scope of this analysis is limited to total traffic, it is reasonable to expect that the volumes of traffic of any particular classification could be estimated with the same accuracy as the total traffic of comparable volumes It, therefore, seems reasonable to conclude that many of the advantages mentioned in connection with short-counts used in combination with the pattern method should apply in studies of traffic by vehicle types.

While the scope of this analysis has been confined largely to a consideration of certain short-count schedules, this was not done with any thought of excluding other types of schedules many of which produce equally reliable results. The characteristics of traffic flow are so complex as to preclude any expectation of finding a universal schedule capable of satisfying all conditions, and, instead, it seems to be a matter of using the proper schedule in the right place. Although mechanical counters have replaced manual methods in a large number of instances, there remains an important field for the development and use of low-cost manual counting procedures in many important phases of traffic survey work.

EFFECT OF LENGTH OF GRADE ON SPEED OF MOTOR VEHICLES

By A. Taragin, *Highway Engineer, Division of Highway Transport Research, Public Roads Administration*

In 1942, the Public Roads Administration published the results of extensive studies on the hill-climbing ability of motor trucks and tractor-trucks with semi-trailer combinations in various stages of usage and wear Using the vehicle performance and tractive resistance data from this report, the effect of the length of grade on the speed of motor vehicles was determined for a wide range of load, grade, and vehicle size The results were checked with exhaustive data collected in the field for a rather limited set of conditions.

The grade ability of motor vehicles for various sustained speeds is reduced to tractive effort The tractive effort added to the energy supplied due to vehicle motion (kinetic energy) is expended against the grade and tractive resistance A formula is then developed by which calculations are made to determine the length of grade that a motor truck travels during a given speed interval The results are shown by graphs for light, medium, and heavy vehicles with gross loads up to 40,000 lb , for operation on grades of 2 to 7 per cent

Momentum of the vehicles, principally at speeds above 30 miles per hour, accounts for a considerable portion of the total energy available in overcoming grades It was found, for example, that if vehicles, regardless of the gross load, could approach grades at 40 m p h with the engine disengaged, a speed of 20 m p h would be realized at the tops of 3- and 7-percent grades 1,000 and 500 ft long, respectively Utilizing the power of the engine, a typical vehicle with 30,000 lb would reach the tops of these grades at speeds of 32 5 and 27.7 m.p.h. respectively

In quest of a rational solution to the problem of traffic congestion resulting from slow-moving vehicles on grades, the Public Roads Administration has conducted extensive investigations of motor truck performance As a result, a report was published in 1942[1] revealing very significant and until then unknown facts about the hill-climbing ability of motor trucks and tractor-trucks with semi-trailer combinations in various stages of usage and wear. The information thus far published has applied primarily to the sustained or crawl speed of motor trucks with various gross loads on different grades The published results have been valuable to truck operators and have practical applications in highway design. As the construction of new highways is resumed, increasing application

[1] C. C. Saal, "Hill-climbing Ability of Motor Trucks," *Public Roads*, May 1942

of the results may be expected to improve the safety and economy of highway transportation.

One problem for which highway engineers desire more complete data is the effect of the length of grade on motor vehicle speed If a grade is sufficiently long, a vehicle operated at full throttle will eventually reach a constant speed. This speed, which is independent of the initial speed at the bottom of the grade is commonly called the vehicle's sustained speed. For highway design it is important to know what this speed is It is also important to know the time and distance required for the vehicle to reach its sustained speed, and the time required to traverse the grade The latter figure is necessary in an evaluation of traffic congestion. This paper deals with an analysis of basic truck performance data in relation to the length of grade, speed on the grade, and the application of such data to highway design, traffic control, and truck operation

Basic to all the calculations and analyses are the data published in the May 1942 issue of *Public Roads* for the maximum performance and tractive resistance of new and used vehicles properly maintained, and adjusted to operate efficiently at full throttle with gasoline having an A.S.T.M. octane rating number of 71 to 72. For the purpose of this paper that study will be referred to as the "truck study" Data for single-unit trucks and tractor-truck-semitrailer combinations are combined, because no significant difference in performance was found between these two types of units with the same size motors and identical total weights To simplify the analysis, the grade abilities of the light, medium, and heavy power units are given in terms of tractive effort, which is the net force available at the tire surface of the driving wheels to overcome the rolling and grade resistance.

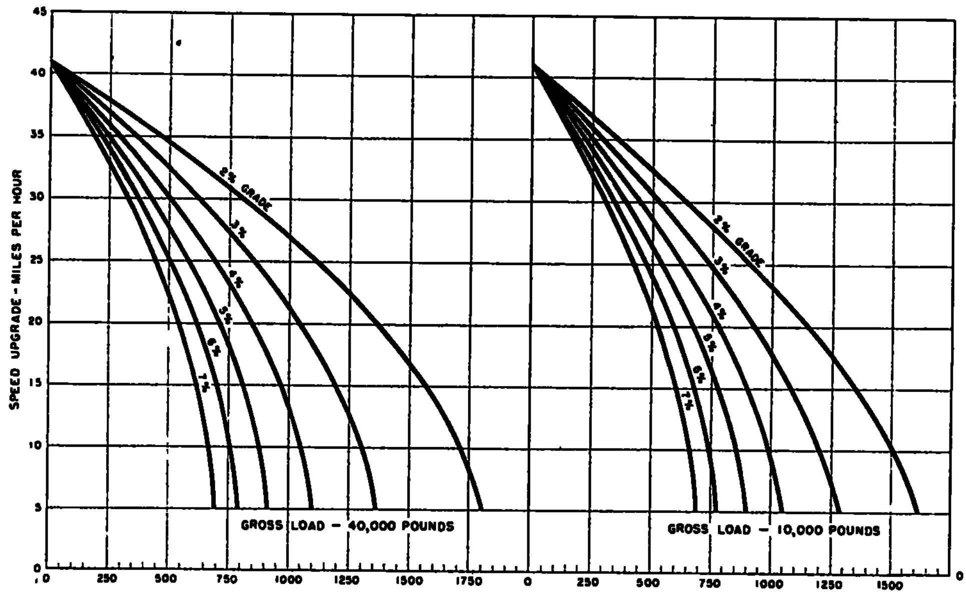

Figure 1. Distance Upgrade that the Momentum Alone Will Carry Vehicles Traveling at Various Speed (Engine disengaged).

