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New Methods for Determining Requirements for Truck-Climbing Lanes

Research, Development, and Technology
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McLean, Virginia 22101-2296

FOREWORD

This report is part of a four-part series summarizing recent research findings in the area of selected truck geometric features. One of the critical large truck research areas is safety impacts of trucks--including geometric and operational issues, vehicle stability and handling, and accident rates. A number of research studies have been completed in the following areas: truck climbing lanes, grade severity rating systems for trucks, interchange ramp geometry design, and the operation of larger trucks on roads with restrictive geometry. This report summarizes the findings of the research in the area of truck climbing lanes. For specific details on the research, the reader should consult the research reports referenced in the summary report.

Sufficient copies of this report are being distributed to provide one copy to each Regional office, Division office, and State highway agency. Direct distribution is being made to the Division offices. Additional copies are available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Stanley R. Byington
Director, Office of Implementation

NOTICE

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Janet Coleman (HRT-20), Contracting Officer's Technical Representative. This summary report was based on the following study: "Methods for Predicting Truck Speed Loss on Grades - Final Technical Report: FHWA/RD-86/059."

16. Abstract

To facilitate traffic flow and to improve highway safety on upgrades, highway design engineers have constructed hill-climbing lanes. A recent FHWA-sponsored study found that current guidelines may be leading designers to overdesign highways, adding and maintaining unnecessary hill-climbing lanes.

The report summarized here highlights four major findings of the earlier FHWA study: (1) current design guidelines are conservative for single-unit trucks and tractor-semitrailers and current critical lengths of grade are thus shorter than these two truck types would warrant, (2) single-unit trucks with trailers and doubles do not perform nearly as well as single-unit trucks and tractor-semitrailers, which may indicate that the performance of the latter two types of trucks match current guidelines, (3) critical length of grade should be based on the weight-to-available power ratio of current truck mix, rather than on assumptions about the performance of a 300-lb/hp truck which was typical in 1965, and (4) highway designers need more comprehensive methods for deciding when hill-climbing lanes are warranted.

This report also presents tools developed in the study for designing hill-climbing lanes. This report was based on the following study: "Methods for Predicting Truck Speed Loss on Grades - Final Technical Report: FHWA/RD-86-059."

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

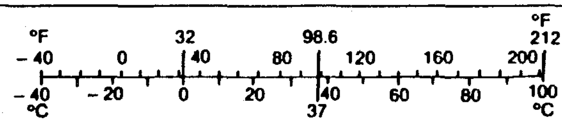
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

These factors conform to the requirement of FHWA Order 5190.1A.

(Revised April 1989)

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CHAPTER I
INTRODUCTION

Trucks have a difficult time climbing hills. As they climb, they often impede the flow of traffic, reduce the highway's capacity to carry traffic, and create possible hazards to other vehicles. Studies have indicated that accidents happen more frequently and are more severe as speed differentials increase. These studies support the conclusion that hill-climbing lanes make highway travel safer. A new study suggests, however, that maintaining costly hill-climbing lanes may not always represent the best use of highway safety dollars.

In the past, highway designers have determined the need for hill-climbing lanes based on relationships developed for a "typical" (i.e., 300-lbs/hp [182 kg/kW]) heavy truck. Figure 1 presents the relationships of speed versus distance for various percent grades. Current design guidelines are based on these relationships.

A study by the University of Michigan Transportation Research Institute (UMTRI) recommends revising these guidelines.[1] Researchers developed a new procedure for estimating truck speed loss and based their recommendations on the current performance of the 12.5 percentile of trucks. The 12.5 percentile was selected for the following reasons:

- It falls near the bottom of the linear portion of the probability distribution.

- It is a real value that can be determined directly from experimental observations.

