METHODS FOR PREDICTING TRUCK SPEED LOSS ON GRADES

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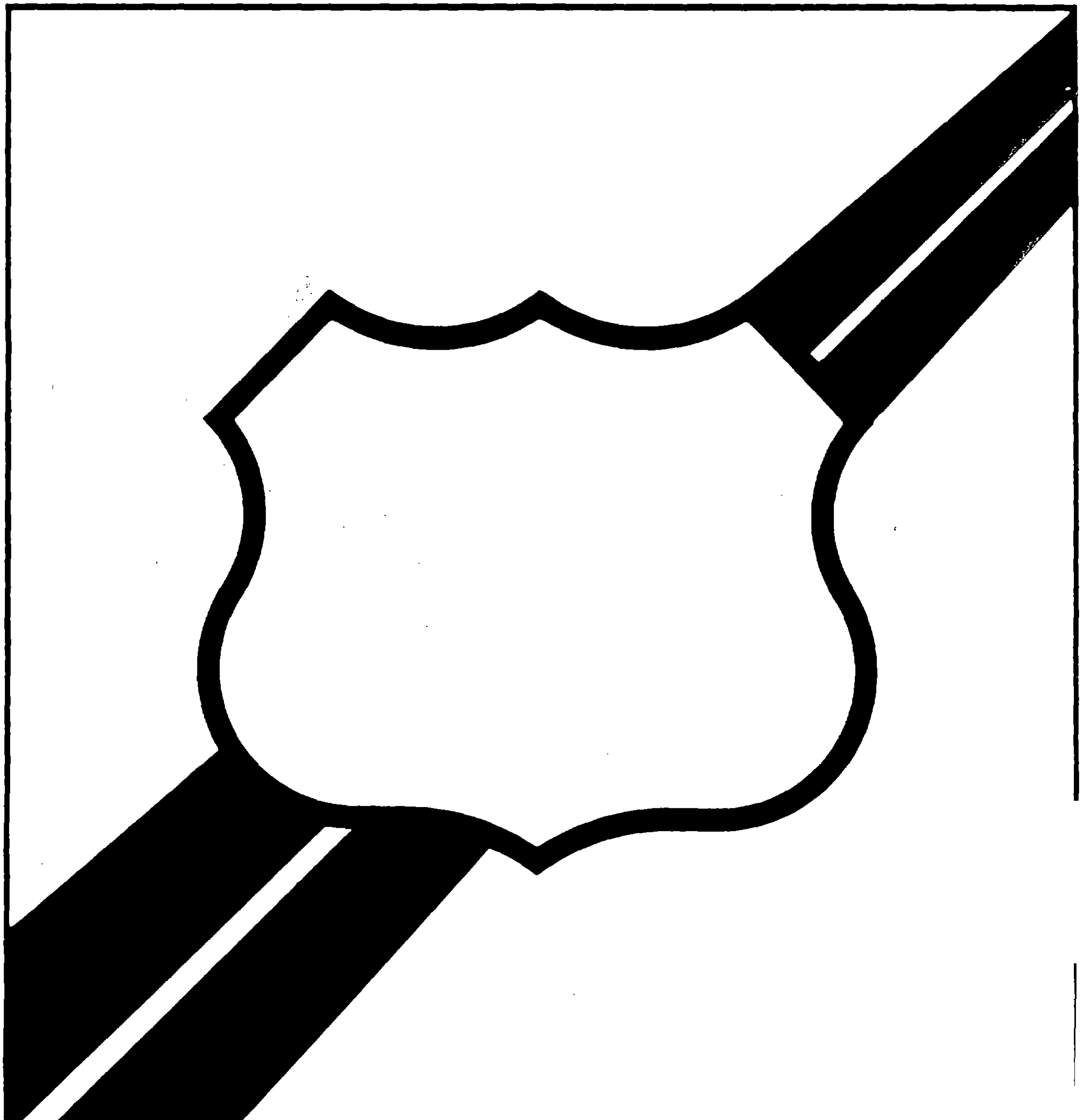

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16. Abstract

Truck speed loss on grades reduces highway capacity and increases the risk of accidents. The rational design of a truck climbing lane as a solution to this problem requires means for predicting truck speed changes on grades.

Experimental measurements of the speed loss of trucks operating on highways were conducted at 20 sites throughout the country. These data were analyzed to compare performance to present guidelines for highway design embodied in the AASHTO Policy on Geometric Design of Highways and Streets. The performance of the straight truck and tractor-trailer population is notably better than that reflected in the AASHTO publication.

Methods were developed for modeling the hill-climbing performance of the four major truck classes at the 12.5 and 50 percentile population level using empirically determined weight-to-power values. Speed-distance plots are provided for each class on constant grades, along with a simple computer program for calculating speed versus distance on arbitrary grades defined by the user. These speed-loss models are recommended as alternatives to the AASHTO standard for highways carrying primarily straight trucks and tractor-trailers.

Trucks pulling trailers, and doubles and triples are the truck classes with lowest hill-climbing performance. For the limited data obtained, the AASHTO model appears to provide a reasonable performance prediction for the 12.5 percentile population.

Methods for estimating performance at the 12.5 percentile level for mixed truck populations are presented. The need of a rationale for making design decisions with mixed truck populations is recognized, and suggested as a future research topic.

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INTRODUCTION

Background

This document is the final report for the FHWA study, "Truck Tractive Power Criteria," Contract Number DTFH61-83-C-00046, performed over the period July 1983 to October 1985. The study focuses on the problem of predicting the speed loss of trucks encountering grades on our nation's highways.

For purposes of this project, the term "truck" refers to any combination of single- or multi-unit vehicles having at least one axle with dual wheels. Vehicles of this type normally have a gross vehicle weight rating (GVW) of 10,000 lb or more, and are thus separated from the much larger population of light trucks (pickups), which are similar in hill-climbing performance to passenger cars. The trucks considered in the project then range from the smaller 2-axle straight trucks with GVW ratings over 10,000 lb, to tractor-semitrailers, and doubles or triples combinations with GVW ratings to the maximum allowable on the highways.

Trucks characteristically exhibit the lowest level of hill-climbing performance of all vehicles using the nation's highways. Thus, at uphill grades of sufficient length and steepness their speed loss may be great enough that they impede the traffic flow, reducing the capacity of the highway to carry traffic, and creating possible hazards to other vehicles. To counteract these influences, climbing lanes may be added along the uphill grade section. The additional construction and maintenance costs, however, warrant careful consideration with regard to when climbing lanes are needed, and over what portion of the grade.

To aid highway designers in making decisions on this and other matters, the American Association of State Highway and Transportation Officials (AASHTO) publishes a Policy on Geometric Design of Highways and Streets.[1] The Policy addresses the issue of truck uphill performance and the need for climbing lanes. In brief, a truck's weight-to-power (W/P) ratio is considered to be the most important characteristic affecting hill-climbing performance, with a value of 300 lb/hp taken as the representative W/P value for design purposes. Plots of speed versus distance on constant grades are presented for a typical truck of 300 lb/hp as a tool for the highway engineer to estimate truck speed losses on a proposed design. Studies are referenced that indicate that truck accident frequency increases with differential in speed, thus climbing lanes are advantageous when excessive speed differentials are anticipated. A speed difference of 10 mi/h (16 km/h) is suggested as a limit at which point a given grade is of the "critical" length justifying consideration for a climbing lane.

The decision to add a climbing lane carries with it an economic penalty, and in many cases complicates the overall design. For determination of where on the grade the climbing lane must start, the characterization of truck performance is very critical. The basis for characterizing truck performance by a W/P of 300 lb/hp derives from a number of past studies ranging in time from 1945 to 1978.[2,3,4,5,6] Other and more recent data on truck performance is available.[7,8,9,10,11,12] Yet, there is need for a more comprehensive study examining truck hill-climbing performance in a more general way—considering the possible differences in geography, road type, and, particularly, the temporal changes in truck properties.

Objectives

This study addressed the broad issue of how truck hill-climbing performance could be best characterized, and what methods could or should be applied by the highway engineer to quantitatively estimate truck speed losses for a particular design. The individual objectives may be stated as follows:

1) To determine how to model or characterize hill-climbing performance in a way that is most useful for the highway design process.

2) To determine the primary variables affecting hill-climbing performance that may be specific to a site (i.e., truck class, grade, speed, road classification, and location).

3) To develop guidelines and/or procedures for the highway engineer that can be used to quantitatively estimate hill-climbing performance of the general truck population at a site, taking into account the above variables.

Methods

As reflected in the AASHTO's Policy on Geometric Design of Highways and Streets, weight-to-power ratio has been adopted as the means of characterizing trucks for their hill-climbing performance.(1) Other representations are possible. Which is best depends on the performance measure to be predicted and the ease with which it can be applied.

In order to determine means for predicting hill-climbing performance, an experimental data base of measurements of actual trucks on the nation's highways is needed. Furthermore, the experimental data must be collected over a broad range of conditions and geographic locations, so that the significant variables affecting performance can be extracted. Thus, the foundation of the research program was a program of data collection in the field, by which to examine hill-climbing performance of present-day trucks. Based on economic and other factors, a program of field tests at 20 sites throughout the country was conducted. In those tests, the hill-climbing performance of a sample of trucks was determined, along with descriptions of the vehicles making up the population of vehicles using the road.

This data base was analyzed to determine the averages and distributions of performance properties for the trucks at each site. By selecting sites with appropriate representation of geographic location and road class, differences in performance attributable to these variables could be determined. Within each site, the classification by vehicle allowed inquiry into differences between classes of vehicles.

At the same time, the overall measures of hill-climbing performance allowed examination of the typical behavior over a large sample of vehicles, so that past assumptions as to how trucks decelerate on a grade could be critically tested.

Report Organization

Chapter 2 of this report provides a background on how hill-climbing performance can be characterized. Certain key issues are identified which establish a direction in evaluating the results observed in the experimental measurements of hill-climbing performance obtained in this study. In chapter 3 the performance capabilities of modern trucks are examined, using the data base of experimental measurements. The relationships between performance and truck type on different road classes are examined to identify which variables should be considered by the highway engineer in attempting to predict speed loss in a design analysis. Chapter 4 presents the application of the information in the form of suggested means for predicting hill-climbing performance for highway design purposes. In Chapter 5, the overall findings from the project are summarized in the form of conclusions and recommendations. The appendices provide background information on the methods employed to collect data in the field, and summaries of the data that were collected.

CHARACTERIZATION OF HILL-CLIMBING PERFORMANCE

Mechanics of Truck Accelerations

Choosing a "best" means to quantify hill-climbing performance must start with a basic understanding of the mechanics involved. The ability for a truck to accelerate on the road depends on the summation of the forces acting on the vehicle. The propulsive effort (drive force) is derived from the engine. This acts to overcome the drag forces due to aerodynamic and rolling resistance at the particular speed of travel. Any reserve in drive force available from the engine may be used either to accelerate the vehicle or to overcome the drag arising from road grade. When encountering a grade greater than the available drive force, the deficiency is made up by a deceleration of the vehicle.

Governing Equations. The governing equation for the forward travel of any motor vehicle when it encounters a grade is determined by the summation of forces on the vehicle in the longitudinal direction. The equational form is:

$$W (1 + e) A_x = F_d - F_r - F_a - W G_r \tag{1}$$

where

W = the vehicle gross weight

e = effective weight of all rotating components normalized by W

A_x = the instantaneous acceleration in g's

F_d = engine drive force at the ground

F_r = rolling resistance force

F_a = aerodynamic drag force

G_r = road grade (expressed in radians or percent/100)

At high speeds, the effective weight of the rotating components is small (on the order of a few percent of the gross vehicle weight). At speeds below 20 mi/h (32 km/h) it may increase to a significant fraction of the gross weight, but to simplify the discussion at this point it will be neglected. Then this equation can be written in an alternate form in which all terms are normalized by the weight:

$$A_x + G_r = F_d/W - (F_r + F_a)/W \qquad (2)$$

This equation accounts for the instantaneous acceleration of the vehicle on the grade. The right side of the equation represents the normalized drive force, less the normalized drag forces. At any instant in time the acceleration (in g's) plus the grade must equal this total force. When the grade is large, the acceleration must be small (or even negative) in order for the equation to be satisfied.

In order to use the equation to predict velocity as a function of time, the equation is integrated over the desired interval beginning from a set of initial conditions (an entry velocity at the grade entry point). In general the forces will be a function of velocity and the grade may be a function of distance traveled. Reduction to a closed-form analytical expression is difficult due to the complexity of the expressions for the forces acting on the vehicle, and due to the influence of transmission shifts on speed maintenance. (Closed-form solutions have been obtained for some of the simpler forms of the equation. For example, in vehicle coastdown tests the engine power term is zero and transmission shifting does not occur.[13]) However, the equation can be solved readily on a small desktop computer, or approximate solutions can be performed on a calculator.

Forces Acting on a Vehicle. The exact solution obtained in any particular case is dependent on the expressions and values used to describe the various forces acting on the vehicle. Figure 1 shows the nature of the various forces acting on the vehicle as a function of speed.

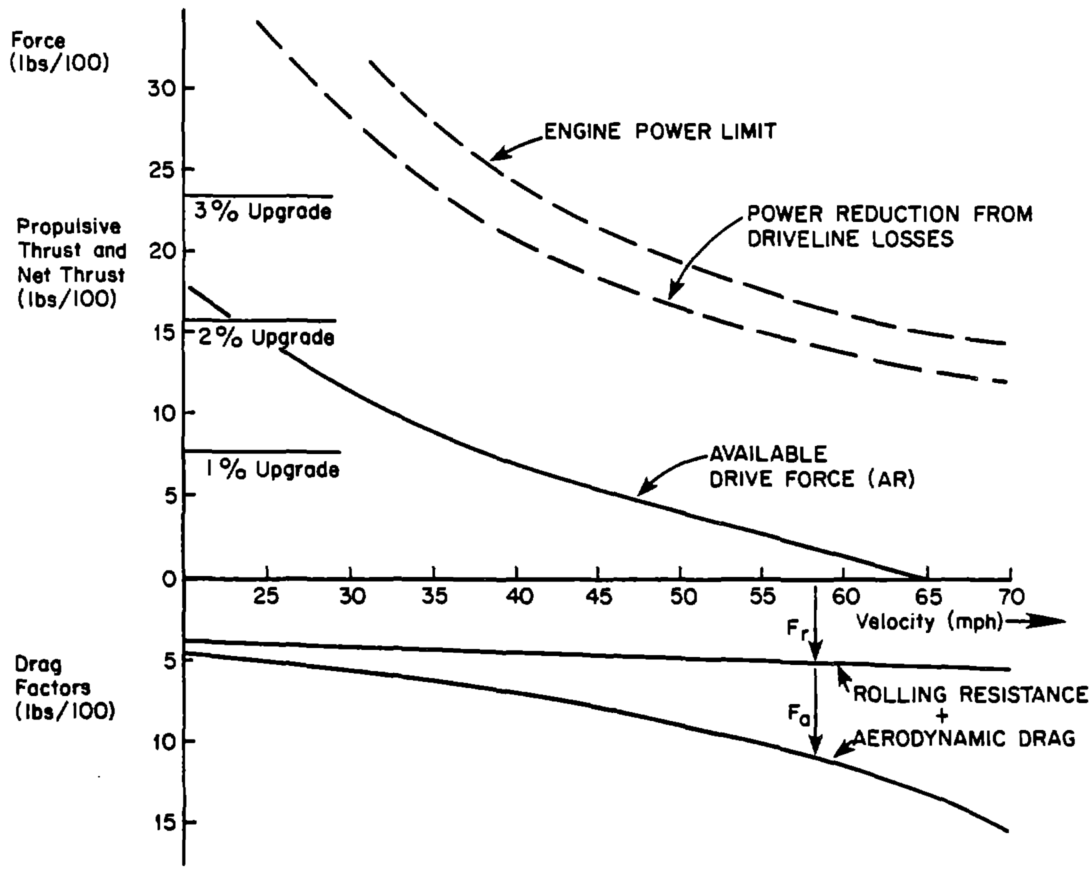


Figure 1. Forces acting on a vehicle as a function of speed.

Drive force--The power available from the engine represents an absolute upper bound on the drive force as a function of speed. Power is force times velocity, hence the power limit of the engine plots as a hyperbola in the figure. In actuality, only a portion of that power is available because of the inefficiency of the drive train, the efficiency factor lowering the level of the hyperbola. Maximum power is available from the engine only at a specific engine speed. To allow the engine to operate near this limit, various gear ratios are provided in the transmission. Within each gear the drive force available is then simply the image of the engine torque curve. Acceleration (or deceleration) over a wide speed range will require that the transmission be shifted from one gear ratio to the next. The majority of heavy trucks have manual transmissions. When the shift is made, the engine power is disengaged from the drive train for the shift interval. Typical time intervals of 1 to 2 seconds are assumed for shifting.

Rolling resistance--The drag force arising from the tires is generally accepted to consist of a constant value, plus a smaller component that increases linearly with speed. The absolute magnitude of the rolling resistance is directly proportional to the load carried; hence, rolling resistance is represented by a coefficient times the gross vehicle weight.

Aerodynamic resistance--The drag due to aerodynamic interaction with the surrounding air is dependent on the square of the relative wind speed. In the absence of ambient wind, the square of the vehicle speed is used. The absolute magnitude of the drag at any speed is proportional, as well, to the frontal area of the vehicle, its drag coefficient, and the local air density.

When all of these forces are added together, the available drive force at any speed is as shown in figure 2. The ordinate in this plot is the drive force divided by weight. It represents the ability for the vehicle to accelerate at full engine power. The numerical scale on the ordinate represents "g's" of acceleration (longitudinal acceleration/gravitational acceleration). Thus it might be appropriately called the "acceleration reserve," (AR), and the AR may be

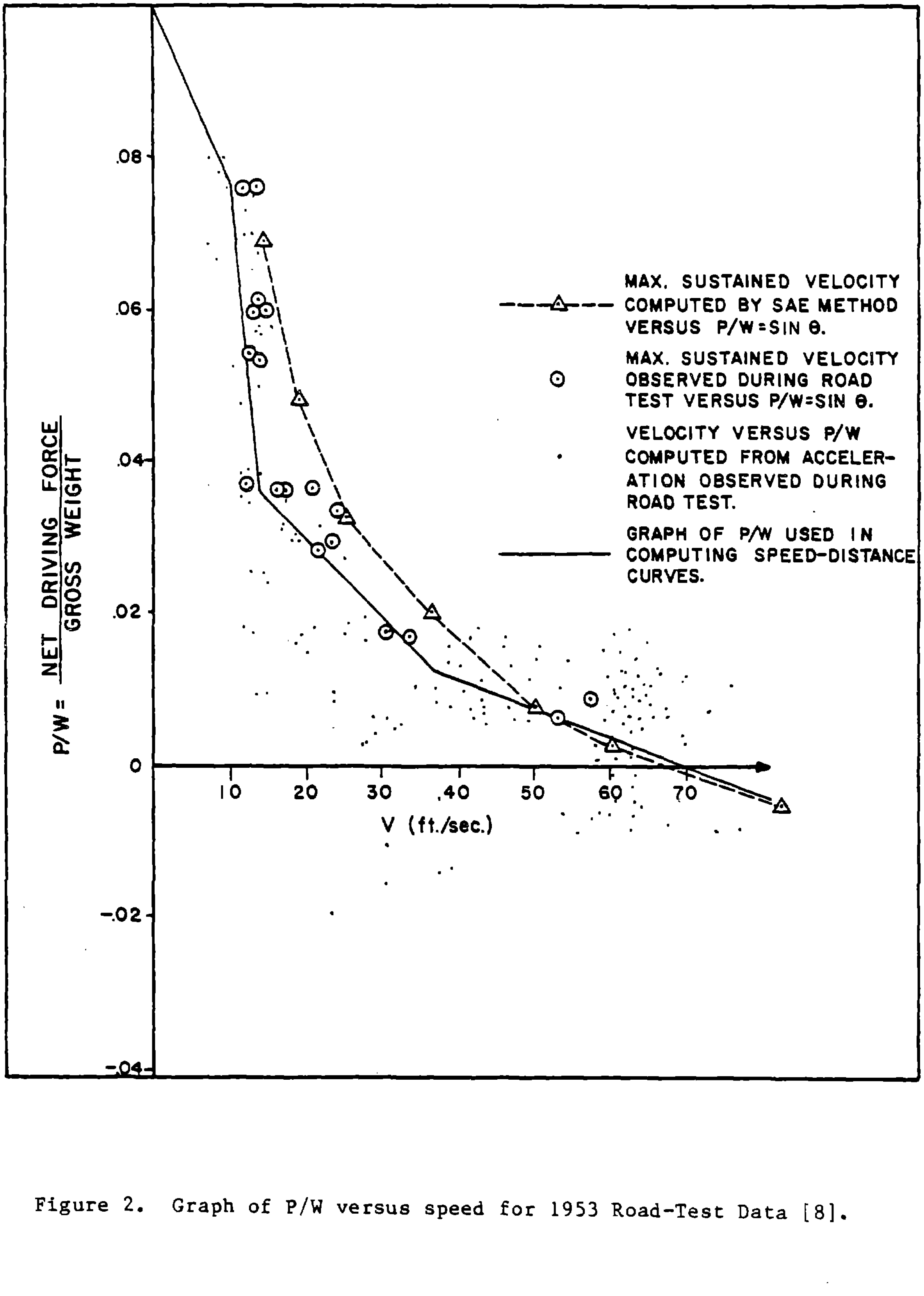


Figure 2. Graph of P/W versus speed for 1953 Road-Test Data [8].

interpreted as the net force available to accelerate the vehicle, normalized by its weight. The acceleration can be applied either to changing the speed of the vehicle, or counteracting the acceleration component of gravity when the vehicle is on a grade. At the point where the curve intersects the abscissa, there is no acceleration reserve, thus the vehicle cannot accelerate beyond this speed on a level surface, and it represents the theoretical maximum speed determined by engine power. (The actual maximum speed may be less than this due to the gearing selected for the driveline.)

On a grade, the drag force is equivalent to the gross vehicle weight times the grade percentage divided by 100. Because the drag is not dependent on speed, grades can be represented by horizontal lines on the plot. The intersection between a particular grade and the acceleration reserve represents the steady-state speed (final climbing speed) that the vehicle can maintain on that grade. At other speeds, the acceleration or deceleration that will be experienced is equivalent to the difference between the grade line and the AR line.

This plot characterizes the acceleration ability of a truck on a grade while the engine power is applied. It does not represent directly the performance during shifting intervals when the engine is disengaged.

Definitions of Terms. Throughout the rest of this report, many references will be made to the "power" of a truck, often used in the context of a weight-to-power ratio. As seen above, the power available to motivate the truck is different at various points on the vehicle (especially differing between the engine and the drive wheels), and it is helpful for clarity in the discussion to establish certain definitions. Three power symbols will be defined.

P_1—Engine size may be characterized by its "rated power," either gross or net, the latter including allowances from losses associated with the driven accessories. The P_1 designation will be used to identify power at the engine, as would be quoted by the truck owner or driver.

P_2--For certain purposes it becomes necessary to estimate the average or "effective power" being delivered at the flywheel of the engine, based on the performance observed. The performance mode of interest here will be hill-climbing. P_2 will be lower than P_1 because of accessory losses, ambient conditions, the maintenance condition of the engine, shifting losses, or inability of the driver to maintain the engine at its maximum power operating point.

P_3—Refers to the power available to accelerate the vehicle or overcome grade. It will be lower than P_2 because of losses in the drive train, rolling resistance losses, and aerodynamic drag. P_3 is the "drive power," and is the net force, represented in the right-hand side of equation 2, times the forward speed.

Characterization of Hill-Climbing Performance

In the past, the highway community has characterized trucks by a weight-to-power ratio for purposes of modeling hill-climbing performance. Other methods can be used. Each involves different levels of comprehensiveness with which the behavior is predicted, the more comprehensive approaches usually carrying a burden of greater complexity in their utilization. The different alternatives are reviewed here as background for identifying the best choice for particular applications.

Simulation Models. The most comprehensive means to characterize a truck is simply to take the approach of analytical prediction using a detailed "simulation" model of a truck climbing a grade. This approach is reflected in a number of computer simulations that calculate speed versus time and distance by integration of the governing equation, such as equation 1. Appropriate descriptions of the aerodynamic and rolling resistance forces are developed for the calculation process. With this approach the effect of transmission shifts can be incorporated directly in the calculations to provide a more realistic estimation of performance. Overall, this approach requires an extensive list of parameters to describe the vehicle in the necessary detail. In return, the calculations yield velocity plots that can closely match the performance of typical trucks. Figure 3 shows the form of the velocity-distance relationships obtained from simulation of a typical vehicle of 300 lb/hp, where the net engine horsepower is used. Of course, every vehicle will be slightly different. Even the same vehicle with different gearing will produce different results. The multiple plots in figure 3 are obtained from the same vehicle with different sets of gearing, which alters the speeds at which shifts are made. For comparison, the figure also shows the computed performance presuming an infinitely variable transmission, which would not require shifting, but would allow the engine to always operate at maximum power.

Weight-to-(Effective) Power Ratio. For many years the highway community has used an approach based on the simulation method described above for characterizing hill-climbing performance.[1,6] For this purpose, typical parameter values are assumed to describe the truck and the drag losses. The key variable quantifying truck performance is the estimate of the weight and the effective power (P_2) available from the engine. Weight-to-power values that have been used over the years have been selected on the basis of what was known about truck weights and engine power values, and the agreement between predicted and observed hill-climbing performance. This approach takes into account the changes in drag force with speed, rationalizing the use of only one power value to describe the truck, although its value is dependent on the estimates of drag used in its determination. The variations in performance due to shifting (see figure 3) are overcome by arbitrarily smoothing the curves. The predictions of performance obtained are illustrated in the AASHTO curves, shown in figure 4.

Semi-Empirical Equations. Semi-empirical equations for the effective acceleration of a truck on grades have been developed by some researchers.[10] The effective acceleration is a function of road speed. At any particular speed, the value is determined by solution of the force equations, like that of equation 1, but yielding an acceleration value that is averaged over the period which includes the gear shifting interval. Given the same vehicle and road parameters, the semi-empirical equations simply generate a "smoothed" form of the

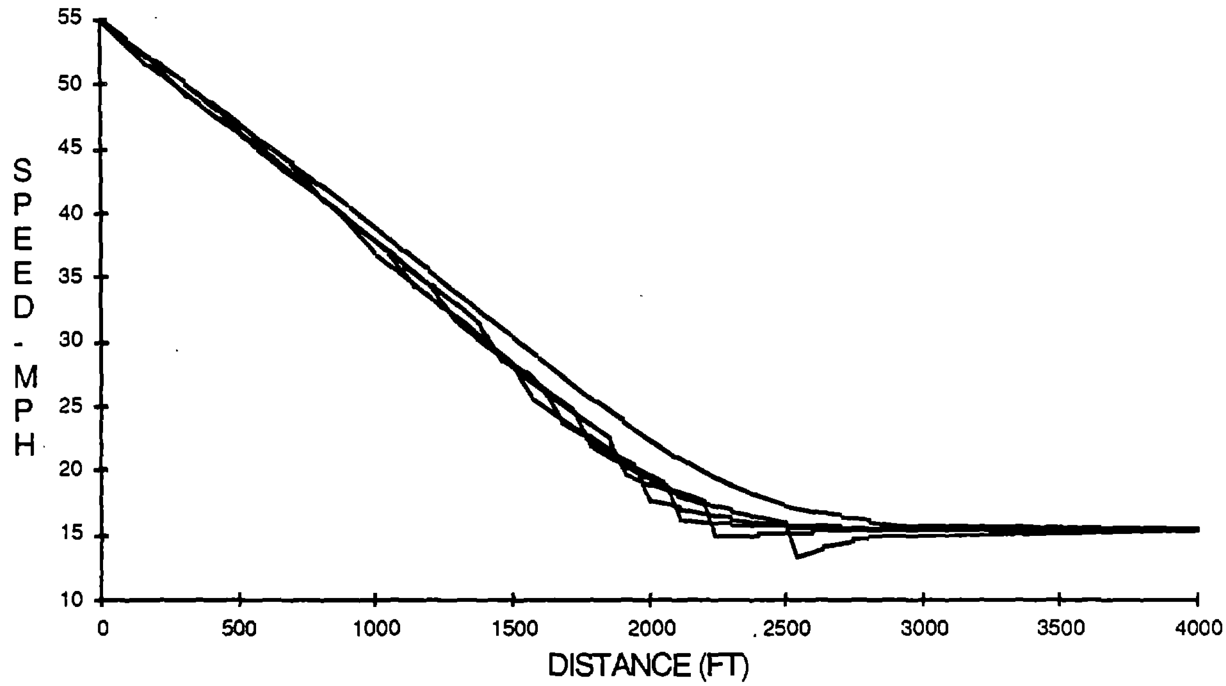


Figure 3. Speed-distance plots obtained from simulation of a typical truck on a 6 percent grade.

Deceleration (on Percent Upgrades Indicated)

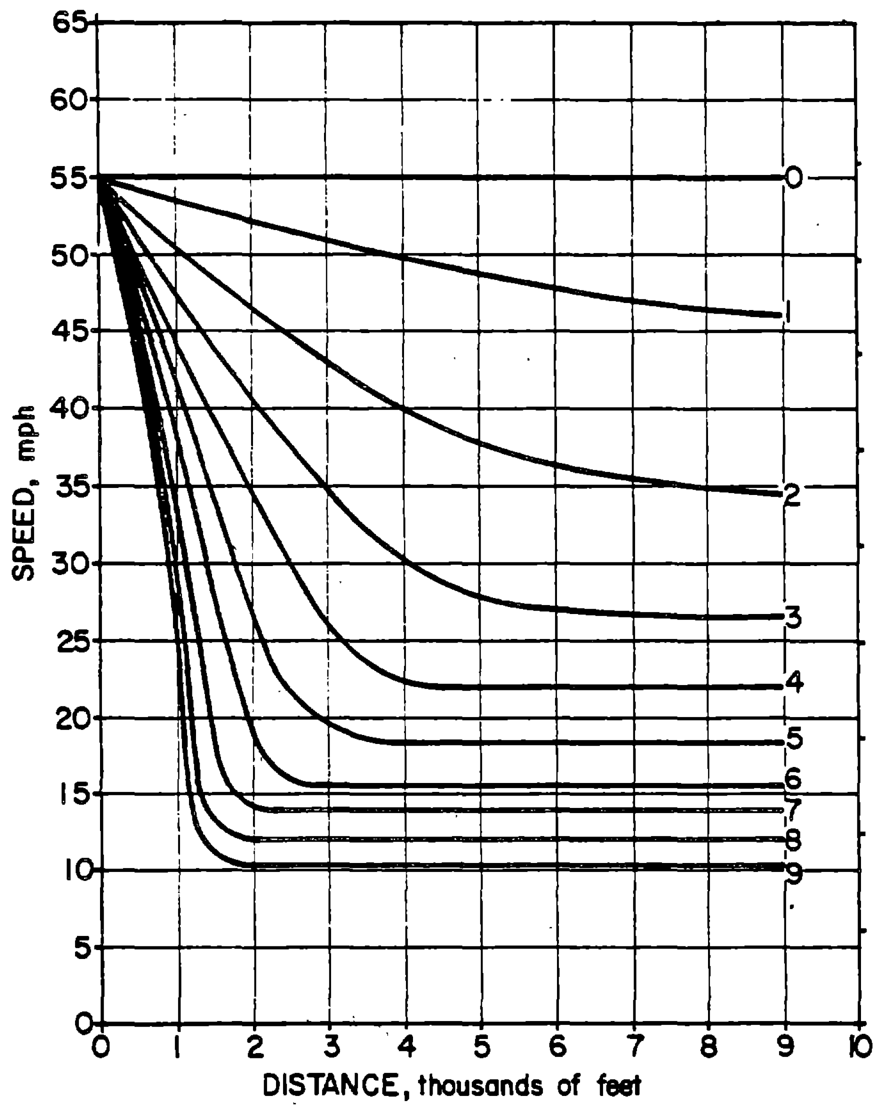


Figure 4. **Speed-distance curves for a typical heavy truck of 300 lb/hp for deceleration (on percent upgrades).** [1]

velocity-time or velocity-distance curves that would be obtained using the simulation models described previously.

Acceleration Reserve. The acceleration reserve described in the section entitled Forces Acting on a Vehicle is another means of representing the performance capabilities of a truck as a function of speed. It is the most direct method for quantifying climbing performance because it is a direct expression of the combination of deceleration and grade. Although analytical predictions of this quantity, based on assumptions for truck properties, will be no more accurate than the three methods described previously, AR values determined from experimental measurements are the most direct characterization of the truck. No assumptions need to be made with regard to drag losses, efficiencies, or other factors, and the reduction in effective climbing ability due to shifting is directly reflected in the AR value observed. From equation 2, AR can be defined as:

$$AR = A_x + G_r = F_d/W - (F_r + F_a)/W = f(V) \qquad (3)$$

At any speed and grade condition the AR then determines the deceleration that will be observed.

$$dV/dt = A_x\, g = (AR - G_r)\, g \qquad (4)$$

where,

t = time

g = gravitational constant

Because the velocity, V, equals dX/dt (X being the distance along the road), the equation can also be written:

$$dV/dX = (AR - G_r)\, g/V \qquad (5)$$

The equations can be integrated to obtain V as a function of time or distance, presuming AR is known as a function of speed. Note from figure 1 that for speeds above 20 mi/h (32 km/h) the acceleration reserve is nearly linearly related to speed. In that case equation 2 can be rewritten as:

$$AR = A_x + G_r = C_1 + C_2 V \qquad (6)$$

where

A_x = longitudinal acceleration (g's)

G_r = upgrade (%/100)

C_1, C_2 = truck characterization coefficients

V = velocity (fps)

This method is attractive for its directness in describing the acceleration capability on a grade. Only two coefficients are needed to characterize the truck, and no assumptions need be made about the truck. The AR is seen as a means to empirically characterize a truck. There is no direct analytical means to adjust the AR for losses incurred during shifting; however, empirical measurements of the AR will produce an effective value that includes shifting losses.

Using the accleration reserve function of equation 5, velocity-distance curves can be generated by integrating to obtain the velocity as a function of distance. Figure 5 shows the form of the curves obtained on constant grades.