It is a common practice for truck drivers to enter long grades at the highest possible speed consistent with the approach conditions. By experience, the drivers have learned that if the grade is not too long and too steep, "they can make it in high" provided their speed is not restricted on the approach. The momentum of the vehicle when entering a grade at high speed is an important factor in overcoming the resistance of the grade

Let us examine to what extent the momentum affects the speeds of motor vehicles on grades. Figure 1 shows the distances that vehicles with gross loads of 10,000 and 40,000 lb. will coast up 2- to 7- per cent grades utilizing only the momentum of the vehicle. The curves in this figure and also those in

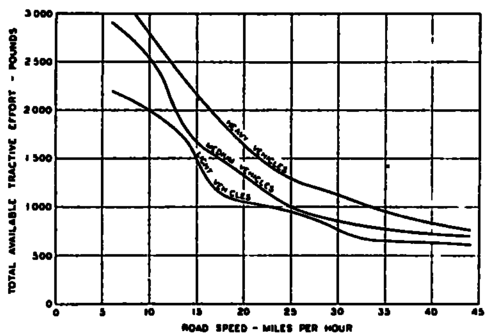

Figure 2. A Relation between Available Tractive Effort and Speed of New Trucks and Tractor-Semitrailer Combinations.

complete field data were recorded during the truck study for the grade ability and tractive resistance of vehicles only at speeds within these limits. To obtain the coasting distance upgrade when a vehicle enters a grade at some speed other than 41 m.p.h., the travel distance as shown by Figure 1 for a decrease in speed from 41 miles per hour to the desired entering speed must be subtracted from the total distance for the final speed. For example, assume that it is desired to determine the distance up a 4-per cent grade that a vehicle with a gross load of 40,000 lb. would coast while the speed dropped from 30 to 20 m.p.h. Figure 1 shows that a vehicle with a 40,000-lb. gross load will coast 840 ft. up a 4-per cent grade while the speed drops from 41 to 20 m.p.h. and 500 ft. as the speed drops from 41 to 30 m.p.h. The momentum would therefore carry the vehicle 340 ft. (840 minus 500) upgrade as the speed dropped from 30 to 20 m.p.h.

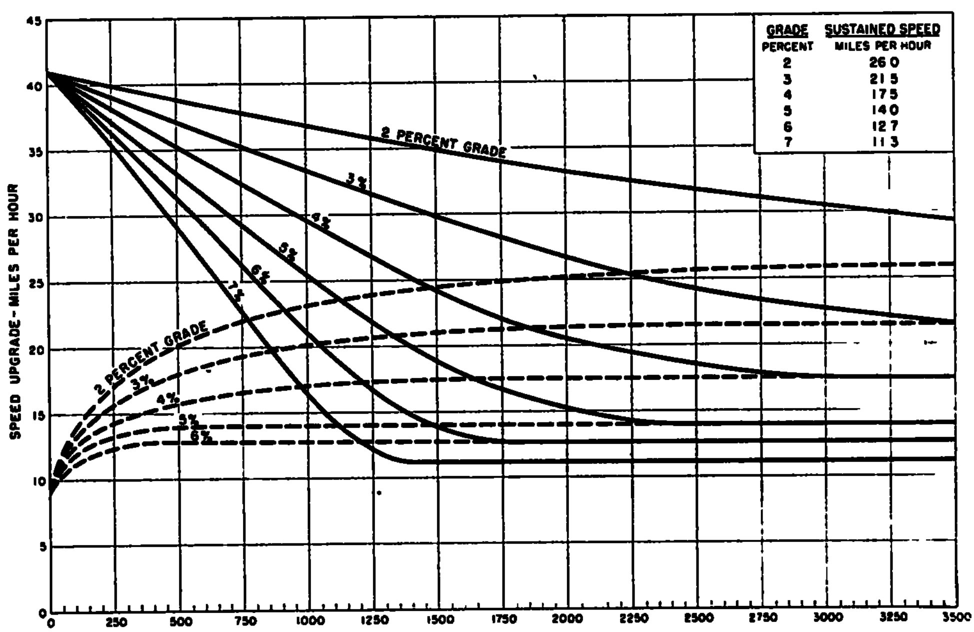

Figure 3. Effect of Length and Steepness of Grade on the Speed of Medium Motor Vehicles with a Gross Load of 30,000 lb.

