |
|---|---|
| Annual cut | 130,000M |
| Savings per M | $0.04 |
| Annual savings | $5200.00 |

$$Co = \frac{\$5200.00\ (1.06^{20}-1)}{0.06 \times 1.06^{20}}$$

$$= \frac{\$5200.00\ (2.207)}{0.06 \times 3.207}$$

$$= \$5200.00\ (11.47)$$

= \$59,500 to reduce the grade in Sections 1, 2 and 3.

Amount that can be spent to reduce the grade in Sections 5 and 6, if interest is at 6% and the investment is to be returned at the end of the operation.

| | |
|---|---|
| Cost if Grade 1 is reduced | \$0.72 |
| Cost if both grades are reduced | .70 |
| Savings per M per trip | \$0.02 |

| | |
|---|---|
| Annual cut | 130,000M |
| Savings per M | \$0.02 |
| Annual savings | \$2600.00 |

$$Co = \frac{\$2600.00\ (1.06^{20}-1)}{0.06 \times 1.06^{20}}$$

$$= \frac{\$2600.00\ (2.207)}{0.06 \times 3.207}$$

$$= \$2600.00\ (11.47)$$

= \$29,800 to reduce the grade in Sections 5 and 6.

# Appendix A

TRACTIVE RESISTANCE TABLES

In order to eliminate the necessity of individual calculations, tables are given from which unit resistance can be obtained for any vehicle at any speed and any load; they were developed by the Public Roads Administration by method previously described (see Section I). Figures 11 and 12 are given to show the variation in unit resistances for all types of trucks with a 16,000 pound gross vehicle weight. It can be seen that the variation is not excessive.

Test weights as originally given went only to 42,000 pounds with speed of 40 miles per hour. Since the gross weights logging trucks will exceed 42,000 pounds in many cases, formulae were developed for heavy tractor-trucks by which resistance can be determined for any combination weight and speed. The development of the formulae is as follows:

The total resistance offered to a vehicle has been shown to be proportional to its weight. In other words when total resistance is plotted over vehicle weight the resulting graph is a straight line (as shown in Figure 7). The slope of this line can be found by the following formula:

$$\text{Slope} = \frac{x_2 - x_1}{y_2 - y_1}$$

When the slope of the line is determined actual weights and resistances were substituted and the Formula determined.

Example:

At 6 mph the total resistance for 12,000 pounds is 90 pounds and for 42,000 pounds, 323.4 pounds.

$$\text{Slope} = \frac{323.4 \text{ lbs.} - 90 \text{ lbs.}}{42{,}000 \text{ lbs.} - 12{,}000 \text{ lbs.}}$$

$$= \frac{233.4 \text{ lbs.}}{30{,}000 \text{ lbs.}}$$

$$= 0.00778$$

Substituting the 12,000 pound values,

$$0.00778 = \frac{TR - 90 \text{ lbs.}}{GVW - 12{,}000 \text{ lbs.}}$$

$$0.00778\ (GVW - 12{,}000 \text{ lbs}) = TR - 90 \text{ lbs.}$$

$$0.00778\ GVW - 93.36 \text{ lbs} = TR - 90 \text{ lbs.}$$

$$TR = 0.00778\ GVW - 3.36 \text{ lbs.}$$

The following table shows the formulae for any road speed from 6 to 40 miles per hour. At the right is shown the total and unit resistances for the 360,000 pound vehicle used is the sample problem.

Table 7. Tractive Resistance Formulae for Heavy Tractor-Truck Semi-trailers.

| Speed | Formulae | 360,000 lbs. Total Resistance | 360,000 lbs. Unit Resistance |
|---|---|---|---|
| 6 mph | TR = 0.00778 GVW - 3.36 lbs. | 2797.44 lbs. | 7.75 lbs. |
| 8 | TR = 0.00782 GVW + 3.24 " | 2818.44 " | 7.80 " |
| 10 | TR = 0.00796 GVW + 10.08 " | 2875.40 " | 7.98 " |
| 12 | TR = 0.00806 GVW + 18.48 " | 2920.28 " | 8.13 " |
| 14 | TR = 0.00813 GVW + 27.24 " | 2954.04 " | 8.20 " |
| 16 | TR = 0.00826 GVW + 35.28 " | 3008.88 " | 8.35 " |
| 18 | TR = 0.00832 GVW + 45.36 " | 3040.56 " | 8.45 " |
| 20 | TR = 0.00838 GVW + 55.44 " | 3062.24 " | 8.51 " |
| 22 | TR = 0.00854 GVW + 65.52 " | 3139.92 " | 8.70 " |
| 24 | TR = 0.00840 GVW + 84.00 " | 3108.00 " | 8.80 " |
| 26 | TR = 0.00864 GVW + 90.72 " | 3201.12 " | 8.90 " |
| 28 | TR = 0.00872 GVW +117.60 " | 3321.60 " | 9.21 " |
| 32 | TR = 0.00897 GVW +133.56 " | 3362.73 " | 9.33 " |
| 34 | TR = 0.00910 GVW +151.20 " | 3427.20 " | 9.50 " |
| 36 | TR = 0.00926 GVW +169.68 " | 3503.28 " | 9.73 " |
| 38 | TR = 0.00940 GVW +192.20 " | 3516.20 " | 9.77 " |
| 40 | TR = 0.00956 GVW +220.08 " | 3601.68 " | 10.00 " |

where

TR is the total resistance in pounds, and
GVW is the gross vehicle weight in pounds.

Note - The slope for the 24 miles per hour speed does not follow in sequence, however, this cannot be explained. Liberty was taken to change this figure when calculating the unit resistance for the 360,000 pound truck.

For an explanation of the table showing conversion factors see pages 48 and 49.