Weight-to-(Drive) Power Ratio. Similar to the AR function, a truck may be characterized by the ratio of weight to drive power (P_3). This method is attractive because a weight-to-power value is more intuitive than AR. This characterization is simply an alternate form of the AR. From equation 3:

$$AR = A_x + G_r = F_d/W - (F_r + F_a)/W = (P_3/W)/V \qquad (7)$$

or:

$$W/P_3 = 550/(AR\ V) \qquad (8)$$

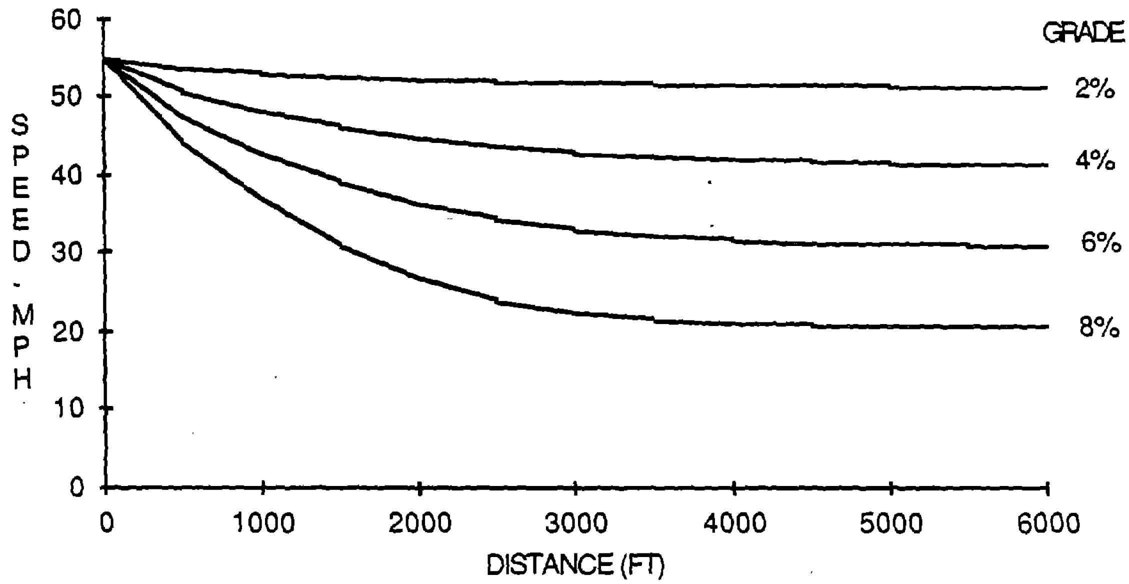


Figure 5. Speed-distance plots calculated from an AR function that is linearly dependent on speed.

where:

$\bar{P}_3$ = Drive horsepower

A constant W/P value implies a hyperbolic shape for the acceleration reserve of the vehicle as a function of speed; in fact, we observe that it is more likely to be linear. At high speed, characterization by a constant may be a poor representation for the steady-state acceleration reserve, which has a linear form. However, at low speed, the constant W/P more closely matches the characteristic shape of the acceleration reserve function.

To accommodate the inconsistency at high and low speeds, it may be anticipated that two W/P_3 values may be needed to characterize typical truck performance--one value to quantify the high-speed decelerations on entry to a grade, and one value to quantify the final climbing speed. Like the AR, the W/P_3 representation does not directly account for the shifting losses as a truck decelerates on a grade, although these effects will be reflected in the W/P_3 values determined from empirical measurements. Figure 6 shows the form of the speed-distance curves obtained on a constant grade from calculation with a fixed value of W/P_3.

Evaluation of Characterization Methods

The choice of what constitutes the best method for characterizing the truck should be made with first priority given to its ability to reasonably match the performance of typical trucks. The format in which the performance is evaluated assumes critical importance. For example, for the prediction of instantaneous acceleration of a particular 4vehicle, the computer simulation method provides the most detailed record of actual speeds at an arbitrary time, yet the "smoothed" curves of the AR and W/P methods are more appealing for representing the

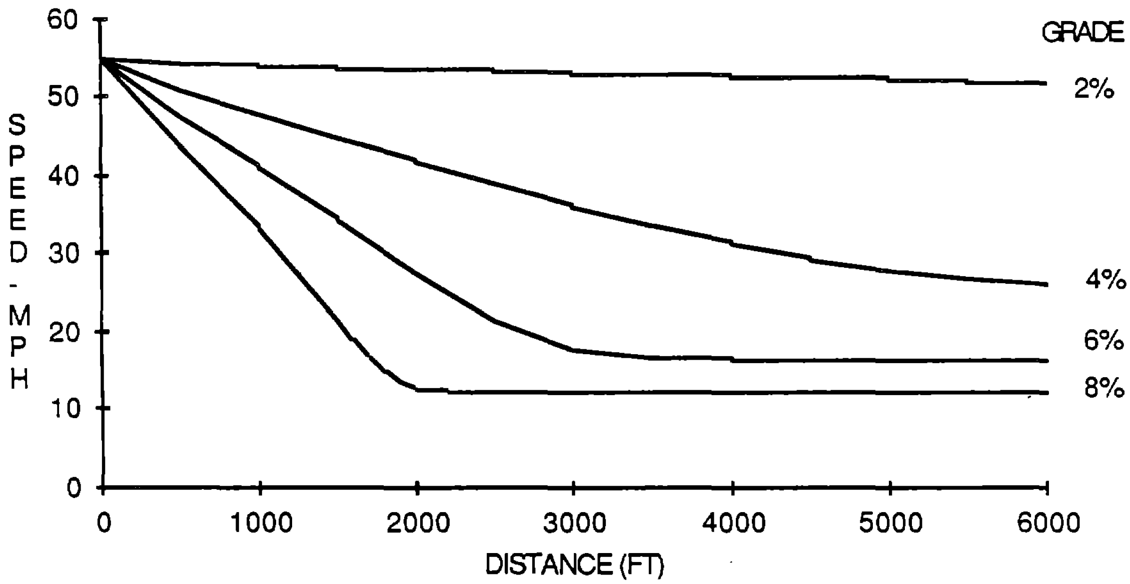


Figure 6. Speed-distance plots resulting from a constant W/P_3 value.

average performance of a sample of trucks. Thus one must ask, what performance predictions are most critical to the highway designer.

For determining critical length of grade, the change of velocity with distance at high speed has assumed the greatest importance. A speed loss of 10 mi/h (16 km/h) is recognized as the threshold of increase in accident frequency. On open highways, where truck entry speeds will be near 55 mi/h (89 km/h), the distances required for speeds to drop to 45 or 40 mi/h (64 or 72 km/h) are the most important for determining where a climbing lane should start. On steep grades the AASHTO curves imply a rather linear relationship between speed and distance, thus the gradient is the most important. On the other hand, on the more shallow grades, the prediction of final climbing speed (and whether it is more than 10 or 15 mi/h (16 or 24 km/h) below mean traffic speed) assumes great importance in determining whether a climbing lane will be needed at all. Again, the predictions of truck speeds in the range of 40 to 45 mi/h (64 to 72 km/h) is the most important. Accurate predictions at lower speeds may not be as critical. Certainly, roads on which mean traffic speeds are 35 to 40 mi/h (56-64 km/h) are less frequent than those with higher speeds, and are less likely to involve long, steep grades.

From the standpoint of estimating highway capacity, the speed-time relationship and final climbing speeds assume greater importance. The integral of speed reduction over time represents the impediment to the free flow of traffic.

Comparing figures 4 and 5 indicates that different speed-distance relationships are obtained from each method of characterization. The AR representation of a vehicle's ability to overcome grade yields a continuous curve. Representation by constant engine power, as in the AASHTO method, results in a nearly bilinear speed-distance relationship, at least when starting from high speeds on steep grades. It is not clear which method more accurately represents actual performance.

In addition to the issue of parameters for characterizing a vehicle, there is also the question of which vehicle to characterize.

The existing AASHTO guidelines describe a single "typical" truck of 300 lb/hp used in the context of a "design truck." Inasmuch as the population of trucks using a road encompasses a broad range of performance capabilities, there is no "typical" performance representative of all. The nature of the problem is illustrated in figure 7, which shows the cumulative distribution of tractor-trailer decelerations measured near the beginning of a grade on five different roads with different grade values. Trucks near the top of the distribution, which are decelerating very little or not at all, are not impediments to other traffic. It is the trucks from the midpoint of the curves and down that impact on traffic flow. The midpoint can be represented by the 50^{th} percentile truck, or the average. In general, the averages will differ somewhat from the 50 percentile, reflecting a skewness in the distribution, especially on sites such as "Coyote" identified in the figure. The trucks at the bottom of the distribution (experiencing the greatest decelerations) are the vehicles creating the greatest traffic impedance.

The relationships and models that have been established to link truck speed loss to its impact on traffic safety and highway capacity do not provide an adequate basis to deal with the issue of these performance variations in the truck population. Applying the 10 mi/h (16 km/h) criterion to the real world, where decelerations of the truck population on a given grade exhibit this distribution of performance, a "no-risk" design is not practical. The extremes of performance would dictate ultra-conservative design practices. Given limited resources, the highway engineer must choose to minimize the risk over the whole network, which means minimizing the frequency with which the 10 mi/h (16 km/h) rule is violated on the overall road system. On a lightly traveled road, a higher percentage of the truck traffic at this threshold would equate with a lower percentage on a more heavily traveled road, and the highway managers must ultimately incorporate this risk-taking assessment in their decision process. To do so requires that the distribution of deceleration performance be known. The distribution of decelerations for tractor-trailers shown in figure 7 tends to be rather linear from the midpoint (median truck) down to the

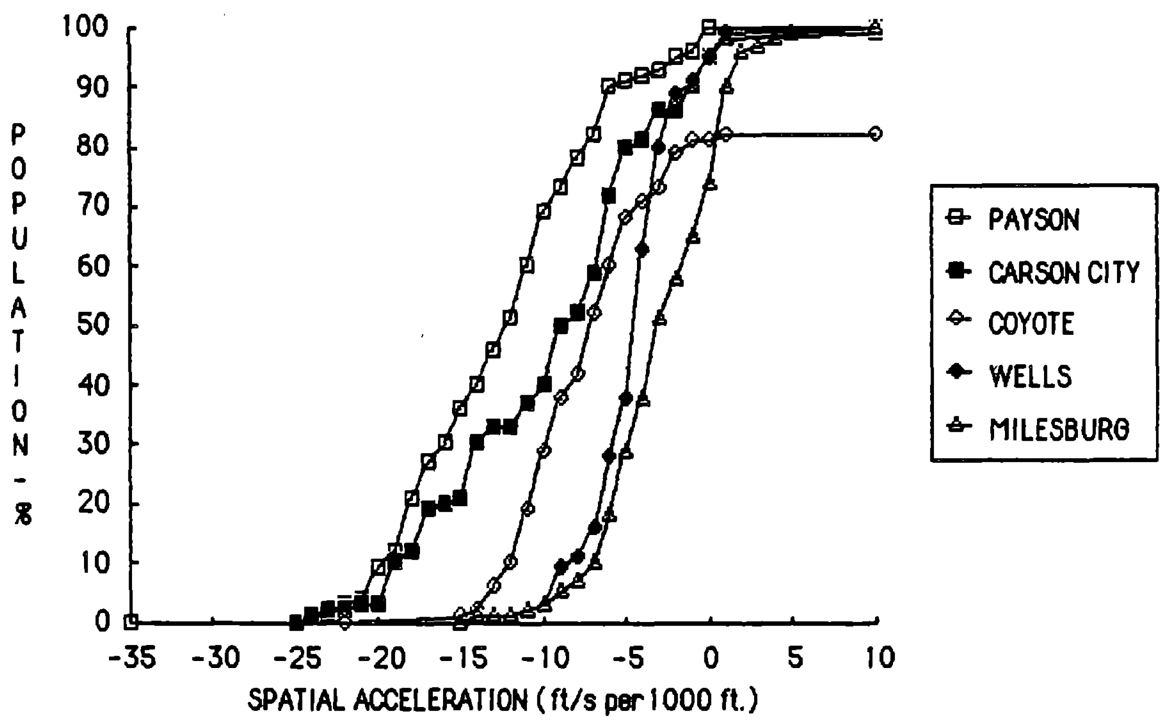


Figure 7. Probability distributions of spatial accelerations for tractor-trailers on five interstate road sites.

12.5 percentile level. Thus a feasible means for characterizing the distribution (suitable for use in more formal and sophisticated decision-making models that will presumably be developed in the future) is to characterize the performance of interest by both a 12.5 and 50 percentile value. Thence, performance at any other percentile level can be predicted by assuming the linear shape. Studies in the State of California have emphasized the 12.5 percentile truck, thus its use allows comparison with that data base.[11] Further, the 12.5 percentile level is reasonable because it falls near the bottom of the linear range and is a "real" value that can be determined directly from experimental observations.

Although vehicles below the 12.5 percentile depart markedly in their performance, these vehicles may be considered atypical, and they would be unreasonable to use as a benchmark for highway design. Included in this group would be over-weight and/or over-width trucks operating by special permit, those with engine problems, or those that are recognized by owners or operators as marginal for highway use.

With these questions in mind, a study of truck hill-climbing performance was conducted, involving both experimental measurements and analyses to identify suitable methods for characterizing the performance observed.

EXPERIMENTAL RESULTS

In order to provide answers to some of the questions posed in chapter 2, experimental measurements of the climbing performance of over 4,000 trucks were made throughout the country. Appendix A details the methods that were used. From 20 sites distributed both in the East and West, the speed loss of trucks was measured on grades from 2 to 6 percent, along with descriptive data about the trucks. Individual trucks were tracked through the grades, and at some sites additional data on weight and power were obtained while they were stopped at nearby weigh stations. This base of data allows many types of analyses to answer questions about hill-climbing performance. In the sections that follow, analyses of the key issues will be discussed with the objective of providing more quantitative data on hill-climbing performance.

Final Climbing Speeds

On constant grades of sufficient length a truck will decelerate to a steady speed, often called the "final climbing" speed. Final climbing speed is significant both because of its influence on highway capacity, and because of what it tells about truck performance capabilities. At this operating condition, shifting is no longer required and the speed achieved represents a balance between engine tractive effort and the drag forces acting on the truck. On steep grades the primary drag is that due to grade which can be determined independently by measurement of the grade angle. This contrasts with measurements during the deceleration phase at the beginning of grade where deceleration levels must also be determined to quantify performance.

Examination of the final climbing speed is selected as the first step in presentation of experimental results because it can be compared directly with data provided in the AASHTO guide, and it provides a simple format for illustrating the distribution of truck population.

Figure 8 shows the final climbing speed of tractor-trailers as a function of grade observed on the 20 sites. Tractor-trailers are selected for the plot because they tend to represent one of the most homogeneous classes in the population (with the least data scatter). Especially on shallower grades, some tractor-trailers have sufficient power to climb the grade at normal traffic speed. Thus the "average" speeds tend to be higher than those for the median (50 percentile) vehicles. This is an indication of an asymmetric population distribution, and the use of an "average" reflects a bias when compared to the median. Alternately, the properties of trucks at the lower end of the performance range can be characterized by the velocity of lower percentile vehicles. The 12.5 percentile value has been used by the California Department of Transportation.[11] This precedent and the fact that it generally falls on the linear portion of the probability distribution of decelerations (see figure 7) makes it a reasonable choice for use here. Superimposed on the plot is the curve of speed versus grade corresponding to the AASHTO values obtained from reference 6.

The general slope of the data points for all three measures is similar, closely matching that of the AASHTO curve. The data points do not fall exactly along a constant weight-to-power (W/P3) curve, although the random scatter in the data points is larger than the deviation between a trend line and a constant power line.

Figure 9 shows the 12.5 percentile values for final climbing speed by truck class and road class. As would be expected, the experimental data points reflect a variation in the performance of trucks at different sites. Several interpretations can be applied to the data. On the one hand, one could establish a "trend" line that best fits the data points, minimizing mean square errors, or such. This would be an estimate of typical 12.5 percentile performance for which a variance is still required to characterize the limit. A special problem that will be encountered in many cases with this approach is that the limited data will result in a trend that does not relate properly to the independent variable (grade in this case). For example, the best fit line may show

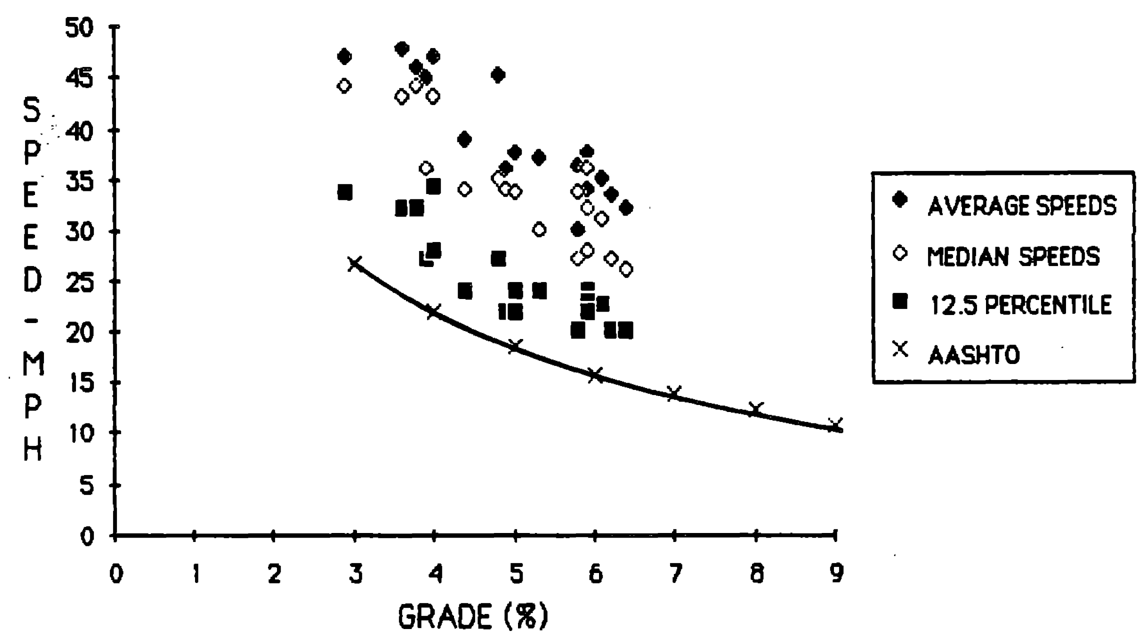


Figure 8. Average, median, and 12.5 percentile of final climbing speeds for tractor-trailers.

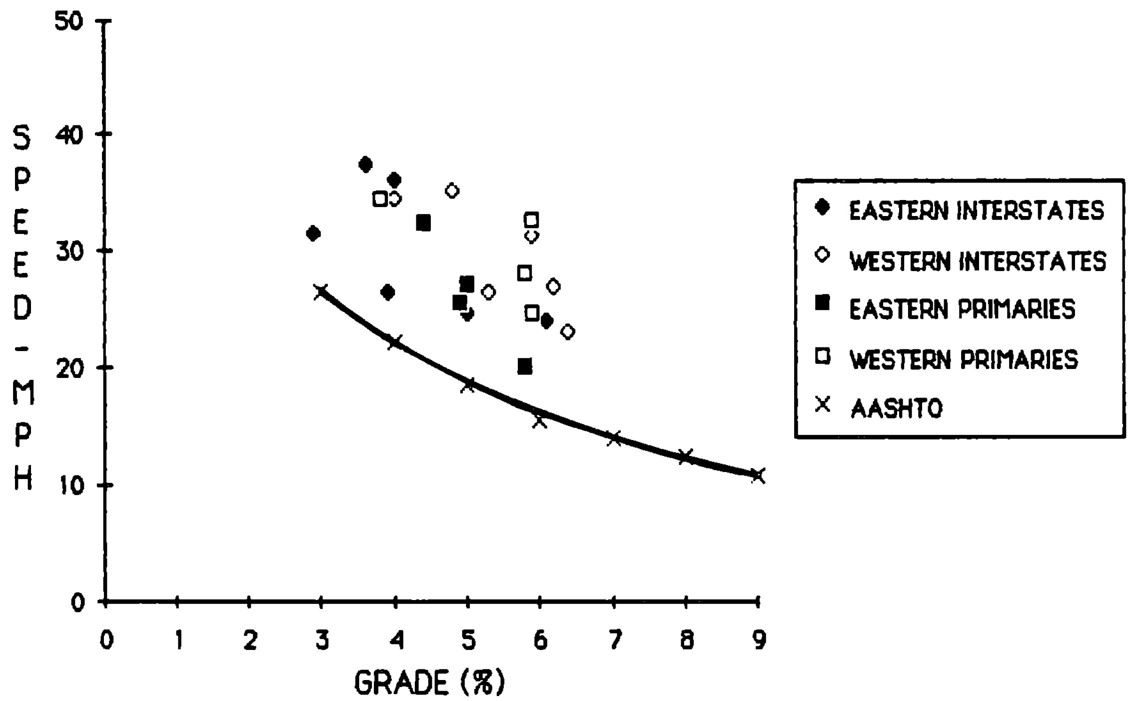


Figure 9a. Final climbing speeds of straight trucks (12.5 percentile level).

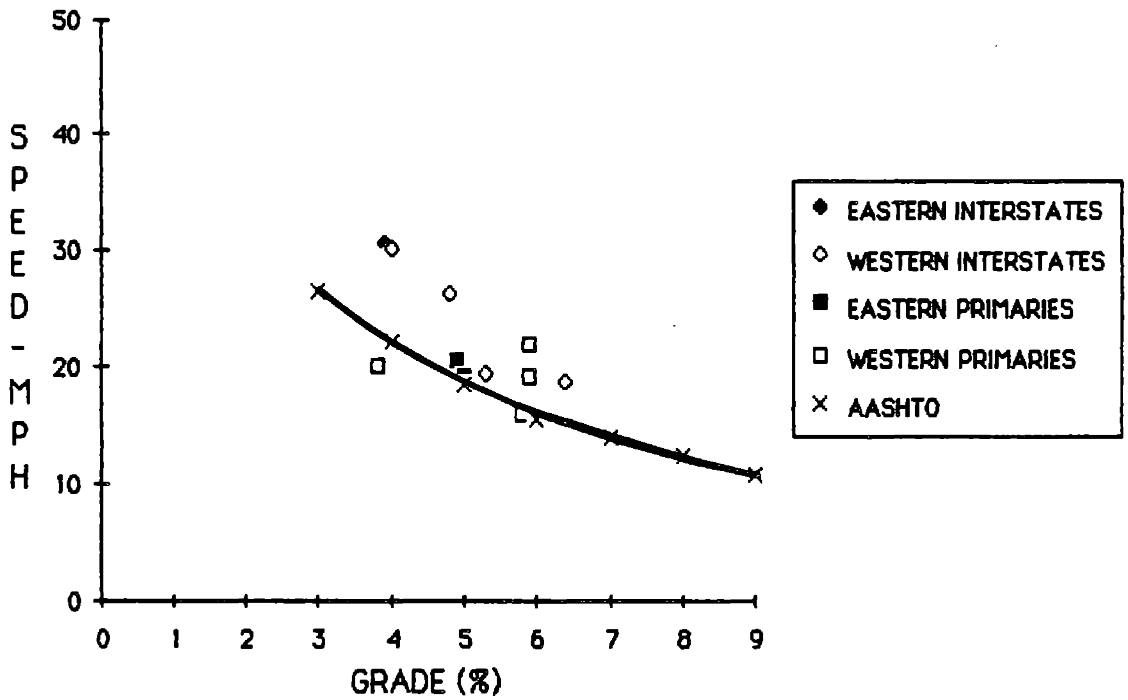


Figure 9b. Final climbing speeds of trucks with trailers (12.5 percentile level).

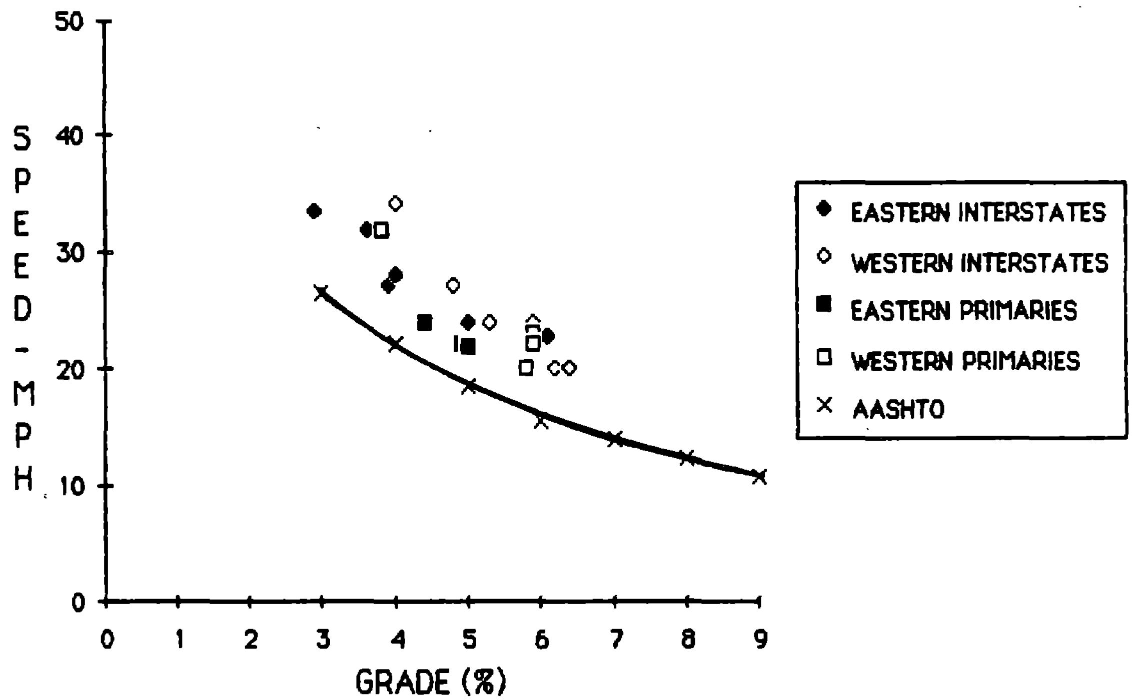


Figure 9c. Final climbing speeds of tractor-trailers (12.5 percentile level).

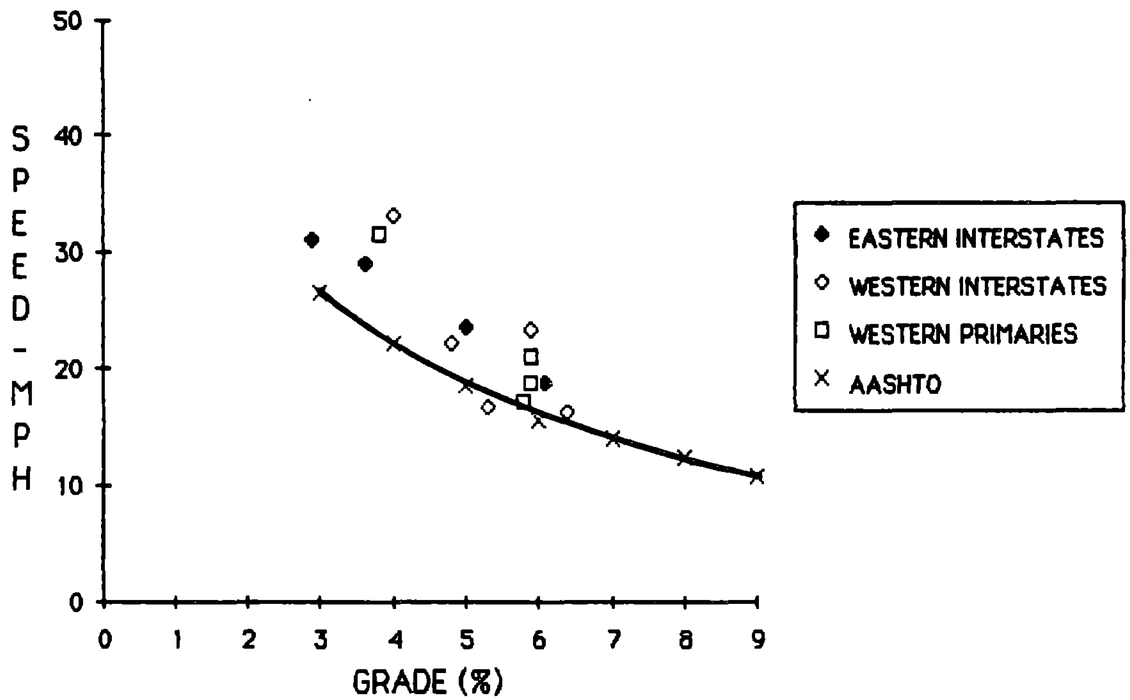


Figure 9d. Final climbing speeds of doubles and triples (12.5 percentile level).

final climbing speed increasing with grade, which conflicts with the mechanics involved.

An alternative approach is to attempt to bound the experimental observations with a limit that reasonably matches the mechanics involved. In figure 9a this would be equivalent to shifting the AASHTO curve upward to the level of the lowest data points, using the AASHTO curve as a reasonable reflection of how final climbing speed should vary with grade. As will be seen with much of the experimental data, this approach can provide a very good match to the data. In effect the bound represents a performance limit--the nominal limit of performance at which the owners or drivers choose to operate the vehicles. At whatever percentile may be chosen, this is a conservative estimate of performance. By and large, at any arbitrary site on the highway network, truck performance should be at least as good as the limit selected.

The AASHTO values for final climbing speed are clearly conservative in estimating the performance of trucks and tractor-trailers. They are roughly equivalent to perhaps a 5 percentile vehicle in those cases. On the other hand, the curve closely approximates the 12.5 percentile limit for trucks with trailers (figure 9b) and for doubles and triples combinations (figure 9d). Only one data point, a western primary for the trucks with trailer (figure 9b), falls significantly below the AASHTO curve, and then, only 16 vehicles were in the sample from which this 12.5 percentile point was determined. To reflect performance of all vehicles at the 12.5 percentile level, the AASHTO speeds would have to be increased by about 3 mi/h (5 km/h) for straight trucks and tractor-trailers.

Figure 9 shows that the distinction between final climbing speeds on different road classes is not especially significant. For straight trucks, the final climbing speeds tend to be somewhat lower on Eastern roads than on Western roads (figure 9a). A slight indication of the same trend is seen also with tractor-trailers. The same tendency is not seen for straight trucks with trailers, or for doubles and triples.

The final climbing speeds observed here can be related directly to a weight-to-power ratio. From equation 7, a relationship can be derived as follows:

$$U_{fc} = 375/(W/P_3*G_r) \qquad (9)$$

where

U_{fc} = Speed (MPH)

G_r = Fractional grade (%/100)

Decelerations at Speed

Truck decelerations at high speed on a grade are of primary importance in determining where a climbing lane should start. The AR and W/P_3 values (both being related) are direct measures of high-speed performance. The values may be determined from the observations of deceleration and speed, using a discrete form of equation 5. That is, by noting the change in speed between two points on a known grade and the average speed, the AR can be calculated. The W/P_3 is obtained from equation 8. The three speed measurements in the entry portion of the grade yield two values. An additional value is obtained from the final climbing speed where the acceleration is zero and the AR is simply equivalent to the grade. For the convenience of the reader, the more familiar W/P_3 form will be used in subsequent discussion.

A W/P_3 to characterize a truck population can be determined in several ways. Values for individual vehicles can be calculated, and then the population properties established for that sample. Two values from each vehicle will be obtained from the three speed measurements. Thus the median vehicle in the first set of traps may not be the median vehicle in the second set, or at the final climbing point. Also the vehicles with the largest decelerations (and highest apparent W/P_3) may tend to be the vehicles traveling at the highest speed because of the higher aerodynamic drag acting on the vehicle.

An alternate way to associate a W/P_3 with a grade site is to determine the speed population, like that of figure 7, at various points along the grade. The deceleration properties of the truck population between those two points can then be inferred, and the W/P_3 calculated on that basis. This method is preferable for characterizing speed changes along a grade, although it should be recognized that deceleration used in the calculations is not that of a particular truck (at a given percentile, a different truck is seen at each point in the grade), rather it is that of the population.

The procedure used is to determine the probability distribution of the speeds at each measurement point. Then, at a given percentile level, the drop in speed from point to point along the grade is used to establish the spatial deceleration (dV/dX) for which a W/P_3 is calculated. Because the W/P_3 values are likely to be speed dependent, the average speed must also be calculated. Thus the 12.5 percentile W/P_3 value indicates the rate at which the 12.5 percentile speeds are decreasing on a given grade from a given initial speed, and answers the needs of the highway designer in estimating speed changes of the truck traffic stream along the grade.

It might be expected that the two independent variables most affecting W/P_3 will be the speed and grade. At high speed the aerodynamic and rolling resistance forces are greatest, elevating its value. In turn, on steep grades where the decelerations are greatest, the need to continuously shift the transmission is likely to lower the effective power being extracted from the engine, with an associated decrease in the average drive power.

Figures 10 to 13 show the 12.5 percentile W/P_3 values on different road classes. Figure 10 covers trucks, Figure 11--trucks with trailers, Figure 12—tractor-trailers, and Figure 13—doubles and triples.

Also shown on these plots is an "AASHTO curve." It is difficult to associate a specific W/P_3 value with the AASHTO predictions of truck performance during the deceleration phase, because multiple values exist as a result of the arbitrary way in which speed-distance curves have

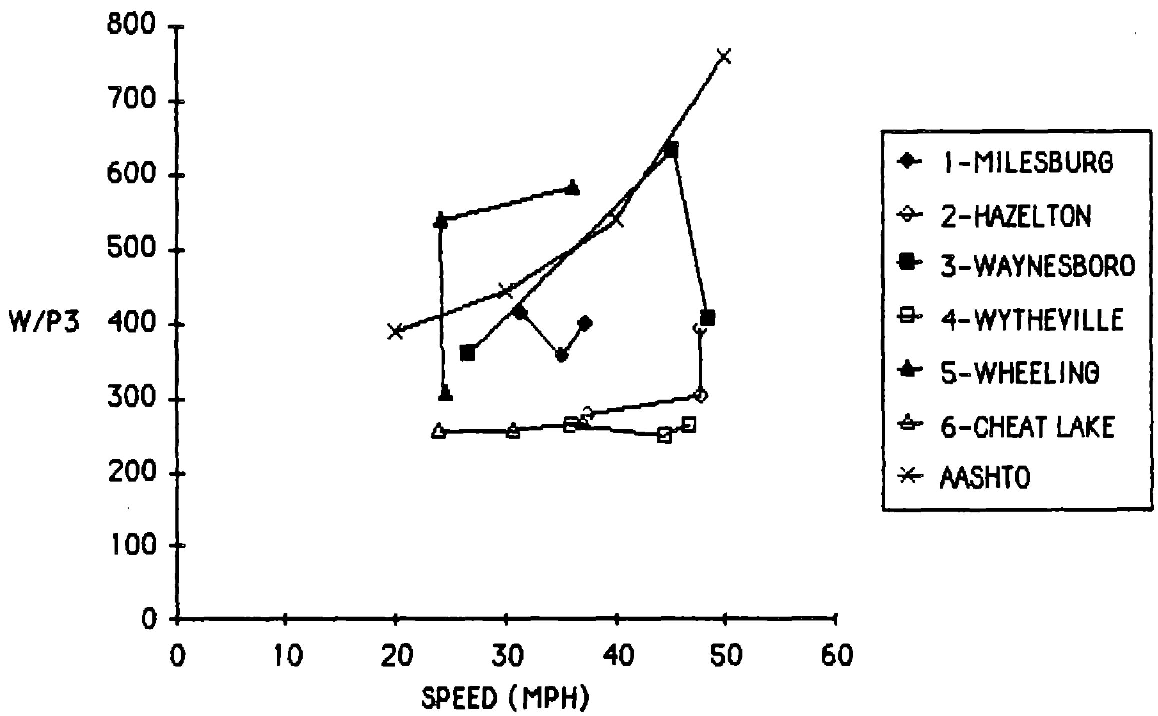


Figure 10a. 12.5 percentile W/P_3 values for straight trucks on Eastern interstate road sites.