Figures 3 through 8 are constructed so that the travel distance up grade can easily be determined for any desired loss in speed when the entering speed is from 9 to 41 miles per hour. This range of speeds has been used because

The curves in Figure 1 show that the distance a vehicle will coast upgrade during a given reduction in speed increases with an

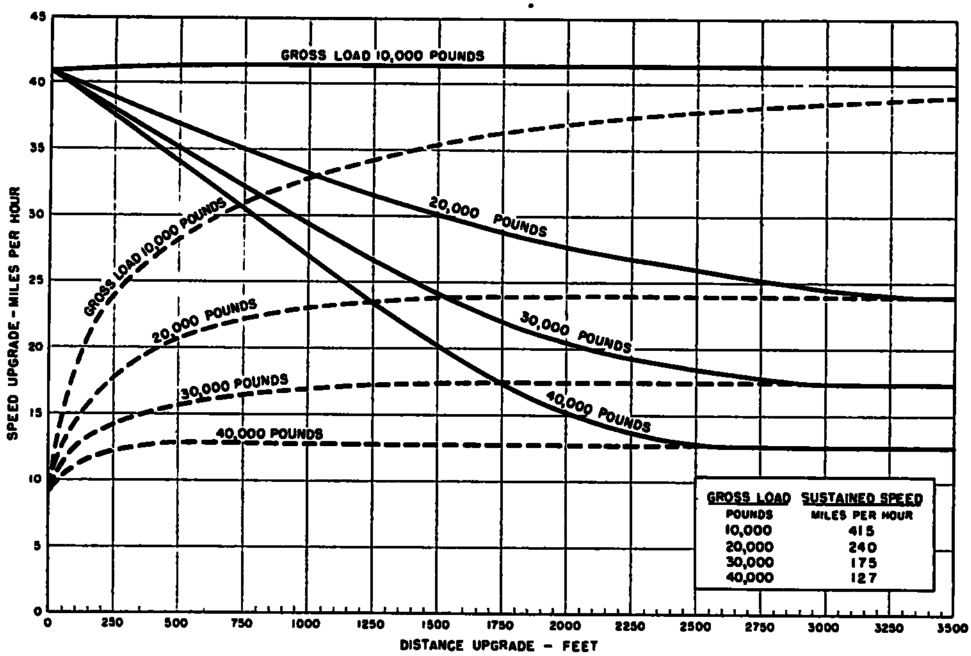

Figure 4. Effect of Gross Load on the Speed of Medium Motor Vehicles on a 4.0 Per Cent Grade.

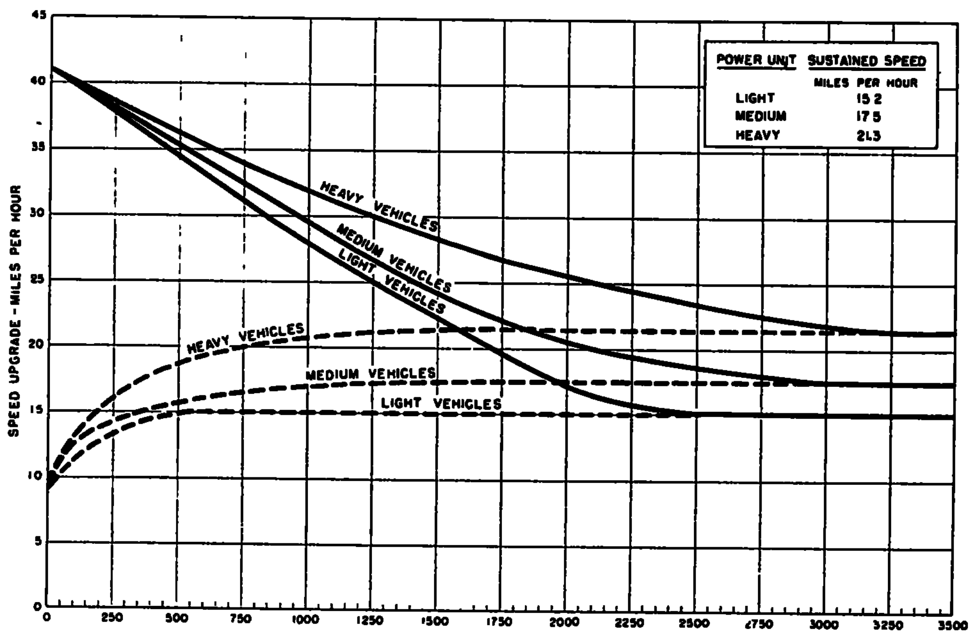

Figure 5. Effect of Engine Power on the Speed of Motor Vehicles Operating with Gross Loads of 30,000 lb. on a 4.0 Per Cent Grade.