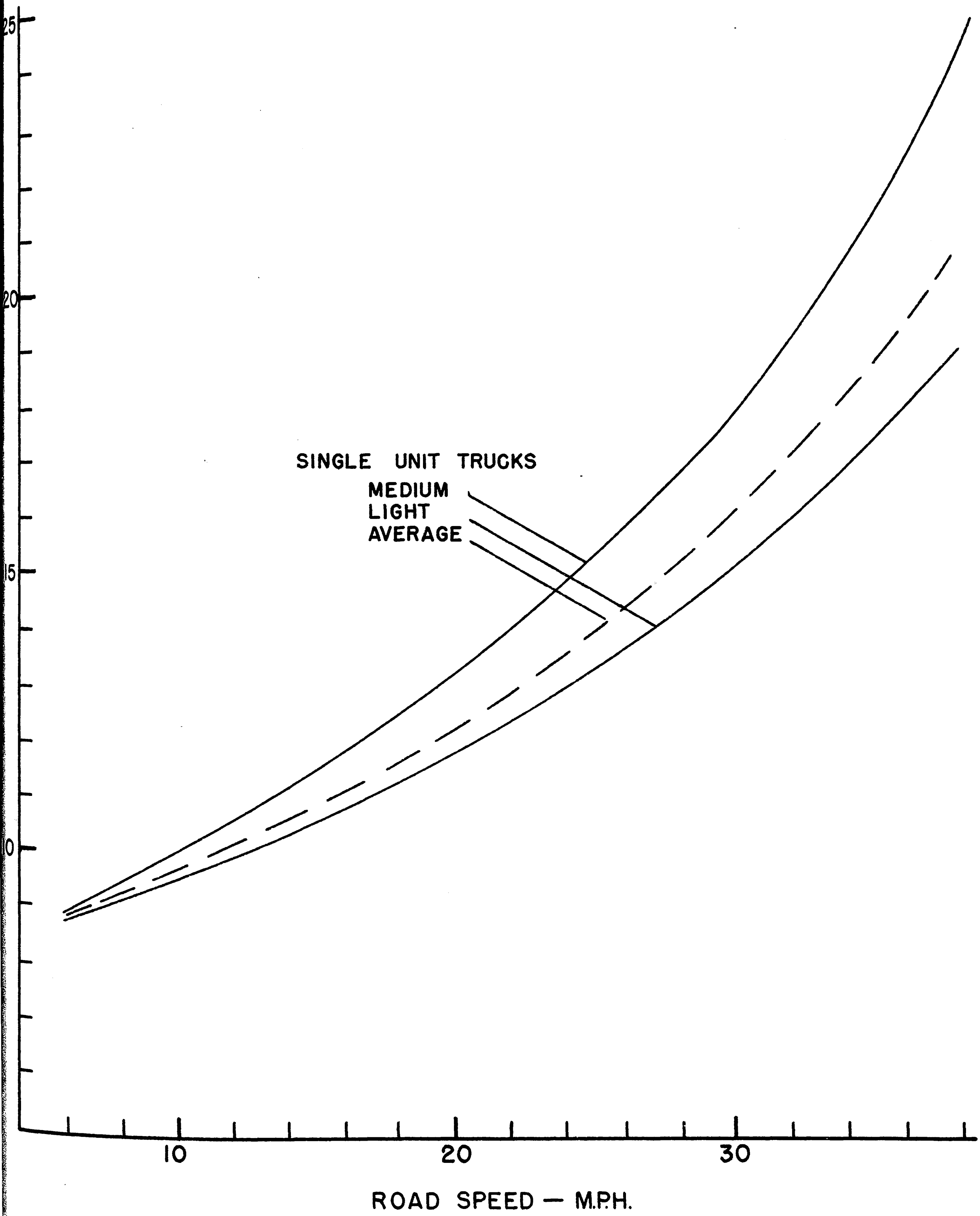


FIGURE 16 - VARIATION OF UNIT RESISTANCE IN SINGLE UNIT TRUCKS - GROSS VEHICLE WEIGHT OF 16,000 POUNDS.

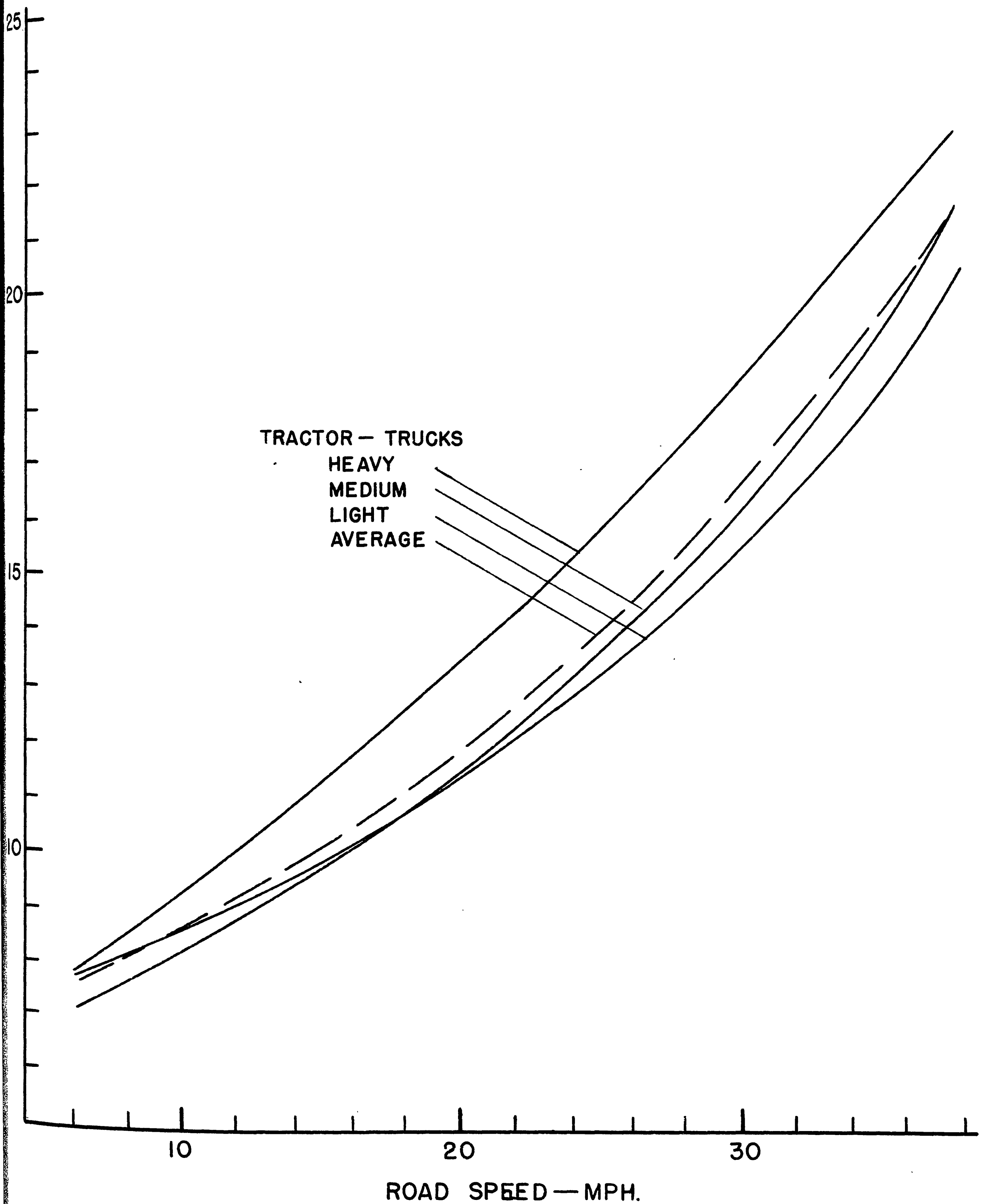


FIGURE 17 - VARIATION OF UNIT RESISTANCE IN TRACTOR TRUCKS - GROSS VEHICLE WEIGHT OF 16,000 POUNDS.

| Speed MPH | Unit Tractive Resistance, in Pounds per 1000 Pounds, for Weights of - Thousands of Pounds | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 8 lbs. | 9 lbs. | 10 lbs. | 11 lbs. | 12 lbs. | 13 lbs. | 14 lbs. | 15 lbs. | 16 lbs. |
| 4 | 8.3 | 8.3 | 8.4 | 8.4 | 8.5 | 8.5 | 8.5 | 8.5 | 8.6 |
| 6 | 8.8 | 8.8 | 8.8 | 8.8 | 8.8 | 8.8 | 8.9 | 8.9 | 8.9 |
| 8 | 9.3 | 9.3 | 9.3 | 9.3 | 9.3 | 9.3 | 9.2 | 9.2 | 9.2 |
| 10 | 10.0 | 9.9 | 9.8 | 9.8 | 9.7 | 9.7 | 9.7 | 9.6 | 9.6 |
| 12 | 10.7 | 10.6 | 10.5 | 10.4 | 10.3 | 10.2 | 10.1 | 10.0 | 10.0 |
| 14 | 11.6 | 11.4 | 11.2 | 11.0 | 10.8 | 10.7 | 10.6 | 10.5 | 10.4 |
| 16 | 12.5 | 12.2 | 11.9 | 11.7 | 11.5 | 11.3 | 11.1 | 11.0 | 10.9 |
| 18 | 13.6 | 13.1 | 12.7 | 12.4 | 12.2 | 11.9 | 11.7 | 11.5 | 11.4 |
| 20 | 14.7 | 14.1 | 13.6 | 13.2 | 12.9 | 12.6 | 12.3 | 12.1 | 11.9 |
| 22 | 15.9 | 15.2 | 14.6 | 14.1 | 13.7 | 13.3 | 13.0 | 12.7 | 12.5 |
| 24 | 17.2 | 16.3 | 15.6 | 15.0 | 14.5 | 14.1 | 13.7 | 13.4 | 13.1 |
| 26 | 18.5 | 17.5 | 16.7 | 16.0 | 15.4 | 14.9 | 14.5 | 14.1 | 13.8 |
| 28 | 19.9 | 18.8 | 17.8 | 17.1 | 16.4 | 15.9 | 15.4 | 14.9 | 14.6 |
| 30 | 21.4 | 20.1 | 19.0 | 18.2 | 17.4 | 16.8 | 16.3 | 15.8 | 15.4 |
| 32 | 22.9 | 21.4 | 20.3 | 19.3 | 18.5 | 17.8 | 17.2 | 16.7 | 16.2 |
| 34 | 24.5 | 22.9 | 21.6 | 20.5 | 19.7 | 18.9 | 18.2 | 17.6 | 17.1 |
| 36 | 26.1 | 24.4 | 23.0 | 21.9 | 20.9 | 20.1 | 19.3 | 18.6 | 18.1 |
| 38 | 27.9 | 26.1 | 24.9 | 23.3 | 22.3 | 21.4 | 20.5 | 19.8 | 19.2 |
| 40 | 29.9 | 27.9 | 26.3 | 25.0 | 23.9 | 22.8 | 21.9 | 21.1 | 20.4 |

Table 8. Average Unit Tractive Resistance for Light Trucks. (Six Makes.)