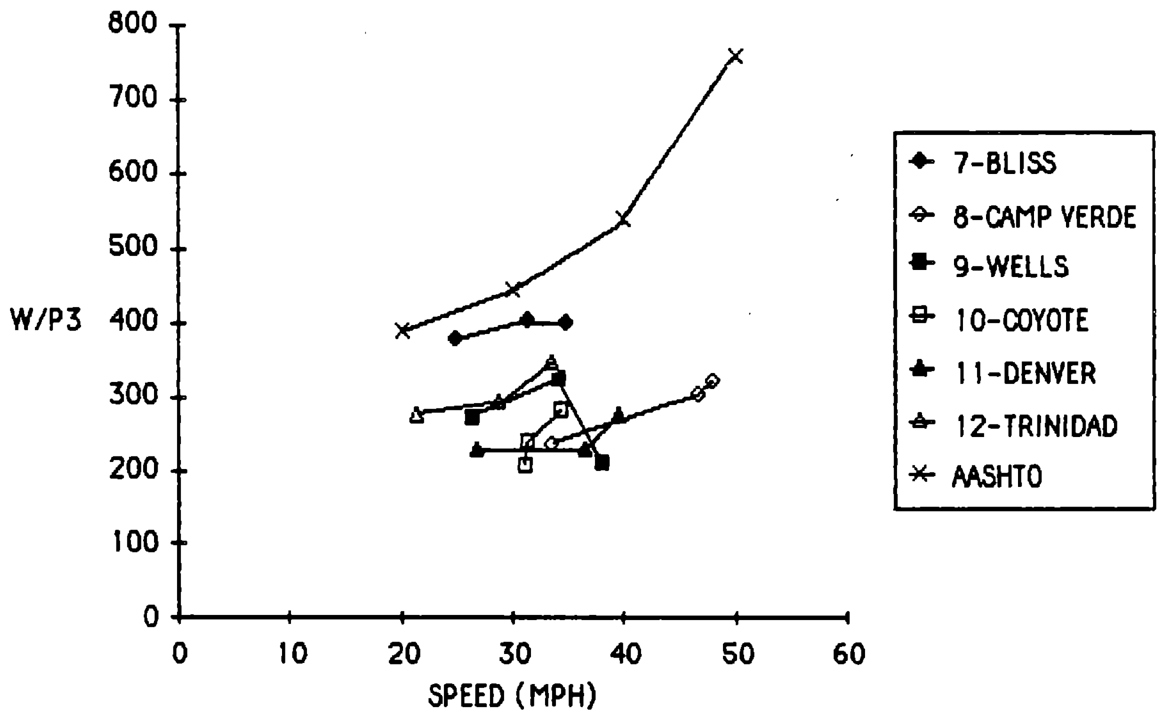


Figure 10b. 12.5 percentile W/P_3 values for straight trucks on Western interstate road sites.

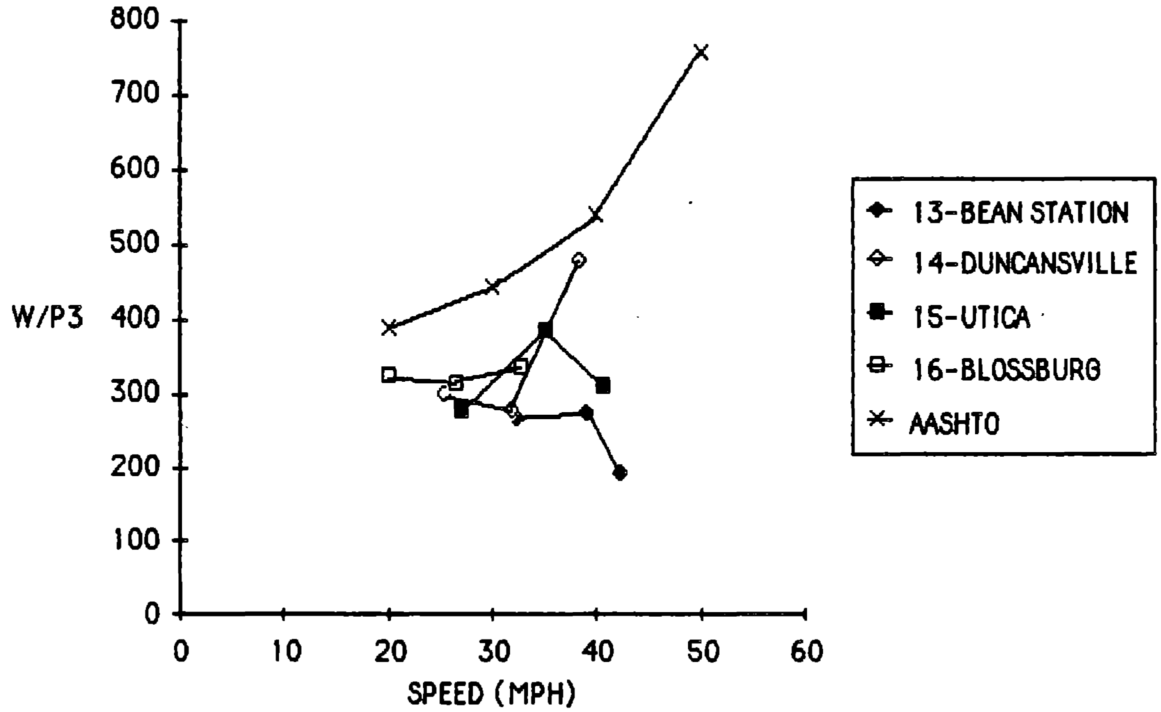


Figure 10c. 12.5 percentile W/P_3 values for straight trucks on Eastern primary road sites.

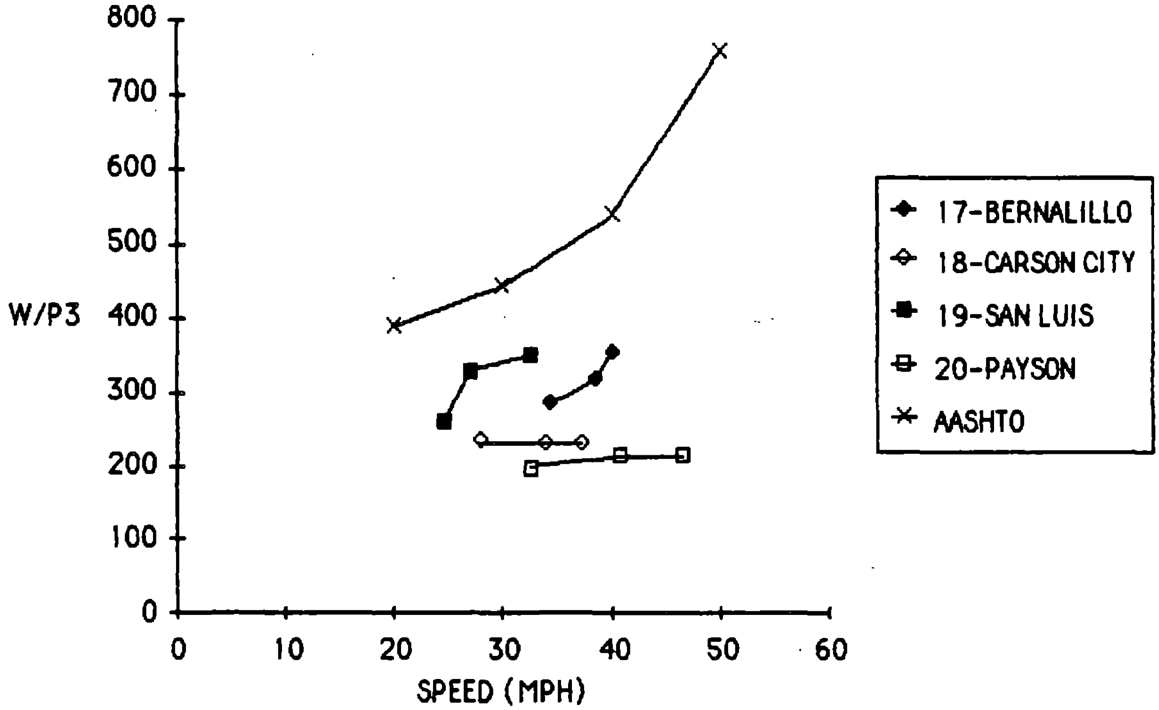


Figure 10d. 12.5 percentile W/P_3 values for straight trucks on Western primary road sites.

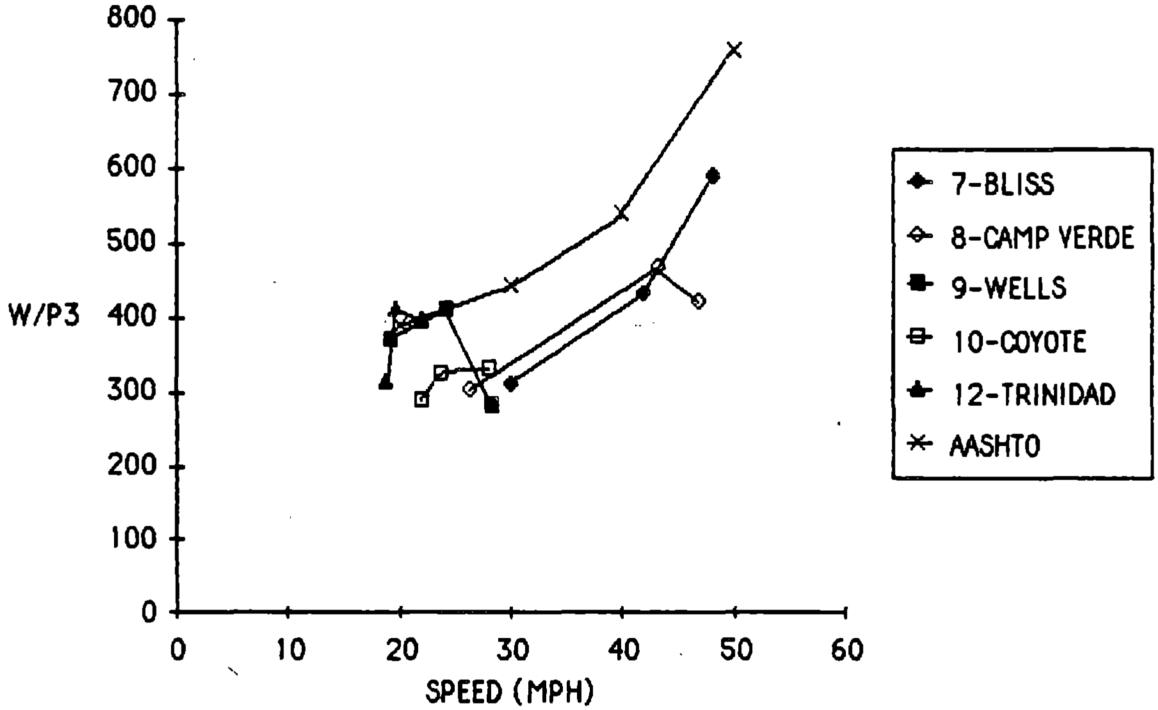


Figure 11a. 12.5 percentile W/P_3 values for trucks with trailers on Western interstate road sites.

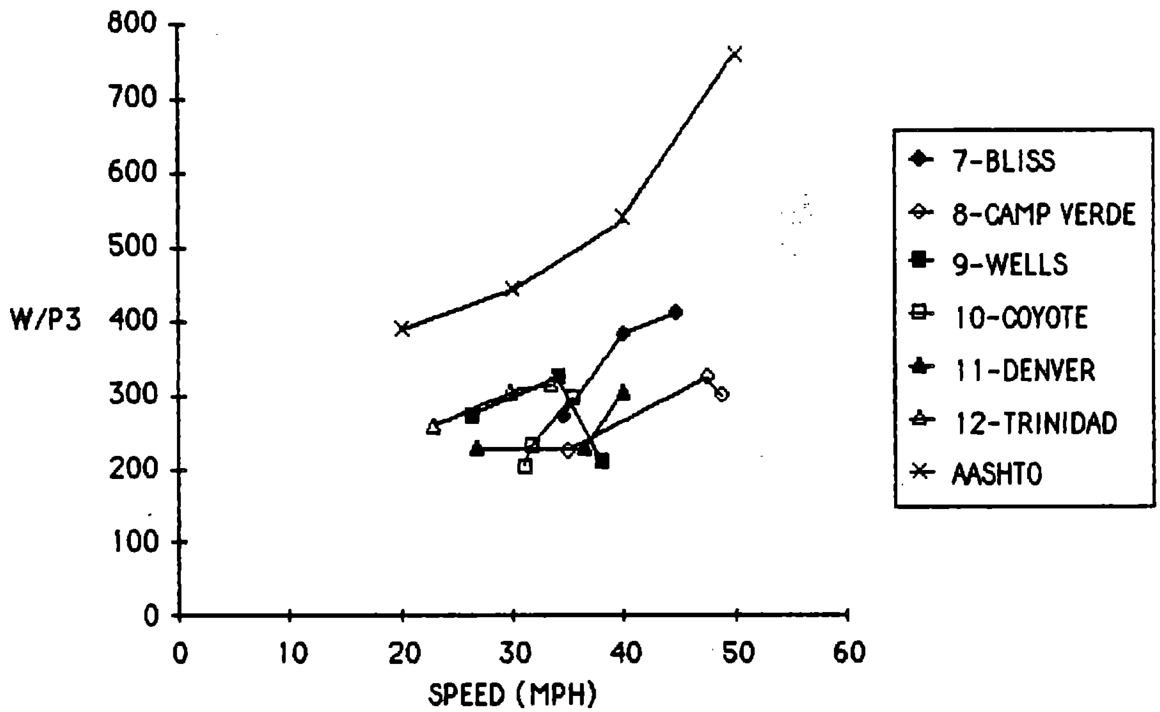


Figure 11b. 12.5 percentile W/P_3 values for trucks with trailers on Western primary road sites.

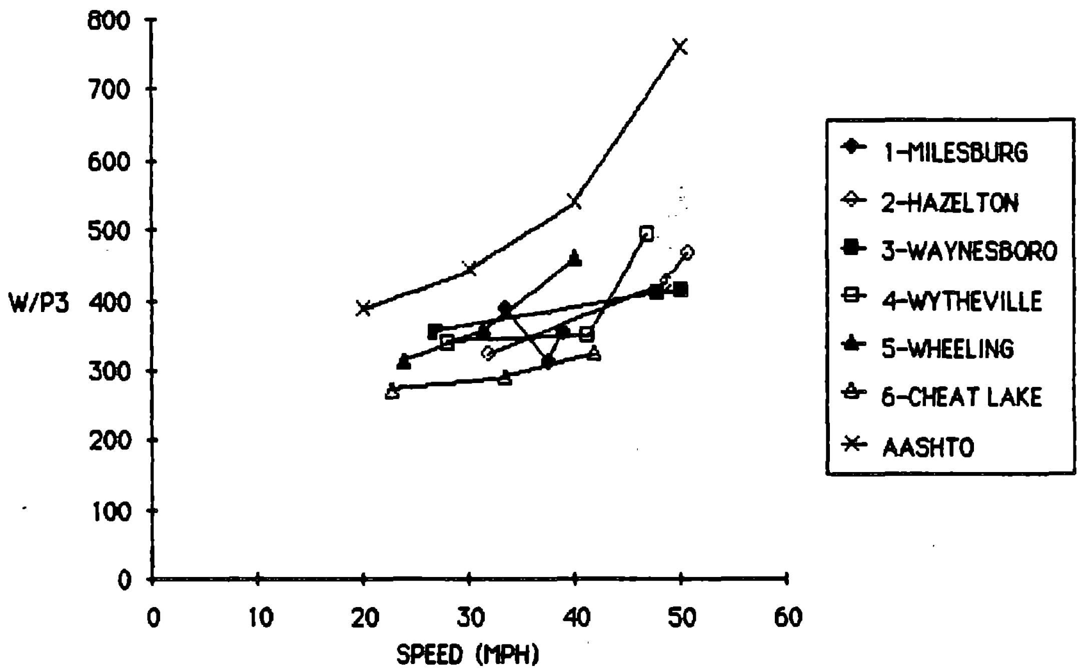


Figure 12a. 12.5 percentile W/P_3 values for tractor-trailers on Eastern interstate road sites.

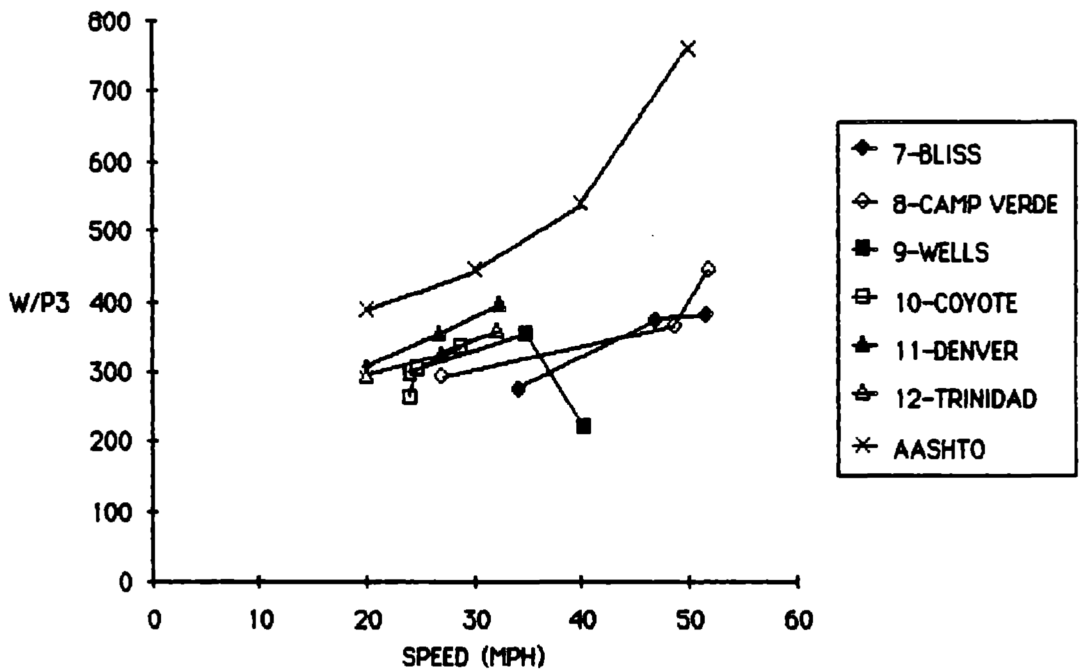


Figure 12b. 12.5 percentile W/P_3 values for tractor-trailers on Western interstate road sites.

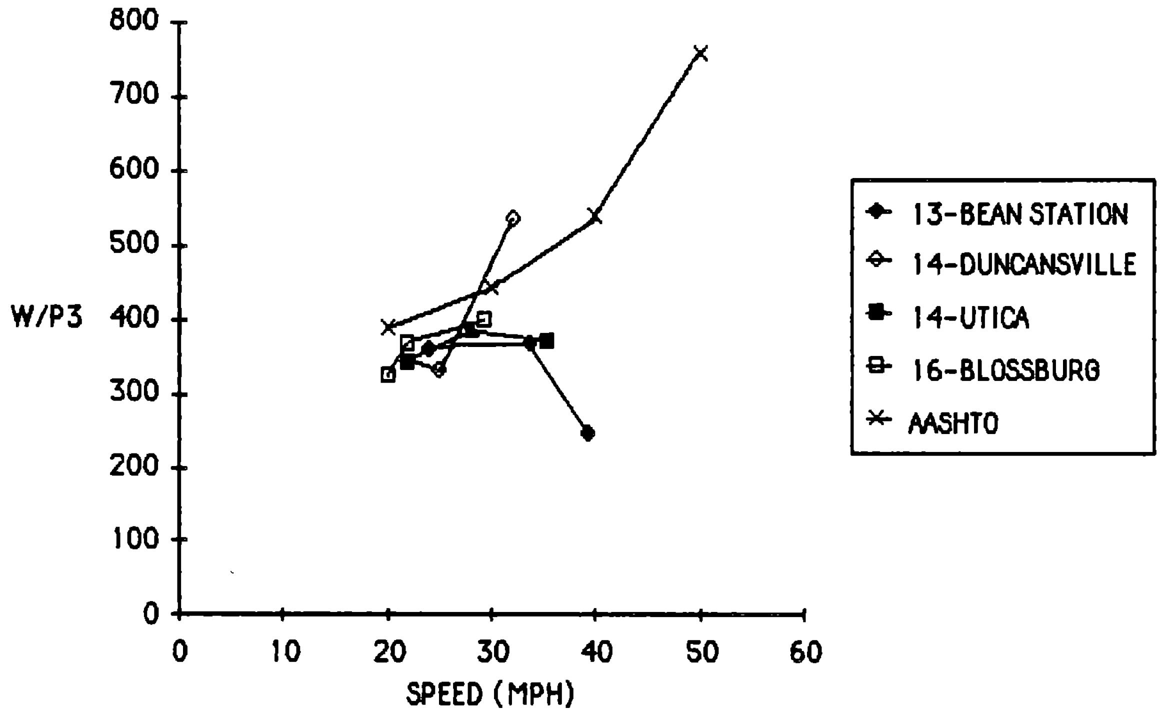


Figure 12c. 12.5 percentile W/P_3 values for tractor-trailers on Eastern primary road sites.

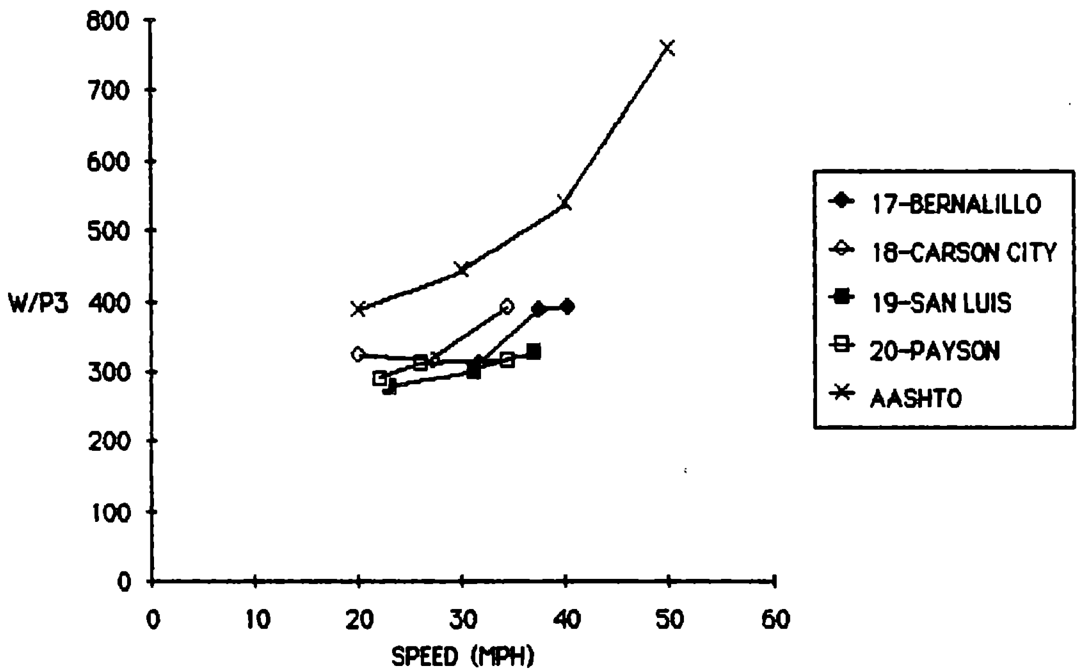


Figure 12d. 12.5 percentile W/P_3 values for tractor-trailers on Western primary road sites.

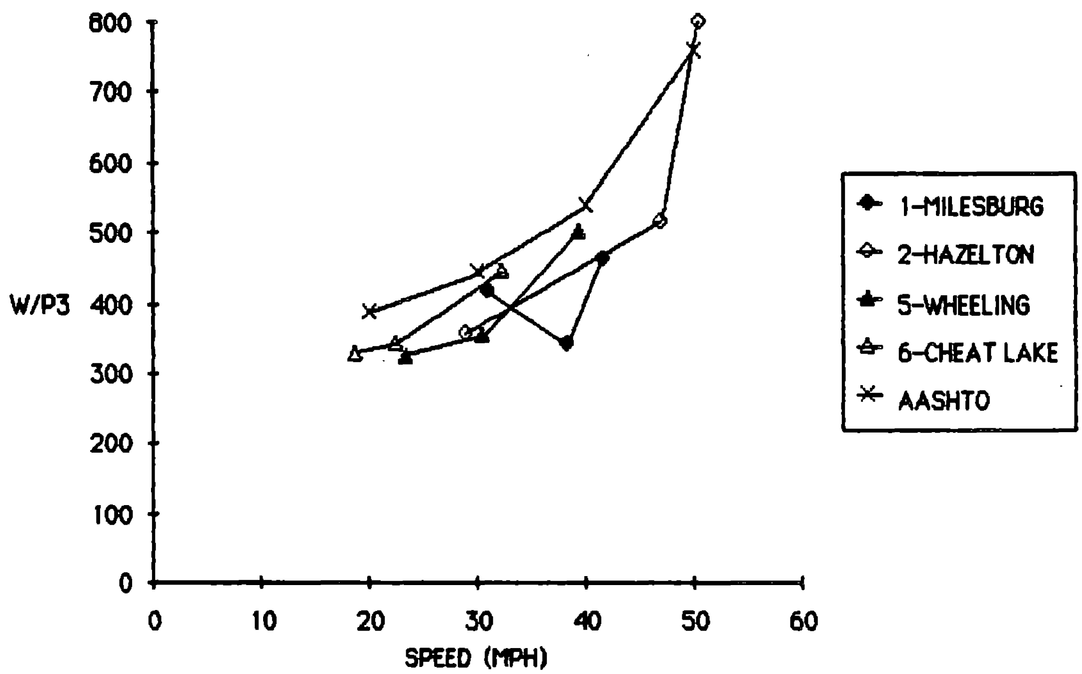


Figure 13a. 12.5 percentile W/P_3 values for doubles and triples on Eastern interstate road sites.

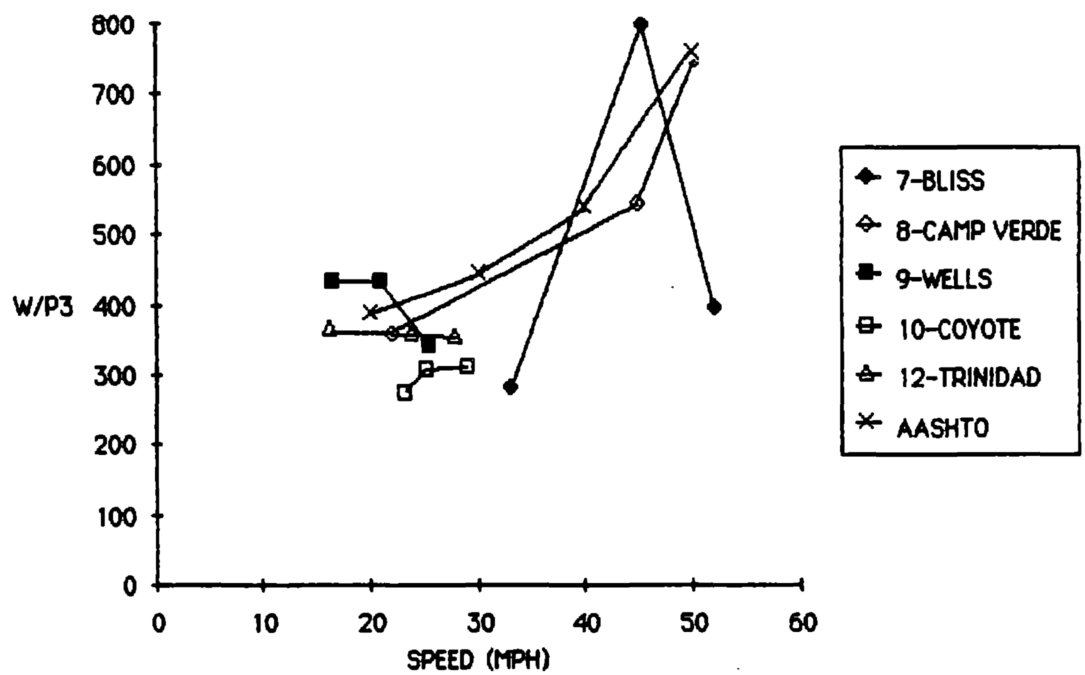


Figure 13b. 12.5 percentile W/P_3 values for doubles and triples on Western interstate road sites.

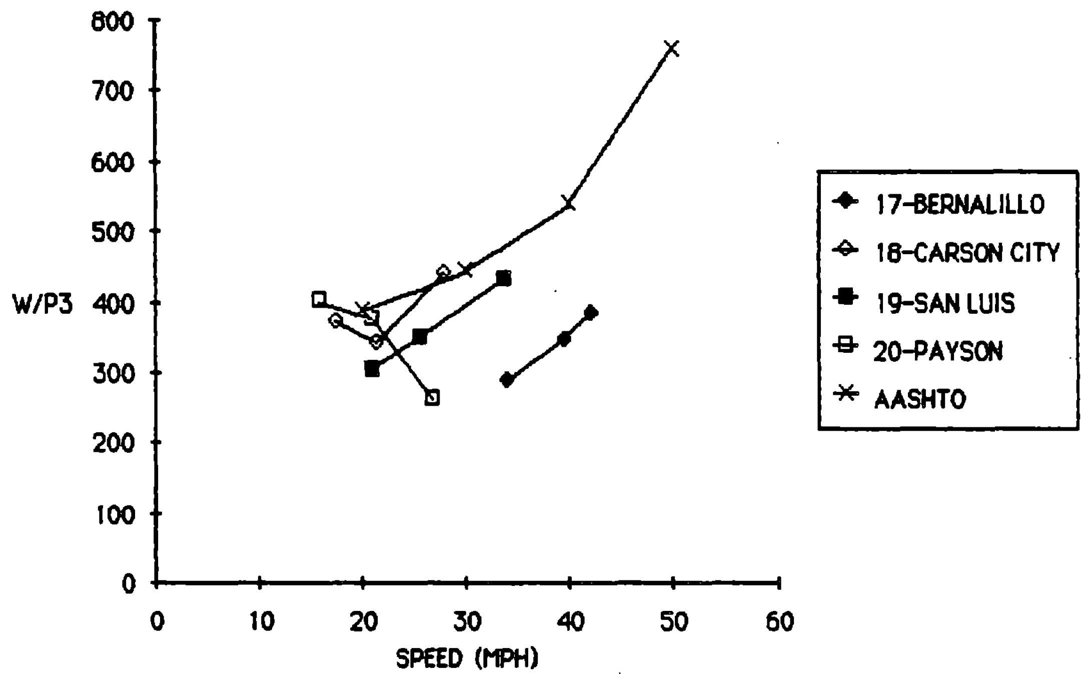


Figure 13c. 12.5 percentile W/P_3 values for doubles and triples on Western primary road sites.

been smoothed. In the absence of shifting, W/P_3 values can be calculated using the equations for truck performance given in reference 6. These represent the lower limit of W/P_3 as a function of speed. But the truck simulation algorithm used for computation of speed-distance performance curves includes shifting intervals during which there is complete loss of engine power. The shifting losses vary with calculations for each grade condition; thus, at a given speed multiple values for W/P_3 exist, one for each grade. For example, at 40 mph (64 km/h) the steady-state W/P_3 value will be 537 lb/hp; on the other hand, the slopes of the speed-distance curves at the same speed reflect W/P_3 values ranging from about 680 to 930 lb/HP (the different values depending on which grade curve was taken on the AASHTO plot). The steady-state values of W/P_3 were used for the AASHTO curve in these figures. Thus it can be interpreted as a conservative choice.

Consider first figure 10. In each plot three points for each site are shown connected by straight lines (the lines shown only for convenience in associating the data points for a site). The two data points at the highest speeds usually represent performance calculated for the intervals between the first and second speed measurements, and between the second and third. The third data point at the lowest speed is derived from the final climbing speed measurement.

In figure 10a, six sites are shown, labeled in the legend according to the city nearest the site. The sites are listed in the legend in order of increasing grade at the final climbing point (which is not necessarily the same as at the beginning of grade). With the exception of "Wheeling," all data points fall below the AASHTO curve. Thus the 12.5 percentile speed changes at these sites were representative of trucks with a lower weight-to-power ratio than used for the AASHTO predictions. The Wheeling data are peculiar for no explanable reason and will be excluded from the discussion. Otherwise, the data appear to show a slight trend of W/P_3 rising with speed. A trend of this nature would be expected simply from the mechanics of the forces acting on trucks.

Examining the plots for straight trucks on the other types of roads, it is clear that the AASHTO assumptions on W/P_3 are very conservative. The general level of the AASHTO curve could be dropped by 50 lb/hp and still have the majority of data points fall below its level.

The same is true for tractor-trailer combinations shown in figure 12. The tractor-trailers generally show more consistent performance in every case with no profound differences in performance between the East and West or between interstate and primary roads.

Straight trucks with trailers (figure 11) are remarkably different. Data are shown only for Western sites (interstate and primary), because there were insufficient vehicles in this class at the Eastern sites to determine a 12.5 percentile. The AASHTO curve falls near the midpoint of the data spread. The fact that more consistent performance was observed with tractor-trailers on each of these same sites would suggest that the variability is associated with the vehicles rather than being due to site factors.

Figure 13 shows the performance of doubles and triples. No data are shown for primary eastern sites because of the few number of doubles encountered on these roads. The AASHTO curve is generally a good estimate of the minimum performance of these vehicles, with only a few of the data points exceeding its value.

Performance Characterization

It is clear from the previous figures that the AASHTO curves for decelerations on grades are overly conservative for several types of vehicles, since they do not account for some of the differences between vehicle classes. The dilemma that arises with availability of more detailed data on truck performance is how to characterize those observations. The characterization problem involves two dimensions; what percentile truck should be chosen and what functional relationship to use.

In chapter 2 the rationale for use of the 12.5 and 50 percentile values was presented as a means to characterize the population distribution. From these, predictions of performance at any other percentile value can be made based on the assumption of linearity in the critical range of the distribution. This does not, however, solve the problem of which percentile value to use for setting performance limits. In the absence of a recognized basis for making such a choice, it is arrived at by default. In the interest of choosing limits that are more conservative than those of the median population, the 12.5 percentile value is reasonable. The 12.5 percentile truck is one truck in eight. Other choices, such as the 10 percentile (one truck in ten), may also seem reasonable from the intuitive viewpoint, although it is less desirable from the practical viewpoint. The 10 percentile value falls closer to the curved ends of the distribution (see figure 7). Thus, finding 10 percentile performance carries with it greater risk of misrepresenting the true slope of the distribution. Even though the 12.5 percentile is chosen as a limit in this report, the results and conclusions that are presented can be adjusted to reflect any other percentile point once a rationale is developed to justify its choice.