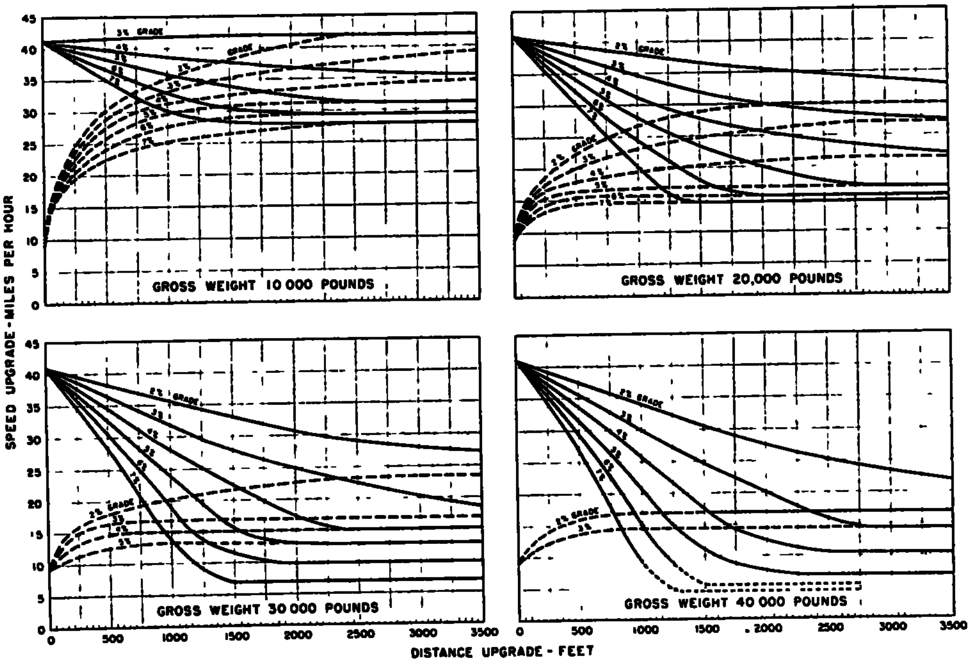

Figure 6. Effect of Length of Grade on the Speed of Light Motor Vehicles

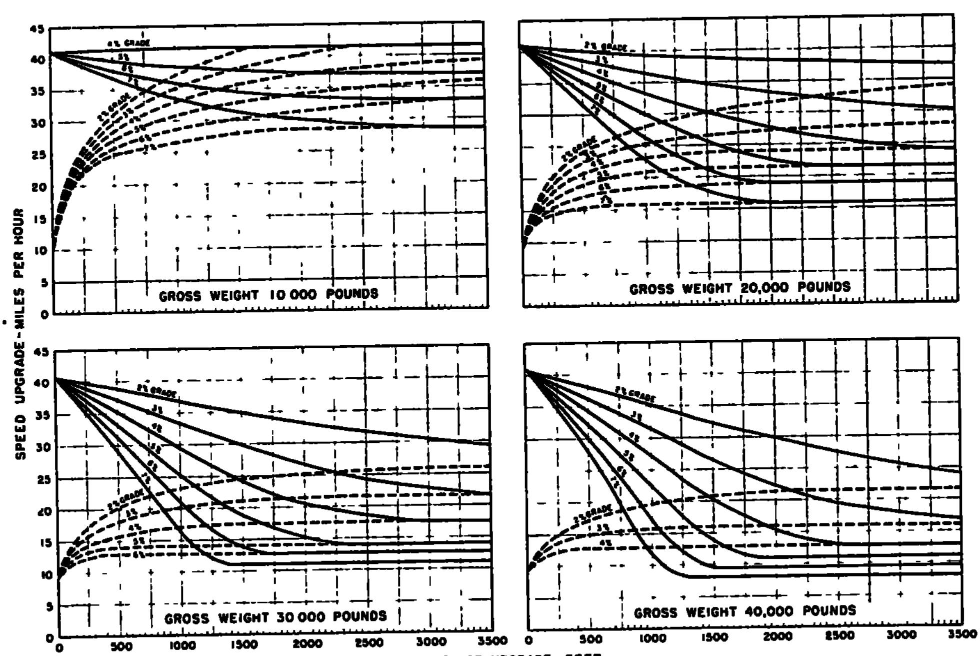

Figure 7. Effect of Length of Grade on the Speed of Medium Motor Vehicles

increase in the initial speed. For example, a vehicle with a gross load of 40,000 lb. will coast 215 ft. up a 4-per cent grade before the speed drops from 35 to 30 m.p.h., a reduction of 5 m.p.h , but only 90 ft. while the speed drops from 15 to 10 m.p.h., which is also a reduction of 5 m.p.h. The reason is that the difference between the momentums for two speeds varies directly as the difference between the squares of the two speeds

lb. vehicle is 40 m.p.h., the speed with the engine disengaged will be at least 20 m.p.h. at the top of a 7-per cent grade 500 ft. long and also at the top of a 3-per cent grade 1,000 ft. long. If the initial speed is 20 m.p.h., the total momentum will carry a vehicle with a 40,000-lb. gross load only 150 ft. up a 7-per cent grade or 325 ft. up a 3-per cent grade There is, therefore, a very definite advantage in entering a grade at a reasonably high speed

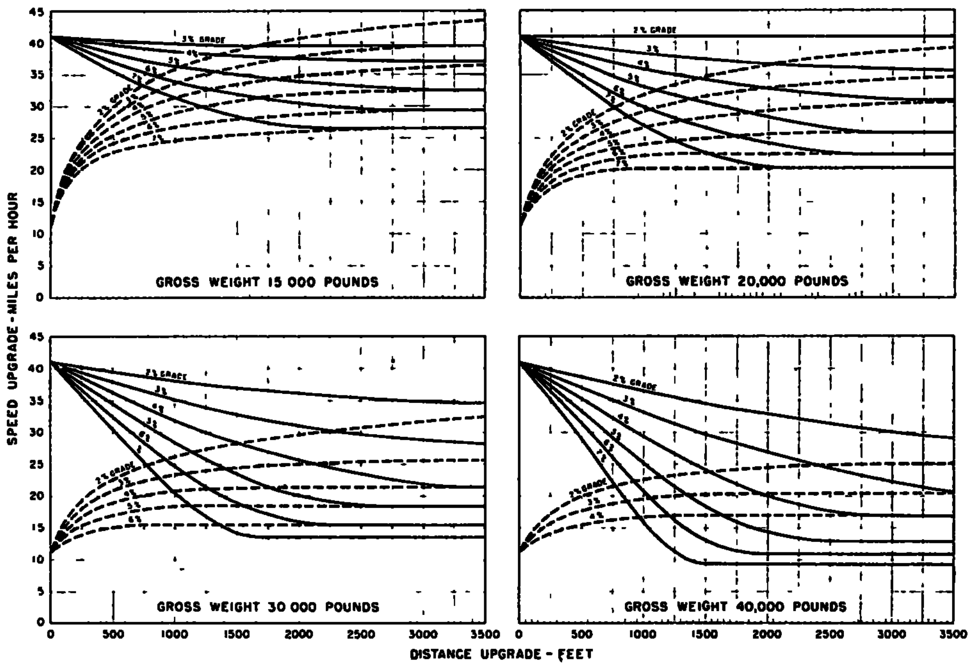

Figure 8. Effect of Length of Grade on the Speed of Heavy Motor Vehicles

It should be noted that the coasting distance upgrade is slightly longer for the heavier gross weights than for the lighter ones. The difference, however, is small when the initial speeds are low. With a gross load of 40,000 lb. on a 4-per cent grade, a vehicle will travel 215 ft. while the speed drops from 35 to 30 m p h , whereas with a 10,000-lb load the corresponding distance is 195 ft. or 20 ft less than for the heavier vehicle. A vehicle weighing 40,000 lb. will travel 155 ft. while the speed drops from 25 to 20 m p h on a 4-per cent grade, whereas one weighing 10,000 lb. will coast 150 ft. under similar conditions, or only 5 ft less than the heavier vehicle.