Unit Tractive Resistance, in Pounds per 1000 Pounds, for Weights of -

Thousands of Pounds

| peed MPH | 11 lbs. | 12 lbs. | 13 lbs. | 14 lbs. | 15 lbs. | 16 lbs. | 17 lbs. | 18 lbs. | 19 lbs. | 20 lbs. | 21 lbs. | 22 lbs. | 23 lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 8.7 | 8.7 | 8.6 | 8.6 | 8.6 | 8.5 | 8.5 | 8.7 | 8.9 | 9.1 | 9.3 | 9.4 | 9.5 |
| 6 | 9.4 | 9.3 | 9.2 | 9.1 | 9.1 | 9.0 | 9.0 | 9.1 | 9.3 | 9.4 | 9.5 | 9.7 | 9.7 |
| 8 | 10.0 | 9.9 | 9.8 | 9.7 | 9.6 | 9.6 | 9.5 | 9.6 | 9.7 | 9.8 | 9.9 | 9.9 | 10.0 |
| 10 | 10.9 | 10.9 | 10.5 | 10.3 | 10.2 | 10.1 | 10.0 | 10.1 | 10.1 | 10.1 | 10.2 | 10.2 | 10.2 |
| 12 | 11.6 | 11.4 | 11.2 | 11.0 | 10.8 | 10.7 | 10.6 | 10.5 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 |
| 14 | 12.6 | 12.4 | 11.9 | 11.7 | 11.5 | 11.3 | 11.1 | 11.1 | 11.2 | 11.1 | 11.1 | 11.1 | 11.0 |
| 16 | 13.5 | 13.1 | 12.8 | 12.5 | 12.2 | 12.0 | 11.8 | 11.7 | 11.6 | 11.6 | 11.6 | 11.6 | 11.5 |
| 18 | 14.6 | 14.1 | 13.7 | 11.3 | 12.9 | 12.7 | 12.4 | 12.4 | 12.3 | 12.2 | 12.2 | 12.1 | 12.1 |
| 20 | 15.7 | 15.1 | 14.6 | 14.1 | 13.8 | 13.4 | 13.1 | 13.0 | 13.0 | 12.9 | 12.8 | 12.8 | 12.7 |
| 22 | 16.9 | 16.2 | 15.6 | 15.1 | 14.6 | 14.2 | 13.9 | 13.8 | 13.7 | 13.6 | 13.5 | 13.4 | 13.4 |
| 24 | 18.1 | 17.3 | 16.6 | 16.0 | 15.5 | 15.1 | 14.7 | 14.5 | 14.4 | 14.3 | 14.2 | 14.1 | 14.1 |
| 26 | 19.4 | 18.5 | 17.7 | 17.0 | 16.5 | 15.9 | 15.5 | 15.4 | 15.2 | 15.1 | 15.0 | 14.9 | 14.8 |
| 28 | 20.8 | 19.8 | 18.9 | 18.2 | 17.5 | 16.9 | 16.5 | 16.3 | 16.1 | 16.0 | 15.9 | 15.8 | 15.6 |
| 30 | 22.5 | 21.4 | 20.4 | 19.4 | 18.8 | 18.1 | 17.5 | 17.3 | 17.2 | 17.0 | 16.9 | 16.7 | 16.6 |
| 32 | 24.1 | 22.9 | 21.8 | 20.9 | 20.1 | 19.4 | 18.7 | 18.5 | 18.3 | 18.1 | 17.9 | 17.7 | 17.6 |
| 34 | 26.1 | 24.7 | 23.5 | 22.5 | 21.7 | 20.9 | 20.2 | 19.9 | 19.6 | 19.3 | 19.1 | 18.8 | 18.6 |
| 36 | 28.5 | 26.9 | 25.6 | 24.5 | 23.5 | 22.6 | 21.9 | 21.5 | 21.1 | 20.8 | 20.5 | 20.2 | 20.0 |
| 38 | 31.6 | 29.9 | 28.4 | 27.2 | 26.1 | 25.1 | 24.3 | 23.7 | 23.2 | 22.7 | 22.3 | 21.9 | 21.6 |

Table 9. Average Unit Tractive Resistance for Medium Trucks. (Three Makes.)

Unit Tractive Resistance, in Pounds per 1000 Pounds, for Weights of -

Thousands of Pounds

| Speed MPH | 8 lbs. | 10 lbs. | 12 lbs. | 14 lbs. | 16 lbs. | 18 lbs. | 20 lbs. | 22 lbs. | 24 lbs. |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 8.4 | 8.5 | 8.5 | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 |
| 6 | 9.0 | 9.0 | 9.0 | 9.0 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 |
| 8 | 9.8 | 9.6 | 9.5 | 9.4 | 9.3 | 9.3 | 9.2 | 9.2 | 9.2 |
| 10 | 10.6 | 10.3 | 10.0 | 9.9 | 9.8 | 9.7 | 9.6 | 9.5 | 9.5 |
| 12 | 11.5 | 11.0 | 10.6 | 10.4 | 10.2 | 10.1 | 10.0 | 9.9 | 9.8 |
| 14 | 12.4 | 11.7 | 11.3 | 11.0 | 10.7 | 10.5 | 10.4 | 10.2 | 10.1 |
| 16 | 13.5 | 12.6 | 12.0 | 11.6 | 11.2 | 11.0 | 10.8 | 10.6 | 10.5 |
| 18 | 14.8 | 13.6 | 12.8 | 12.2 | 11.8 | 11.5 | 11.2 | 11.0 | 10.8 |
| 20 | 16.0 | 14.6 | 13.6 | 12.9 | 12.4 | 12.0 | 11.7 | 11.4 | 11.2 |
| 22 | 17.4 | 15.7 | 14.5 | 13.7 | 13.1 | 12.6 | 12.2 | 11.9 | 11.6 |
| 24 | 18.8 | 16.8 | 15.4 | 14.5 | 13.8 | 13.2 | 12.8 | 12.4 | 12.1 |
| 26 | 20.3 | 18.0 | 16.5 | 15.3 | 14.5 | 13.9 | 13.4 | 12.9 | 12.6 |
| 28 | 21.9 | 19.3 | 17.5 | 16.3 | 15.4 | 14.6 | 14.0 | 13.6 | 13.2 |
| 30 | 23.6 | 20.6 | 18.7 | 17.3 | 16.3 | 15.5 | 14.8 | 14.3 | 13.9 |
| 32 | 25.3 | 22.1 | 19.9 | 18.4 | 17.3 | 16.4 | 15.7 | 15.1 | 14.6 |
| 34 | 27.2 | 23.7 | 21.3 | 19.6 | 18.4 | 17.4 | 16.6 | 16.0 | 15.4 |
| 36 | 29.5 | 25.5 | 22.9 | 21.0 | 19.6 | 18.5 | 17.6 | 16.9 | 16.3 |
| 38 | 32.0 | 27.7 | 24.8 | 22.7 | 21.2 | 20.0 | 19.0 | 18.2 | 17.5 |