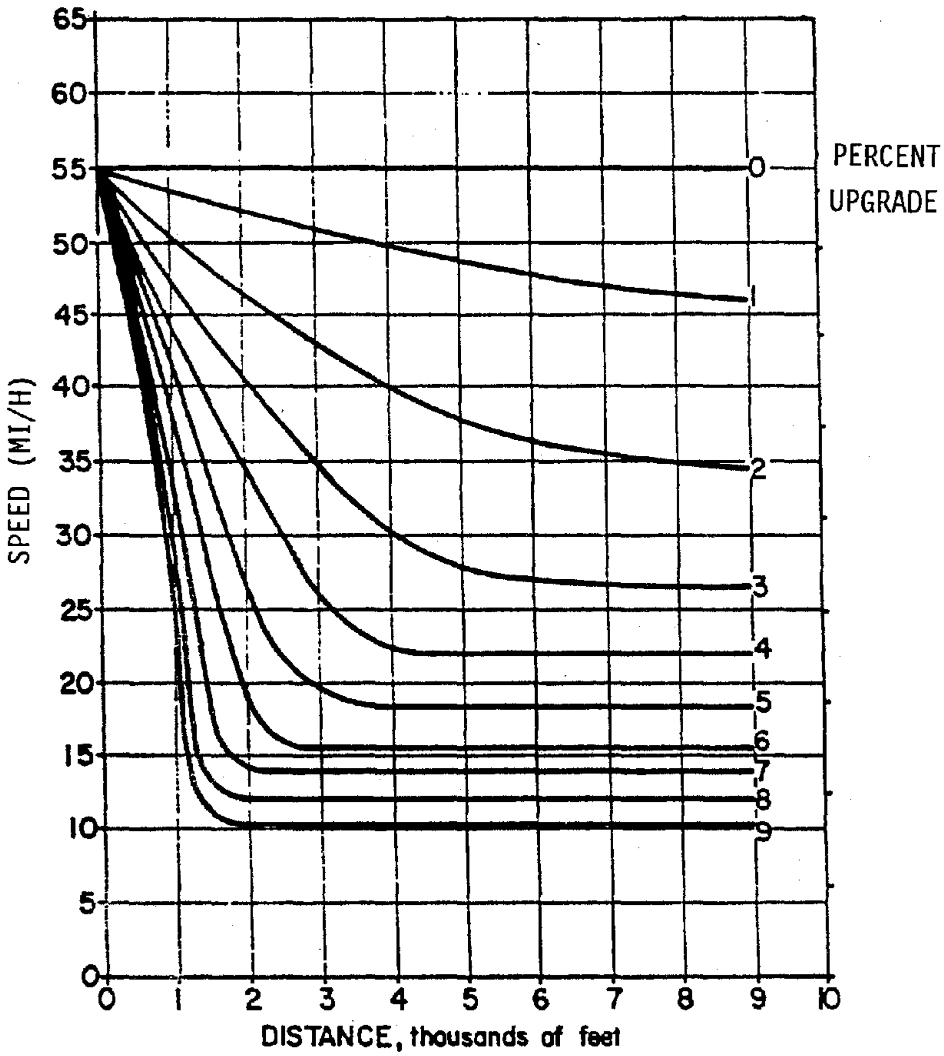

Figure 1. Speed-distance curves for a "typical" heavy truck (i.e., 300 lb/hp) on upgrades.[2]

- It reflects performance of one truck in eight and is more conservative than the median (i.e., one in two).

- Below this value, trucks differ markedly in their performance.

- The California Department of Transportation (CALTRANS) has used this value.

Based on a limited number of observations, UMTRI found that current design guidelines closely correlated with the performance of the 12.5 percentile of single-unit trucks pulling trailers and of doubles. However, UMTRI also found that the performance of the 12.5 percentiles of single-unit trucks and of tractor-semitrailers is significantly better than the current design guidelines suggest.

Therefore, current design guidelines may be leading designers to maintain costly hill-climbing lanes unnecessarily. Highway design engineers may want to use the new methods developed by UMTRI when deciding whether to build or maintain hill-climbing lanes and how long to make them. If fewer or shorter lanes were built, the money saved might be used to improve highway safety more effectively elsewhere.

CHAPTER II
STUDY DESIGN AND RESULTS

The UMTRI study focused on one fundamental question: whether the current method of predicting the speed loss of trucks climbing grades is adequate.

Study Description

To answer this question, the study identified two objectives: to measure trucks' hill-climbing performance and to develop methods for predicting the general truck population's speed loss on arbitrary grades.

The study defined a truck as a vehicle having at least one axle with dual wheels and weighing at least 10,000 lbs (4536.9 kg). Trucks were grouped into single-unit trucks, single-unit trucks pulling trailers, tractor-semitrailers, and doubles and triples, i.e., tractor trucks pulling one semitrailer and one or more additional trailers.

UMTRI conducted field tests at 10 sites in the Eastern United States and 10 sites in the Western United States; geography and road classes were diverse. Hill-climbing performance and vehicle descriptions were recorded in a database, and data were analyzed to determine the distribution of truck performance. Past assumptions about how trucks decelerate on grades were evaluated.

The performance of more than 4,000 trucks was measured. Speed losses were measured on grades ranging from 2 to 6 percent. At weighing stations near test sites, truck weight and power were also recorded.

Major Results

The study determined the following:

- The performance of single-unit trucks and tractor-semitrailers is notably better than standard design guidelines suggest.