Furthermore, if the initial speed of a 40,000-

The consideration of momentum alone applies only to a hypothetical case, because in actual practice drivers of heavily loaded vehicles strive to prevent too great a reduction in speed by utilizing the available engine power in addition to the momentum of the vehicle. Figure 2 shows the total available tractive effort for the range of vehicle speeds included in the truck study. The curve for light vehicles is based on the results of tests conducted on 13 of the most common makes and models rated at $1\frac{1}{2}$ tons (average engine displacement 233 cu. in), the curve for the medium vehicles is based on the results of 10 common makes rated from 2 tons up to but not including 5 tons (average engine displacement 306 cu in), and the curve for heavy vehicles is based on the results of 4 common makes rated at 5 tons or more (average engine displacement 395 cu. in.). These average curves are much smoother than a characteristic curve for any one vehicle and represent the maximum tractive effort possible assuming the driver will utilize the proper gear ratios for the various road speeds.

The effect of length and steepness of grade on speed of the average medium truck carrying a gross load of 30,000 lb. and utilizing all the available tractive effort is shown by Figure 3. The series of curves emanating from 41 m.p.h. on the ordinate and terminating at or near the possible sustained speeds show the reductions in speed caused by grades of various lengths when the approach speed is 41 m.p.h. These curves may also be used to determine the speed reduction due to any length and steepness of grade for other approach speeds. For example, if the approach speed is 40 m.p.h. (initial distance 85), the speed at the top of a 4-per cent grade 1,000 ft. long will be 28.6 m p.h. (final distance 1,085). Similarly, if this same grade is approached at a speed of 30 m.p.h., the speed at the top will be 20.8 m.p.h

TABLE 1

Grade	Speed at top of grade 1,000 ft long, when approach speed is 40 m p.h
per cent	*miles per hour*
2	35.9
3	32.5
4	28.6
5	24.4
6	20.0
7	15.3

The curves emanating from 9 m.p h. show the maximum performance of vehicles when the approach speed is so low that the vehicle can accelerate and eventually reach the sustained speed. These curves show that it takes exceedingly long distances to accelerate on grades when the approach speed is below that of the sustained speed. To change the speed on a 4-percent grade from 15 m.p.h. to the sustained speed of 17.5 m.p h. an increase of only 2.5 m p h., the vehicle would have to travel 1,100 ft.

In addition to the effect of length of grade on speed, Figure 3 shows the effect of steepness of grade on the speed of a medium truck weighing 30,000 lb gross. Table 1 shows the speeds at the top of different grades 1,000 ft. long when the approach speed is 40 m.p.h. On the 2-per cent grade, the rise in elevation is 20 ft. and the drop in speed is 4.1 m.p.h., whereas on the 7-per cent grade the rise in elevation is 70 ft. and the drop in speed is 24.7 m.p.h.

The curves shown by Figure 3 are based on equation 1 which may also be used to calculate the length of grade that will cause a given change in speed for any vehicle, load, or grade. The change in kinetic energy plus the energy developed by the engine is equivalent to the energy required to overcome the grade and tractive resistance.

The equation is

$$\frac{1}{2}\left(\frac{W}{32.2} + K_n\right)(V_1^2 - V_2^2) \times 1.47^2$$

$$+ T.E. \times L = W \times g \times L + W \times f \times L$$

$$\text{Or } L = \frac{1.075\left(\frac{W}{32.2} + K_n\right)(V_1^2 - V_2^2)}{W(g + f) - T.E.} \qquad (1)$$

Where:

W = Gross weight of vehicle, pounds

K_n = Mass equivalent constant for the gear in which the vehicle is operating, which is a factor to compensate for the change in the kinetic energy of the rotating parts when accelerating or decelerating.

V_1 = Speed of vehicle at beginning of interval, miles per hour

V_2 = Speed of vehicle at end of interval, miles per hour

$T.E.$ = Tractive effort in pounds for average speed during interval

L = Length of grade in feet on which speed changes from V_1 to V_2

f = Coefficient of tractive resistance, pounds per pound of gross weight

g = Grade, rise in feet per foot of horizontal distance

The tractive resistance and tractive effort change with the speed of a vehicle. It is, therefore, necessary either to integrate the equation or use small speed intervals when applying the formula For this analysis, arbitrary but convenient intervals of 2 m.p.h. were used for the dfference between V_1 and V_2 to calculate the total distance traveled during a given change in speed. The tractive efforts for light, medium, and heavy vehicles were obtained from Figure 2; the mass equivalent constants from Table 2; and the average unit tractive resistance by 2 mile-per-hour speed groups from Table 3.

The following calculations were made as an example to determine the length of a 4-per cent grade that would reduce the speed of a medium-sized motor vehicle with a gross load of 30,000 lb. from 41 to 39 m.p h.