Table 10. Average Unit Tractive Resistance for all Single Unit Trucks.

| Speed MPH | Unit Tractive Resistance, in Pounds per 1000 Pounds, for Weights of - Thousands of Pounds | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 12 lbs. | 14 lbs. | 16 lbs. | 18 lbs. | 20 lbs. | 22 lbs. | 24 lbs. | 26 lbs. | 28 lbs. | 30 lbs. |
| 4 | 7.2 | 7.3 | 7.3 | 7.4 | 7.5 | 7.6 | 7.6 | 7.7 | 7.8 | 7.8 |
| 6 | 7.6 | 7.7 | 7.7 | 7.7 | 7.7 | 7.8 | 7.9 | 7.9 | 8.0 | 8.0 |
| 8 | 8.2 | 8.2 | 8.1 | 8.1 | 8.1 | 8.2 | 8.2 | 8.3 | 8.3 | 8.3 |
| 10 | 8.8 | 8.7 | 8.6 | 8.6 | 8.5 | 8.6 | 8.6 | 8.6 | 8.6 | 8.7 |
| 12 | 9.4 | 9.3 | 9.1 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 |
| 14 | 10.1 | 9.8 | 9.7 | 9.5 | 9.4 | 9.4 | 9.3 | 9.3 | 9.3 | 9.3 |
| 16 | 10.8 | 10.5 | 10.2 | 10.0 | 9.9 | 9.8 | 9.7 | 9.7 | 9.7 | 9.6 |
| 18 | 11.5 | 11.1 | 10.8 | 10.5 | 10.3 | 10.2 | 10.1 | 10.1 | 10.0 | 10.0 |
| 20 | 12.3 | 11.8 | 11.4 | 11.1 | 10.9 | 10.7 | 10.6 | 10.5 | 10.4 | 10.4 |
| 22 | 13.2 | 12.6 | 12.1 | 11.7 | 11.4 | 11.2 | 11.1 | 11.0 | 10.9 | 10.8 |
| 24 | 14.2 | 13.4 | 12.8 | 12.4 | 12.0 | 11.8 | 11.6 | 11.5 | 11.3 | 11.2 |
| 26 | 15.2 | 14.3 | 13.6 | 13.1 | 12.7 | 12.4 | 12.2 | 12.0 | 11.8 | 11.7 |
| 28 | 16.3 | 15.2 | 14.5 | 13.9 | 13.4 | 13.0 | 12.8 | 12.5 | 12.3 | 12.2 |
| 30 | 17.4 | 16.3 | 15.4 | 14.7 | 14.2 | 13.7 | 13.4 | 13.1 | 12.9 | 12.7 |
| 32 | 18.7 | 17.4 | 16.4 | 15.6 | 15.0 | 14.5 | 14.1 | 13.8 | 13.5 | 13.2 |
| 34 | 20.1 | 18.7 | 17.6 | 16.7 | 16.0 | 15.4 | 14.9 | 14.5 | 14.2 | 13.8 |
| 36 | 21.8 | 20.1 | 18.9 | 17.9 | 17.1 | 16.4 | 15.8 | 15.3 | 14.9 | 14.5 |
| 38 | 23.7 | 21.8 | 20.4 | 19.3 | 18.5 | 17.6 | 16.9 | 16.3 | 15.8 | 15.3 |

Table 11. Average Unit Tractive Resistance for Light Tractor-Trucks. (Seven Makes.)

Unit Tractive Resistance, in Pounds per 1000 Pounds, for Weights of -

Thousands of Pounds

| Speed MPH | 14 lbs. | 16 lbs. | 18 lbs. | 20 lbs. | 22 lbs. | 24 lbs. | 26 lbs. | 28 lbs. | 30 lbs. | 32 lbs. | 34 lbs. | 36 lbs. | 38 lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 7.1 | 7.2 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 7.2 | 7.3 | 7.4 | 7.4 | 7.5 | 7.5 |
| 8 | 7.7 | 7.7 | 7.6 | 7.6 | 7.5 | 7.5 | 7.5 | 7.5 | 7.6 | 7.7 | 7.7 | 7.8 | 7.8 |
| 10 | 8.4 | 8.2 | 8.1 | 8.0 | 7.9 | 7.9 | 7.8 | 7.9 | 7.9 | 7.9 | 8.0 | 8.0 | 8.0 |
| 12 | 9.1 | 8.8 | 8.6 | 8.5 | 8.4 | 8.3 | 8.2 | 8.2 | 8.2 | 8.3 | 8.3 | 8.3 | 8.3 |
| 14 | 9.8 | 9.4 | 9.2 | 9.0 | 8.8 | 8.7 | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 |
| 16 | 10.5 | 10.1 | 9.8 | 9.5 | 9.3 | 9.1 | 9.0 | 9.0 | 9.0 | 8.9 | 8.9 | 8.9 | 8.9 |
| 18 | 11.2 | 10.8 | 10.4 | 10.1 | 9.8 | 9.6 | 9.5 | 9.4 | 9.4 | 9.3 | 9.3 | 9.3 | 9.3 |
| 20 | 12.0 | 11.4 | 11.0 | 10.7 | 10.4 | 10.1 | 9.9 | 9.8 | 9.8 | 9.7 | 9.6 | 9.6 | 9.6 |
| 22 | 12.9 | 12.2 | 11.7 | 11.3 | 10.9 | 10.6 | 10.4 | 10.3 | 10.2 | 10.1 | 10.0 | 10.0 | 9.9 |
| 24 | 13.8 | 13.0 | 12.4 | 11.9 | 11.5 | 11.2 | 10.9 | 10.7 | 10.6 | 10.5 | 10.4 | 10.4 | 10.3 |
| 26 | 14.8 | 13.9 | 13.2 | 12.6 | 12.1 | 11.8 | 11.4 | 11.3 | 11.1 | 11.0 | 10.9 | 10.8 | 10.7 |
| 28 | 15.8 | 14.8 | 14.0 | 13.4 | 12.8 | 12.4 | 12.0 | 11.8 | 11.7 | 11.5 | 11.4 | 11.2 | 11.1 |
| 30 | 17.0 | 15.8 | 14.9 | 14.2 | 13.6 | 13.1 | 12.7 | 12.4 | 12.2 | 12.0 | 11.9 | 11.7 | 11.6 |
| 32 | 18.3 | 17.0 | 16.0 | 15.2 | 14.5 | 13.9 | 13.4 | 13.1 | 12.9 | 12.7 | 12.4 | 12.3 | 12.1 |
| 34 | 19.9 | 18.3 | 17.2 | 16.2 | 15.5 | 14.8 | 14.3 | 13.9 | 13.6 | 13.3 | 13.1 | 12.9 | 12.7 |
| 36 | 21.4 | 19.8 | 18.5 | 17.4 | 16.5 | 15.8 | 15.2 | 14.8 | 14.4 | 14.1 | 13.8 | 13.6 | 13.3 |
| 38 | 23.4 | 21.5 | 20.0 | 18.8 | 17.9 | 17.1 | 16.4 | 15.9 | 15.4 | 15.0 | 14.7 | 14.4 | 14.1 |
| 40 | 25.9 | 23.7 | 22.0 | 20.6 | 19.5 | 18.6 | 17.8 | 17.2 | 16.6 | 16.1 | 15.7 | 15.3 | 14.9 |

Table 12. Average Unit Resistance for Medium Tractor-Trucks. (Six Makes.)