The rationale for choosing a functional form to represent performance limits is also steeped in utility. The decelerations implicit in the speed-distance curves used by AASHTO (see figure 4) are obtained by "smoothing" the speed-distance curves calculated for a "typical" truck. Thus their shape is based on arbitrary assumptions with regard both to the parameters used to characterize the typical truck, and to the method used to smooth the resultant curves. Although the curves were adjusted to ensure overall agreement with what was known about truck performance at the time of their development, the decelerations at any speed and grade condition may not necessarily be representative of any fraction of the truck population.

The experimental data obtained in this project have been reduced to values for the effective power available to accelerate the truck at any condition of speed and grade (P_3/W). With this measure it is not necessary to make any assumptions with regard to the losses due to drag forces acting on the vehicle or the losses due to shifting. It is a direct measure of performance impacting on speed loss on a grade. P_3/W will vary with speed. The functional form should be as follows:

$$P_3/W = P_2/W - A\ V - B\ V^2 - C\ V^3 \qquad (10)$$

The first term on the right-hand side, P_2/W, is the normalized power available at the engine, which is nominally constant. The second and third terms are, respectively, the constant and speed-dependent portions of the rolling resistance power loss. The last term represents power loss from aerodynamic forces. A precise functional relationship between P_3/W and speed would involve all of these terms. Evaluating all constants, however, would require more experimental data than that available here.

Lacking the necessary information to evaluate all terms, a good approximation is to assume P_3/W is a linear function of speed. That is:

$$P_3/W = C_1 + C_2\ V \qquad (11)$$

The linear function can exactly match the higher order function at two speeds. By carefully selecting these speeds, a good approximation of the higher order function is obtained over a limited range. For hill-climbing characterization the speeds of 25 mi/h and 50 mph (40 and 80 km/h) are the logical choices. A good match at 25 mi/h (40 km/h) ensures that final climbing speed is accurate, and a good match at 50 mi/h (80 km/h) ensures that the high-speed decelerations are accurate.

Although this simplified representation of truck performance does not properly represent two of the speed-dependent terms, as will be seen, it provides a reasonable match to experimental observations. It is likely that the losses integral to the higher order terms are insignificant when compared to the influence of shifting losses. Despite the fact that this is an approximation, it should be noted that it does not require making assumptions for truck parameters or curve smoothing as used in development of the present AASHTO curves.

Perhaps the most important consideration in using this characterization method is the ease with which it can be used to relate to experimental observations. Given a large number of experimental data points, it is impossible to choose a set of vehicle parameters which will constitute a truck with performance matching the observations.

Characterization of Tractor-Trailer Performance

Tractor-trailers have been selected as the first vehicle class to characterize because they are the most homogeneous in performance, and they illustrate the application of the method with the least confusion from outlier data points. Figures 12a to d showed the W/P_3 values for the 12.5 percentile decelerations of tractor-trailers on all sites measured. Although the individual data points exhibit a degree of variation, the majority fall below an upper bound similar in shape to the AASHTO curve. There is no systematic difference between interstate and primary roads, nor between Eastern and Western sites.

Figures 14a and 14b show the collective data for all sites plotted for the 12.5 and 50 percentile decelerations. On the 50 percentile plot the upper limit of W/P_3 is clearly evident. At 25 mi/h (40 km/h) the upper bound is approximately 250 lb/hp. Assuming a W/P_3 value of 475 lb/hp at 50 mi/h (80 km/h) and that P_3/W is linearly dependent on speed as in equation 10, produces the 50 percent limit curve shown. Its shape is nonlinear because W/P_3 is the inverse of the linear P_3/W. Most importantly, the limit has a shape that reflects the proper functional relationship to speed. It is comparable to the AASHTO curve, and its level and slope can be matched to the data points by choice of the W/P_3 values at 25 and 50 mi/h (40 and 80 km/h). In a comparable fashion the 12.5 percentile limit is obtained by selection of 375 and 550 lb/hp at the speeds of 25 and 50 mi/h (40 and 80 km/h).

Choosing a boundary for the data is a subjective judgment, but it is perhaps more straightforward than the judgments implicit in the methods used previously for development of AASHTO guidelines. In the 50 percent plot the single point for the interstate-east that falls above the limit has been arbitrarily ignored as an outlier simply because it does not appear to fit the bounds appropriate to the other data points.

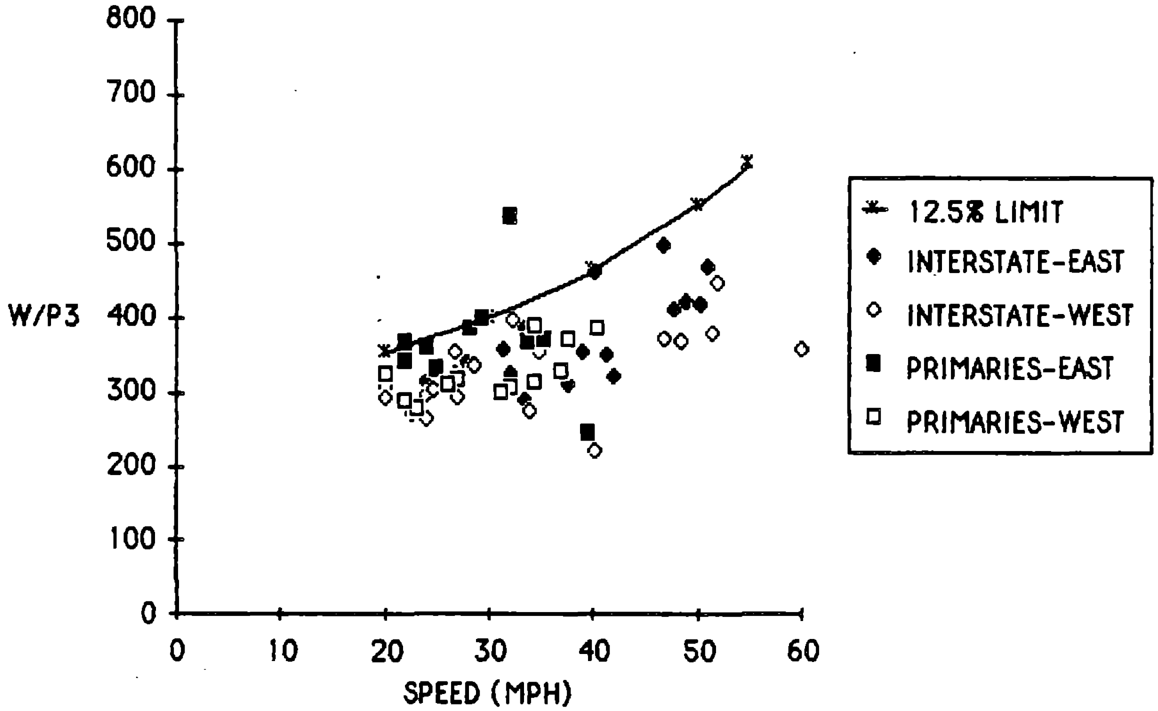


Figure 14a. 12.5 percentile W/P_3 values for tractor-trailers on all roads.

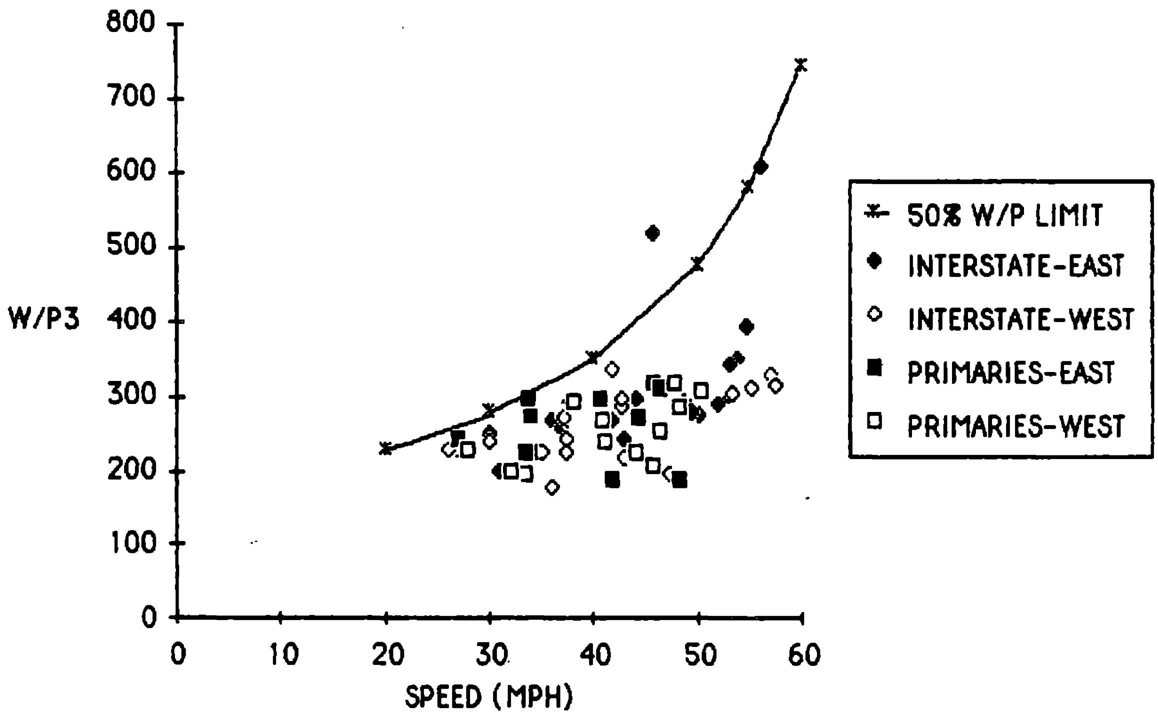


Figure 14b. 50 percentile W/P_3 values for tractor-trailers on all roads.

The same issue arises in the plot for the 12.5 percentile data. Exclusion of outlier points is more easily rationalized in the 12.5 percentile data because we are already dealing with the extreme of the population.

The selection of a performance limit as shown here may appear to be somewhat tenuous with uncertain implications. Its validity can be assessed by looking more explicitly at the performance that it attempts to model. Specifically, the objective is to provide a reasonable estimate of the decelerations in speed and the final climbing speeds. The decelerations will be a function of both speed and grade, and the final climbing speed will be a function of grade. The spatial deceleration is calculated as follows:

$$dU/dX = 0.465\ (375\ P_3/(W\ U) - G_r)\ g/U \tag{12}$$

where

U = velocity in mph

X = distance along the grade in feet

P_3/W = horsepower per pound

G_r = grade fraction (%/100)

g = gravitational constant (32.2 ft/sec^2)

The final climbing speed is also obtained from this equation when dU/dX equals zero. Thus it is determined by solution for the speed at which the term within the parentheses on the right-hand side becomes equal to zero.

The equation may be solved for any assumed form of P_3/W. For the 12.5 percentile tractor-trailer (W/P_3 values of 375 and 550 lb/hp at speeds of 25 and 50 mi/h (40 and 80 km/h), respectively):

$$P_3/W = .001\ (3.515 - .0339\ U) \tag{13}$$

Spatial decelerations were calculated for grades of 3, 4, 5, and 6 percent. These are plotted in figure 15a-d. Also shown are the decelerations extracted from the AASHTO speed-distance curves. They were obtained by evaluating the slope of the curve for each grade at a series of speeds. For comparison, the spatial decelerations for 12.5 percentile tractor-trailers were determined for the speed measurement points at all sites. These represent experimental data points. A grade value is associated with each data point, although not precisely equal to 3, 4, 5, or 6 percent. Thus they were grouped into ranges of 2.4 to 3.4, 3.5 to 4.4, 4.5 to 5.4, and 5.5 to 6.5. These data points are entered, respectively, on the 3, 4, 5, and 6 percent plots. Because we are attempting to bound the performance, the experimental data should fall under the curves to be valid. The plots clearly illustrate that the 12.5 percent limit is a more reasonable boundary than that of the AASHTO curves. The intercept of the 12.5 percent limit with the abscissa determines the final climbing speed for each grade. Its proximity to at least one data point on the abscissa in each plot shows it to be a much more reasonable estimate of final climbing speed than the current AASHTO curves. Throughout the plots the data points at higher speeds approach, but do not exceed, the 12.5 percent limit. They are not all expected to fall on the curve because it is, in fact, a limit intended to bound performance. The higher level of the AASHTO deceleration indicates that it is a more conservative estimate of performance limits for modern trucks--one that is perhaps inappropriately conservative.

Characterizing Straight Truck Performance

The experimental data show that the performance of straight trucks is more variable. The W/P_3 values that were shown in figure 10 appear more dependent on the road class, and they are slightly less consistent than those for tractor-trailers.

For trucks on interstate routes, the 12.5 and 50 percentile W/P_3 data are shown in figure 16. Eastern and Western sites are

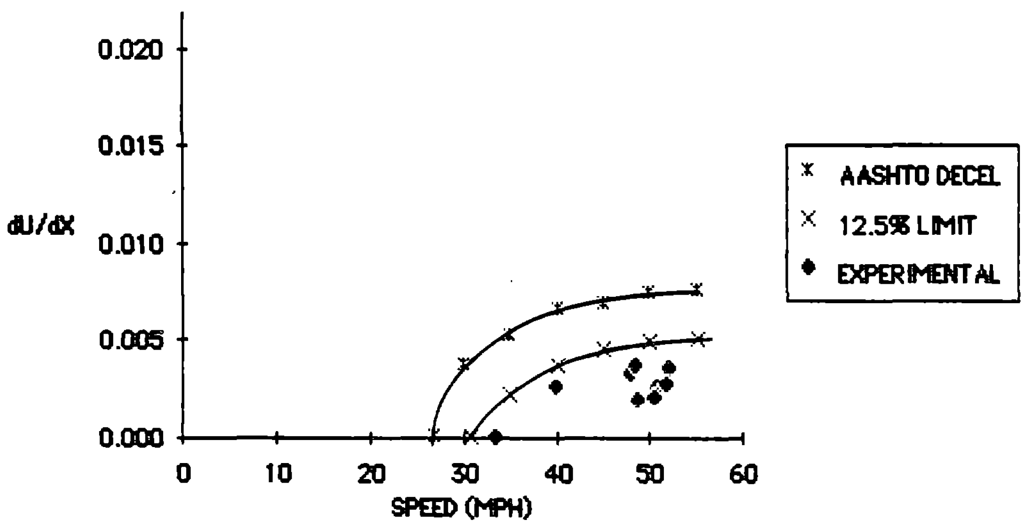


Figure 15a. Decelerations on 3% grades, 12.5 percentile tractor-trailers.

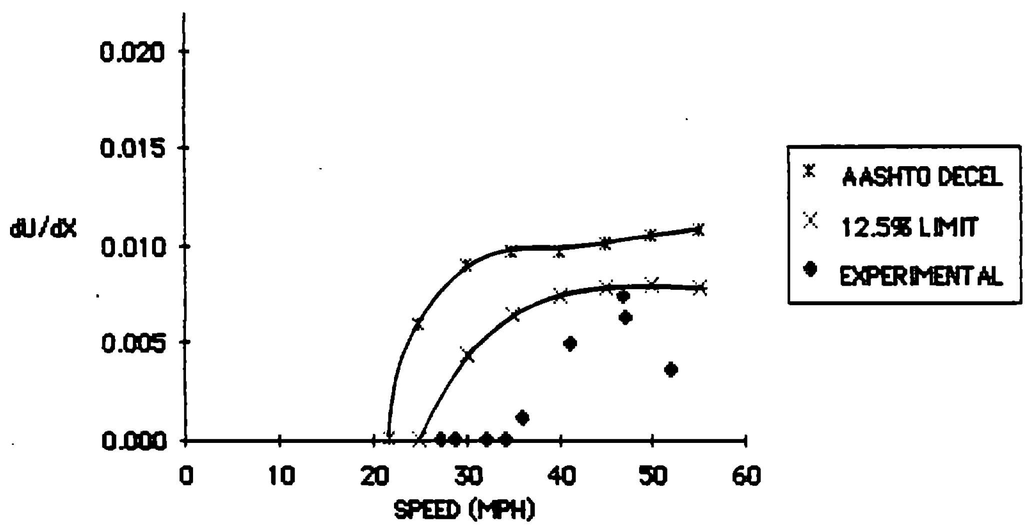


Figure 15b. Decelerations on 4% grades, 12.5 percentile tractor-trailers.

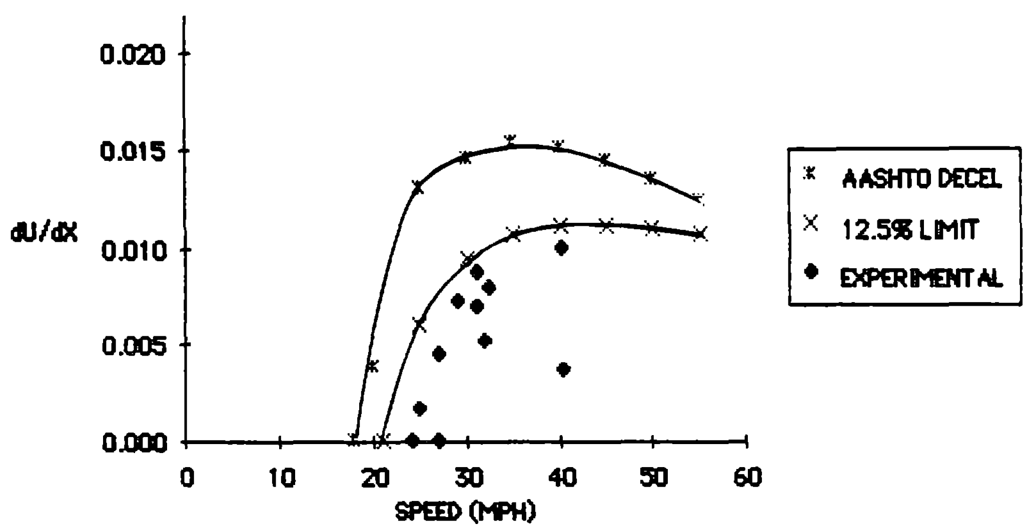


Figure 15c. Decelerations on 5% grades, 12.5 percentile tractor-trailers.

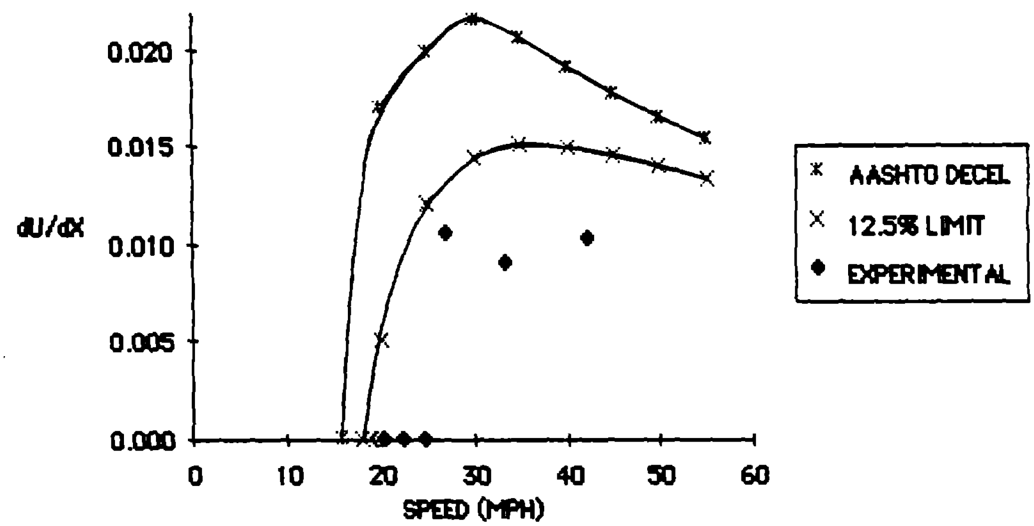


Figure 15d. Decelerations on 6% grades, 12.5 percentile tractor-trailers.

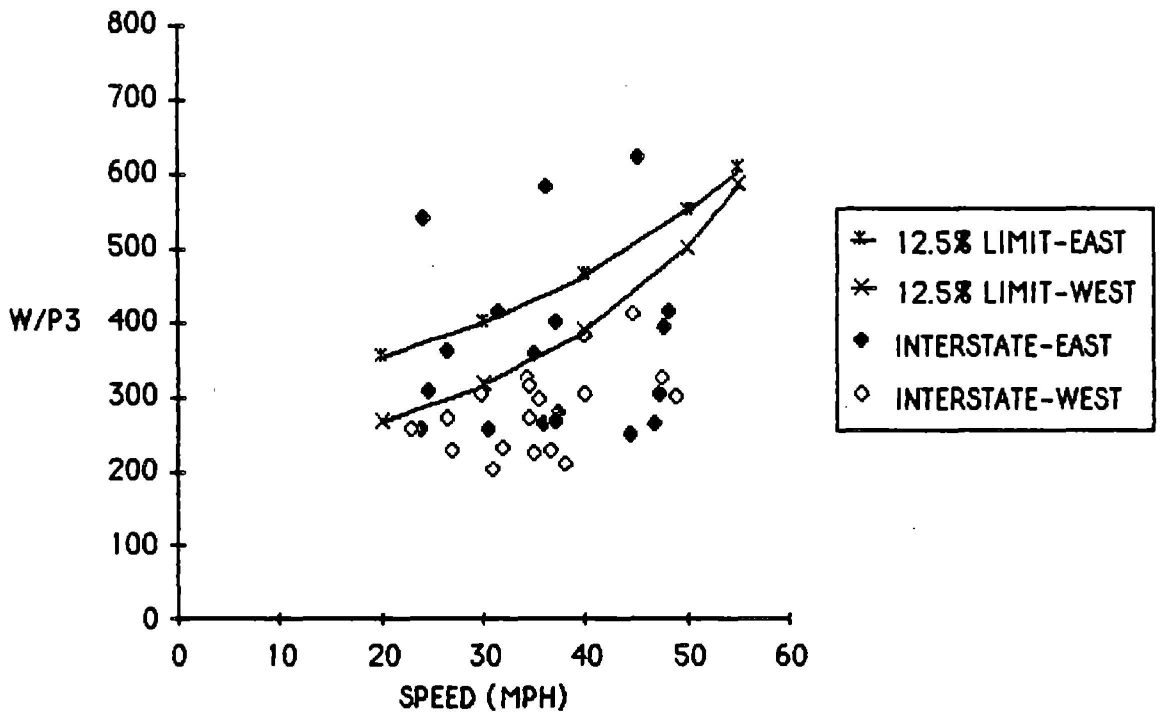


Figure 16a. 12.5 percentile W/P3 values for straight trucks on interstate roads.

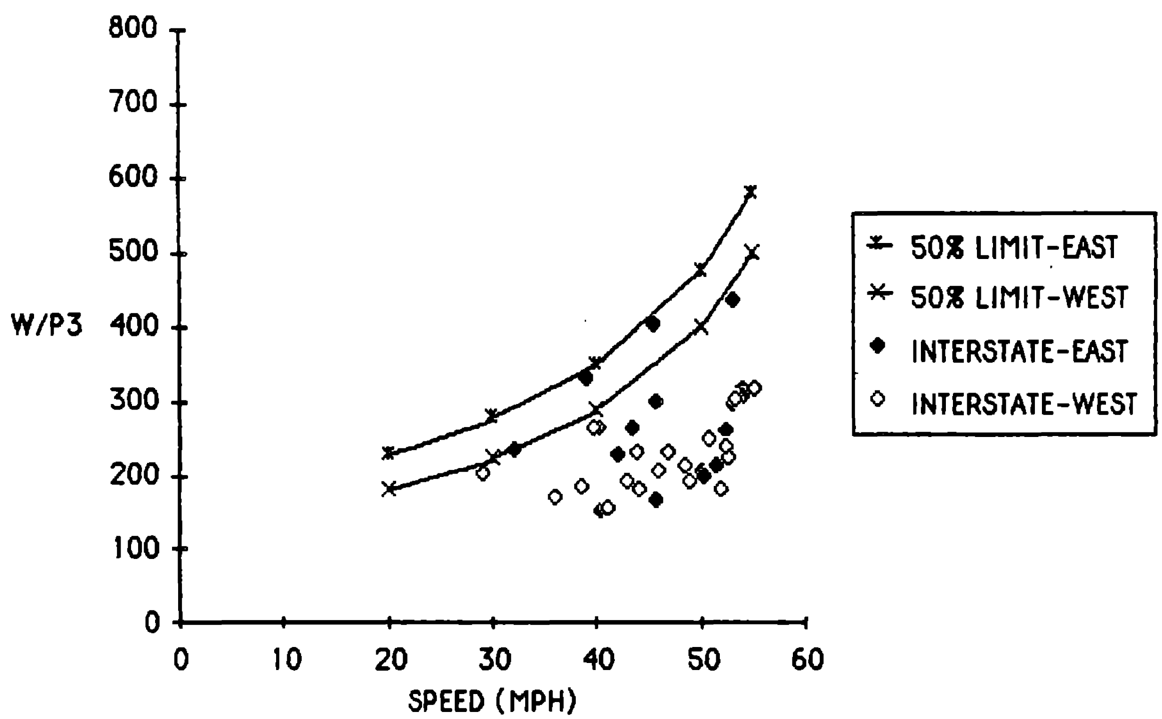


Figure 16b. 50 percentile W/P_3 values for straight trucks on interstate roads.

distinguished in the plots by the symbol used. The distinction between East and West is a little more obvious with straight trucks than with tractor-trailers. The Western data points generally exhibit a limit that is about 50-75 lb/hp lower than that for the east.

The 12.5 percentile limit used for tractor-trailers fits the eastern data points for this vehicle class. That is, the curve established by W/P_3 values of 375 lb/hp at 25 mi/h (40 km/h) and 550 lb/hp at 50 mi/h (80 km/h) yields a reasonable bound for the Eastern straight truck data. The actual expression for the P_3/W is presented in a summary at the end of this chapter. Although one might independently come up with a somewhat different limit, as will be seen later, there is great advantage to being able to apply the same limit to both types of vehicles. Certainly, it is difficult to say that the straight trucks are significantly different from the tractor-trailers to justify a different limit. Note that in the 12.5 percentile plots for interstate routes the two data points above the limit have been treated as outliers based on the subjective judgment that they do not appear consistent with the remainder of the data.

The Western data in this figure for the 12.5 percentile trucks fall somewhat below the limit just selected for the Eastern data, indicating that straight trucks operating on the Western interstates have a generally higher performance level (lower W/P_3). A second limit is shown for these points based on 290 and 500 lb/hp.

The 50 percentile limit for tractor-trailers also matches well the data for straight trucks on Eastern interstate routes. That boundary is established from W/P_3 values of 250 lb/hp at 25 mi/h (40 km/h) and 475 lb/hp at 50 mi/h (80 km/h). For the Western data a limit based on 200 and 400 lb/hp is more appropriate.

Straight trucks on primary roads tend to be higher in performance than on interstates (lower W/P_3 values). The explanation may be that they tend to be more lightly loaded. Straight trucks operating on interstates are presumably traveling for longer distances, and for economic reasons are loaded more heavily. The 12.5 and 50 percentile performance is presented in figure 17. The limits used for tractor-trailers are a little high to closely match the straight truck performance on primary roads. The 12.5 percentile limit is based on W/P_3 values of 350 and 500 lb/hp at 25 and 50 mi/h (40 and 80 km/h). Those for the 50 percentile are based on 150 and 300 lb/hp. The 50 percentile exhibits an especially clear boundary. The 12.5 percentile is not so clear and has one data point that falls above the limit. The presence of data points from both the East and the West near the limit suggests that there is no geographic distinction between straight truck performance on primary roads.

Characterizing Straight Trucks with Trailers

Characterizing the performance limits of straight trucks with trailers is difficult because of the absence of conclusive data. On Eastern sites very few were encountered, resulting in samples of a half-dozen or less at many sites. Although a median can be inferred from measurements of only a few trucks, a 12.5 percentile cannot. Thus the 12.5 percentile performance could only be determined for some of the Western sites. Their performance is shown in figure 18a. The limit is based on 525 lb/hp at 25 mi/h (40 km/h) and 625 lb/hp at 50 mi/h (80 km/h). The data are consistent enough to state that trucks with trailers are much lower in performance than straight trucks without trailers and should be recognized as a separate class of vehicles.

Comparisons between East and West and between interstates and primaries can only be made at the 50 percentile level. Figure 18b shows the 50 percentile performance data. The distribution of data points would seem to justify a distinction between performance in the East and West. Thus two limits are shown in the plot. For the East, the limit is established by W/P_3 values of 350 and 1200 lb/hp at 25 and 50 mi/h (40 and 80 km/h), respectively. For the West, the limits are based on 325 and 550 lb/hp.

In light of the fact that the Eastern trucks with trailers are so much lower in performance at the 50 percentile level, it is likely that

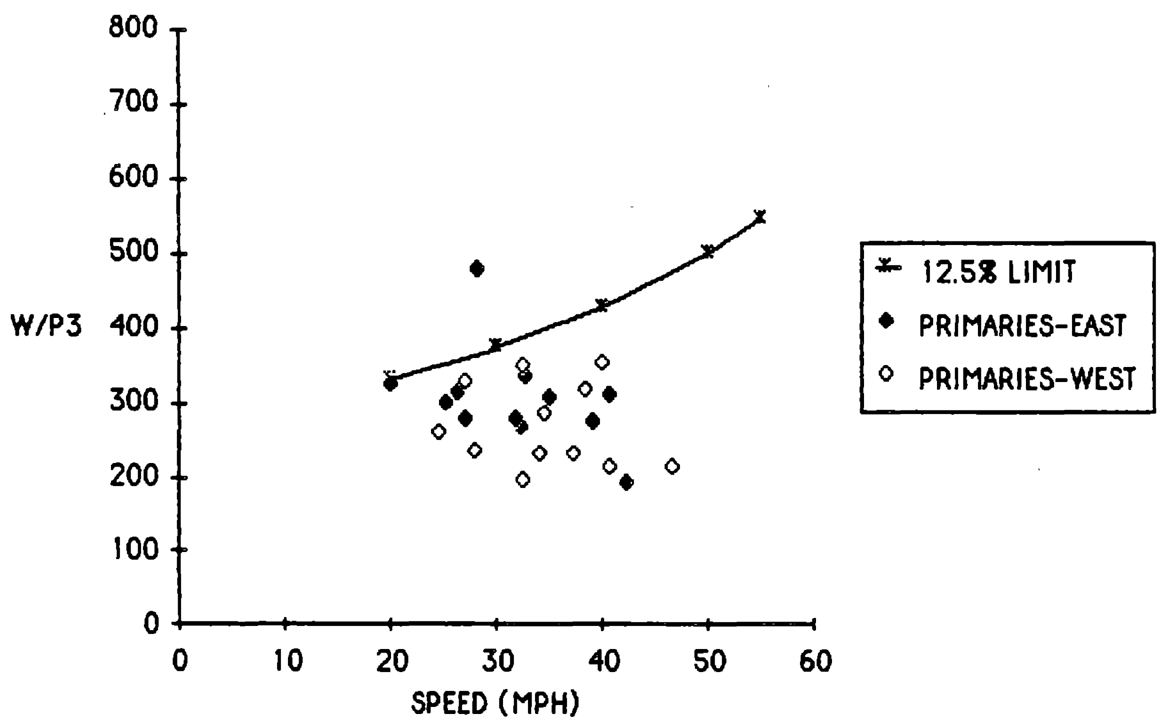


Figure 17a. 12.5 percentile W/P_3 values for straight trucks on primary roads.

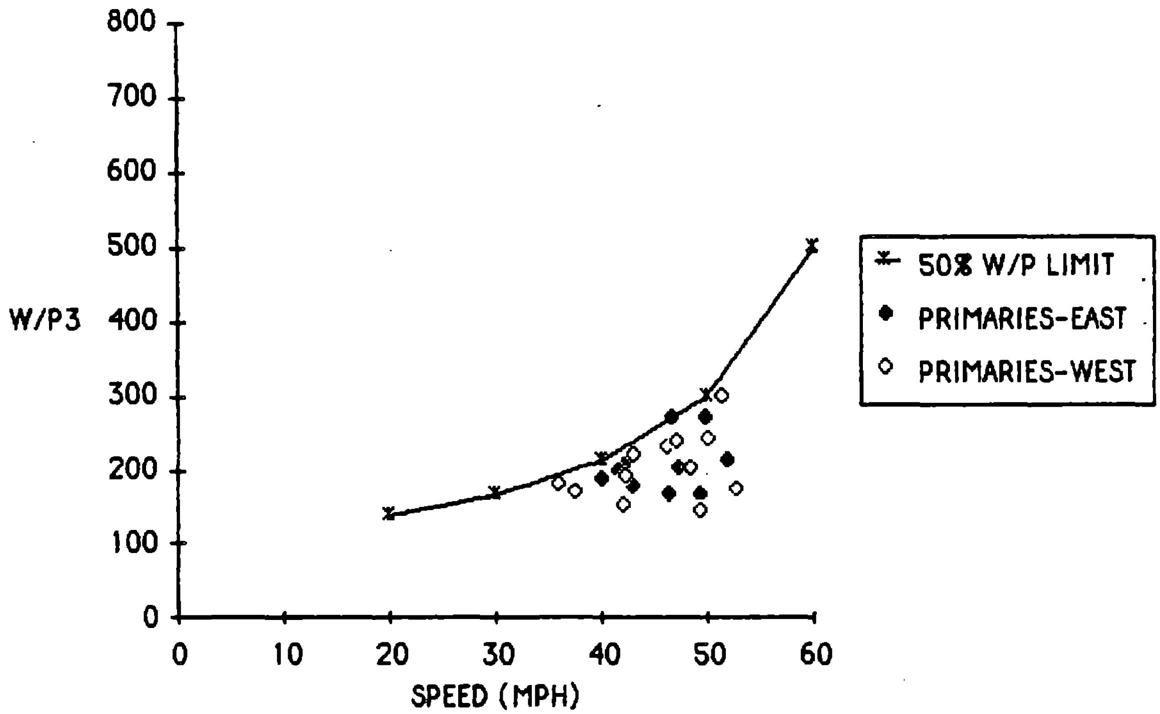


Figure 17b. 50 percentile W/P_3 values for straight trucks on primary roads.