TABLE 2
MASS, EQUIVALENT CONSTANTS FOR LIGHT, MEDIUM, AND HEAVY MOTOR VEHICLES

Gear	Vehicle size		
	Light	Medium	Heavy
Neutral (Avg)	40	40	40
Direct	40	60	75
Third	53	80	98
Second	160	223	250

TABLE 3
AVERAGE UNIT TRACTIVE RESISTANCE FOR ALL MOTOR VEHICLES

Speed	Unit tractive resistance in pounds per 1,000 lb for weight of —			
	10,000 lb	20,000 lb	30,000 lb	40,000 lb
m p h.				
10	8 9	8 5	8 3	8.2
12	9.8	9 0	8 7	8 5
14	10 7	9 5	9 0	8 8
16	11 7	10 0	9 4	9 1
18	12 7	10 6	9 8	9 4
20	13 7	11.2	10 3	9 8
22	15 4	11 8	10 7	10 2
24	16 9	12 5	11 2	10 5
26	17 6	13 2	11 7	10 9
28	18 9	13 9	12 2	11 4
30	20 4	14 8	12 8	11 8
32	22 1	15 6	13 4	12 3
34	23 9	16 6	14 1	12 9
36	26 2	17 8	14 0	13 5
38	28 7	19 0	15 8	14 2
40	31 4	20 6	16 9	15 1

The change in kinetic energy (the numerator of equation 1) equals.

$$1\,075 \times \left(\frac{30{,}000}{32\,2} + 60\right)(41^2 - 39^2)$$

or 170,570 ft -lb

The grade and tractive resistance $[W(g + f)]$ for the average speed of 40 miles per hour (table 2) is.

$$30{,}000\ (0.04 + 0\,0169) \text{ or } 1{,}707 \text{ lb.}$$

From Figure 2 the tractive effort for a medium vehicle at 40 m.p.h. is 723 lb.

L, or length of 4-per cent grade required to reduce speed from 41 to 39 m.p.h. = $\frac{170{,}570}{1707 - 723}$ or 173 ft.

Similar calculations by 2-m.p.h. intervals were made for the entire speed range of the truck study for different loads, grades, and vehicle sizes and are shown graphically in Figures 3 through 8. When the tractive effort is greater than the combined grade and tractive resistances, the vehicle is accelerating rather than decelerating Values for accelerating vehicles are shown by the dotted curves in these figures.

Truck operators are materially interested in the possible speeds of their vehicles on grades. The allowable pay load and the speed affect the operators' margin of profit Figure 4 shows the effect of load on the speed of an average medium truck operating on a 4-per cent grade. With a gross load of 40,000 lb. or less, this vehicle is capable of traveling at approximately 20 m p.h. at the top of a 4-per cent grade 1,400 ft. long if it enters the grade at 40 m p h. Under these same conditions, the speed at the top will be 24 m p h with a 30,000-lb load and 30 m p h with a 20,000-lb load

An important point is that the effect of load on speed is very small when the grade is short and the approach speed is high. At the top of a 4-per cent grade 500 ft long, the difference in speed between a vehicle weighing 40,000 lb gross and one weighing 30,000 lb is less than 1 m p h., if the approach speeds are 40 m.p.h. for both vehicles. However, when the approach speed is lower than the sustained speed (dotted curves) only very light loads, generally below 20,000 lb gross, permit any substantial increase in speed while on the grade For example, if a medium truck hauling a gross load of 20,000 lb approaches a 4-per cent grade at 20 m p h , the maximum speed it could attain would be 24 m p h , and the rate of increase in speed would be too slight to be noticed by drivers of vehicles following the truck

It is also apparent that the heavier the load, the more advantageous it is to enter the grade at the higher speeds The following are possible speeds of medium vehicles with gross loads of 10,000 and 40,000 lb. at various points on a 4-per cent grade 1,000 ft long:

	10,000 lb mph	40,000 lb mph
Speed entering grade ...	40.0	40.0
Speed at top of grade	41 5	26 0
Average speed on grade	41 0	33 0
Speed entering grade.	10 0	10 0
Speed at top of grade	33 0	12 7
Average speed on grade	21 0	11.9

With an entering speed of 40 m.p.h., the average speeds for the two vehicles are high enough to be tolerated by traffic and cause little congestion. With an entering speed of 10 m.p.h., however, the lighter vehicle with the gross load of 10,000 lb. would have enough power to increase its speed to 33 m.p.h. while the heavier vehicle could not increase its speed an appreciable amount. The heavier vehicle might therefore delay passenger cars and other trucks with lighter loads for the entire length of the grade

Figure 5 shows the effect of the power of the engine on the speeds of trucks with gross loads of 30,000 lb. operating on 4-per cent grades. The power has a comparatively small effect on the operating speed on a short grade when the approach speed is high. With an approach speed of 41 m p h., the speed at the top of a 4-per cent grade 500 ft. long is 34.5 m.p h for a light truck, 35.3 m p.h. for a medium truck and 36.2 m p h. for a heavy truck The corresponding speeds at the top of a grade 1,000 ft. long are 27 9, 29 4, and 31.7 m p.h. for the light, medium, and heavy vehicles, respectively. Similar speed differences have been determined for light, medium, and heavy units for other loads and grades The results show that the average light truck will reach the top of a grade traveling at the same speed as the average heavy truck if the gross weight of the smaller unit is approximately 30 per cent less than that of the larger unit. Also, with the same load, the speeds for the two units will be the same at the tops of two grades of the same length if the slope of the grade for the smaller unit is approximately 25 per cent less than the slope of the grade for the larger unit.

It has been shown that the possible speed of a commercial vehicle on a grade depends on the gross vehicle weight, the size of the power unit, the length of the grade, and the speed of the vehicle as it approaches the grade If the power characteristics of a vehicle are known, the effect of the length of any grade on the speed of a vehicle can be calculated by equation 1. Figures 6, 7, and 8, however, show the effects of length and steepness of grade on the speeds of light, medium, and heavy trucks for four gross weights ranging from 10,000 to 40,000 lb.

The primary objective in designing a highway is to obtain a location and an alinement on which motor vehicles may be operated safely and efficiently. This requires that consideration be given to the over-all operating times of commercial vehicles and the effects of their speeds on the speeds of other vehicles, particularly on 2-lane highways, in addition to such factors as sight distance, curvature, etc.