Unit Tractive Resistance, in Pounds per 1000
Pounds, for Weights of -

Thousands of Pounds

| peed MPH | 16 lbs. | 18 lbs. | 20 lbs. | 22 lbs. | 24 lbs. | 26 lbs. | 28 lbs. | 30 lbs. | 32 lbs. | 34 lbs. | 36 lbs. | 38 lbs. | 40 lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 7.9 | 7.8 | 7.7 | 7.6 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| 8 | 8.5 | 8.3 | 8.2 | 8.1 | 8.0 | 8.0 | 8.0 | 7.9 | 7.9 | 7.9 | 7.8 | 7.8 | 7.8 |
| 10 | 9.2 | 9.0 | 8.8 | 8.6 | 8.5 | 8.4 | 8.4 | 8.3 | 8.3 | 8.2 | 8.2 | 8.1 | 8.1 |
| 12 | 10.0 | 9.7 | 9.5 | 9.3 | 9.1 | 9.0 | 8.9 | 8.8 | 8.7 | 8.7 | 8.6 | 8.5 | 8.5 |
| 14 | 10.8 | 10.4 | 10.1 | 9.9 | 9.7 | 9.5 | 9.4 | 9.3 | 9.2 | 9.1 | 9.0 | 8.9 | 8.9 |
| 16 | 11.6 | 11.1 | 10.8 | 10.5 | 10.3 | 10.1 | 9.9 | 9.8 | 9.6 | 9.5 | 9.4 | 9.3 | 9.2 |
| 18 | 12.4 | 11.9 | 11.5 | 11.2 | 10.9 | 10.7 | 10.5 | 10.3 | 10.1 | 10.0 | 9.8 | 9.7 | 9.6 |
| 20 | 13.3 | 12.7 | 12.3 | 11.9 | 11.6 | 11.3 | 11.1 | 10.8 | 10.6 | 10.5 | 10.3 | 10.2 | 10.1 |
| 22 | 14.2 | 13.6 | 13.1 | 12.6 | 12.3 | 11.9 | 11.6 | 11.4 | 11.2 | 11.0 | 10.8 | 10.6 | 10.5 |
| 24 | 15.2 | 14.5 | 13.9 | 13.4 | 13.0 | 12.6 | 12.3 | 12.0 | 11.7 | 11.5 | 11.3 | 11.1 | 10.9 |
| 26 | 16.2 | 15.4 | 14.7 | 14.2 | 13.7 | 13.3 | 12.9 | 12.6 | 12.3 | 12.0 | 11.8 | 11.6 | 11.4 |
| 28 | 17.2 | 16.3 | 15.6 | 15.0 | 14.5 | 14.0 | 13.6 | 13.2 | 12.9 | 12.6 | 12.3 | 12.1 | 11.9 |
| 30 | 18.3 | 17.3 | 16.5 | 15.8 | 15.3 | 14.7 | 14.3 | 13.9 | 13.5 | 13.2 | 12.9 | 12.7 | 12.5 |
| 32 | 19.4 | 18.3 | 17.4 | 16.7 | 16.1 | 15.5 | 15.0 | 14.6 | 14.2 | 13.9 | 13.6 | 13.3 | 13.0 |
| 34 | 20.5 | 19.4 | 18.4 | 17.7 | 17.0 | 16.4 | 15.8 | 15.4 | 15.0 | 14.6 | 14.3 | 14.0 | 13.7 |
| 36 | 21.8 | 20.5 | 19.5 | 18.7 | 18.0 | 17.4 | 16.8 | 16.3 | 15.8 | 15.5 | 15.1 | 14.8 | 14.5 |
| 38 | 23.1 | 21.8 | 20.7 | 19.9 | 19.1 | 18.4 | 17.8 | 17.3 | 16.8 | 16.4 | 16.0 | 15.7 | 15.4 |
| 40 | 24.6 | 23.2 | 22.1 | 21.1 | 20.1 | 19.6 | 19.0 | 18.4 | 17.9 | 17.5 | 17.1 | 16.7 | 16.4 |

Table 13. Average Unit Resistance for Heavy Tractor-Trucks.
(Four Makes.)

Unit Tractive Resistance, in Pounds per 1000
Pounds, for Weights of -

Thousands of Pounds

| Speed MPH | 12 lbs. | 14 lbs. | 16 lbs. | 18 lbs. | 20 lbs. | 22 lbs. | 24 lbs. | 26 lbs. | 28 lbs. | 30 lbs. | 32 lbs. | 34 lbs. | 36 lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 7.5 | 7.5 | 7.5 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 |
| 8 | 8.1 | 8.1 | 8.1 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| 10 | 8.8 | 8.7 | 8.6 | 8.5 | 8.5 | 8.4 | 8.4 | 8.4 | 8.3 | 8.3 | 8.3 | 8.3 | 8.2 |
| 12 | 9.6 | 9.4 | 9.2 | 9.1 | 9.0 | 8.9 | 8.8 | 8.8 | 8.7 | 8.7 | 8.6 | 8.6 | 8.5 |
| 14 | 10.4 | 10.1 | 9.8 | 9.6 | 9.5 | 9.4 | 9.3 | 9.2 | 9.1 | 9.0 | 9.0 | 8.9 | 8.9 |
| 16 | 11.2 | 10.8 | 10.5 | 10.2 | 10.0 | 9.8 | 9.7 | 9.6 | 9.5 | 9.4 | 9.3 | 9.3 | 9.2 |
| 18 | 12.1 | 11.6 | 11.2 | 10.8 | 10.6 | 10.4 | 10.2 | 10.1 | 9.9 | 9.8 | 9.7 | 9.6 | 9.6 |
| 20 | 13.0 | 12.4 | 11.9 | 11.5 | 11.2 | 10.9 | 10.7 | 10.5 | 10.4 | 10.3 | 10.1 | 10.0 | 9.9 |
| 22 | 14.0 | 13.2 | 12.6 | 12.2 | 11.8 | 11.5 | 11.3 | 11.0 | 10.9 | 10.7 | 10.6 | 10.4 | 10.3 |
| 24 | 15.4 | 14.1 | 13.4 | 12.9 | 12.5 | 12.1 | 11.8 | 11.6 | 11.4 | 11.2 | 11.0 | 10.9 | 10.7 |
| 26 | 16.2 | 15.1 | 14.3 | 13.7 | 13.2 | 12.8 | 12.4 | 12.1 | 11.9 | 11.7 | 11.5 | 11.3 | 11.2 |
| 28 | 17.4 | 16.2 | 15.2 | 14.5 | 13.9 | 13.5 | 13.1 | 12.8 | 12.5 | 12.2 | 12.0 | 11.8 | 11.6 |
| 30 | 18.7 | 17.3 | 16.2 | 15.4 | 14.8 | 14.2 | 13.8 | 13.4 | 13.1 | 12.8 | 12.5 | 12.3 | 12.1 |
| 32 | 20.1 | 18.5 | 17.3 | 16.4 | 15.6 | 15.0 | 14.5 | 14.1 | 13.8 | 13.4 | 13.2 | 12.9 | 12.7 |
| 34 | 21.7 | 19.9 | 18.5 | 17.5 | 16.6 | 16.0 | 15.4 | 14.8 | 14.5 | 14.1 | 13.8 | 13.5 | 13.3 |
| 36 | 23.4 | 21.4 | 19.9 | 18.7 | 17.8 | 17.0 | 16.3 | 15.8 | 15.3 | 14.9 | 14.6 | 14.3 | 14.0 |
| 38 | 25.5 | 23.2 | 21.5 | 20.1 | 19.0 | 18.2 | 17.4 | 16.8 | 16.3 | 15.8 | 15.4 | 15.1 | 14.8 |
| 40 | 27.9 | 25.2 | 23.3 | 21.8 | 20.6 | 19.6 | 18.7 | 18.0 | 17.4 | 16.9 | 16.4 | 16.0 | 15.7 |

Table 14. Average Unit Resistance for All Tractor-Trucks.