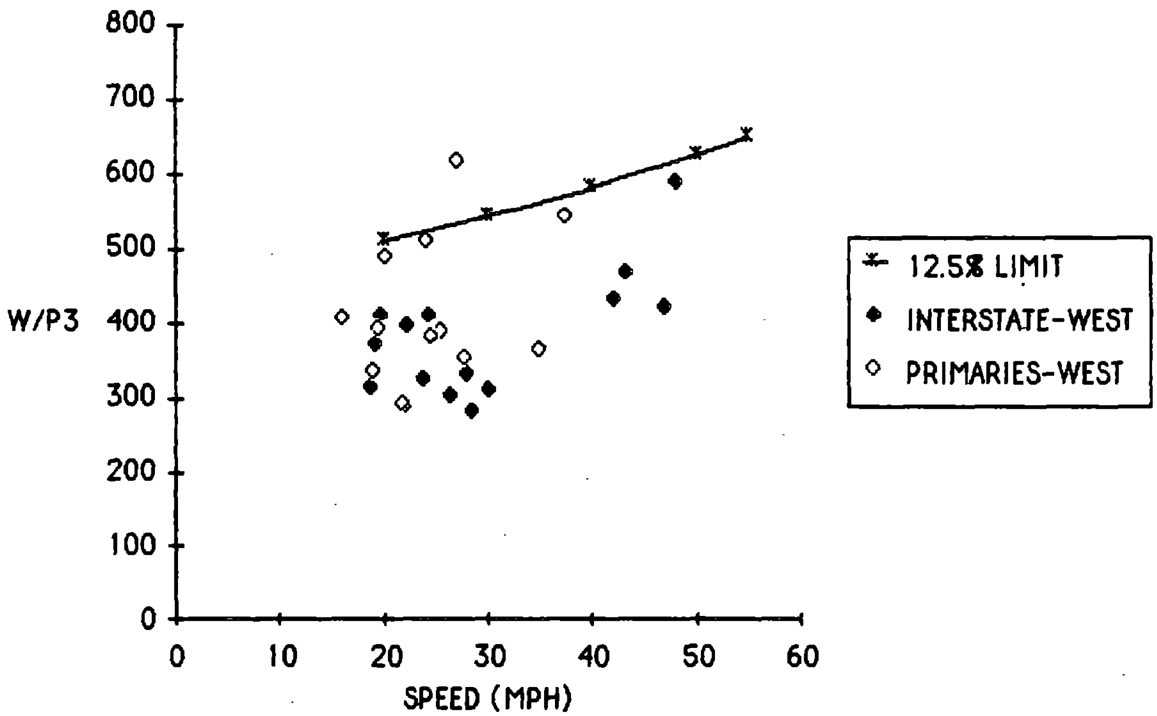


Figure 18a. 12.5 percentile W/P_3 values for trucks with trailers on Western interstate roads.

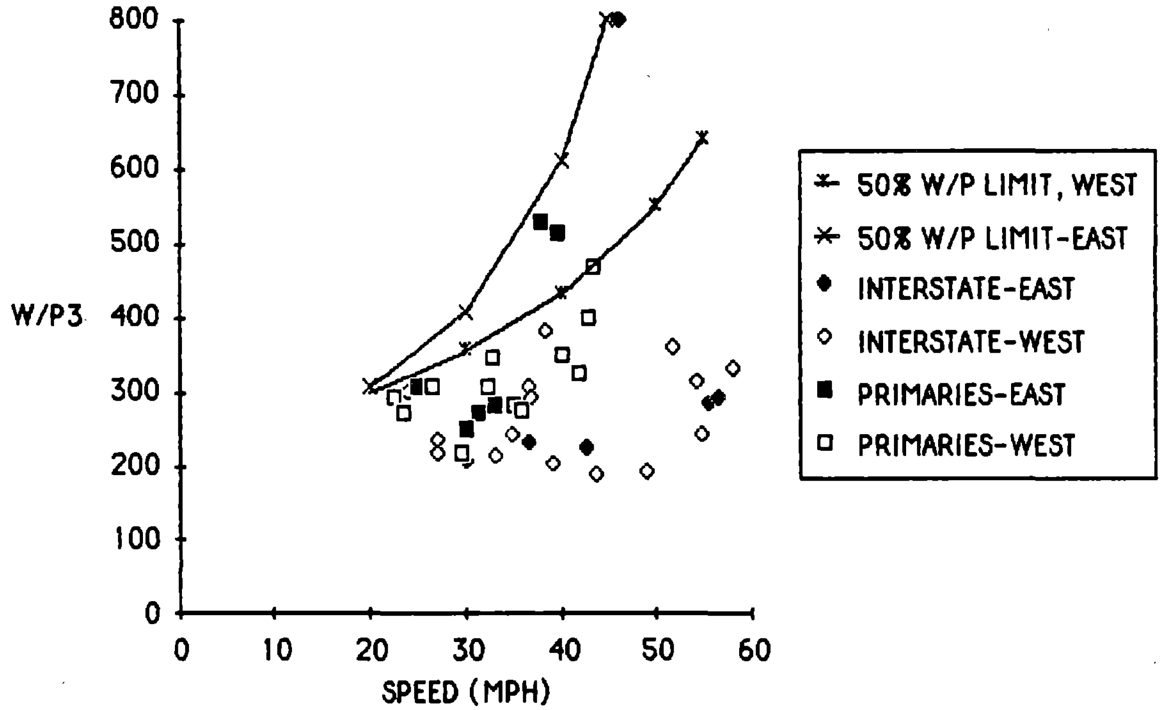


Figure 18b. 50 percentile W/P_3 values for trucks with trailers on all roads.

the 12.5 percentile limit would be much lower than that for the West. Although Eastern trucks with trailers are bounded by a much lower performance limit even at the 50 percentile level, note that the actual data points tend to be more broadlyl distributed in the plot. The implication is that trucks with trailers are much more variable in the East.

Characterizing Performance of Doubles and Triples

Experimental data for doubles and triples suffered from the same problems as that for straight trucks with trailers. Only a marginal number of vehicles were encountered at some sites. Nevertheless, the number of doubles was sufficient to assess 12.5 and 50 percentile performance on interstates in the East and West, and on primary roads in the West.

The majority of vehicles encountered were doubles comprised of two short trailers. The short trailers are nominally 27 ft (8 m) in length, producing a combination vehicle length of about 65 ft (20 m). In the West, a long and a short trailer may be combined into a unit frequently called a "Rocky Mountain Doubles." Several of these were encountered, but were insufficient in number to allow assessment of their hill-climbing performance. Thus the data on doubles vehicles has been limited to the 65-ft (20-m) combination.

Also in the West, 12 triples were included in the measurements, 10 at one site. Ten vehicles provides a sample large enough to calculate 12.5 and 50 percentile values for comparison to performance of the doubles, although one site is not sufficient to generalize about the population as a whole.

Figures 19a and b show the performance plots for doubles at the 12.5 and 50 percentile levels. The 12.5 percentile limit is established by 475 and 800 lb/hp at 25 and 50 mi/h (40 and 80 km/h). The two data points at the lowest speeds fall slightly above this boundary, but were not taken as justification for raising the boundary line. Eastern and

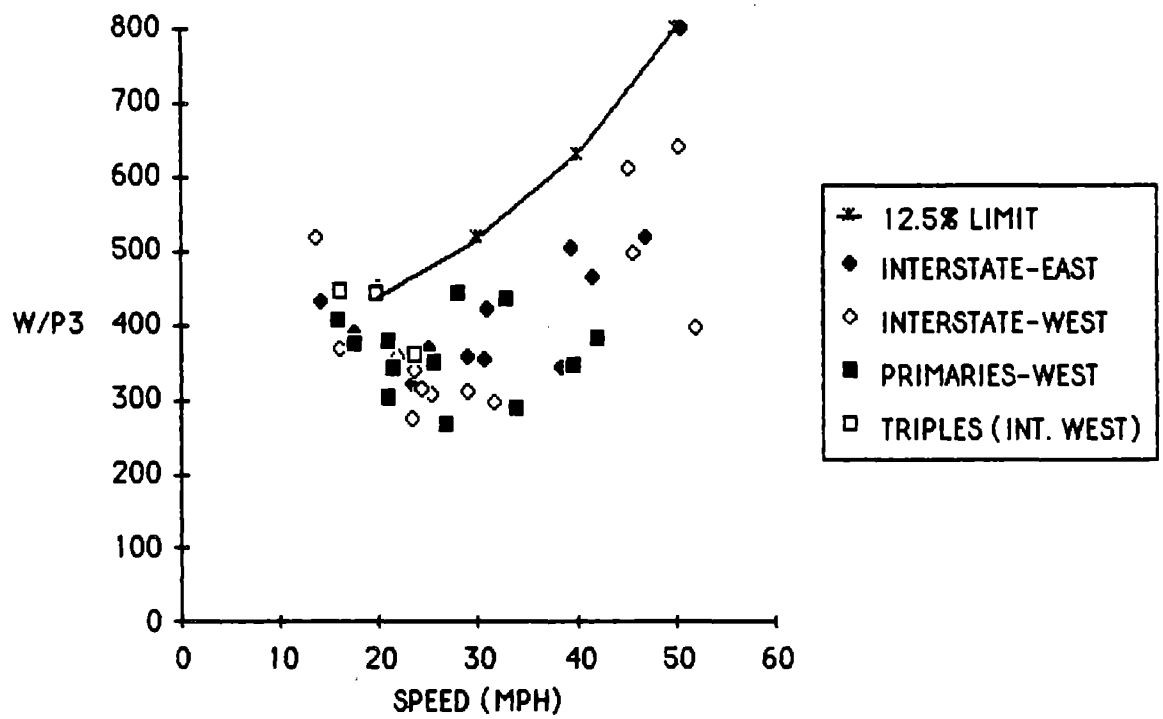


Figure 19a. 12.5 percentile W/P_3 values for doubles and triples on all roads.

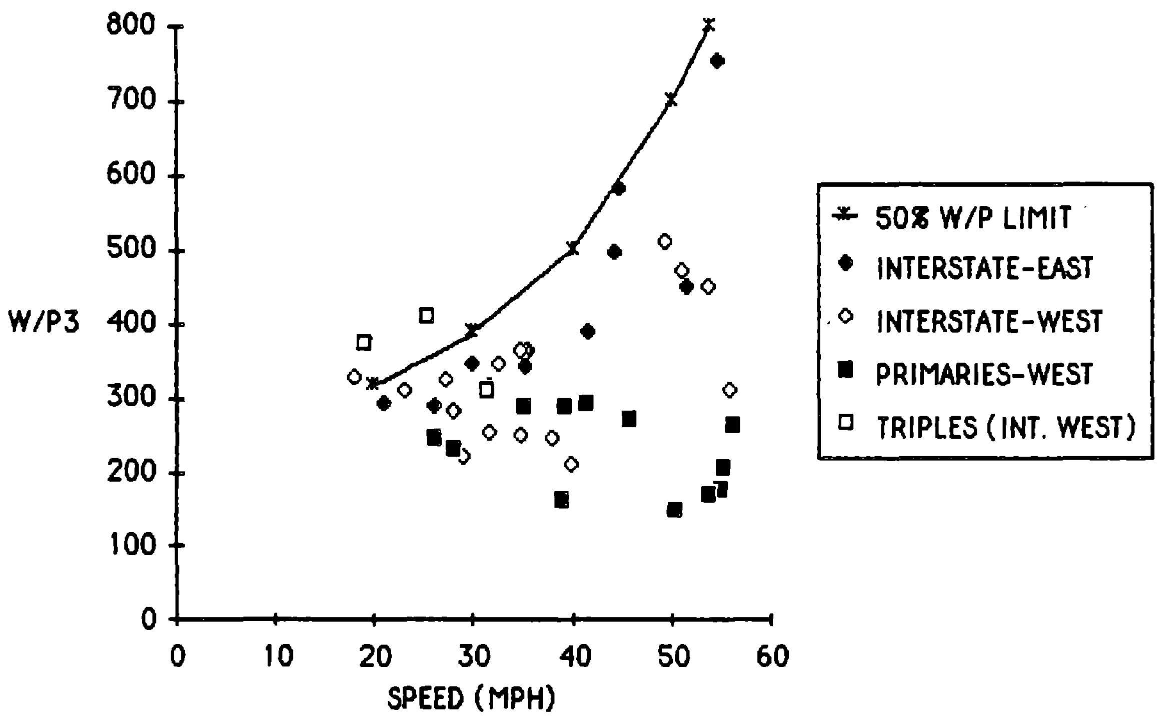


Figure 19b. 50 percentile W/P_3 values for doubles and triples on all roads.

Western interstates and the Western primary roads are all represented near the boundary, thus there is no distinction by geographic location or road type.

Also shown on the plot are three data points (the data from one site) for triples operating on a Western interstate road. These are included to show the performance observed with the triples, even though only ten vehicles were included in the sample. Although no concrete conclusions can be drawn, these data would indicate that the performance of triples is comparable to that of 65-ft (20-m) doubles.

The 50 percentile limit shown in figure 19b is established by 350 and 700 lb/hp at 25 and 50 mi/h (40 and 80 km/h). The Eastern and Western interstates are both near the boundary, indicating no geographic differences. The Western primaries fall further from the boundary, indicating that slightly better performance is obtained at the median level. Data points for the triples are near the 50 percentile limit shown.

Summary of Performance Characteristics

In all the discussion that has preceded, it is difficult to keep a clear picture of the performance characteristics that have been concluded with regard to vehicle classes, road classes, and 12.5 versus 50 percentiles. For convenience, the results are summarized in tables 1 and 2.

Comparison of "Effective" and "Rated" Engine Power

The performance characterization by the "effective" power (P_3/W) available for acceleration or overcoming grade has provided a direct measure by which to predict decelerations of the truck population on grades. However, it can only be evaluated by field measurements. Past prediction methods have been based on estimates of actual vehicle parameters. Those necessary are engine power (P_1), weights, rolling

Table 1. W/P_3 values (lb/hp) at 25 and 50 mi/h (40 and 80 km/h) by vehicle and road class.

	Interstate		Primary	
	East	West	East	West
Straight Trucks				
12.5%	375, 550	290, 500	350, 500	350, 500
50.0%	250, 475	200, 400	150, 300	150, 300
Trucks with Trailers				
12.5%	----	525, 625	----	525, 625
50.0%	350, 1200	325, 550	350, 1200	325, 550
Tractor-trailers				
12.5%	375, 550	375, 550	375, 550	375, 550
50.0%	250, 475	250, 475	250, 475	250, 475
65-ft Doubles				
12.5%	475, 800	475, 800	----	475, 800
50.0%	350, 700	350, 700	----	350, 700

Table 2. P_3/W equations by vehicle and road class.

	Interstate	Primary
Straight Trucks		
12.5% East	$P_3/W=(3.52-.0339\ U)/1000$	$P_3/W=(3.71-.0343\ U)/1000$
12.5% West	$P_3/W=(4.90-.0579\ U)/1000$	$P_3/W=(3.71-.0343\ U)/1000$
50.0% East	$P_3/W=(5.89-.0758\ U)/1000$	$P_3/W=(10.0-.1333\ U)/1000$
50.0% West	$P_3/W=(7.50-.1000\ U)/1000$	$P_3/W=(10.0-.1333\ U)/1000$
Trucks with Trailers		
12.5% East	----	----
12.5% West	$P_3/W=(2.21-.0122\ U)/1000$	$P_3/W=(2.21-.0122\ U)/1000$
50.0% East	$P_3/W=(4.88-.0809\ U)/1000$	$P_3/W=(4.88-.0809\ U)/1000$
50.0% West	$P_3/W=(4.36-.0504\ U)/1000$	$P_3/W=(4.36-.0504\ U)/1000$
Tractor-trailers		
12.5% East & West	$P_3/W=(3.52-.0339\ U)/1000$	$P_3/W=(3.52-.0339\ U)/1000$
50.0% East & West	$P_3/W=(5.89-.0758\ U)/1000$	$P_3/W=(5.89-.0758\ U)/1000$
65-ft Doubles		
12.5% East	$P_3/W=(2.96-.0342\ U)/1000$	----
12.5% West	$P_3/W=(2.96-.0342\ U)/1000$	$P_3/W=(2.96-.0342\ U)/1000$
50.0% East	$P_3/W=(4.29-.0571\ U)/1000$	----
50.0% West	$P_3/W=(4.29-.0571\ U)/1000$	$P_3/W=(4.29-.0571\ U)/1000$

resistance properties, aerodynamic properties, gearing, tire size, and drive line efficiencies.

Population characteristics of the weights of trucks operating on the road system are generally available to the highway community through the routine measurements made at weigh stations. Getting a reasonable picture of the power available to accelerate a truck is more difficult. The Truck Inventory in Use (TIU) survey conducted periodically by the Department of Commerce includes an inquiry on the power installed in each truck.(13) This "reported" power, of course, is not the same as that available at the wheels. However, if it could be related to the power available for hill-climbing, then the TIU survey results could be utilized in conjunction with weight survey results to estimate how truck performance is changing.

In order to address this issue, more comprehensive data were acquired at certain of the field test sites. Two each of the Eastern and Western sites were selected because of close proximity to a truck weigh station. In addition to the measurements of hill-climbing performance, other data were obtained at the weigh station. Gross vehicle weights were obtained from the weight measurements. The driver was interrogated to obtain a figure for the power of the engine. Most drivers know the rated power of the engine in a truck, a figure which should compare closely with that obtained from the owner in the TIU survey. The vehicle type, factors related to its frontal area, the presence of aerodynamic aids, and the type of tires (radial or bias) were also noted. Vehicle descriptions allowed the data from the weigh station to be linked to that obtained on the grade.

The raw averages of the weight and power figures are the first items of interest. Table 3 shows the "actual" values by truck type and road class. The numbers in parentheses following the road class listing indicate the number of vehicles sampled. The weight-to-power figures shown are equivalent to W/P_1. That is, the power figure is based on installed, rather than, effective horsepower. The values are determined from the average weight divided by average power.

Table 3. Average weights and power values for trucks.

	Weight (lb)	Power (HP)	Weight/Power
Straight Trucks			
Interstate - East (14)	15233	219	70
Interstate - West (6)	35050	267	131
Primary - East (6)	16575	273	75
Trucks with trailers			
Interstate - East (2)	12300	193	64
Interstate - West (7)	48430	346	140
Primary - East (1)	76780	400	192
Tractor-trailers			
Interstate - East (157)	54452	328	166
Interstate - West (233)	64775	370	175
Primary - East (134)	57487	330	174
65-ft Doubles			
Interstate - West (19)	64920	331	196

The weight-to-power ratio for the individual trucks was also calculated and averaged to see if it resulted in a different figure that would indicate some bias due to interaction between weight and power. Essentially the same W/P_1 averages were obtained both ways. This would indicate that it is valid to obtain average weights and average power levels for modern trucks and determine the average W/P_1 from their ratios.

The weight-to-power values seen here do not exhibit the same trends as have been observed for the overall populations in the previous sections. For example, straight trucks in the East have a lower W/P ratio than tractor-trailers, although the 12.5 percentile limits were found to be comparable. Several reasons are possible explanations. First, these are averages for one or two sites, not 12.5 percentiles for many. Second, the sample sizes for straight trucks here are small and marginally significant. The reasons for the small sample size for straight trucks, trucks with trailers, and doubles is their small representation in the truck population at the measurement sites, and the fact that the complete data, as needed here, were only captured on a fraction of those vehicles passing the site. These differences in W/P values do not prevent this data from being meaningful. The purpose here is to examine a few trucks in detail to determine how their performance relates to what would be expected.

The weight-to-power values for the trucks sampled in this study are lower than those projected from the TIU data. Figure 20 is a plot from reference 14 showing the weight-to-power ratios for trucks compiled from studies over the years. The triangles show data from the 1977 TIU study based on maximum weight and reported horsepower. Added to the figure are data points obtained from table 3. Data points for the Eastern trucks with trailers have been excluded from the plot because of the small sample size. The data points show a trend that falls significantly below the TIU line. In operation, the trucks have a lower weight-to-power ratio than the TIU data would suggest. Tractor-trailers, which are nominally in the 60,000- to 80,000-lb weight class, appear to operate on the average at about 60,000- to 65,000-lb gross vehicle weight. The average horsepower from this study is approximately

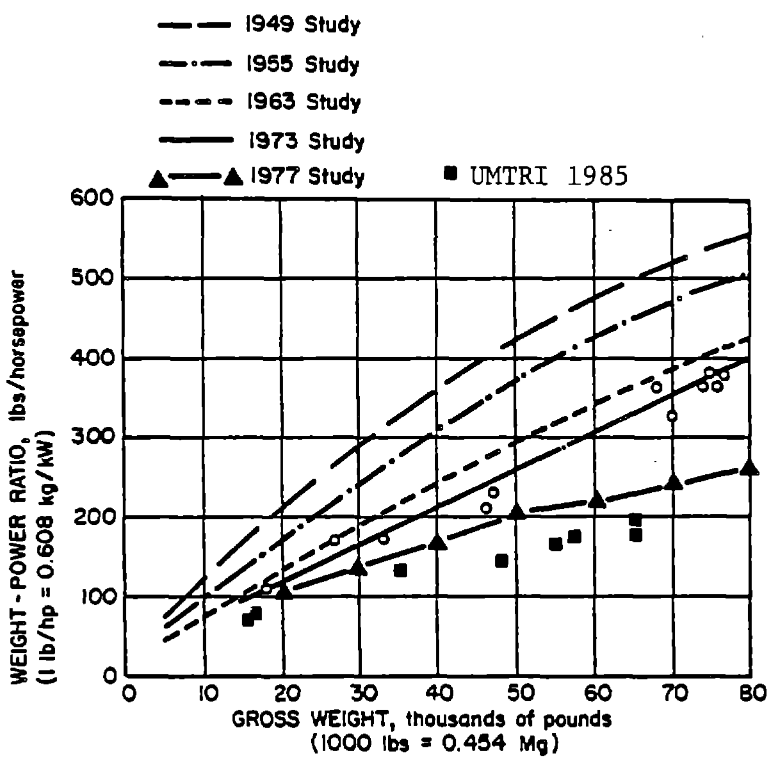


Figure 20. Trends in weight-to-power since 1949 [14].

350, up 25 percent from the 282 hp average for comparable vehicles from the 1977 TIU survey. Thus, the major reason for reduced weight-to-power ratios is the increase in horsepower. Inasmuch as eight years have elapsed since the TIU study, it is likely that the statistics seen in table 3 are more representative of modern trucks even though they are derived from a much smaller sample size.

The data were analyzed in depth to estimate an "effective" power being extracted from the engine during the grade-climbing experience. The estimate is derived from the measured speed and speed loss on grade, to which are added additional power consumption estimates for rolling resistance and aerodynamic drag. Parameters for estimating these contributions were obtained from the additional data acquired on the truck at the weigh station. Rolling resistance was estimated from the SAE equations as follows:

$$C_{rr} = .001(4.1 + .041\ U) \quad \text{for radial tires} \qquad (14a)$$

$$C_{rr} = .001(5.3 + .044\ U) \quad \text{for mixed tires} \qquad (14b)$$

$$C_{rr} = .001(6.6 + .046\ U) \quad \text{for bias-ply tires} \qquad (14c)$$

The aerodynamic drag forces were estimated from the familiar equation:

$$F_a = 0.5\ D\ C_d\ A\ V_2 \qquad (15)$$

where

D = air density, corrected for altitude

C_d = drag coefficient (0.7 with aero-aids, 0.8 without)

A = area (100 ft^2 for van bodies, 75 ft^2 for cab only)

Thus the effective power estimated is that which is available from the engine at the drive wheels. Losses due to drive line efficiency, shifting, engine maintenance condition, or accessories are not included. It is a modified form of P_2 in that these last items are not included.

The "effective" power calculated in this manner can be compared to the "actuals" (table 3) to determine a factor characterizing the utilization of the power that is theoretically available in the vehicle. Separate utilization factors can be determined for performance in the deceleration portion of the grade and at the final climbing condition. The method generally yielded comparable "effective" power values in both phases of the climbing process, typically within 10 to 20 percent. The utilization factors obtained are listed in table 4.

Note that a fairly consistent pattern emerges showing about the same utilization in the deceleration and final climbing stages of the grade. The straight trucks are least consistent, varying from about 40 percent to 60 percent utilization. The generally low values may be indicative of high representation of vehicles powered by gasoline engines in this class. It is reasonable to expect a much higher engine power utilization with diesel power plants than with gasoline because it is routine to run a diesel near maximum r/min (approximately 2,000 r/min), which is the power peak. On the other hand, fewer drivers would climb a long grade with a gasoline engine running near its maximum power as that speed is normally about 4,000 to 4,500 r/min. It is not only unpleasantly loud, but it verges on the point of being abusive of the engine.

From table 4, reasonable utilization factors can be estimated. For straight trucks in the East, utilization factors of about 45 percent of engine power are reasonable. Straight trucks in the West, however, run at about 65 percent of rated power. Highway tractors used with semitrailers or multiple trailers (doubles) generally yield utilization factors of about 80 percent, indicating that the drivers are very effective at using the power available from the engine. Data for trucks with trailers were only available for Western sites. A utilization factor of about 70 percent is indicated.

As average vehicle weights or engine power levels change in the future fleet, these results would suggest that a reasonable estimate of the changes in hill-climbing performance can be made. The installed power can be corrected to an effective value at the drive wheels by

Table 4. Power utilization factors (effective/actual)

	Straight Trucks	Trucks - Trailers	Tractor-Trailers	65-ft Doubles
Final Climbing				
Interstate - east	0.40	----	0.75	----
Interstate - west	0.65	0.74	0.86	0.85
Primary - east	0.43	----	0.79	----
Deceleration				
Interstate - east	0.45	----	0.68	----
Interstate - west	0.62	0.63	0.88	0.81
Primary - east	0.44	----	0.84	----

multiplying by the utilization factor. The power available for acceleration (P_3) is then obtained from this by subtracting off aerodynamic and rolling resistance losses. In the event changes in aerodynamic or rolling resistance losses are projected (from greater use of aerodynamic aids, or radial tires), their impact on the P_3 power can be applied directly. That is, presuming the effective power at the drive wheels is unchanged, the increase in P_3 is simply equivalent to the decrease in these other losses.

INTERPRETATION AND APPLICATIONS

The experimental observations of truck speed loss on grades in this project clearly show the AASHTO speed-distance curves to be a very conservative basis for design of climbing lanes. Yet to use the new information, methods must be defined for predicting speed losses on grades at the design synthesis stage.

Calculations of Speed Loss

The formulation of the P_3/W function to characterize performance provides a very simple and easily applied method for calculating speed losses on grades for a particular class of vehicle. The method is contained in equation 12, which is of the form:

$$dU/dX = 0.465\ (375\ (P_3/W)/\ U - G_r)\ g/U \qquad (12)$$

where

U = speed (mi/h)

X = distance (ft)

G_r = road grade (percent/100)

g = gravitational constant = 32.2 ft/sec^2

The P_3/W functions used in the equation are obtained from those listed in table 1 for the particular class of vehicle of interest. The equation itself cannot be readily integrated to provide a closed-form solution; however, it is simple enough to be programmed on the smallest desktop microcomputer. Figure 21 lists a Basic-language program to calculate speed-distance curves for an arbitrary grade. The initial speed, W/P_3 values for 25 and 50 mi/h (40 and 80 km/h), and elevation-distance (grade) parameters are set within the program. Running the

```
10 REM         Program for calculating speed-distance curves
20 REM         Select entry speed in line 100
30 REM         Select weight-to-power values in line 110
40 REM         Define grade by distance-elevation values in line 300
50 REM                      ........by T. D. Gillespie, 1985

90 pi=100: REM Sets distance intervals at which values print out
100 ENTRSPED=55: U=ENTRSPED: REM Set entry speed to desired value
110 WP25=375: WP50=550: REM Choose W/P3 values at 25 and 50 MPH
120 B=(1/WP50-1/WP25)/25: A=1/WP25-B*25
130 READ DIST,ELEV: REM Read grade on initial segment
140 GR=ELEV/DIST: XL=DIST: YL=ELEV
150 PRINT "Distance (Ft)  Speed (MPH)": PRINT USING "#####.##"; X,U
160 DELU=.464876*(375*(A+B*U)/U-GR)*32.2/U*10
170 U=U+DELU
180 X=X+10
190 IF X>XL THEN 200 ELSE 220
200 READ DIST,ELEV
210 GR=(ELEV-YL)/(DIST-XL): XL=DIST: YL=ELEV
220 IF X MOD pi<1 THEN 230 ELSE 160
230 PRINT USING "#####.##"; X, U: GOTO 160

300 REM       Enter grade data here in distance, elevation values (feet)
310 DATA 500,30
320 DATA 1000,60
330 DATA 1500,90
340 DATA 2000,120
350 DATA 2500,150
360 DATA 10000,600
```

Figure 21. Basic-language program for computing speed-distance curves from W/P_3 values.

program produces a listing of speed versus distance along the arbitrarily defined grade.

Plots of speed-distance are also provided in figure 22 for the various classes of vehicles on constant grades. These may be useful for those without access to a computer, in which case they can be used in a way comparable to that applied to the earlier AASHTO curves. That is, an initial speed is assumed, and the arbitrary grade profile is broken up into sections of constant grade. Then the curves are used to estimate speed loss along each section, producing a speed profile from entry point to final climbing point.

More importantly, the plots in figure 22 provide a visual framework in which to compare the speed-distance performance observed in this project to that in the AASHTO guide. Figure 22a is perhaps the most important in this regard as it applies to the 12.5 percentile tractor-trailers. Tractor-trailers are the most numerous heavy vehicles of any class encountered on many roads, and the AASHTO speed-distance curves were based on performance of tractor-trailers. The predictions for "critical length of grade" for these vehicles in figure 22a make an interesting comparison to the AASHTO data. In an absolute sense, the differences are minor on steep grades. For example, the critical length of grade for a 10 mi/h (16 km/h) speed loss on a 6 percent grade is nominally 600 ft (183 m). In figure 22a a distance of about 700 ft (213 m) is indicated. However, on a shallow grade of 3 percent the AASHTO distance is 1,400 ft (427 m), compared to about 2,100 ft (640 m) in figure 22a. The 700-ft (213-m) difference represents a major change in highway design. The differences become even more profound near 2 percent; where the AASHTO guide indicates a 2,500-ft (762-m) critical length, figure 22a shows 6,000 ft (1,829 m). Clearly the performance levels reflected by this new data indicate that longer values for critical length of grade are appropriate.

SPEED-DISTANCE FOR 375, 550

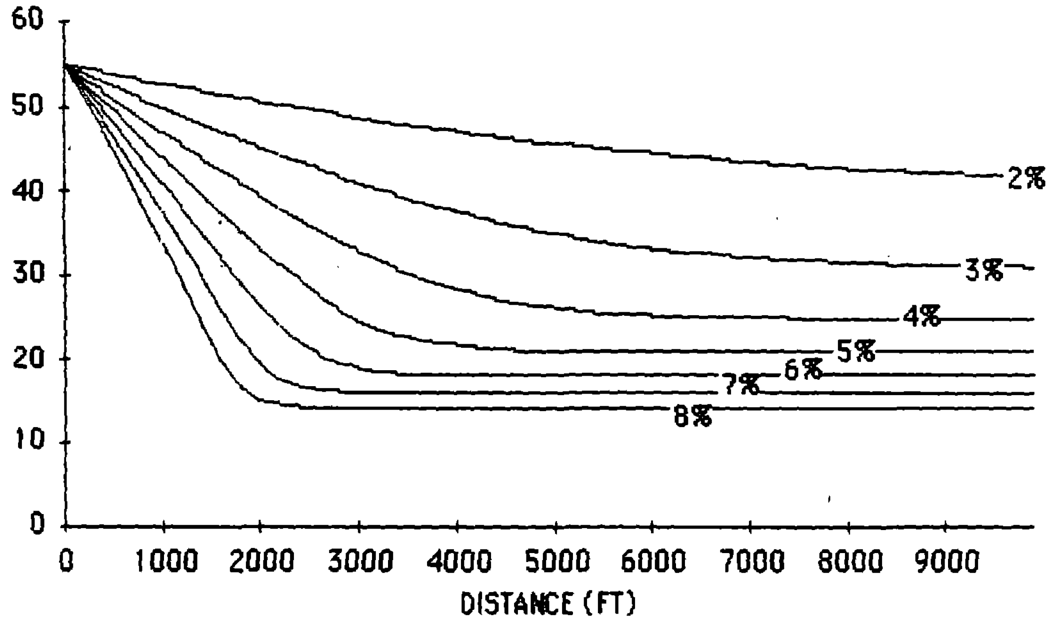


Figure 22a. Speed loss for vehicles at W/P_3 values of 375 and 550 -- 12.5% tractor-trailers on all roads, 12.5% straight trucks on Eastern interstates, and 12.5% straight trucks on all roads (optional).

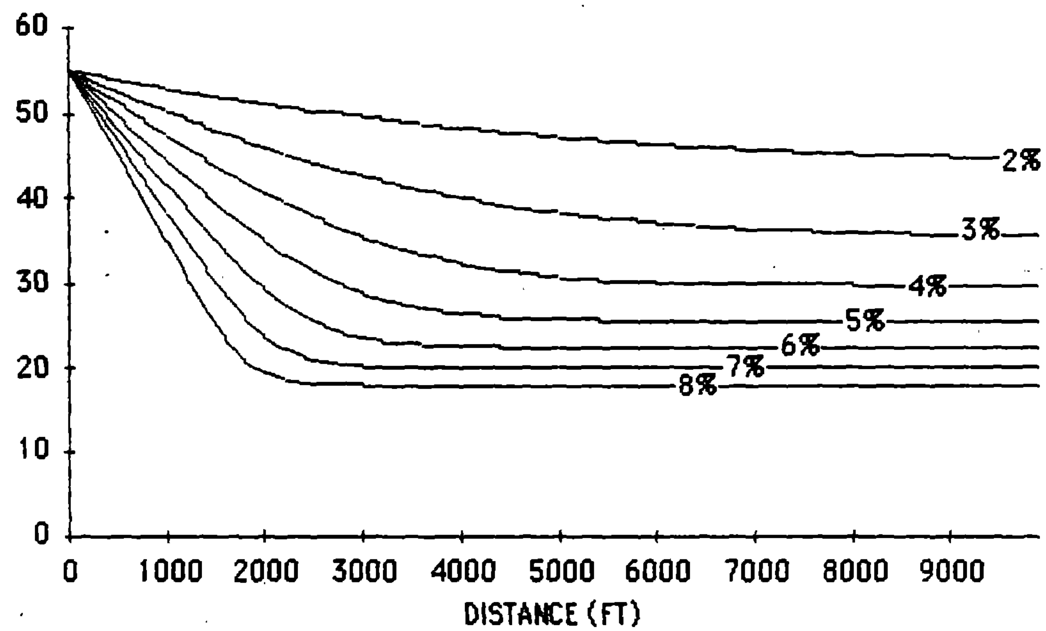


Figure 22b. Speed loss for vehicles at W/P_3 values of 290 and 500--12.5% straight trucks on Western interstates.