It is frequently necessary to select the most desirable location between two fixed points at different elevations. The truck performance data in the form shown by Figures 9, 10 and 11 may be more helpful to the designer in the proper solution of such problems than in the form shown by Figures 6, 7, and 8. Figures 9, 10 and 11 show the relation between approach speeds and speeds at tops of grades connecting differences in elevation of 25, 50, 75, and 100 ft This information is shown for a medium truck with a gross load of 30,000 lb. operating on various gradients by Figure 9; for a medium truck operating on a 4-per cent grade with loads of 10,000 to 40,000 lb. by Figure 10; and for trucks with various power units carrying 30,000-lb. gross loads up 4-per cent grades by Figure 11 A gross load of 30,000 lb. was exceeded by only 0 2 per cent of the single-unit trucks and by 20 per cent of the combination units weighed on main rural highways by the State Highway Planning Surveys during 1940

Figure 9 shows that when the difference in elevation between the top and bottom of a grade is 25 ft or less and the approach speed is high, the gradient has a relatively small effect on the speed of a medium truck with a gross load of 30,000 lb. as it reaches the top of the grade. The effect of the gradient on the speed at the top is, however, more pronounced for lower entrance speeds and for larger differences in elevation. As an example, with a difference in elevation of 25 ft. and an approach speed of 40 m p h. (Fig. 9), the speed at the top of a 2-per cent grade is 35 m.p h and the speed at the top of a 7-per cent grade is 31.3 m.p.h, a difference of only 3.7 m.p.h. for the two gradients For the same approach speed, the difference between the speeds at the tops of 2- and 7-per cent grade is 15 m.p h when the elevation change is 75 ft. or more When the approach speed is 25 m.p h or less and the difference in elevation is 50 ft. or more, the speed at the top of a grade is affected only by the gradient since the speeds at the tops of grades resulting in a difference of elevation of 75 and 100 ft. are the same as the speeds at the top of a grade resulting in a difference in elevation of 50 feet. When the difference in elevation is 100 ft. or more, the approach speed has practically no effect on the speed at the top of a grade.

Figure 10 shows that a typical medium truck without a load, or one weighing about 10,000 lb., would not be slowed down on a 4-per cent grade regardless of the length of the grade or the approach speed In fact it would have enough power to gain speed when entering such a grade at a speed under 40 m p.h.

As the load is increased, the effect of each 1,000 lb. increase in load has a smaller effect on the speed at the top of a grade than a previous increase of 1,000 lb. For example, increasing the gross load from 10,000 to 20,000 lb. when the entering speed is 40 m.p.h. makes a difference of 15 m.p.h. in the speed at the top of a 4-per cent grade 2,500 ft. long, whereas increasing the gross load from 30,000 to 40,000 lb. only makes a difference of 6 m.p.h. in the speed at the top of the same grade.

Figure 11 shows the variation in speed with the power of the engine for vehicles with gross loads of 30,000 lb. operating on 4-per cent grades. On the 625-ft. grade (difference in

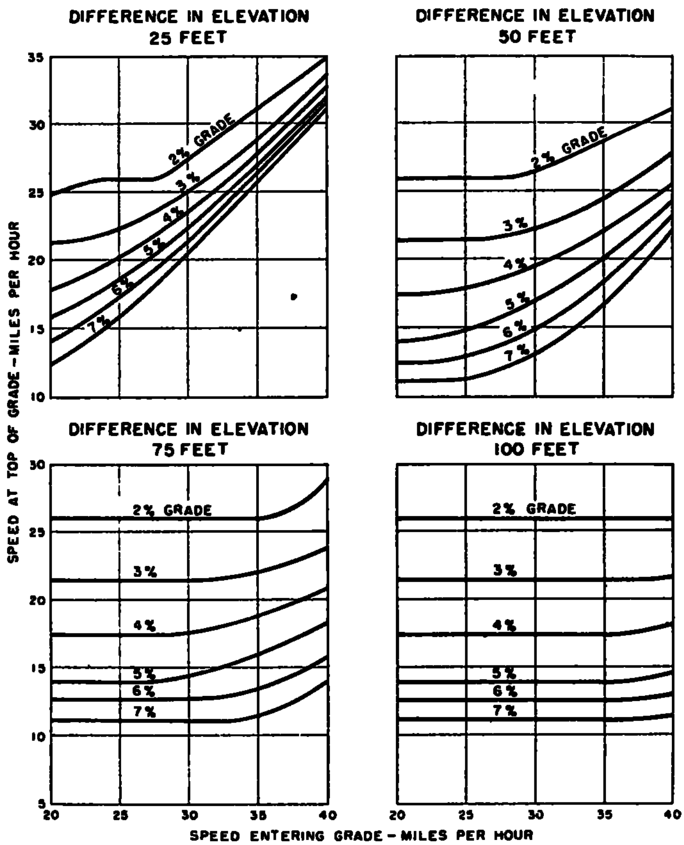

Figure 9. Relation between Approach Speed and Speed at the Top of Various Grades. (Medium truck with a gross load of 30,000 lb.)

elevation of 25 ft.) the speeds of vehicles are affected comparatively little by the power. At the tops of the longer grades and with approach speeds of 35 m.p.h. or less, the possible speeds of light vehicles are about 2 m p h slower than the speeds of medium vehicles; the speeds of medium vehicles are in turn about 4 m.p.h. slower than those of the heavy vehicles.