Section I

Unit Tractive Resistance, in Pounds per 1000 Pounds, for Weights of -

Thousands of Pounds

| peed MPH | 38 lbs. | 40 lbs. | 42 lbs. | 44 lbs. | 46 lbs. | 48 lbs. | 50 lbs. | 52 lbs. | 54 lbs. | 56 lbs. | 58 lbs. | 60 lbs. | 62 lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 |
| 8 | 8.0 | 8.0 | 8.0 | 8.0 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 |
| 10 | 8.2 | 8.2 | 8.2 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.0 | 8.0 | 8.0 | 8.0 |
| 12 | 8.5 | 8.5 | 8.5 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.2 | 8.2 | 8.2 |
| 14 | 8.8 | 8.8 | 8.8 | 8.6 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.4 | 8.4 | 8.4 |
| 16 | 9.2 | 9.1 | 9.1 | 8.9 | 8.9 | 8.8 | 8.8 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.6 |
| 18 | 9.5 | 9.4 | 9.4 | 9.3 | 9.2 | 9.2 | 9.1 | 9.1 | 9.0 | 9.0 | 9.0 | 9.0 | 8.9 |
| 20 | 9.9 | 9.8 | 9.7 | 9.7 | 9.6 | 9.5 | 9.5 | 9.4 | 9.4 | 9.4 | 9.3 | 9.3 | 9.3 |
| 22 | 10.2 | 10.2 | 10.1 | 9.9 | 9.9 | 9.8 | 9.8 | 9.7 | 9.7 | 9.7 | 9.6 | 9.6 | 9.5 |
| 24 | 10.6 | 10.5 | 10.4 | 10.4 | 10.3 | 10.2 | 10.1 | 10.1 | 10.0 | 10.0 | 9.9 | 9.9 | 9.8 |
| 26 | 11.1 | 10.9 | 10.8 | 10.7 | 10.6 | 10.5 | 10.4 | 10.3 | 10.3 | 10.3 | 10.2 | 10.1 | 10.1 |
| 28 | 11.5 | 11.4 | 11.2 | 11.1 | 11.0 | 10.9 | 10.8 | 10.7 | 10.6 | 10.6 | 10.5 | 10.4 | 10.4 |
| 30 | 12.0 | 11.8 | 11.7 | 11.4 | 11.3 | 11.2 | 11.1 | 11.0 | 11.0 | 10.9 | 10.8 | 10.7 | 10.7 |
| 32 | 12.5 | 12.3 | 12.2 | 12.0 | 11.8 | 11.7 | 11.6 | 11.5 | 11.4 | 11.4 | 11.3 | 11.2 | 11.0 |
| 34 | 13.1 | 12.9 | 12.7 | 12.5 | 12.4 | 12.2 | 12.1 | 12.0 | 11.9 | 11.8 | 11.7 | 11.6 | 11.5 |
| 36 | 13.7 | 13.5 | 13.3 | 13.1 | 12.9 | 12.8 | 12.6 | 12.5 | 12.4 | 12.3 | 12.2 | 12.1 | 12.0 |
| 38 | 14.5 | 14.2 | 14.0 | 13.8 | 13.5 | 13.4 | 13.2 | 13.1 | 13.0 | 12.8 | 12.7 | 12.6 | 12.5 |
| 40 | 15.3 | 15.1 | 14.8 | 14.5 | 14.3 | 14.1 | 13.9 | 13.7 | 13.5 | 13.4 | 13.3 | 13.2 | 13.1 |

Table 15. Average Unit Resistance for All Tractor-Trucks.

Section II

Unit Tractive Resistance, in Pounds per 1000 Pounds, for Weights of -

Thousands of Pounds

| Speed MPH | 64 lbs. | 66 lbs. | 68 lbs. | 70 lbs. | 72 lbs. | 74 lbs. | 76 lbs. | 78 lbs. | 80 lbs. | 82 lbs. | 84 lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 |
| 8 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 |
| 10 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| 12 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 |
| 14 | 8.4 | 8.4 | 8.4 | 8.4 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 |
| 16 | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| 18 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.8 | 8.8 | 8.8 | 8.8 | 8.8 | 8.8 |
| 20 | 9.2 | 9.2 | 9.2 | 9.2 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.0 | 9.0 |
| 22 | 9.5 | 9.4 | 9.4 | 9.4 | 9.4 | 9.4 | 9.4 | 9.4 | 9.3 | 9.3 | 9.3 |
| 24 | 9.8 | 9.7 | 9.7 | 9.7 | 9.6 | 9.6 | 9.6 | 9.5 | 9.5 | 9.5 | 9.5 |
| 26 | 10.1 | 10.0 | 10.0 | 10.0 | 9.9 | 9.9 | 9.9 | 9.8 | 9.8 | 9.8 | 9.7 |
| 28 | 10.3 | 10.3 | 10.3 | 10.2 | 10.2 | 10.1 | 10.1 | 10.0 | 10.0 | 10,0 | 10.0 |
| 30 | 10.6 | 10.6 | 10.5 | 10.5 | 10.4 | 10.4 | 10.3 | 10.3 | 10.2 | 10.2 | 10.2 |
| 32 | 11.0 | 10.9 | 10.8 | 10.8 | 10.8 | 10.7 | 10.7 | 10.6 | 10.6 | 10.5 | 10.5 |
| 34 | 11.5 | 11.4 | 11.3 | 11.3 | 11.2 | 11.2 | 11.1 | 11.0 | 11.0 | 10.9 | 10.9 |
| 36 | 11.9 | 11.8 | 11.7 | 11.7 | 11.6 | 11.5 | 11.5 | 11.4 | 11.4 | 11.3 | 11.3 |
| 38 | 12.4 | 12.3 | 12.2 | 12.1 | 12.1 | 12.0 | 11.9 | 11.8 | 11.8 | 11.7 | 11.7 |
| 40 | 12.9 | 12.8 | 12.7 | 12.6 | 12.5 | 12.4 | 12.4 | 12.3 | 12.2 | 12.1 | 12.1 |

Table 16. Average Unit Resistance for All Tractor-Trucks.

Section III

Table 17 - Road Types and Their Approximate Conversion Factors.

| Federal, State or County Roads. | Resistance Expressed as % Grade |
|---|---|
| 1. Best Concrete to Good Macadam. | 1.00 - 1.50 |
| 2. Good Macadam to Hard Clay Bound Gravel. | 1.50 - 2.00 |
| 3. Hard Clay Bound Gravel to Loose Gravel and Poor Broken Macadam. | 2.00 - 4.00 |
| **Private Construction.** | |
| 4. Good Haul Roads. (Almost equivalent to 3 or better.) Hard packed natural soil. | 1.75 - 4.00 |
| 5. Fair Haul Roads. Partially packed to spongy under extreme loads. | 3.00 - 5.00 |
| 6. Poor Haul Roads. Sandy to Rough, displacement under average loads. | 4.00 - 10.00 |
| 7. Strip Roads. Rough, no alignment, off-the-road hauling to mud. | 5.00 - 15.+ |

Note - actually when substituting in the formula concrete is entered as 0% since the formula has already taken this resistance into account.

# APPENDIX B

Transportation Cost Estimate

Equipment Recommended

Model____________ Type No.____________ W. B.____________
Engine________________________________________
Rear Axle Type____________________ Ratio________________
Transmission________________________________________
Tires: Front________________________________________
Rear________________________________________
Brakes________________________________________
Cab________________________________________
Body________________________________________
Other Equipment________________________________________

Operator____________________ Business________________
Address________________________________________
Compiled by____________________ Date________________
Approved by____________________ Date________________