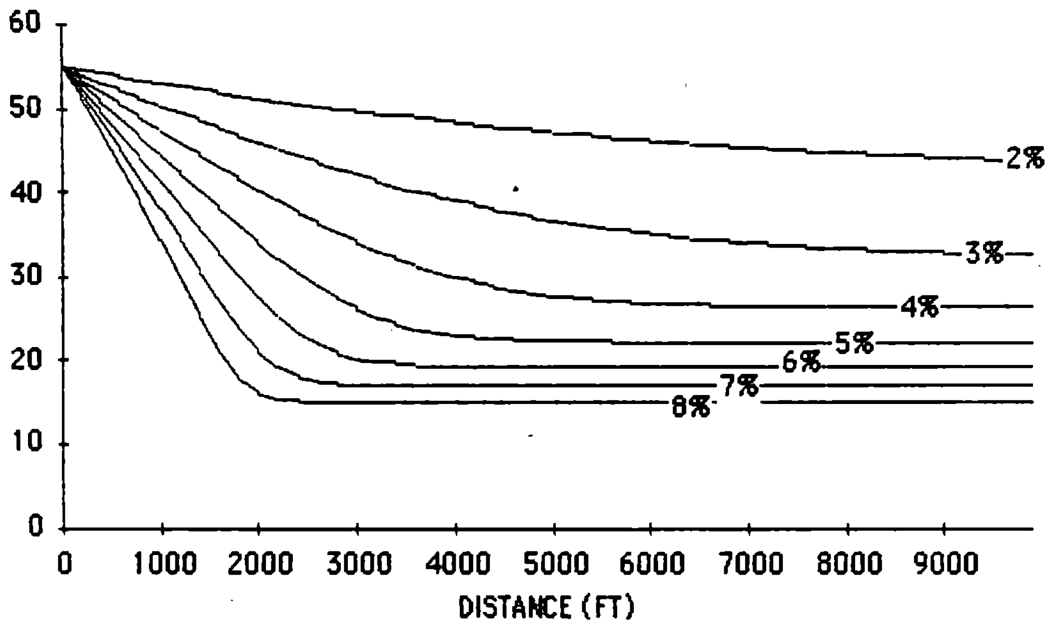


Figure 22c. Speed loss for vehicles at W/P_3 values of 350 and 500. 12.5% Straight trucks on primary roads

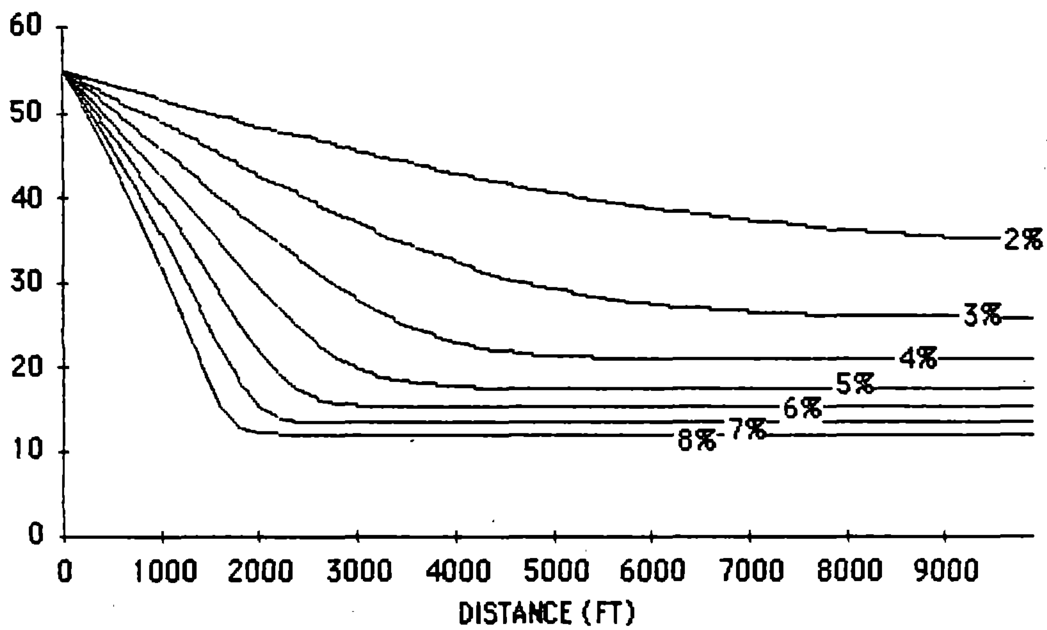


Figure 22d. Speed loss for vehicles at W/P_3 values of 525 and 625--12.5% trucks with trailers on Western roads.

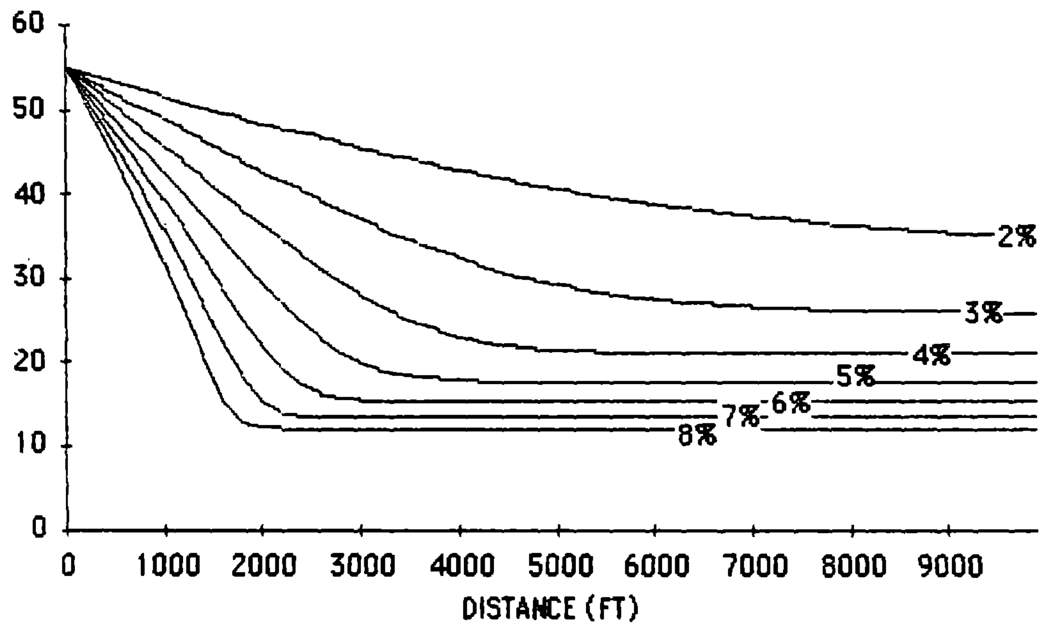


Figure 22e. Speed loss for vehicles at W/P_3 values of 475 and 800--12.5% doubles and triples on all roads.

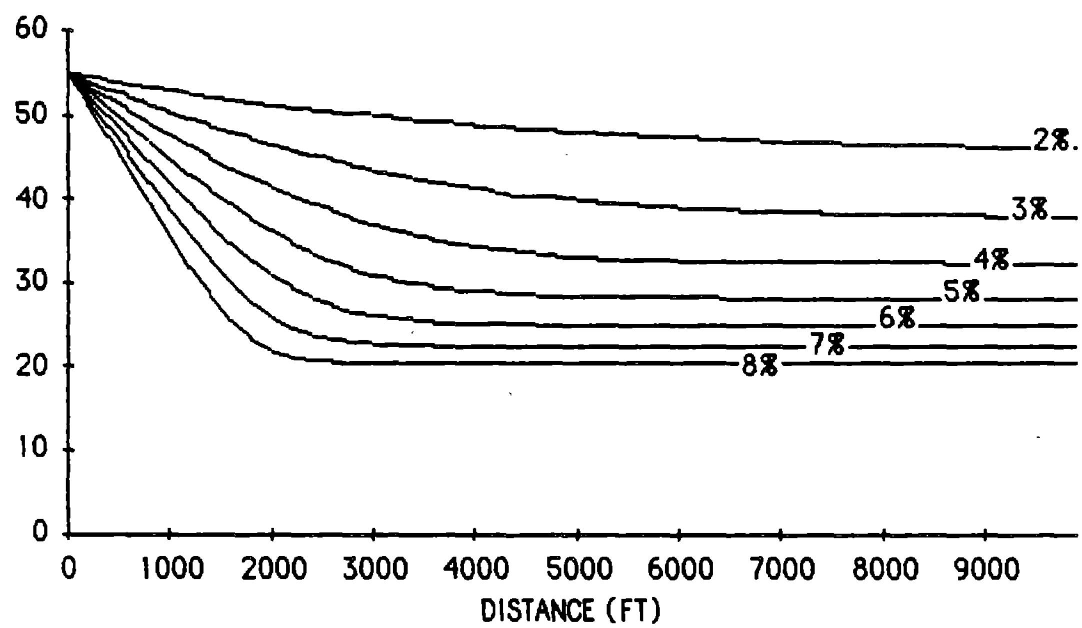


Figure 22f. Speed loss for vehicles at W/P_3 values of 250 and 500--50% tractor-trailers on all roads, 50% straight trucks on Eastern interstates, and 50% straight trucks on all roads (optional.

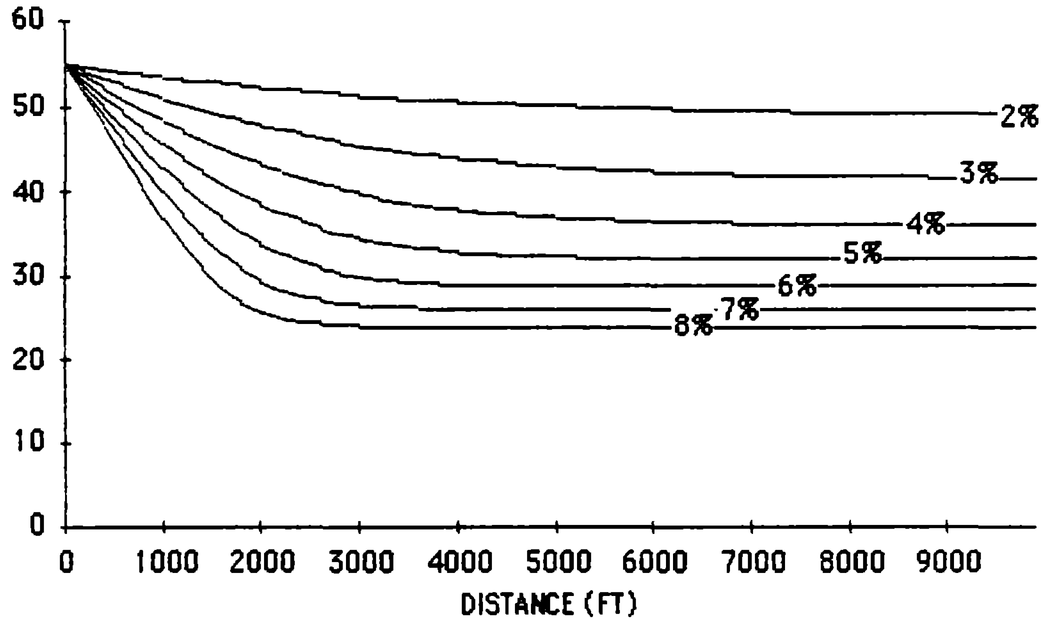


Figure 22g. Speed loss for vehicles at W/P_3 values of 200 and 400 -- 50% straight trucks on Western interstates.

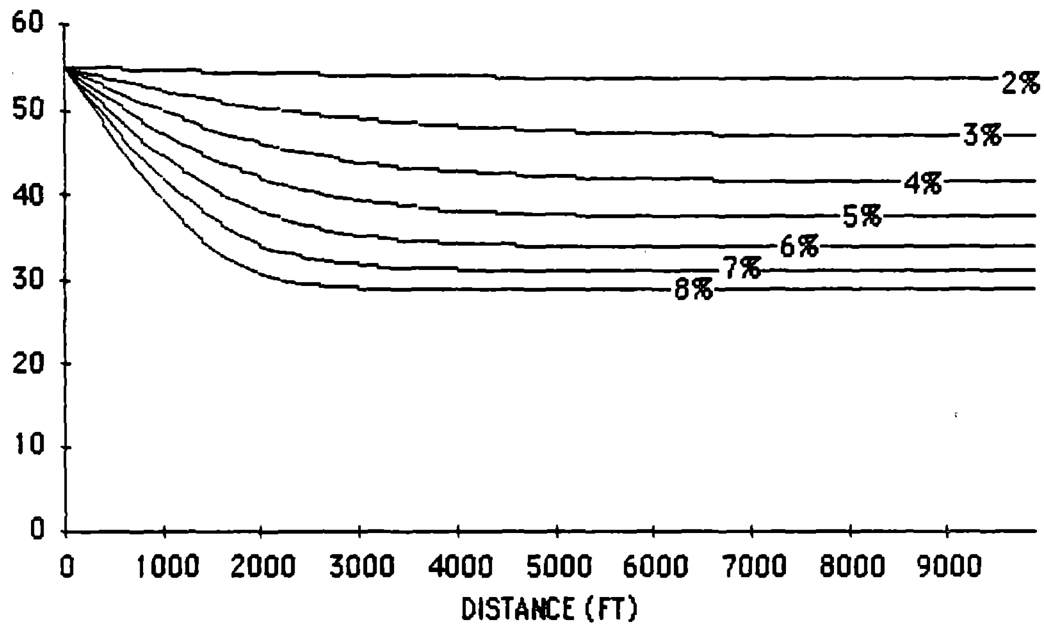


Figure 22h. Speed loss for vehicles at W/P_3 values of 150 and 300--50% straight trucks on primaries.

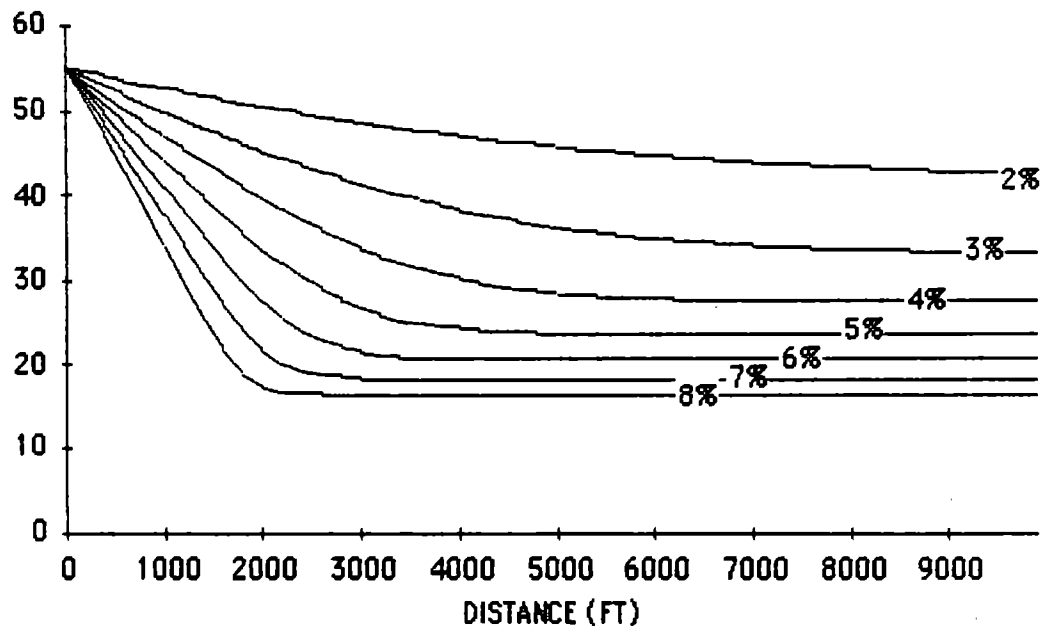


Figure 22i. Speed loss for vehicles at W/P_3 values of 325 and 550 -- 50% trucks with trailers in the West.

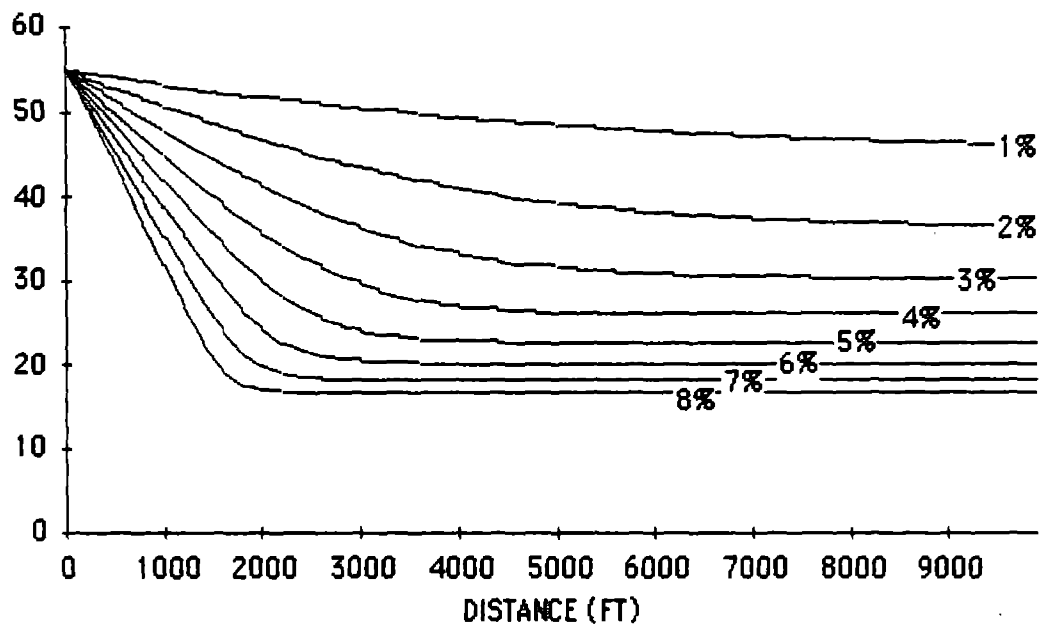


Figure 22j. Speed loss for vehicles at W/P_3 values of 350 and 1200--50% trucks with trailers in the East.

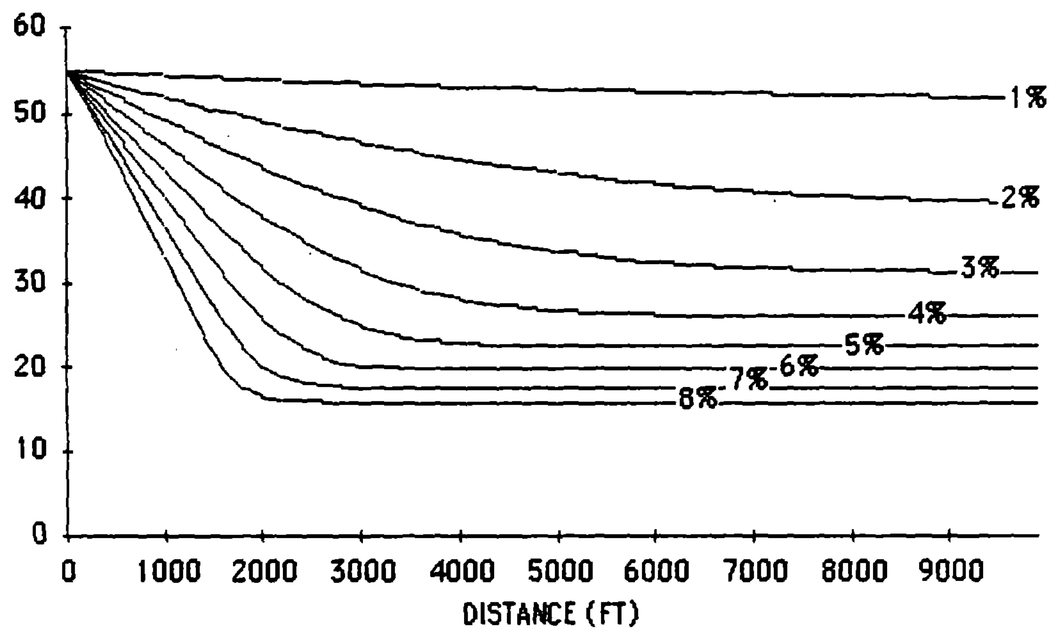


Figure 22k. Speed loss for vehicles at W/P_3 values of 350 and 700--50% doubles and triples on all roads.

Dealing with Traffic Mixes

The experimental observations clearly show distinctive differences in performance among different classes of vehicle and roads. To use this information constructively, methods must be developed for estimating performance of a mixed population.

It has been argued previously that the frequency of vehicles operating at the critical speed on a grade is a measure of hazard created. Thus the traffic density and the distribution of speed deficiencies among the trucks are the determinants of that frequency. The distribution of speeds (more accurately, speed changes) for an arbitrary mix of trucks is somewhat complicated to calculate analytically.

To do so, a deceleration distribution (similar to that shown in figure 9) must be calculated for the mix of vehicles expected to use the site. The procedural steps are as follows:

1) Assume values for the vehicle mix, initial speed, and initial grade.

2) Calculate the spatial deceleration, dU/dX, for the 12.5 and 50 percentile vehicles in each truck class using equation 12 as illustrated in the example below.

3) Plot the distribution of spatial deceleration for each vehicle class as a fraction of the total population.

4) Determine the distribution for the total population by summing the values for each vehicle class at specific levels of deceleration. Then from the distribution for the total population, the deceleration for the 12.5 percentile of the traffic mix (or any other percentile of choice) can be read from the graph.

As an example consider an assumed mix of 20 percent doubles and 80 percent tractor-trailers on an interstate of 4 percent grade, where the entry speed is expected to be 55 mi/h (88 km/h). These assumptions are step 1 in the procedure.

For step 2, the spatial decelerations are calculated. The P_3/W functions given in table 2 for each truck class are different, so the decelerations will differ. The spatial deceleration will be given by the equation:

$$dU/dX = 0.465\ (375\ (P_3/W)/\ U - G_r)\ g/U \qquad (12)$$

where

$P_3/W = (3.52 - .0339\ U)/1000$ - 12.5% Tractor-trailers (table 2)

$P_3/W = (5.89 - .0758\ U)/1000$ - 50% Tractor-trailers (table 2)

$P_3/W = (2.96 - .0342\ U)/1000$ - 12.5% Doubles (table 2)

$P_3/W = (4.29 - .0571\ U)/1000$ - 50% Doubles (table 2)

From this equation, spatial deceleration values at 55 mi/h (88 km/h) are calculated with the following results:

12.5% Tractor-trailers	-7.82 mi/h per 1000 ft
50% Tractor-trailers	-7.70 mi/h per 1000 ft
12.5% Doubles	-8.89 mi/h per 1000 ft
50% Doubles	-8.70 mi/h per 1000 ft

After these are calculated, the deceleration is plotted for step 3 as shown in figure 23.

The tractor-trailers represent 80 percent of the population, thus, their distribution establishes the decelerations for that fraction of the vehicles. The 12.5 percentile tractor-trailer is the 10 percentile of the population (.125 x 80 percent). Thus its deceleration (the value of -7.82) is plotted at the 10 percent point, as shown in figure 23a. The 50 percentile tractor-trailer is the 40 percentile of the population (.4 x 80 percent). Thus its deceleration (the value of -7.70) is plotted at the 40 percent point. The actual distribution for the

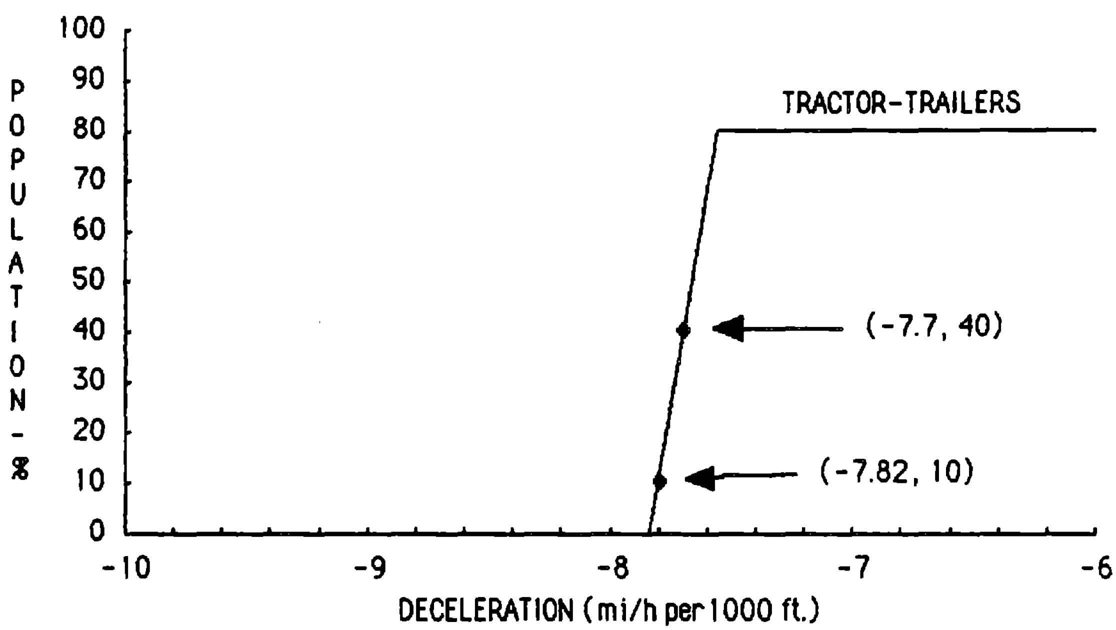
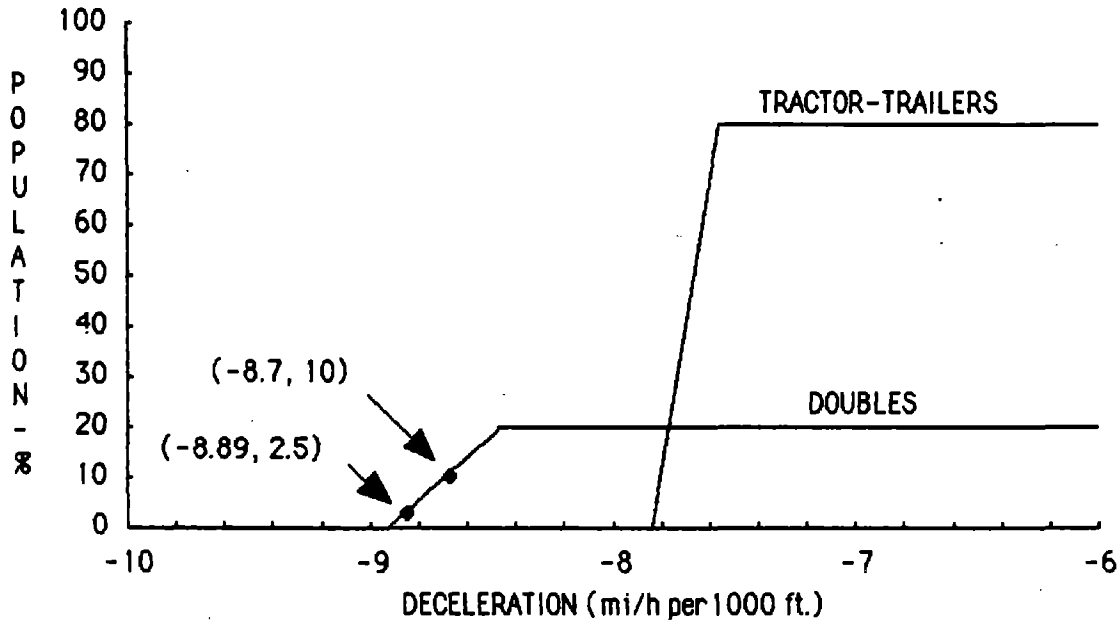


Figure 23a. Plot of deceleration distribution for tractor-trailers.



23b. Addition of deceleration distribution for doubles.

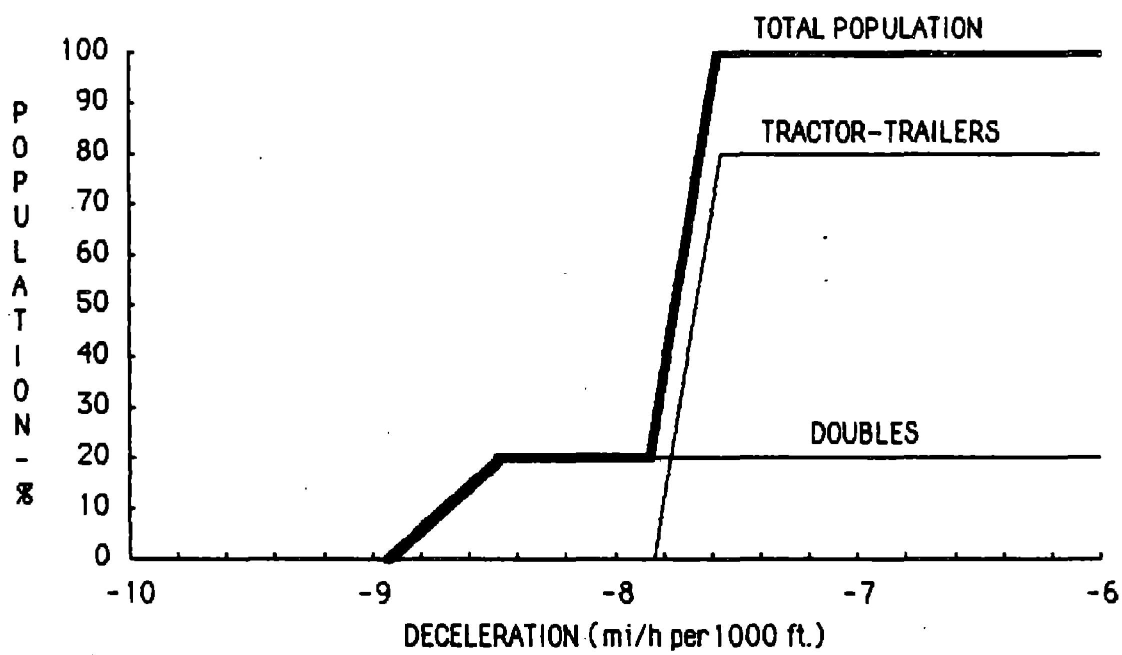


Figure 23c. Deceleration distribution for the total population.

tractor-trailers can then be approximated by drawing a straight line through these points from zero to the 80 percent level on the ordinate.

A similar procedure is used to plot the estimated distribution for the doubles in figure 23b, using the 20 percent level on the ordinate because the doubles represent that fraction of the vehicles. That is, points are established at -8.89 and 2.5 percent (.125 x 20 percent), and at -8.70 and 10 percent (.5 x 20 percent). Then a straight line is drawn through these points from zero to 20 percent.

As the last step, the distribution for the total population is determined by summing values for the doubles and the tractor-trailers at specific levels of deceleration. The resultant curve is the distribution for the total population as shown by the bold line in figure 23c. Now presuming that the need for a climbing lane will be based on the 12.5 percentile decelerations, the 12.5 percentile value from the total population would be used for estimating speed loss at that point on the grade. In this case it will be dominated by the doubles, because the complete population of doubles decelerates more rapidly than the tractor-trailers. The 12.5 percentile for the total vehicle population is equivalent to the 62.5 percentile doubles.

As the speed changes along the grade, the same process must be repeated to estimate spatial decelerations at subsequent points. A similar process is required to estimate the distribution of speeds at the final climbing point.

The process can be simplified somewhat by making some reasonable assumptions and approximations. Presuming the entry speed is 55 mi/h (88 km/h), and a speed drop of 10 mi/h (16 km/h) is the critical value, the calculations can be made for an assumed speed of 50 mi/h (80 km/h). Thence, the resultant deceleration may be assumed correct for that first region of the grade, and the critical length determined on that basis.

The differences between vehicle classes are not so critical when only straight trucks and tractor-trailers are involved because their performance is reasonably comparable. However, trucks with trailers, or doubles represent classes of vehicles with much lower performance. A simple approach would be to design on the basis of the lower performing vehicles, although that could be overly conservative in some cases. If the lower performing vehicles make up more than 12.5 percent of the truck population on the road, then in most cases their spatial deceleration distribution will determine that for the 12.5 percentile level of the total population. However, to determine the 12.5 percentile deceleration properly, the method in figure 23 should be used.

If the lower performing vehicles represent much less than 12.5 percent of the population, then the deceleration distribution for the larger fraction of vehicles will determine the deceleration for the 12.5 percentile level of the population. However, it will occur at the larger class percentile level equivalent to 12.5 minus the percent of the lower performing vehicles.

Once the 12.5 percentile deceleration level has been determined, the critical length of grade is calculated by dividing the acceptable speed reduction (i.e., 10 or 15 mi/h) (16 or 24 km/h) by the deceleration level.

All this presents a rather complicated picture for estimating 12.5 percentile performance of a mixture of truck traffic. The methodology grows even more complicated in the case of arbitrarily varying grade, or cases where different entry speeds would be expected for different classes of vehicles. Simpler rules of thumb can be applied in some cases.

Speed-Distance for Truck and Tractor-Trailer Mixed Traffic

Because of the close similarity of the performance of straight trucks and tractor-trailers, one simplification is to use the speed-distance plots of figure 22a for traffic of this mix. Straight trucks in the East and on Western interstates exhibited somewhat better performance (less speed loss) than indicated here. Thus, the critical lengths of grade determined from this plot will be conservative in these geographic areas. Inasmuch as some judgment must always be applied in the decision-making process, the other appropriate speed-distance plots from figure 22 can be referenced to estimate the range in variation of the "critical length of grade" that might be possible by analysis of the separate vehicle classes. On steep grades (4 to 8 percent), the differences in critical length will be on the order of 100 ft (30 m) or less. Only on the shallow grades (2 to 3 percent) do the differences stretch out to several hundred feet.

A second benefit from using a single plot for both straight trucks and tractor-trailers is that it is not necessary to know beforehand the actual mix of vehicles on the highway. Were one to try to take advantage of the better performance of straight trucks using the method in the previous section, their representation in the traffic mix would have to be estimated.

Final Climbing Speeds

The final climbing speed is of general interest in determining whether climbing lanes are warranted and the impact of grades on traffic speeds and capacity. The final climbing speeds for the 12.5 percentile vehicles will differ by vehicle class. For the case of straight trucks, it has been found that some differences in performance exist depending on road class and geographic locale. However, the presumption of straight truck performance equivalent to that of tractor-trailers is warranted for reducing the complexity of dealing with traffic mixes. In final climbing speeds the difference between the various straight truck limits is on the order of 2 to 3 mi/h (3 to 5 km/h). Thus they are not treated separately in summarizing the final climbing speed results. Table 5 lists the final climbing speeds for the 12.5 percentile vehicles by vehicle class. All straight trucks are assumed to be equivalent to tractor-trailers in this table. Note that on 1.5 percent grades all vehicles can maintain speed within 15 mi/h (24 km/h) of the 55 mi/h (89 km/h) national speed limit with doubles at the limit just marginal for consideration of a climbing lane if the number of vehicles on the road

Table 5. Final climbing speeds (mi/h), 12.5% vehicles.

Grade (%)	Straight Trucks	Trucks with Trailers	Tractor-Trailers	65-ft Doubles	AASHTO
1.5	47.5	42.3	47.5	39.9	----
2	40.3	33.7	40.3	33.8	----
3	30.9	24.0	30.9	25.9	26.5
4	25.0	18.6	25.0	21.0	22.0
5	21.0	15.2	21.0	17.7	18.4
6	18.1	12.8	18.1	15.2	15.5
7	15.9	11.1	15.9	13.4	13.8
8	14.2	9.8	14.2	12.0	12.2
9	12.8	8.8	12.8	10.8	10.6

warrant it. By 2 percent grades, straight trucks and tractor-trailers are down by 15 mi/h (24 km/h), as well. If there is significant representation of trucks with trailers or doubles in the traffic mix the 12.5 percentile speed will be down by more than 15 mi/h (24 km/h).