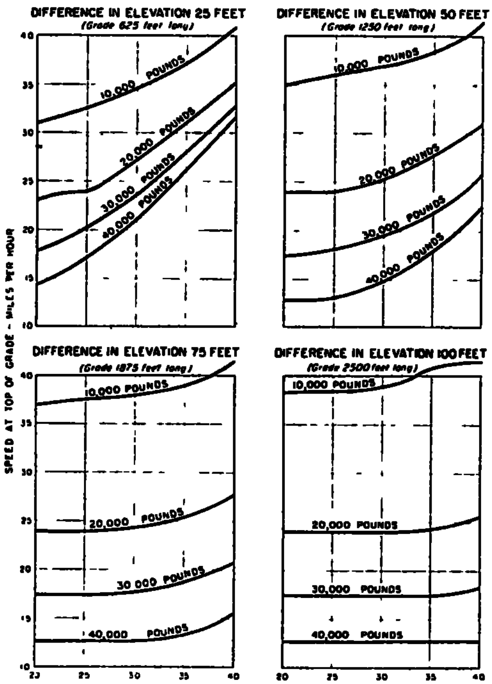

Figure 10. Relation between Approach Speed and Speed at the Top of Grade for Various Loads. (Medium truck operating on 4 per cent grades.)

When considering the traffic congestion caused by slow-moving trucks on grades, the time spent by the trucks on the grades in addition to their speeds at the top of grades is important. This time will affect the number of faster moving vehicles that overtake the trucks on the upgrades where sight distances on 2-lane roads are usually less than necessary for the performance of safe-passing maneuvers.

Figure 12 shows the travel time of a typical medium truck with a gross load of 30,000 lb. on various grades for a range of entering speeds. Thus we see that the travel time of

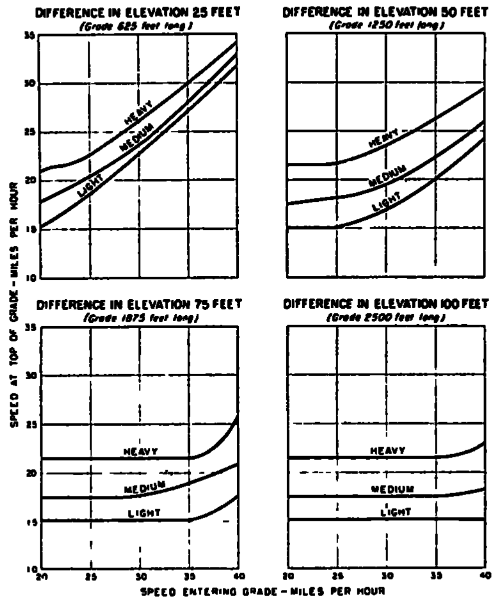

Figure 11. Relation between Approach Speed and Speed at the Top of Grade for Various Sizes of Vehicles. (Trucks with gross loads of 30,000 lb. operating on 4 per cent grades.)

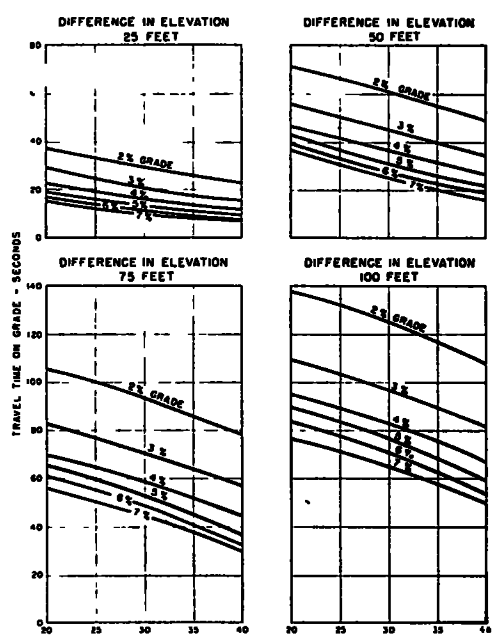

Figure 12. Relation between Approach Speed and Travel Time on Various Grades. (Medium truck with a gross load of 30,000 lb.)

this vehicle on a grade decreases as the slope of the grade increases for any fixed difference in elevation. For example, the time spent on a 7-per cent grade is only 30 to 55 per cent of the time spent on a 2-per cent grade for the same change in elevation. An increase in the steepness of the grade above 4 per cent, however, causes a comparatively small decrease in the time spent on the grade. The relation between gradient and time on the grades for a fixed change in elevation as shown by Figure 12 is also typical for trucks with other power units and other gross loads

From the truck operator's viewpoint, the total travel time between two points is a more important consideration in an economic analysis of gradient than the time spent on the grades. In some cases, the use of an alinement with short steep grades and long level sections might result in less travel time for trucks between two points at a fixed difference in elevation than an alinement with moderate gradients which would necessarily be longer to obtain the same difference in elevation. In other cases, the reverse might be true. In general, however, on rural highways where normal truck speeds on the level are in the neighborhood of 40 m.p.h., the travel time for a truck between two points depends on the total change in elevation and the travel distance rather than on the steepness of the grades.

In the design of a highway, for example, the use of easy grades might require either excessive earthwork on the most direct location between two points or a longer route with more horizontal curvature. The increased number of horizontal curves, by their effect on sight distances, would in some cases have a greater tendency to reduce safe operating speeds than the steeper grades.

From the viewpoint of the passenger car operator and from that of the over-all safety and efficiency of the highway, the more important consideration is the time that commercial vehicles operate at speeds substantially below those generally prevailing on the level sections of a route, for it is during that time that the need for passing is the greatest.

Generally, the designer will have to reach a compromise between the two interests. Where the most important usage of a route is by commercial operators, as for example in hauling ore or timber over roads leading from mines or forests the design should favor their vehicles. For routes expected to be used nearly to capacity, however, and on which commercial vehicles comprise a normal portion of the traffic the design should be such that the interference caused to other traffic is a minimum, even if the total travel time for the trucks may be somewhat increased.