## Transportation Cost Estimate

| | Truck | Trailer | Trailer | Total |
|---|---|---|---|---|
| 1. Model | | | | |
| **Investment** | | | | |
| 2. Total Investment | | | | |
| 3. Tire Value (subtract) | | | | |
| 4. Amount to Depreciate | | | | |
| **Miles Operated** | | | | |
| 5. Miles Operated per Day | | | | |
| 6. Days Operated per Year | | | | |
| 7. Miles Operated per Year | | | | |
| **Fixed Expense Per Year** | | | | |
| 8. Interest on Total Investment (a) ___6% | | | | |
| 9. License and Taxes | | | | |
| 10. Insurance: a. Fire and Theft | | | | |
| b. Property Damage | | | | |
| c. Public Liability | | | | |
| d. Collision | | | | |
| e. Cargo | | | | |
| f. | | | | |
| 11. Garage | | | | |
| 12. Depreciation (If on Time Basis) | | | | |
| 13. Total Fixed Expense Per Year | | | | |
| 14. Total Fixed Expense Per Mile | | | | |
| **Payroll Expense Per Year** | | | | |
| 15. Supervision and Overhead | | | | |
| 16. | | | | |
| 17. Drivers Wages | | | | |
| 18. Helper's Wages | | | | |
| 19. Total Payroll Expense Per Year | | | | |
| 20. Total Payroll Expense Per Miles | | | | |
| **Running Expense Per Mile** | | | | |
| 21. Fuel (a) $___Per Gal.___Miles Per Gal. | | | | |
| 22. Oil (a) $___Per Gal.___Miles Per Gal. | | | | |
| 23. Tires (a)___Tire Expectancy | | | | |
| 24. Reserve for Maintenance and Repair | | | | |
| 25. Depreciation (If on Mileage Basis) | | | | |
| 26. Mileage on Ton Mile Tax | | | | |
| 27. Total Running Expense Per Mile | | | | |
| 28. Total Running Expense Per Year | | | | |
| **Summary** | | | | |
| 29. Total Cost Per Mile | | | | |
| 30. Total Cost Per Day | | | | |
| 31. Total Cost Per Year | | | | |
| 32. Avg. No. of Trips per Day | | | | |
| 33. Total Cost per Trip | | | | |
| 34. Average Units per Trip | | | | |
| 35. Cost per Unit | | | | |

## Instructions For Preparing Transportation Cost Estimate, Form 601 Equipment Recommendation

The preceding form provides space for a description of the type of equipment recommended, together with all special equipment and modifications from standard chassis.

Only a few items are listed, and balance of page has been left blank to facilitate complete description of all special equipment items, including painting and lettering, finance charge, sales taxes, freight and handling charges, discounts, trade-in allowances and other related items.

Where trailer quotations are involved, give model, length, tires, brakes and other equipment, finance charge, sales taxes, freight and handling and any other expenses incurred. Trailer specifications may be inserted in any suitable place on the sheet below the complete truck specifications.

Lines at the right side of the page are blank, facilitating the use of this form for necessary computations of price quotations. Sufficient room is available for two or more vertical columns of figures.

### Transportation Cost Estimate - Gasoline Equipment

Item 1 - Place proper model designation directly beneath headings "Truck" or "Trailer" in space provided.

## Investment

Item 2 - Indicate total delivered net price of complete vehicle, including tax, finance charge, body costs and other cost items. Trade-in allowance must not be deducted from total cost price when establishing investment figure.

Item 3 - Indicate local cost to operator for replacement of tire equipment. Inner tube prices are to be included in tire value. If spare tire is included in item 2, cost of same must be included in this item.

Item 4 - After deducting item 3 from total investment, item 2, the balance in item 4 represents the amount to be used in the depreciation figures in either item 12 or item 25.

## Miles Operated

Items 5, 6 and 7 - Indicate miles operated per day, days operated per year and miles operated per year. These figures must be established on an average basis in order to serve as guide in the cost per mile calculations.

## Fixed Expense Per Year

Item 8 - Interest should be charged on the total investment figure, item 2. If the depreciation is assumed as taking place at a uniform rate, the average interest over the assumed life of the equipment on its undepreciated value may be accurately determined from the following formula:

$$\text{Interest per Year} = I \times \tfrac{1}{2}\ 0.px\ \left(\frac{n + 1}{n}\right)$$

where

I is the total investment valuation,
p is the rate of interest, and
n is the number of years life, or length of time over which equipment is to be depreciated.

Item 9 - Enter total State and City vehicle license fees, personal property and special taxes of State, County, and City. Fuel and oil taxes are to be included in items 21 and 22.

Item 10 - It is necessary to use the applicable local insurance rates, and it is best to obtain the cost of insurance from a local insurance agency, since rates are different for various localities, vehicle types and operating conditions.

Item 11 - If the garage is the property of the truck owner, enter an amount equivalent to the pro rate cost per vehicle, based on rental value of building, taxes, heat, light and power and other expenses. If washing is included, insert the words, "and washing" in item 11 and include this cost. As a rule, the prevailing local storage rate can be used in estimating the garage cost.

Note: In reference to items, 9, 10 and 11 the following figures can be used in determining yearly averages, according to the minimum and maximum ranges given below.

| | Trucks | | Trailers | |
|---|---|---|---|---|
| | Minimum | Maximum | Minimum | Maximum |
| Taxes | $ 24.00 | 400.00 | 27.50 | 230.00 |
| Insurance | 50.00 | 290.00 | 4.00 | 280.00 |
| Garage | 100.00 | 217.50 | 48.00 | 93.50 |

Item 12 - (Based on item 4.) It should be appreciated that there is no exact limit to the life of any piece of equipment so long as the wearing parts can be replaced. However, it is well to set a safe limit on the economic life of the truck equipment because of obsolescence and other factors. At the end of this period, there may be a certain resale or trade-in value on the equipment, depending on the care it has had and on the current value. It is not common practice to credit this salvage or resale value in the cost estimate, as it is better to let this amount act as a factor of safety in the cost estimate figures.

Note: The following tables are approximations of the mileage possible, based on truck and trailer costs.

| Range of Truck Investment | Range of Estimated Mileage |
|---|---|
| $ 600.00 - 1000.00 | 50,000 to 70,000 miles |
| 1000.00 - 2300.00 | 70,000 to 100,000 miles |
| 2300.00 - 4100.00 | 100,000 to 150,000 " |
| 4100.00 - 6700.00 | 150,000 to 200,000 " |
| 6700.00 - 10000.00 | 200,000 to 300,000 " |

| Range of Trailer Investment | Range of Estimated Mileage |
|---|---|
| $ 500.00 to 1000.00 | 125,000 to 150,000 miles |
| 1000.00 to 2800.00 | 150,000 to 200,000 " |
| 2800.00 to 5000.00 | 200,000 to 300,000 " |

In general practice, it is suggested that trailers be depreciated on a basis of twice the year's life or twice the mileage life of the tractor-truck.

The above data may be used as a guide for estimating the depreciation of General Motors trucks and trailers. (The data may be used as a comparative basis for other trucks and trailers as well.) Common sense and knowledge of the conditions under which the truck is being operated will be helpful to determine a fair and reasonable rate of depreciation.

If depreciation is figured on a time basis, divide item 4 by the estimated number of years life. If the truck should be depreciated over a period of four years, for example, then one-fourth the total amount to be depreciated should be entered as item 12.

If depreciation is figured on a mileage basis, divide item 4 by the "miles life" to obtain the depreciation cost per mile and enter this amount as item 25. Items 12 and 25 are alternatives and cost must be entered in one or the other - not both.

Item 13 - Add all expense items from 8 to 12 inclusive.

Item 14 - Divide item 13 by item 7.

Payroll Expense per Year

Item 15 - In fleet operation, it is customary to pro-rate the total supervision and overhead expense on the basis of the number of units. The figure used will depend upon the accounting practice of the individual operation.

Item 16 - Enter special expenses, such as terminal costs or other overhead items not directly chargeable to item 15, figured on a unit pro-rate basis.

Items 17 and 18 - Enter total yearly expense on this equipment based on prevailing local driver's and helper's wages. This item also depends largely on operating practice. Where no helper is used, strike out the word "helper". Where owner drives the truck himself, indicate wages equal to a hired driver.

Note: In reference to items 17 and 18, payroll expenses for drivers are based on a sliding scale, increasing with the size of the truck and the mileage covered per day. For high mileages, allowance should be made for a relief driver or helper. The following table may be used for quick reference.

| Range of Truck Investment | Range of Drivers Wages | | |
|---|---|---|---|
| | To 100 Miles per Day | To 175 Miles per Day | To 300 Miles per day |
| $ 600.00 - 1,200.00 | $4.00 - 4.50 | $5.00 | $ 6.00 |
| 1,200.00 - 2,300.00 | 4.50 - 5.00 | 6.50 | 9.00 |
| 2,300.00 - 4,100.00 | 5.00 - 5.50 | 7.50 | 10.50 |
| 4,100.00 - 6,700.00 | 5.50 - 6.00 | 8.50 | 12.00 |
| 6,700.00 -10,000.00 | 6.00 - 6.50 | 9.50 | 13.00 |

Payroll expenses vary considerably between low labor costs in Southern rural districts and high union wages in the large metropolitan centers. Cost allowances must be made to local wage scales.