Estimating a distribution of final climbing speeds is performed in a manner similar to that for the spatial decelerations. Distributions for each vehicle class are constructed from the 12.5 and 50 percentile values, and the distribution for the total population is determined from their sum. For this purpose, table 6 lists the final climbing speeds for the 50 percentile vehicles. The speeds shown for the trucks with trailers are based on W/P_3 values for the West, as was data for the 12.5 percentile speeds shown in table 5.

Table 6. Final climbing speeds (mi/h), 50% vehicles.

Grade (%)	Straight Trucks	Trucks with Trailers (W)	Tractor-Trailers	65-FT Doubles	AASHTO
1.5	50.9	48.0	50.9	44.1	----
2	45.7	41.8	45.7	38.8	----
3	37.8	33.3	37.8	31.3	26.5
4	32.3	27.6	32.3	26.2	22.0
5	28.2	23.6	28.2	22.5	18.4
6	25.0	20.6	25.0	19.7	15.5
7	22.5	18.3	22.5	17.6	13.8
8	20.4	16.4	20.4	15.8	12.2
9	18.7	14.9	18.7	14.4	10.6

CONCLUSIONS AND RECOMMENDATIONS

The main objective in this project was to obtain experimental measurements of the hill-climbing performance of modern trucks, and develop methods for predicting speed loss of the general truck population on arbitrary grades. The data and methods have significance as potential aids in the decision-making process with regard to the need for, and design of, truck climbing lanes. The work has resulted in some significant conclusions with regard to truck performance prediction:

1) The AASHTO curves for speed versus distance on different grades are conservative estimates of truck performance, nominally equivalent to the 12.5 percentile of the lower performing truck classes (trucks with trailers, and doubles). The performance limits for 12.5 percentile straight trucks and tractor-trailers are somewhat higher than the AASHTO values. For these vehicles the final climbing speeds are 2 to 4 mi/h (3 to 6 km/h) higher. The rate of speed loss on grades (spatial decelerations) observed for straight trucks and tractor-trailers was lower than that of the AASHTO speed-distance curves. Thus, the "critical length of grade" indicated in the AASHTO guide is shorter than warranted for these vehicles. On a 6 percent grade the "critical length" based on AASHTO is approximately 100 feet shorter than necessary. On a 3 percent grade it is about 700 feet shorter.

2) Measurable differences in performance were observed among certain truck classes, road classes, and geographic locations. Tractor-trailers exhibited consistent performance throughout the country on both interstate and primary roads. Straight trucks had slightly better performance on primary roads, and on interstates in the West. Trucks pulling trailers and doubles are significantly lower in performance than trucks and tractor-trailers.

3) A simplified means of predicting truck hill-climbing performance was developed based on characterization of the available power for accelerating and overcoming grade (denoted by the symbol "P_3"). The ratio of available power to weight (P_3/W) is speed

dependent, but it provides an easy means for calculating truck speed profiles on arbitrary grades. Appropriate P_3/W ratios, representative of the 12.5 and 50 percentile of most vehicle classes, was determined from the experimental data acquired in the project.

4) The recognition that performance variations exist within vehicle classes, and between vehicle classes, brings to focus a need for more comprehensive methods for decision making on climbing lane design. Minimizing the frequency of trucks operating below a critical speed on the highway network is suggested as the goal in a decision model. The performance of the 12.5 percentile truck in a population has been suggested as a benchmark for conservatively estimating critical length of grade. Methods for determining performance of the 12.5 percentile vehicle in a mixed population of truck classes is provided.

Although the project was successful at answering many of the questions posed at the outset, and clarifying many of the issues involved, it has become obvious that there are many areas of need for data and methodology by which to refine the climbing-lane design process. Extensive data were obtained on tractor-trailer vehicles and reasonable samples were obtained for straight trucks. The homogeneity observed with tractor-trailer vehicles suggests that their characterization is well founded. The more limited data on trucks, and the differences observed on interstate and primary highways would argue that more experimental data should be acquired to refine the estimates of their performance limits. In the meantime, it is recommended that the speed-distance relationships for the 12.5 percentile vehicle given in figure 22a be used for prediction of straight truck and tractor-trailer performance. This figure should be considered as an alternative to the AASHTO speed-distance curves on roads where essentially all truck traffic is of these two classes.

The data on straight trucks pulling trailers, and doubles and triples are so limited that the performance limits determined here should be taken only as estimates of the population as a whole. More experimental data on these particular vehicle classes are warranted before performance limits can be confidently assessed. The speed loss on grade for the 12.5 percentile of both of these vehicle classes appears comparable to that in the current AASHTO guide. Thus, the AASHTO is still appropriate for characterizing these vehicles, pending more experimental data to improve predictions of their performance. For optimal design, the AASHTO guidelines should not be applied casually to highways simply because truck traffic of these vehicle classes is present. Consideration of the performance for the overall traffic mix may allow a longer critical length of grade at the 12.5 percentile performance level.

The characterization of performance within truck and road classes, as has been determined in this work, results in a more complex decision-making process for the rational design of climbing lanes. There is need for improved methodology to guide the decision-making process which properly considers the distribution of vehicle performance on a grade. Insights from this work have been suggested. The notion that the goal in the decision process is to minimize the frequency of encounters with low-speed trucks in a highway network points to the need for treatment from a probabilistic approach. The 12.5 and 50 percentile performance levels, plus the observation that deceleration distributions are approximately linear, provides a basis for describing the distributions of performance among vehicles. Further research in this area is recommended.

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APPENDIX A

FIELD DATA COLLECTION ON HILL-CLIMBING PERFORMANCE

The objective of the field data collection exercise was to acquire data on a variety of trucks throughout the country, by which to characterize their hill-climbing performance. A primary interest was to determine whether their performance was variable with geographic location within the country, and with road type. That objective dictates that field measurements be carried out in various regions of the country. Yet, a truly random sample throughout the country is not economically feasible. Instead, a purposeful random sampling method was used.

Sites

In the purposeful sample, sites were selected to achieve stratification in the variables of geography, interstate/primary road classes, and urban/rural locations. Inasmuch as long grades greater than 2 percent in slope are required to get measurements that include a final climbing speed condition, the sites are necessarily going to be located primarily in the eastern and western mountain regions.

Inquiries were sent to state highway departments and transportation agencies in both regions requesting candidate sites for measurement. Respondees were requested to complete a data form on each proposed site covering such essentials as route, location, road classification, grade, average daily truck traffic, number of lanes, and roadside conditions. Also, candidate sites in close proximity to a truck weigh station were requested to allow collection of more detailed data on truck parameters at these sites.

State personnel proved very cooperative and provided lists of approximately 100 sites. These were reviewed and site selections were made to obtain a balanced representation at each level of stratification. Thus 10 Eastern and 10 Western sites were chosen, including 2 weigh scale sites in each region. The eight remaining sites in each region were then chosen to provide two sites each in the categories of:

- Interstate urban
- Interstate rural
- Primary urban
- Primary rural

In the selection process, consideration was given to obtaining representation of grades over the range of 3 to 8 percent; and preference was given to sites for which an alternate was located in close proximity. The identification of alternate sites in close proximity proved to be an advantageous feature for this type of operation, as many of the selected sites often proved unsatisfactory from the standpoint of visibility, traffic interferences from on-ramps, etc. Overall, many of the sites that were first choice were not used, and suitable sites with grades above 6 percent were not found. The list of sites where data were collected is provided in table 7. The interpretation of what constitutes an urban site, in contrast to a rural site, leaves much room for judgment. In the descriptions shown, those indicated as urban sites were not just close to a city, but also carried what appeared to be local traffic. Only four sites closely matched this intention. Although that disrupts the balance of rural/urban samples, they were balanced in that two each were in the East and West, and a primary and interstate road was obtained in each case. In the original plan, it was the intention as well to try and classify traffic in the local/long distance categories. As it turned out, the state personnel had no information of this nature, and it was not possible to classify thusly in the data collection, so that objective had to be dropped.

Table 7. List of sites for truck hill-climbing performance measures.

Route	Nearest city	Location	Weigh Scales	Grade(%)[1]
I-81	Hazelton, PA	Rural		2.4, 2.5, 3.6
I-80	Milesburg, PA	Rural		3.3, 3.5, 2.9
I-64	Waynesboro, VA	Rural		2.5, 2.9, 3.9
I-77	Wytheville, VA	Rural	X	4.0, 4.0, 4.0
I-70	Wheeling, WV	Urban		4.7, 5.1, 5.0
I-48	Cheat Lake, WV	Rural		6.1, 6.4, 6.1
I-8	Coyote, CA	Rural		5.2, 5.3, 5.9
I-17	Camp Verde, AZ	Rural		2.8, 3.2, 4.8
I-25	Trinidad, CO	Rural	X	4.5, 5.2, 6.4
I-70	Denver, CO	Urban		4.6, 5.9, 6.2
I-84	Bliss, ID	Rural	X	3.1, 4.0, 4.0
I-80	Wells, NV	Rural		5.4, 4.7, 5.3
SR22	Duncansville, PA	Rural		4.7, 5.8, 4.9
SR12	Utica, NY	Urban		4.7, 4.9, 5.0
SR15	Blossburg, PA	Rural	X	6.3, 4.7, 5.8
SR23E	Bean Station, TN	Rural		5.1, 4.9, 4.4
SR152	San Luis, CA	Rural		4.9, 4.9, 5.9
SR87	Payson, AZ	Rural		5.8, 6.1, 5.9
SR44	Bernallilo, NM	Rural		3.3, 3.4, 3.8
US395	Carson City, NV	Urban		5.6, 5.7, 5.8

[1]For Traps 1 and 2, Traps 2 and 3, and at Final Climbing location

Data Collection Procedures

For this experiment, procedures were used by which individual trucks could be tracked thoughout their climb up the grade. Philosophically, the intent was to obtain samples of vehicle speed over the initial portion of the grade where the first 10 to 20 mph (16 to 32 km/h) was lost, and then catch the final climbing speed of the vehicle. No attempt was made to observe the actual entry speed into the grade (at the level tangent point), because it was desired that the trucks be under full power during all measurements. Thus, first measurements were obtained at a distance of 500 to 1,000 ft (152 to 305 m) up the grade, where the experimenters were assured that the engine was fully applied.

For reliability over these multi-week expeditions, tapeswitch speed traps were devised for the speed measurements in the initial portion of the grade. Radar was excluded at the entry region of the grade for fear that it would cause drivers (especially those at higher speeds) to voluntarily slow down. Radar was used for final climbing speed measurements (typically a mile further up the road) because driving patterns would not be influenced at this point.

A typical site layout is illustrated in figure 24. Three speed measurement traps were placed in the initial part of the grade. An instrumentation van was located at approximately the midpoint of the three traps. Wires connected each of the tapeswitches to a timer system located in the van. Each trap consisted of two tapeswitches placed 40 ft (12 m) apart--far enough that measurement errors due to inaccuracies in placement were negligible, yet, not so far that other vehicles could interfere with the measurement. The traps were separated by a distance of 900 to 1000 ft (274 to 305 m). Average grades between the traps were measured with a surveyor's transit. At a point much farther up the hill where grade was constant, and the vehicles appeared to be settled into a final climbing speed, an experimenter was stationed with a radar to measure that speed.

The data collection procedure specified that the first truck (a vehicle with at least one axle with dual wheels) entering the traps,

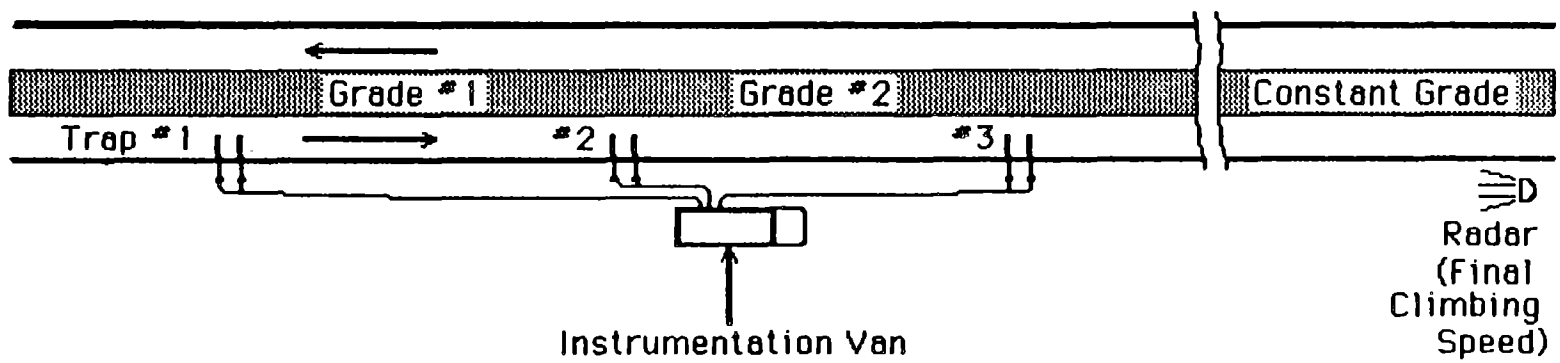

Figure 24. Typical Site Layout.

when the experimenters were free to accept a vehicle, be taken. This was done to avoid biasing the data by the natural tendency to always take a larger truck when two choices are presented. The tapeswitch traps were "armed" as the truck approached, and the travel time through the trap was measured and recorded. The vehicle was visually tracked, and the time (speed) to travel across each of the subsequent traps was measured similarly. As the vehicle passed, the experimenters noted the type of vehicle (number of axles, number of units, and size) and color and make identification of the power unit. Figure 25 shows the data entered for each vehicle. Prominent identification features of the vehicle were listed in the description. The number of units established whether it was a truck, truck with trailer, tractor-semitrailer, double and triple combination. The gross body size (in front silhouette view) was indicated as maximum, intermediate, or minimum. The number of axles on each unit, and whether a trailer was long (generally over 30 ft [9 m]) or short was entered in the appropriate location. The descriptive information on each vehicle was transmitted via radio link to the observer in the final climbing area. When the vehicle passed that area, the final climbing speed was reported back on the radio and entered on the data sheet. Thus three speeds during the initial deceleration phase (derived from the times T1, T2, and T3) and a final climbing speed (V_{ss}) were measured for each truck, along with its identification and classification. With this procedure the same sample of trucks was always represented in measurements at each point on the grade.

Because of the length of grade required, at least two uphill lanes were present at nearly every site. As a consequence, some trucks (generally those with better hill-climbing capability) would take the left-hand lane precluding measurement. When time permitted, the experimenter at the uphill location would take a 100 percent classification sample for some period of the day to get an idea of the number of vehicles being missed in the measurements. Depending on location, the sampling captured from 60 to 90 percent of the trucks passing the site. There did not appear to be any strong bias in the distribution of trucks among classes as a result of those vehicles that were missed. Figure 26 shows the distribution of the total population

---

\# ____ Descr. ____ Time ________

Unit #1 **No. of Axles** _____ ____ Tractor ____ COE
____ Straight truck ____ Conv
____ Dromedary

Unit #2 **No. of Axles** _____ ____ Semi ____ Max
____ Full trailer ____ Interm. ____ Long
____ Min ____ Short

Unit #3 **No. of Axles** _____ **Unit #4** **No. of Axles** _____
____ Max ____ Long ____ Max ____ Long
____ Interm. ____ Short ____ Interm. ____ Short
____ Min ____ Min

T1 = ________ **T2 =** ________ **T3 =** ________ V_{ss} = ________

Figure 25. Data recording form used at the uphill measurement sites.

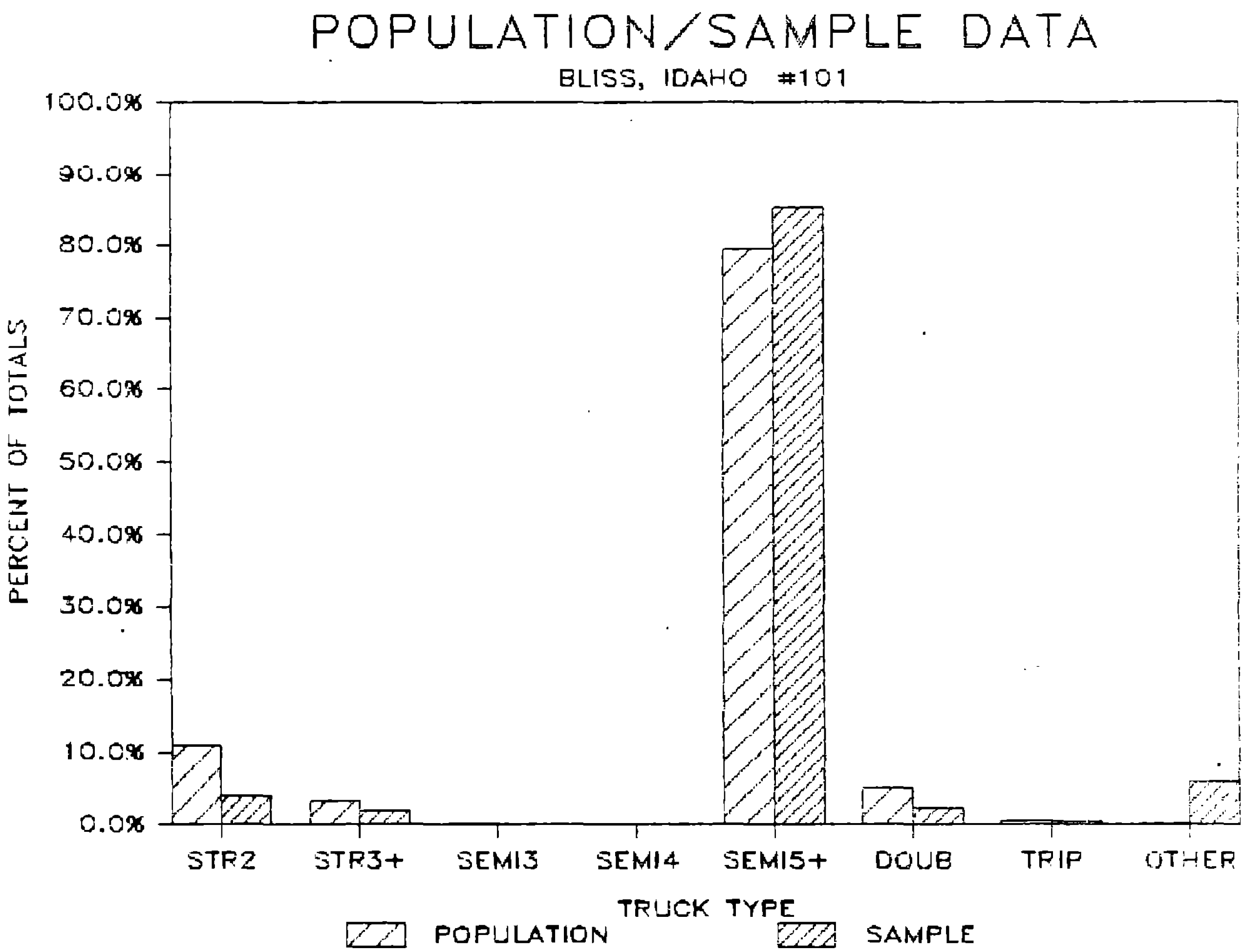

Figure 26a . Total population and sampled population obtained at Bliss site.

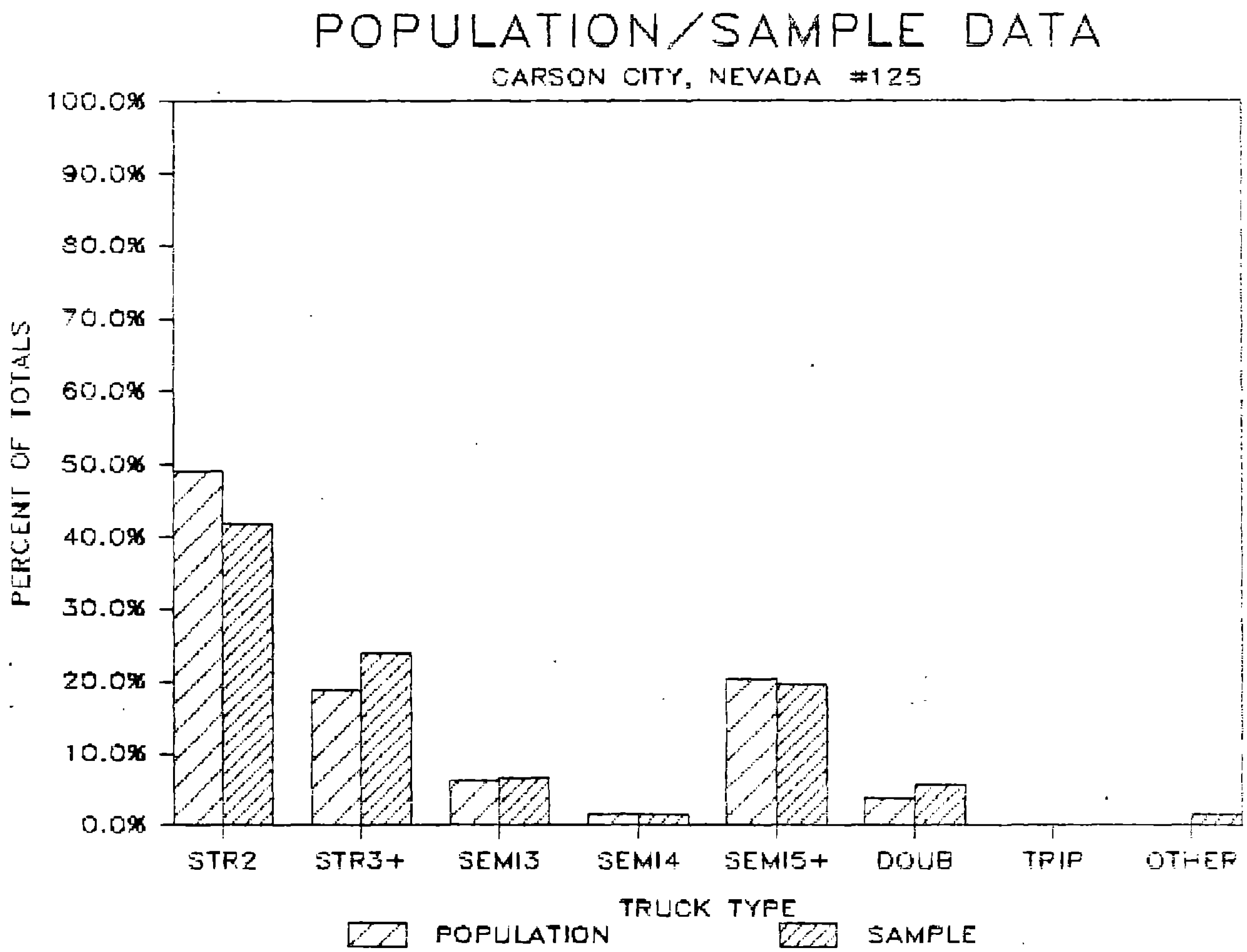

Figure 26b. Total population and sampled population obtained at Carson City site.

by truck class passing the site and the distribution of the sampled vehicles for a rural interstate site in Idaho and an urban primary road site in Nevada. The coding on the abscissa identifies the vehicles by straight truck (STR), tractor-semitrailer (SEMI), doubles (DOUB) and triples (TRIP), with the number of axles indicated by the numeral following the abbreviation. The charts illustrate that the sample population very closely matched the total population by truck class. Comparing the two charts gives an overview of the way in which the types of trucks vary by location. Traffic on the rural interstate site is dominated by five-axle tractor-trailers, presumably representing long distance transport. The urban primary route was selected specifically because of the expectation of a different traffic mix in such locations, borne out by the high percentage of straight trucks seen in the chart.

Data were collected at each site until a total of 200 or more trucks were sampled, expecting to obtain a reasonable number in each truck class. Normally two long days were required at each site. When completed, all data were reviewed and checked for errors or inconsistencies. On all except the urban sites, tractor-trailers dominated the sampling numerically, with most of these of the five-axle type. Although the number of straight trucks sampled was marginal in many cases, no effort was made to alter this situation because of the desire to have a "random" sample at each site.

At some point in the test operations at a site, a site survey was made recording relevant geometric information about the site. The distances identifying the speed trap locations were recorded and a surveyor's transit was used to determine the average vertical angle between traps and at the top of the hill.

At the weigh scale sites, additional data was obtained. An observer was stationed at the scale to obtain the gross vehicle weight on all vehicles passing through. The observer inquired of the driver as to the engine horsepower, and noted the vehicle size, identification, types of tires (bias or radial) and what, if any, aerodynamic aids were present on the vehicle. At the end of each day the data sheets from the weigh scale and the measurements on grade were compared, and the individual trucks were matched by identification and time. The procedure proved very successful, generally matching 90-95 percent of the vehicles. Thus for these sites, hill-climbing performance and truck weight and power data were available.

On return to UMTRI, the data were entered into computer files for subsequent processing and analysis.

APPENDIX B

SUMMARY OF FIELD DATA

The following pages provide a summary of the data on truck performance collected at the field sites. Each page covers a separate site, identified by name on the first line. The second line lists

a) The distance (in feet) between the first and second, and between the second and third speed measurement points, and

b) The grades (%/100) in each of the first two deceleration intervals and at the final climbing point.

The first page for each site provides data summaries for three classes of vehicles--straight trucks, trucks with trailers, and tractor-trailers. On the second page a summmary is provided for the various types of doubles and triples. The distinctions relate to whether the trailers are "long" (40 to 45 ft [13 to 14 m]) or "short" (27 to 28 ft [8 to 9 m]). The classes are divided into 65-ft doubles (a tractor with 2 short trailers), Rocky Mountain doubles (a long and a short trailer), turnpike doubles (2 long trailers), and triples (3 short trailers). Under each class the first group of information indicates the speeds (ft/sec and mi/h) at the 12.5% and median (50%) level. The number in parenthesis is the number of data samples. The second summary group under each vehicle class is the calculated weight-to-power values, derived from the speeds compiled previously. If there was insufficient sample size to permit these calculations, the weight-to-power summary is omitted.

MILESBURG

900.0000	900.0000	0.0326	0.0346	0.0290

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(37)	56.5039	38.52539	69.26453	47.22582
Trap 2 ---	(37)	52.67663	35.91588	64	43.63637
Trap 3 ---	(35)	50.1785	34.21261	63.33697	43.1843
Fnl Clmbg--	(35)	46.01667	31.375	57.2	39

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	397.1622	354.7169	412.376
At MPH of	37.22064	35.06425	31.375
Median Weight/Power	403.1846	260.7745	331.7512
At MPH of	45.43109	43.41033	39

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(169)	58.60828	39.96019	77.6702	52.95696
Trap 2 ---	(168)	55.94406	38.14368	74.76635	50.97706
Trap 3 ---	(165)	54.60353	37.22968	71.87787	49.00764
Fnl Clmbg--	(164)	49.13333	33.5	64.53333	44

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	351.5946	310.6978	386.2178
At MPH of	39.05193	37.68668	33.5
Median Weight/Power	289.3399	275.0206	294.0522
At MPH of	51.96701	49.99235	44

MILESBURG

900.00000	900.00000	0.03258	0.03458	0.02898

65 foot Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(15)	64.15653	43.74309	68.43501	46.66023
Trap 2 ---	(14)	57.90918	39.48353	61.53847	41.95804
Trap 3 ---	(15)	54.78316	37.35216	59.81332	40.78181
Fnl Clmbg--	(15)	45.28333	30.875	52.06667	35.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	464.034	342.434	419.0541
At MPH of	41.61331	38.41784	30.875
Median Weight/Power	494.5854	292.6787	364.459
At MPH of	44.30914	41.36992	35.5

Rocky Mountain Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

HAZELTON

900.0000	900.0000	0.0244	0.0250	0.0363

Trucks	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(33)	70.8279	48.29175	79.44397	54.16635
Trap 2 ---	(33)	69.07489	47.09651	76.41053	52.09809
Trap 3 ---	(33)	69.61345	47.46372	77.44441	52.80301
Fnl Clmbg--	(33)	54.81667	37.375	73.33334	50

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	390.2682	301.8361	276.0648
At MPH of	47.69413	47.28012	37.375
Median Weight/Power	435.104	257.7996	206.3585
At MPH of	53.13222	52.45055	50

Trucks with trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(2)	0	0	77.66991	52.95675
Trap 2 ---	(2)	0	0	70.29877	47.93097
Trap 3 ---	(2)	0	0	72.85974	49.6771
Fnl Clmbg--	(2)	0	0	64.53333	44

Tractor trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(162)	76.33588	52.04719	84.38818	57.5374
Trap 2 ---	(164)	72.99271	49.76776	79.68128	54.32814
Trap 3 ---	(162)	70.29943	47.93143	77.82101	53.05978
Fnl Clmbg--	(159)	46.93334	32	63.06667	43

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	467.2667	418.7971	322.4351
At MPH of	50.90747	48.84959	32
Median Weight/Power	606.5193	350.3654	239.9517
At MPH of	55.93278	53.69396	43

HAZELTON

900.00000	900.00000	0.02438	0.02499	0.03634

65 foot Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(11)	77.32202	52.71956	82.81893	56.46745
Trap 2 ---	(15)	70.92101	48.35524	77.29533	52.70137
Trap 3 ---	(15)	66.90814	45.61918	73.93816	50.41239
Fnl Clmbg--	(15)	42.35	28.875	44	30

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	926.7988	516.6955	357.3307
At MPH of	50.5374	46.98721	28.875
Median Weight/Power	753.3721	448.1832	343.9308
At MPH of	54.58441	51.55688	30

Rocky Mountain Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

WAYNESBORO

900.0000	900.0000	0.0250	0.0294	0.0393

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(62)	72.07486	49.14195	80	54.54546
Trap 2 ---	(62)	69.56521	47.43083	78.89546	53.79236
Trap 3 ---	(61)	62.56399	42.65727	76.84983	52.39761
Fnl Clmbg--	(60)	38.86667	26.5	61.6	42

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	411.8731	620.1473	360.3099
At MPH of	48.28639	45.04405	26.5
Median Weight/Power	315.2366	295.6627	227.3384
At MPH of	54.16891	53.09498	42

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(5)	76.69241	52.29029	83.09389	56.65492
Trap 2 ---	(5)	74.1177	50.5348	82.31708	56.12528
Trap 3 ---	(4)	70.95047	48.37532	80.32129	54.76452
Fnl Clmbg--	(5)	44.91667	30.625	62.33334	42.50001

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	398.8082	353.3764	311.7784
At MPH of	51.41254	49.45506	30.625
Median Weight/Power	292.033	284.3625	224.6638
At MPH of	56.3901	55.4449	42.50001

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(143)	75.02935	51.15637	81.54953	55.60195
Trap 2 ---	(143)	72.2678	49.2735	78.81781	53.73942
Trap 3 ---	(143)	67.99838	46.36254	76.70189	52.29674
Fnl Clmbg--	(143)	39.6	27	52.8	36

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	415.562	411.6065	353.6375
At MPH of	50.21494	47.81802	27
Median Weight/Power	393.5223	298.3474	265.2282
At MPH of	54.67068	53.01808	36

WAYNESBORO

900.00000	900.00000	0.02499	0.02938	0.03927

65 foot Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(2)	19.53125	13.31676	78.125	53.26705
Trap 2 ---	(2)	18.93939	12.91322	75.75758	51.65289
Trap 3 ---	(2)	18.11594	12.35178	72.46377	49.40712
Fnl Clmbg--	(2)	12.46667	8.5	49.86667	34

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	1162.524	1028.651	1123.319
At MPH of	13.11499	12.6325	8.5
Median Weight/Power	382.1968	354.0429	280.8298
At MPH of	52.45997	50.53	34

Rocky Mountain Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

WYTHEVILLE

900.0000	900.0000	0.0399	0.0396	0.0396

Trucks	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(30)	70.41179	48.00804	82.81574	56.46528
Trap 2 ---	(30)	66.49845	45.33985	76.48184	52.14671
Trap 3 ---	(29)	64.01926	43.6495	74.3497	50.69298
Fnl Clmbg--	(30)	52.8	36	67.46667	46

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	262.3637	247.9689	263.2411
At MPH of	46.67395	44.49468	36
Median Weight/Power	307.4612	214.3567	206.0148
At MPH of	54.30599	51.41985	46

Trucks with trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(2)	0	0	70.17544	47.84689
Trap 2 ---	(2)	0	0	67.00168	45.68296
Trap 3 ---	(2)	0	0	63.79586	43.49718
Fnl Clmbg--	(2)	0	0	44	30

Tractor trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(199)	73.80074	50.31868	81.30081	55.43237
Trap 2 ---	(197)	63.82145	43.51463	74.1428	50.5519
Trap 3 ---	(198)	57.30659	39.07268	68.84682	46.94102
Fnl Clmbg--	(199)	41.06667	28	54.26667	37

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	494.2392	349.8771	338.4529
At MPH of	46.91666	41.29365	28
Median Weight/Power	342.3556	290.2373	256.1265
At MPH of	52.99214	48.74646	37

WYTHEVILLE

900.00000	900.00000	0.03987	0.03957	0.03957

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(1)	9.615385	6.555945	38.46154	26.22378
Trap 2 ---	(1)	8.064516	5.498534	32.25807	21.99414
Trap 3 ---	(1)	6.849315	4.669987	27.39726	18.67995
Fnl Clmbg--	(1)	.3666667	.25	1.466667	1

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	1579.358	1878.771	37906.73
At MPH of	6.027239	5.084261	.25
Median Weight/Power	481.5878	533.4225	9476.682
At MPH of	24.10896	20.33704	1

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

WHEELING

1100.00000	800.00000	0.04653	0.05089	0.05000

Trucks	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (11)	62.50947	42.62009	72.27646	49.27941
Trap 2 --- (12)	43.34057	29.55039	62.1311	42.36211
Trap 3 --- (12)	27.33659	18.63859	55.55556	37.87879
Fnl Clmbg--(12)	35.93334	24.5	46.93334	32

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	581.0395	537.967	306.1433
At MPH of	36.08524	24.09449	24.5
Median Weight/Power	300.0188	260.6116	234.3909
At MPH of	45.82076	40.12045	32

Trucks with trailers	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (3)	0	0	66.78969	45.53843
Trap 2 --- (3)	0	0	57.71606	39.35186
Trap 3 --- (3)	0	0	49.39738	33.68003
Fnl Clmbg--(3)	0	0	44.73334	30.5

Tractor trailers	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (155)	66.65985	45.4499	75.25166	51.30795
Trap 2 --- (168)	50.88412	34.69372	59.04931	40.26089
Trap 3 --- (170)	41.12479	28.03963	51.24264	34.93816
Fnl Clmbg--(161)	35.2	24	44	30