- The critical length of grade used in current design guidelines is shorter than single-unit trucks and tractor-semitrailers warrant, due to improved truck performance.

- Current design guidelines seem reasonable for predicting the 12.5 percentile of single-unit trucks pulling trailers and of doubles and triples. However, more study on these trucks' performance is needed.

In addition, the study produced a new, simplified method to predict trucks' hill-climbing performance. However, the study indicated that further improvements are needed in the decision-making process for the design of hill-climbing lanes.

CHAPTER III
FINAL CLIMBING SPEED

Final climbing speed is the steady speed to which a truck decelerates when climbing a constant grade. Final climbing speeds influence highway capacity and affect decisions on whether hill-climbing lanes are necessary.

When considering adding such lanes, highway designers determine whether trucks slow to a steady speed that is at least 10 mi/h (16 km/h) below the prevailing highway speed. The determination depends on the distribution of trucks by type.

Final Climbing Speeds for Tractor-Semitrailers

Figure 2 shows the final climbing speed of tractor-semitrailers as a function of grade observed at the 20 test sites. Superimposed on the plot is the curve of speed versus grade that indicates values used in current design practice. As can be seen, the data indicate that tractor-semitrailers achieve higher final climbing speeds than assumed in current design practice. In fact, some tractor-semitrailers, especially those climbing shallower grades, have sufficient power to climb the grade at normal traffic speed.

Final Climbing Speeds for 12.5 Percentile Trucks

Figures 3a-d show the findings for the 12.5 percentile of each truck group. The experimental data points reflect a variation in truck performance at different test sites and show that the distinction between final climbing speeds on different road classes is not especially significant.

Figures 3a and 3b also indicate that the values for final climbing speed used in current design practice are clearly conservative in estimating the performance equivalent to the 12.5 percentile of single-unit trucks and tractor-semitrailers, respectively. The design values currently used roughly

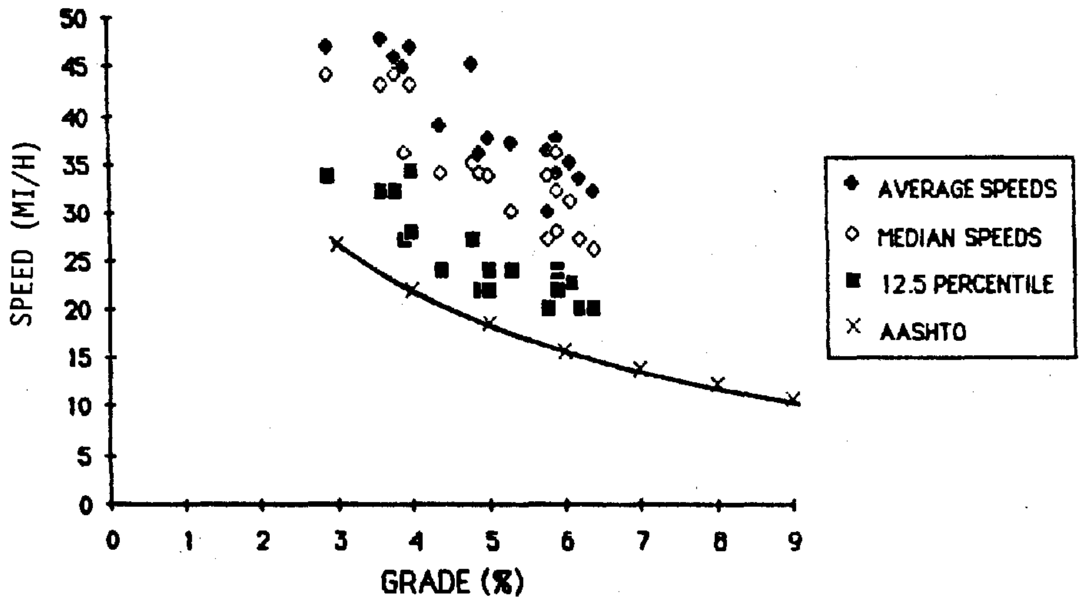

Figure 2. Average, median, and 12.5 percentile final climbing speeds for tractor-semitrailers.(1)