Item 19 - Add all items from 15 to 18 inclusive.

Item 20 - Divide item 19 by item 7.

## Running Expense per Mile

Items 21 and 22 - For miles per gallon of fuel or oil, refer to local experience or to tables covering fuel and oil consumption. Base the cost per gallon on the current prices paid by the operator, including taxes. Divide price per gallon by miles per gallon and enter expense per mile in the spaces provided.
The following data shows estimated ranges of gasoline and oil consumption indexed by the range of gross vehicle weight for vehicles of standard design and average normal operating conditions. Gross vehicle weights in this tabulation include trailer weights.

## Oil and Gasoline Consumption

| Range of Gross Weight | Range in Estimated Miles per Gallon | |
|---|---|---|
| | Oil | Gas |
| 4000 - 6000 | 350 - 500 Miles | 14.0 to 10.0 Miles |
| 6000 - 10000 | 325 - 475 " | 12.0 to 7.1 " |
| 10000 - 16000 | 300 - 450 " | 9.2 to 5.6 " |
| 16000 - 24000 | 275 - 425 " | 7.3 to 4.1 " |
| 24000 - 35000 | 250 - 400 " | 5.6 to 3.2 " |
| 35000 - 50000 | 225 - 375 " | 4.7 to 2.6 " |
| 50000 - 75000 | 200 - 350 " | 3.8 to 2.1 " |
| 75000 - 100000 | 175 - 325 " | 3.2 to 1.8 " |

Item 23 - To determine the tire cost per mile, take the same tire price as used in item 3 and divide by the tire mileage expectancy. For operating conditions over good roads and with normal tire loads, a tire mileage of 30,000 to 45,000 miles per tire may be expected for trucks and 40,000 to 60,000 miles for trailers. Excessive speeds, overloads, and particularly under-inflation will materially shorten the tire life. The approximate relation between tire load and mileage and inflation versus mileage is indicated below:

How Loads Affect Tire Mileage

| | | | | |
|---|---|---|---|---|
| 70% | load | means | 200% | tire mileage |
| 80% | " | " | 155% | " " |
| 90% | " | " | 123% | " " |
| 100% | " | " | 100% | " " |
| 110% | " | " | 83% | " " |
| 120% | " | " | 70% | " " |
| 130% | " | " | 60% | " " |

How Inflation Affects Tire Mileage

| | | | | |
|---|---|---|---|---|
| 100% | inflation | means | 100% | tire mileage |
| 90% | " | " | 95% | " " |
| 80% | " | " | 70% | " " |
| 70% | " | " | 48% | " " |

Proper allowance must be made for other than normal conditions. Where tires are furnished on a mileage basis at a certain cost per mile, or when tires are purchased with a definite mileage guaranty, the tire cost per mile is a known quantity. The cost per mile for tires may be set up as a reserve for renewals.

Item 24 - This expense is subject to wide variation. Local operating conditions, prices for labor and material, maintenance methods, mileage per day and many other factors influence the final cost per mile for maintenance. Maintenance cost estimates based on the first period of mileage life while the vehicle is new, do not give a true conception of the actual average maintenance cost per mile for a vehicle during its entire profitable service. Therefore, any cost estimate, to be useful in setting up a budget for maintenance, must include preventative maintenance operations, washing, greasing, chassis repairs and overhauling, body repairs and repainting, and accident repairs not covered by insurance for the entire operating life of the vehicle. As wear on mechanical parts increases with the accumulation of vehicle mileage, a budget reserve should be built in order to provide for repair and maintenance expenses as the vehicle gets older. In the following tables the range between minimum and maximum estimates is wide enough to permit the establishment of a fairly safe budget figure to cover all maintenance costs.

| Gross Weight | Maintenance Cost per Mile: Truck | | Trailer | |
|---|---|---|---|---|
| 4,000 | $0.006 - | $0.020 | $0.0020 - | $0.0050 |
| 5,000 | .007 - | .021 | .0022 - | .0055 |
| 6,000 | .008 - | .022 | .0025 - | .0060 |
| 7,000 | .009 - | .023 | .0029 - | .0066 |
| 8,000 | .010 - | .024 | .0033 - | .0073 |
| 9,000 | .011 - | .025 | .0037 - | .0081 |
| 10,000 | .012 - | .026 | .0040 - | .0090 |
| 15,000 | .015 - | .031 | .0055 - | .0120 |
| 20,000 | .018 - | .036 | .0070 - | .0150 |
| 25,000 | .020 - | .041 | .0085 - | .0180 |
| 30,000 | .022 - | .045 | .0100 - | .0210 |
| 35,000 | .024 - | .049 | .0115 - | .0240 |
| 40,000 | .025 - | .052 | .0130 - | .0270 |
| 45,000 | .026 - | .054 | .0145 - | .0300 |
| 50,000 | .027 - | .056 | | |

In the above the maintenance costs are for the individual weights of the units, not as a combination.
Trailer maintenance cost estimates are on the basis of trailer axle, or axles gross weight range as an index and include body maintenance, minor accidents not covered by insurance, also the additional maintenance expense to truck or tractor brought about by pulling the additional trailer weight.

Item 25 - See item 12.

Item 26 - Mileage or Ton Mile taxes now prevail in many States, especially for inter-state commercial operations. This item must be checked for each State involved in the operation.

Item 27 - Total the cost per mile for all items under running expense by adding item 21 to 26 inclusive.

Item 28 - Multiply item 27 by item 7.

Summary

Item 29 - For total cost per mile, add items 14, 20 and 27.

Item 30 - For total cost per day, multiply item 5 by item 29.

Item 31 - For total cost per year, add items 13, 19 and 28. For checking of calculations, divide item 31 by item 6 and the result should equal item 30. Multiply item 7 and item 29; the result should equal item 31.

Item 32 - Establish the average number of trips per day.

Item 33 - Total cost per trip is obtained by dividing item 30 by item 32.

Item 34 - Indicate units after word "Trip". Units may be designated by pounds, tons, cords, or thousand board feet (M).

Item 35 - Cost per unit is obtained by dividing item 33 by item 34.

The method used in estimating transportation costs for gasoline powered equipment as given on the preceding pages may be employed when estimating transportation costs for Diesel powered trucks and tractors using the same values, with exceptions as noted below.

Transportation Cost Estimate - Diesel Equipment.

Items 1 to 12, inclusive may be followed without change using the tables under items 11 and 12.

Items 13 to 20, inclusive will not change except that "Drivers Wages" should be conservatively taken from the higher rates shown in the table under item 17 and 18. Use the actual wage scale if available.

Items 21 and 22 will be unchanged except for the substitution of the following table for the one shown.

| Gross Weight | Diesel Fuel Consumption | Oil Consumption |
|---|---|---|
| 15,000 - 24,000 | 11.7 to 6.6 miles | 185 - 285 miles |
| 24,000 - 35,000 | 8.9 to 5.1 " | 165 - 270 " |
| 35,000 - 50,000 | 7.5 to 4.1 " | 150 - 250 " |
| 50,000 - 75,000 | 6.1 to 3.3 " | 135 - 235 " |
| 75,000 - 100,000 | 5.1 to 2.9 " | 115 - 215 " |

Items 23 to 28, inclusive may be followed without change except that the higher figures shown in the table for maintenance cost per mile in item 24 should be used until further data are available which cover actual costs of diesel engine maintenance.

Items 29 to 35, inclusive will not change.

While the form of the transportation analysis is mathametically correct, care should be taken to use the tables, given under appropriate items, only as rough estimates. The tables should not be taken as indicating actual costs for any given operation; they are meant as guides only.

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