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	459.8351	357.341	312.5213
At MPH of	40.07181	31.36667	24
Median Weight/Power	518.0385	291.8515	250.017
At MPH of	45.78442	37.59952	30

WHEELING

1100.00000	800.00000	0.04653	0.05089	0.05000

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(11)	66.3055	45.2083	74.07457	50.50539
Trap 2 ---	(10)	49.42805	33.70094	56.7215	38.67375
Trap 3 ---	(11)	40.25049	27.44351	46.88435	31.9666
Fnl Clmbg--	(11)	34.28333	23.375	38.13334	26

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	501.4433	351.3561	320.8775
At MPH of	39.45462	30.57223	23.375
Median Weight/Power	580.495	341.353	288.4812
At MPH of	44.58957	35.32018	26

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

CHEAT LAKE

780.00000	710.00000	0.06104	0.06383	0.06104

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(49)	59.58862	40.6286	77.59514	52.90578
Trap 2 ---	(48)	48.93565	33.36522	69.61365	47.46385
Trap 3 ---	(49)	40.871	27.86659	64.77839	44.16709
Fnl Clmbg--	(49)	35.2	24	59.4	40.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	266.5348	255.2251	255.9627
At MPH of	36.99691	30.6159	24
Median Weight/Power	198.4503	164.9567	151.6816
At MPH of	50.18482	45.81547	40.5

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(6)	62.93663	42.91134	77.33953	52.7315
Trap 2 ---	(6)	53.89187	36.74446	57.92904	39.49707
Trap 3 ---	(6)	34.57122	23.57128	49.51721	33.76174
Fnl Clmbg--	(6)	6.049999	4.124999	44	30

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	235.341	470.1	1489.238
At MPH of	39.8279	30.15787	4.124999
Median Weight/Power	926.8251	232.3361	204.7702
At MPH of	46.11428	36.6294	30

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(153)	68.37914	46.62214	78.42368	53.47069
Trap 2 ---	(158)	54.83979	37.39077	66.78911	45.53803
Trap 3 ---	(159)	43.24961	29.48837	55.47923	37.82675
Fnl Clmbg--	(158)	33.36667	22.75	45.46667	31

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	320.7522	287.788	270.0266
At MPH of	42.00646	33.43957	22.75
Median Weight/Power	276.359	267.854	198.1647
At MPH of	49.50436	41.68239	31

CHEAT LAKE

780.00000	710.00000	0.06104	0.06383	0.06104

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(6)	43.45937	29.63139	68.59886	46.77195
Trap 2 ---	(6)	29.79146	20.31236	53.01525	36.14676
Trap 3 ---	(6)	21.84996	14.8977	39.92016	27.21829
Fnl Clmbg--	(6)	20.9	14.25	30.8	21

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	365.2606	388.2625	431.0951
At MPH of	24.97187	17.60503	14.25
Median Weight/Power	387.9419	318.0505	292.5288
At MPH of	41.45936	31.68252	21

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

BLISS

1000.00000	1000.00000	0.03106	0.04030	0.04030

Trucks	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(15)	68.12126	46.44631	82.66721	56.36401
Trap 2 ---	(15)	62.92365	42.90249	78.81781	53.73942
Trap 3 ---	(15)	54.26264	36.99725	75.40599	51.41318
Fnl Clmbg--	(14)	50.6	34.5	71.86667	49

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	409.8032	382.4606	269.6948
At MPH of	44.6744	39.94987	34.5
Median Weight/Power	318.2021	221.9702	189.8871
At MPH of	55.05171	52.5763	49

Trucks with trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(12)	74.66401	50.90728	87.14598	59.41771
Trap 2 ---	(12)	66.52295	45.35656	82.81574	56.46528
Trap 3 ---	(12)	56.30976	38.39301	77.97271	53.16321
Fnl Clmbg--	(12)	44	30	71.86667	49

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	589.717	430.0626	310.149
At MPH of	48.13191	41.87478	30
Median Weight/Power	329.6783	242.4994	189.8871
At MPH of	57.94149	54.81425	49

Tractor trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(199)	78.23975	53.34528	85.83691	58.52517
Trap 2 ---	(204)	73.19311	49.90439	81.63265	55.65862
Trap 3 ---	(200)	64.41224	43.91744	74.62686	50.88195
Fnl Clmbg--	(201)	50.05	34.125	63.06667	43

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	378.4744	371.1026	272.6584
At MPH of	51.62484	46.91091	34.125
Median Weight/Power	326.3526	302.07	216.383
At MPH of	57.09191	53.27029	43

BLISS

1000.00000	1000.00000	0.03106	0.04030	0.04030

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(12)	79.05138	53.89867	83.85745	57.17553
Trap 2 ---	(12)	73.66483	50.22602	80.16032	54.65476
Trap 3 ---	(12)	60.78705	41.44571	69.56521	47.43083
Fnl Clmbg--	(12)	46.2	31.5	55.73334	38

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	393.9014	609.7542	295.38
At MPH of	52.06235	45.83587	31.5
Median Weight/Power	309.8662	468.8331	244.8545
At MPH of	55.91515	51.04279	38

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(3)	33.18584	22.62671	90.33073	61.58914
Trap 2 ---	(3)	28.03738	19.1164	79.04985	53.89762
Trap 3 ---	(3)	25.12563	17.13111	74.5686	50.84223
Fnl Clmbg--	(3)	20.9	14.25	68.2	46.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	686.6801	545.9456	652.9452
At MPH of	20.87155	18.12375	14.25
Median Weight/Power	4674.376	241.7997	200.0961
At MPH of	57.74338	52.36992	46.5

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(1)	9.363296	6.384066	37.45319	25.53626
Trap 2 ---	(1)	8.417509	5.739211	33.67004	22.95684
Trap 3 ---	(1)	6.887052	4.695718	27.54821	18.78287
Fnl Clmbg--	(1)	8.983334	6.125	35.93334	24.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	2008.688	1799.572	1519.097
At MPH of	6.061639	5.217464	6.125
Median Weight/Power	575.3448	521.0701	379.7742
At MPH of	24.24655	20.86986	24.5

CAMP VERDE

1000.00000	1000.00000	0.02762	0.03198	0.04754

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(45)	72.11001	49.16592	79.12966	53.95204
Trap 2 ---	(45)	71.24534	48.57637	77.29822	52.70333
Trap 3 ---	(45)	67.7536	46.19563	76.40941	52.09733
Fnl Clmbg--	(42)	51.33333	35	64.53333	44

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	298.5903	323.7016	225.3799
At MPH of	48.87114	47.386	35
Median Weight/Power	303.4375	239.6449	179.2794
At MPH of	53.32768	52.40032	44

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(21)	70.70776	48.20984	80.40274	54.82005
Trap 2 ---	(21)	66.66648	45.45442	78.20324	53.32039
Trap 3 ---	(21)	59.89223	40.83561	73.19311	49.90439
Fnl Clmbg--	(21)	38.5	26.25	57.2	39

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	421.3851	465.5059	300.5065
At MPH of	46.83213	43.14502	26.25
Median Weight/Power	312.3218	359.5833	202.264
At MPH of	54.07023	51.61239	39

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(117)	78.52768	53.5416	85.47009	58.27506
Trap 2 ---	(117)	73.69899	50.24932	82.90165	56.52385
Trap 3 ---	(117)	68.80245	46.91076	78.89546	53.79236
Fnl Clmbg--	(117)	39.6	27	51.33333	35

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	445.8028	364.9881	292.1591
At MPH of	51.89545	48.58003	27
Median Weight/Power	312.4735	310.1704	225.3799
At MPH of	57.39945	55.15811	35

CAMP VERDE

1000.00000	1000.00000	0.02762	0.03198	0.04754

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(26)	77.55701	52.87979	81.1359	55.31994
Trap 2 ---	(26)	70.61049	48.14352	76.19048	51.94805
Trap 3 ---	(26)	63.19545	43.08781	68.61063	46.77998
Fnl Clmbg--	(26)	32.63333	22.25	41.06667	28

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	637.755	495.9014	354.5301
At MPH of	50.51165	45.61566	22.25
Median Weight/Power	449.8801	508.4393	281.7248
At MPH of	53.634	49.36402	28

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(1)	9.861932	6.724045	39.44773	26.89618
Trap 2 ---	(1)	8.532423	5.817561	34.12969	23.27025
Trap 3 ---	(1)	7.575757	5.165289	30.30303	20.66116
Fnl Clmbg--	(1)	4.033333	2.75	16.13333	11

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	2195.073	2151.165	2868.471
At MPH of	6.270804	5.491425	2.75
Median Weight/Power	693.8394	606.3501	717.1178
At MPH of	25.08322	21.9657	11

WELLS

880.00000 1000.00000 0.05350 0.04681 0.05263

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(28)	57.51927	39.21768	78.58546	53.581
Trap 2 ---	(28)	54.20542	36.95824	73.5294	50.13368
Trap 3 ---	(28)	46.02003	31.37729	68.72851	46.86035
Fnl Clmbg--	(27)	38.68334	26.375	56.46667	38.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	209.6298	322.16	270.1586
At MPH of	38.08796	34.16777	26.375
Median Weight/Power	181.1075	213.5938	185.0762
At MPH of	51.85735	48.49701	38.5

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(17)	43.81882	29.87647	65.83072	44.88458
Trap 2 ---	(18)	39.47213	26.91281	62.3053	42.48088
Trap 3 ---	(18)	31.45032	21.4434	50.25126	34.26222
Fnl Clmbg--	(18)	28.23333	19.25	35.2	24

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	280.3295	408.4522	370.1524
At MPH of	28.39464	24.17811	19.25
Median Weight/Power	188.5541	379.6923	296.893
At MPH of	43.68273	38.37155	24

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(148)	61.58675	41.99096	72.07207	49.14005
Trap 2 ---	(148)	56.25924	38.35857	66.88963	45.60657
Trap 3 ---	(148)	46.02999	31.38408	58.65103	39.98934
Fnl Clmbg--	(148)	35.2	24	44	30

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	220.035	351.9027	296.893
At MPH of	40.17477	34.87132	24
Median Weight/Power	194.0528	284.98	237.5145
At MPH of	47.37331	42.79796	30

WELLS

880.00000	1000.00000	0.05350	0.04681	0.05263

65 foot Doubles	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (5)	37.03704	25.25253	60.44282	41.21102
Trap 2 --- (5)	31.84713	21.71396	56.46206	38.49686
Trap 3 --- (5)	26.65245	18.17213	45.70552	31.16286
Fnl Clmbg--(5)	20.16667	13.75	33.73333	23

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	338.3839	446.7688	518.2134
At MPH of	23.48324	19.94304	13.75
Median Weight/Power	207.7667	362.0021	309.8015
At MPH of	39.85394	34.82986	23

Rocky Mountain Doubles	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (5)	26.09604	17.79275	46.48726	31.69586
Trap 2 --- (5)	20.81599	14.19272	40.59251	27.67671
Trap 3 --- (5)	17.61804	12.0123	30.56118	20.83716
Fnl Clmbg--(5)	15.58333	10.625	25.66667	17.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	477.2769	637.4541	670.629
At MPH of	15.99273	13.10251	10.625
Median Weight/Power	284.237	432.7567	407.1676
At MPH of	29.68628	24.25694	17.5

Turnpike Doubles	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (0)	0	0	0	0
Trap 2 --- (0)	0	0	0	0
Trap 3 --- (0)	0	0	0	0
Fnl Clmbg--(0)	0	0	0	0

Triples	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (10)	38.55382	26.28669	50.63291	34.52244
Trap 2 --- (10)	30.7995	20.99966	41.58004	28.35003
Trap 3 --- (10)	26.73069	18.22547	32.38867	22.08318
Fnl Clmbg--(10)	23.46667	16	27.86667	19

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	360.3889	442.8904	445.3396
At MPH of	23.64318	19.61256	16
Median Weight/Power	307.6879	410.2435	375.0228
At MPH of	31.43624	25.2166	19

COYOTE

900.00000	900.00000	0.05233	0.05320	0.05930

Trucks	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(55)	56.49471	38.51912	70.05255	47.7631
Trap 2 ---	(75)	47.29577	32.24712	64.62053	44.05945
Trap 3 ---	(75)	46.01077	31.37098	61.20891	41.73335
Fnl Clmbg--	(73)	45.65	31.125	60.13334	41

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	295.5514	230.5493	203.1667
At MPH of	35.38312	31.80905	31.125
Median Weight/Power	205.6867	190.8859	154.2333
At MPH of	45.91127	42.8964	41

Trucks with trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(16)	45.45455	30.99174	58.73715	40.04806
Trap 2 ---	(22)	36.98432	25.21658	48.48485	33.05785
Trap 3 ---	(22)	32.95428	22.46883	48.48485	33.05785
Fnl Clmbg--	(22)	32.26667	22	39.6	27

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	331.2242	325.36	287.4347
At MPH of	28.10416	23.84271	22
Median Weight/Power	307.4709	213.2144	234.2061
At MPH of	36.55295	33.05785	27

Tractor trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(69)	46.78459	31.89858	63.59445	43.35985
Trap 2 ---	(85)	37.55592	25.60631	56.89947	38.79509
Trap 3 ---	(83)	35.0685	23.91034	52.39051	35.7208
Fnl Clmbg--	(85)	35.2	24	52.8	36

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	335.2536	302.4039	263.4818
At MPH of	28.75244	24.75832	24
Median Weight/Power	237.6514	225.1602	175.6545
At MPH of	41.07747	37.25795	36

COYOTE

900.00000	900.00000	0.05233	0.05320	0.05930

65 foot Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(12)	45.95515	31.33306	53.40454	36.41219
Trap 2 ---	(17)	38.79788	26.4531	48.49151	33.06239
Trap 3 ---	(17)	35.20626	24.00427	44.54685	30.37285
Fnl Clmbg--	(17)	34.1	23.25	42.53333	29

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	310.0083	305.7333	271.9812
At MPH of	28.89308	25.22868	23.25
Median Weight/Power	247.0618	252.2448	218.0539
At MPH of	34.73729	31.71762	29

Rocky Mountain Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

DENVER

600.00000	600.00000	0.04623	0.05930	0.06157

Trucks	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(71)	61.04326	41.6204	76.42343	52.10689
Trap 2 ---	(74)	56.08142	38.23733	72.20216	49.22875
Trap 3 ---	(73)	51.08243	34.82892	65.28607	44.51323
Fnl Clmbg--	(71)	39.41667	26.875	52.8	36

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	301.1017	225.9054	226.6405
At MPH of	39.92887	36.53313	26.875
Median Weight/Power	246.7495	230.6119	169.1934
At MPH of	50.66781	46.87099	36

Trucks with trailers	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(2)	0	0	52.08333	35.51137
Trap 2 ---	(2)	0	0	45.83477	31.25098
Trap 3 ---	(2)	0	0	35.46099	24.17795
Fnl Clmbg--	(1)	0	0	18.33333	12.5

Tractor trailers	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(121)	51.02939	34.79276	64.31931	43.85407
Trap 2 ---	(125)	44.11364	30.07748	58.17495	39.66474
Trap 3 ---	(126)	34.49547	23.51964	51.9548	35.42373
Fnl Clmbg--	(125)	29.33334	20	39.6	27

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	395.9061	352.1668	304.5481
At MPH of	32.43512	26.79856	20
Median Weight/Power	335.6655	240.2537	225.5912
At MPH of	41.7594	37.54423	27

DENVER

600.00000	600.00000	0.04623	0.05930	0.06157

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(1)	7.654624	5.219062	30.6185	20.87625
Trap 2 ---	(1)	7.144899	4.871522	28.57959	19.48609
Trap 3 ---	(1)	6.624271	4.516548	26.49708	18.06619
Fnl Clmbg--	(1)	5.683334	3.875	22.73333	15.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	1614.531	1351.377	1571.861
At MPH of	5.045292	4.694035	3.875
Median Weight/Power	431.0529	354.5334	392.9653
At MPH of	20.18117	18.77614	15.5

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

TRINIDAD

1100.00000	900.00000	0.04506	0.05176	0.06395

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(25)	54.17096	36.93475	66.32446	45.22123
Trap 2 ---	(27)	47.08813	32.10554	62.01496	42.28293
Trap 3 ---	(26)	40.45001	27.57955	54.10523	36.88993
Fnl Clmbg--	(26)	33.73333	23	42.53333	29

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	310.9194	301.1158	254.9434
At MPH of	34.52014	29.84255	23
Median Weight/Power	230.0586	263.7954	202.1964
At MPH of	43.75208	39.58643	29

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(19)	33.59439	22.90527	60.41962	41.1952
Trap 2 ---	(20)	31.30498	21.3443	52.9661	36.11325
Trap 3 ---	(19)	26.11132	17.80317	49.26116	33.58715
Fnl Clmbg--	(18)	27.5	18.75	39.6	27

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	394.4835	411.0168	312.7305
At MPH of	22.12479	19.57374	18.75
Median Weight/Power	292.7995	237.9429	217.174
At MPH of	38.65422	34.8502	27

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(105)	51.72386	35.26627	67.02811	45.70099
Trap 2 ---	(138)	42.52519	28.99445	58.30904	39.75617
Trap 3 ---	(136)	36.29764	24.74839	50.71637	34.57934
Fnl Clmbg--	(137)	29.33334	20	38.13334	26

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	355.5594	322.3852	293.1848
At MPH of	32.13036	26.87142	20
Median Weight/Power	296.1312	269.2313	225.5268
At MPH of	42.72858	37.16775	26

TRINIDAD

1100.00000	900.00000	0.04506	0.05176	0.06395

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(6)	33.67759	22.962	52.05622	35.49288
Trap 2 ---	(8)	37.73585	25.72899	43.36984	29.57034
Trap 3 ---	(8)	31.34796	21.37361	36.52968	24.9066
Fnl Clmbg--	(8)	23.46667	16	26.4	18

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	313.365	360.7061	366.4811
At MPH of	24.34549	23.5513	16
Median Weight/Power	345.5188	325.2556	325.7609
At MPH of	32.53161	27.23847	18

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(1)	7.434944	5.06928	29.73978	20.27712
Trap 3 ---	(1)	6.989097	4.765294	27.95639	19.06118
Fnl Clmbg--	(1)	5.683334	3.875	22.73333	15.5

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

BEAN STATION

900.00000	900.00000	0.05089	0.04897	0.04362

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(47)	63.01333	42.96364	73.39672	50.04322
Trap 2 ---	(47)	60.88595	41.51315	71.30148	48.61464
Trap 3 ---	(48)	53.76344	36.65689	67.34008	45.91369
Fnl Clmbg--	(49)	47.3	32.25	61.6	42

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	191.5966	275.0762	266.5962
At MPH of	42.23839	39.08502	32.25
Median Weight/Power	166.5114	200.9025	204.7078
At MPH of	49.32893	47.26416	42

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(2)	0	0	56.65723	38.62993
Trap 2 ---	(2)	0	0	58.30904	39.75617
Trap 3 ---	(2)	0	0	56.25879	38.35827
Fnl Clmbg--	(2)	0	0	45.46667	31

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(154)	61.09269	41.65411	72.85974	49.6771
Trap 2 ---	(158)	55.02094	37.51428	68.96551	47.02194
Trap 3 ---	(150)	44.15028	30.10246	61.0687	41.63775
Fnl Clmbg--	(156)	35.2	24	49.86667	34

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	244.6553	365.2485	358.2386
At MPH of	39.58419	33.80837	24
Median Weight/Power	187.5404	270.6845	252.8743
At MPH of	48.34952	44.32985	34

BEAN STATION

900.00000	900.00000	0.05089	0.04897	0.04362

65 foot Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Rocky Mountain Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(1)	10.20408	6.957328	40.81633	27.82931
Trap 2 ---	(1)	9.920635	6.764069	39.68254	27.05628
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(1)	7.7	5.25	30.8	21

Turnpike Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

DUNCANSVILLE

750.00000	750.00000	0.04653	0.05813	0.04942

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(68)	61.81361	42.14564	75.95899	51.79022
Trap 2 ---	(71)	50.65355	34.53651	69.77153	47.5715
Trap 3 ---	(72)	42.58491	29.03516	66.313	45.21341
Fnl Clmbg--	(68)	37.4	25.5	63.06667	43

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	476.1432	277.2082	297.561
At MPH of	38.34108	31.78584	25.5
Median Weight/Power	270.9427	167.0417	176.4606
At MPH of	49.68086	46.39246	43

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(4)	52.55042	35.82984	61.51953	41.94514
Trap 2 ---	(4)	41.34476	28.18961	49.42543	33.69916
Trap 3 ---	(4)	38.04071	25.93685	42.14519	28.73535
Fnl Clmbg--	(4)	30.06667	20.5	36.66667	25

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	473.4579	262.9094	370.1369
At MPH of	32.00972	27.06323	20.5
Median Weight/Power	528.8588	270.9667	303.5123
At MPH of	37.82215	31.21726	25

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(125)	53.28272	36.32913	70.67769	48.18933
Trap 2 ---	(130)	40.65626	27.72017	63.22112	43.10531
Trap 3 ---	(133)	32.43278	22.11326	59.16914	40.3426
Fnl Clmbg--	(130)	32.26667	22	49.86667	34

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	532.9773	329.3915	344.9003
At MPH of	32.02465	24.91672	22
Median Weight/Power	317.723	187.762	223.1708
At MPH of	45.64732	41.72395	34

DUNCANSVILLE

750.00000	750.00000	0.04653	0.05813	0.04942

65 foot Doubles	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (0)	0	0	0	0
Trap 2 --- (0)	0	0	0	0
Trap 3 --- (0)	0	0	0	0
Fnl Clmbg--(0)	0	0	0	0

Rocky Mountain Doubles	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (0)	0	0	0	0
Trap 2 --- (0)	0	0	0	0
Trap 3 --- (0)	0	0	0	0
Fnl Clmbg--(0)	0	0	0	0

Turnpike Doubles	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (0)	0	0	0	0
Trap 2 --- (0)	0	0	0	0
Trap 3 --- (0)	0	0	0	0
Fnl Clmbg--(0)	0	0	0	0

Triples	12.5 Percentile		Median	
No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 --- (0)	0	0	0	0
Trap 2 --- (0)	0	0	0	0
Trap 3 --- (0)	0	0	0	0
Fnl Clmbg--(0)	0	0	0	0

UTICA

900.00000	900.00000	0.04733	0.04933	0.04993

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(124)	63.95085	43.60285	78.58546	53.581
Trap 2 ---	(135)	55.43074	37.79369	73.59711	50.17985
Trap 3 ---	(132)	47.31063	32.25725	68.96551	47.02194
Fnl Clmbg--	(127)	39.6	27	58.66667	40

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	309.4017	306.4224	278.1846
At MPH of	40.69827	35.02547	27
Median Weight/Power	211.1524	203.3604	187.7746
At MPH of	51.88043	48.6009	40

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(7)	55.06916	37.54715	65.28346	44.51145
Trap 2 ---	(8)	34.18804	23.31002	50.89058	34.69813
Trap 3 ---	(8)	32	21.81818	45.76659	31.20449
Fnl Clmbg--	(8)	27.86667	19	44	30

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	812.2221	354.8437	395.315
At MPH of	30.42859	22.5641	19
Median Weight/Power	512.346	279.0059	250.3662
At MPH of	39.60479	32.95131	30

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(76)	56.85859	38.76722	72.59528	49.49678
Trap 2 ---	(79)	46.47436	31.68707	63.59317	43.35898
Trap 3 ---	(77)	36.12013	24.62736	55.89046	38.10713
Fnl Clmbg--	(79)	32.08333	21.875	49.13333	33.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	369.4164	385.1472	343.3593
At MPH of	35.22714	28.15721	21.875
Median Weight/Power	308.5507	275.1822	224.2085
At MPH of	46.42788	40.73305	33.5

UTICA

900.00000	900.00000	0.04733	0.04933	0.04993

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

BLOSSBURG

900.00000	900.00000	0.06277	0.04695	0.05789

Trucks	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(30)	56.71801	38.67137	75.32957	51.36107
Trap 2 ---	(30)	39.60396	27.0027	61.3497	41.82934
Trap 3 ---	(30)	38.21713	26.05713	60.79028	41.44792
Fnl Clmbg--	(30)	29.33334	20	52.8	36

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	332.682	313.5254	323.8855
At MPH of	32.83704	26.52992	20
Median Weight/Power	270.0536	196.7797	179.9364
At MPH of	46.59521	41.63863	36

Trucks with trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(1)	0	0	44.74273	30.50641
Trap 2 ---	(1)	0	0	38.83495	26.47838
Trap 3 ---	(1)	0	0	37.95067	25.87545
Fnl Clmbg--	(1)	0	0	37.4	25.5

Tractor trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(215)	53.23583	36.29715	67.28386	45.87536
Trap 2 ---	(225)	32.58752	22.21876	52.05053	35.489
Trap 3 ---	(219)	32	21.81818	46.64763	31.8052
Fnl Clmbg--	(213)	29.33334	20	39.6	27

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	398.1205	367.9119	323.8855
At MPH of	29.25796	22.01847	20
Median Weight/Power	293.5189	295.2681	239.9152
At MPH of	40.68218	33.6471	27

BLOSSBURG

900.00000	900.00000	0.06277	0.04695	0.05789

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

BERNALILLO

900.00000	900.00000	0.03258	0.03373	0.03838

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(49)	60.22127	41.05995	76.99776	52.49847
Trap 2 ---	(49)	57.28863	39.06043	73.86945	50.36553
Trap 3 ---	(49)	55.74932	38.0109	72.73112	49.5894
Fnl Clmbg--	(49)	50.6	34.5	71.13333	48.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	351.4989	316.7078	283.1723
At MPH of	40.06019	38.53566	34.5
Median Weight/Power	298.3996	243.2285	201.4319
At MPH of	51.432	49.97746	48.5

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(16)	43.38395	29.57996	65.25285	44.49058
Trap 2 ---	(16)	35.97122	24.52584	60.33183	41.13534
Trap 3 ---	(16)	33.75528	23.01496	56.98006	38.85004
Fnl Clmbg--	(16)	29.33334	20	51.33333	35

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	618.0521	507.8765	488.4722
At MPH of	27.0529	23.7704	20
Median Weight/Power	399.6909	348.0036	279.127
At MPH of	42.81296	39.99269	35

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(92)	61.20977	41.73393	75.32957	51.36107
Trap 2 ---	(92)	57.1021	38.93325	72.07207	49.14005
Trap 3 ---	(92)	53.48368	36.46614	69.44445	47.34849
Fnl Clmbg--	(92)	46.93334	32	64.53333	44

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	384.3152	370.8189	305.2952
At MPH of	40.33359	37.6997	32
Median Weight/Power	307.1942	284.5913	222.0328
At MPH of	50.25056	48.24426	44

BERNALILLO

900.00000	900.00000	0.03258	0.03373	0.03838

65 foot Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(17)	63.88561	43.55837	84.03509	57.29666
Trap 2 ---	(17)	59.53638	40.59299	81.46775	55.54619
Trap 3 ---	(17)	56.38068	38.44137	81.05445	55.26439
Fnl Clmbg--	(17)	49.68334	33.875	80.66666	55

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	382.2529	346.118	288.3969
At MPH of	42.07568	39.51718	33.875
Median Weight/Power	263.2644	207.8117	177.6263
At MPH of	56.42142	55.40529	55

Rocky Mountain Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

CARSON CITY

750.00000	750.00000	0.05582	0.05669	0.05756

Trucks		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(95)	57.37853	39.12172	71.42858	48.7013
Trap 2 ---	(96)	52.01561	35.46518	64	43.63637
Trap 3 ---	(96)	47.7327	32.54502	59.88024	40.82744
Fnl Clmbg--	(94)	41.06667	28	52.8	36

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	230.2533	230.4958	232.6773
At MPH of	37.29345	34.00511	28
Median Weight/Power	232.1445	192.522	180.9712
At MPH of	46.16883	42.2319	36

Trucks with trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(41)	43.04927	29.35178	53.79962	36.68156
Trap 2 ---	(41)	31.51988	21.49082	42.37293	28.89063
Trap 3 ---	(40)	25.46149	17.36011	35.74621	24.37241
Fnl Clmbg--	(41)	23.46667	16	33	22.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	388.0168	389.6658	407.1853
At MPH of	25.4213	19.42547	16
Median Weight/Power	345.9165	306.3048	289.554
At MPH of	32.7861	26.63152	22.5

Tractor trailers		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(57)	56.9518	38.83077	69.80803	47.59639
Trap 2 ---	(58)	43.62618	29.74512	64.10256	43.70629
Trap 3 ---	(58)	35.85838	24.4489	56.81819	38.73967
Fnl Clmbg--	(57)	29.51667	20.125	49.13333	33.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	389.6442	315.2028	323.7249
At MPH of	34.28795	27.09701	20.125
Median Weight/Power	205.3654	236.5777	194.4766
At MPH of	45.65133	41.22298	33.5

CARSON CITY

750.00000	750.00000	0.05582	0.05669	0.05756

65 foot Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(11)	48.61112	33.14395	71.62093	48.83245
Trap 2 ---	(11)	33.6547	22.94639	62.46221	42.58787
Trap 3 ---	(11)	29.49738	20.11185	52.63194	35.88542
Fnl Clmbg--	(10)	25.66667	17.5	41.06667	28

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	440.6679	339.8493	372.2837
At MPH of	28.04516	21.52912	17.5
Median Weight/Power	269.9318	287.3189	232.6773
At MPH of	45.71016	39.23665	28

Rocky Mountain Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(1)	6.830601	4.657228	27.32241	18.62891
Trap 2 ---	(1)	4.99002	3.402286	19.96008	13.60914
Trap 3 ---	(1)	3.607504	2.459662	14.43001	9.838646
Fnl Clmbg--	(1)	3.483333	2.375	13.93333	9.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	1680.745	2266.798	2743.143
At MPH of	4.029758	2.930974	2.375
Median Weight/Power	478.5918	606.3555	685.7856
At MPH of	16.11903	11.7239	9.5

Turnpike Doubles	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples	No.	12.5 Percentile Ft/sec	12.5 Percentile MPH	Median Ft/sec	Median MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

SAN LUIS

1000.00000	1000.00000	0.04942	0.04885	0.05901

Trucks	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(15)	53.10183	36.20579	72.67134	49.54864
Trap 2 ---	(14)	42.19504	28.76934	65.25285	44.49058
Trap 3 ---	(15)	37.02528	25.24451	60.6646	41.36223
Fnl Clmbg--	(15)	35.93334	24.5	55	37.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	346.8214	326.8158	259.4001
At MPH of	32.48757	27.00693	24.5
Median Weight/Power	237.8347	219.0815	169.4747
At MPH of	47.01961	42.9264	37.5

Trucks with trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(23)	57.40021	39.13651	67.11882	45.76283
Trap 2 ---	(22)	44.89406	30.60958	55.71031	37.9843
Trap 3 ---	(23)	36.51349	24.89556	49.24869	33.57865
Fnl Clmbg--	(23)	31.9	21.75	43.26667	29.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	363.8232	353.2399	292.1978
At MPH of	34.87304	27.75257	21.75
Median Weight/Power	323.7471	273.5291	215.434
At MPH of	41.87357	35.78148	29.5

Tractor trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(122)	59.7238	40.72077	72.33273	49.31777
Trap 2 ---	(122)	48.82582	33.29033	64	43.63637
Trap 3 ---	(122)	42.623	29.06114	56.17978	38.3044
Fnl Clmbg--	(117)	33.73333	23	46.93334	32

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	326.3406	300.4286	276.3175
At MPH of	37.00556	31.17573	23
Median Weight/Power	253.8759	267.22	198.6032
At MPH of	46.47707	40.97038	32

SAN LUIS

1000.00000	1000.00000	0.04942	0.04885	0.05901

65 foot Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(56)	55.86592	38.0904	65.14658	44.41812
Trap 2 ---	(57)	40.44519	27.57626	55.36547	37.74918
Trap 3 ---	(57)	34.68327	23.64769	47.96501	32.70342
Fnl Clmbg--	(57)	30.8	21	38.13334	26

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	433.291	347.5799	302.6335
At MPH of	32.83333	25.61198	21
Median Weight/Power	293.3264	287.9325	244.4347
At MPH of	41.08365	35.2263	26

Rocky Mountain Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(1)	6.25	4.261364	25	17.04545
Trap 2 ---	(1)	4.464286	3.043831	17.85714	12.17533
Trap 3 ---	(1)	4.226543	2.881734	16.90617	11.52694
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

PAYSON

900.00000	900.00000	0.05813	0.06104	0.05901

Trucks	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(60)	72.57295	49.48156	80.64516	54.98534
Trap 2 ---	(60)	64.06607	43.68141	74.07408	50.50505
Trap 3 ---	(61)	55.60385	37.91172	70.54674	48.10005
Fnl Clmbg--	(60)	47.66667	32.5	61.6	42

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	211.4077	210.9595	195.5478
At MPH of	46.58149	40.79656	32.5
Median Weight/Power	175.1414	145.5916	151.3167
At MPH of	52.7452	49.30255	42

Trucks with trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(19)	65.21496	44.46475	72.59744	49.49825
Trap 2 ---	(19)	44.28311	30.19303	54.54647	37.19078
Trap 3 ---	(19)	27.48168	18.73751	40.40817	27.55102
Fnl Clmbg--	(19)	27.86667	19	34.46667	23.5

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	540.3811	380.9024	334.4896
At MPH of	37.32889	24.46527	19
Median Weight/Power	466.7146	305.8079	270.4384
At MPH of	43.34451	32.3709	23.5

Tractor trailers	No.	12.5 Percentile Ft/sec	MPH	Median Ft/sec	MPH
Trap 1 ---	(113)	57.14618	38.9633	76.92564	52.4493
Trap 2 ---	(113)	43.68398	29.78453	63.19179	43.08531
Trap 3 ---	(113)	32.67315	22.27715	48.96027	33.382
Fnl Clmbg--	(113)	32.26667	22	41.06667	28

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	314.2551	309.5515	288.8774
At MPH of	34.37392	26.03084	22
Median Weight/Power	314.8614	292.7254	226.9751
At MPH of	47.76731	38.23366	28

PAYSON

900.00000	900.00000	0.05813	0.06104	0.05901

65 foot Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(7)	41.07981	28.00896	82.09697	55.97521
Trap 2 ---	(7)	37.31343	25.44098	75.76003	51.65457
Trap 3 ---	(7)	24.3563	16.60657	71.61502	48.82842
Fnl Clmbg--	(6)	23.1	15.75	57.2	39

	Traps 1-2	Traps 2-3	Fnl Clmbg
12.5% Weight/Power	264.5489	377.441	403.5113
At MPH of	26.72497	21.02377	15.75
Median Weight/Power	170.4759	147.7877	162.9565
At MPH of	53.81489	50.2415	39

Rocky Mountain Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Turnpike Doubles		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0

Triples		12.5 Percentile		Median	
	No.	Ft/sec	MPH	Ft/sec	MPH
Trap 1 ---	(0)	0	0	0	0
Trap 2 ---	(0)	0	0	0	0
Trap 3 ---	(0)	0	0	0	0
Fnl Clmbg--	(0)	0	0	0	0