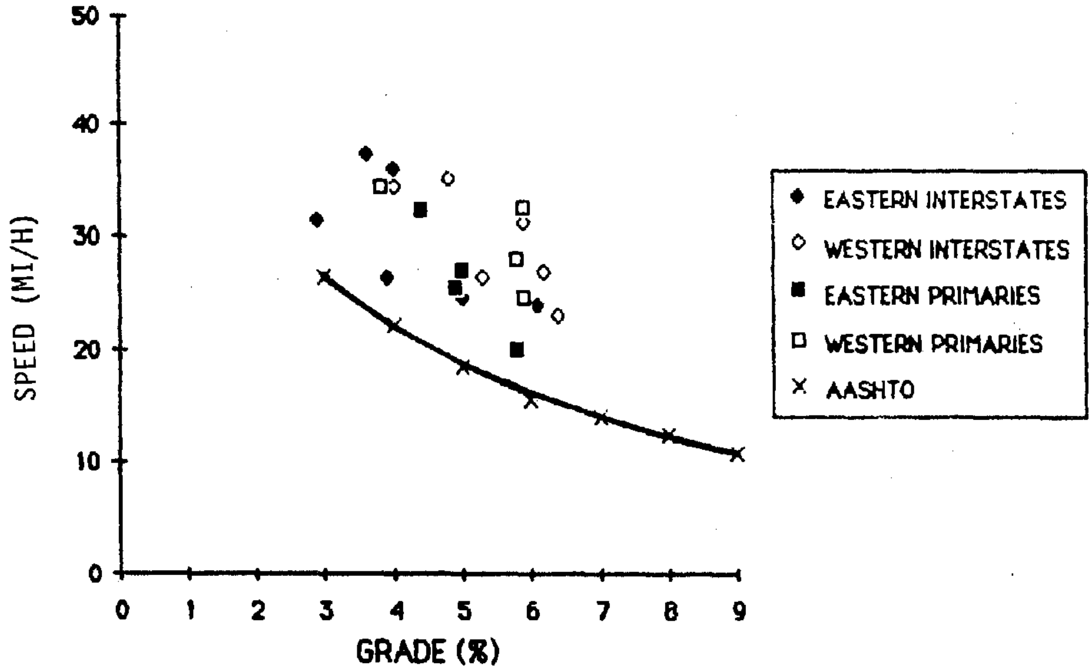

Figure 3a. Final climbing speeds for the 12.5 percentile of single-unit trucks.(1)

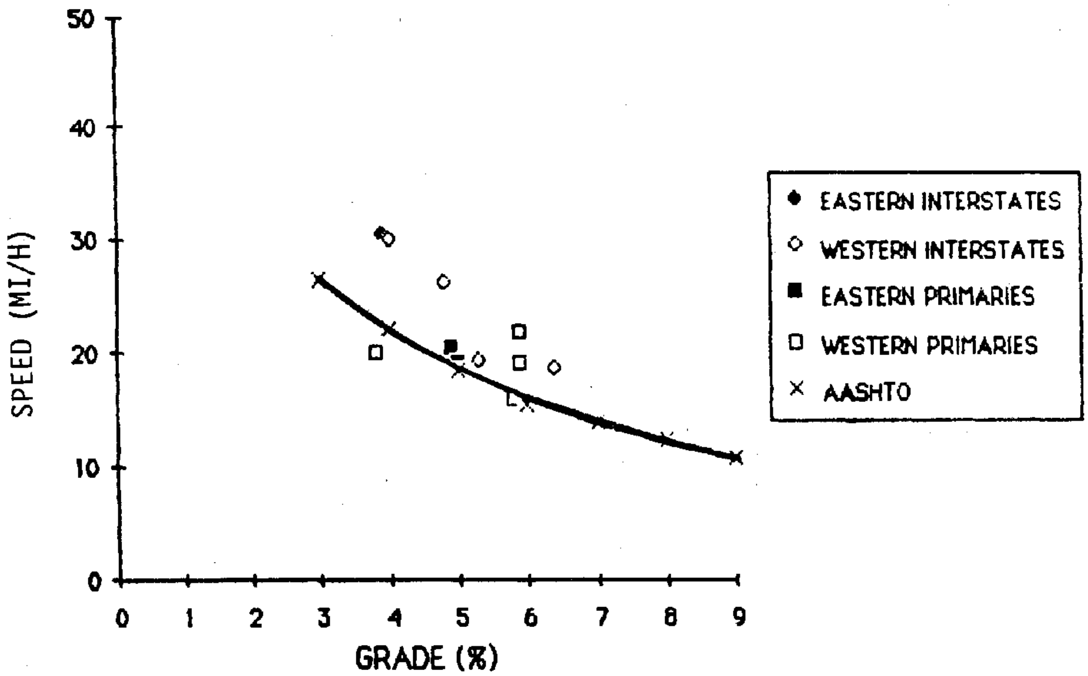

Figure 3b. Final climbing speeds for the 12.5 percentile of tractor-semitrailers.(1)

equal the performance of a vehicle in the 5th percentile; in general, current design guidelines are about 3 mi/h (5 km/h) below the performance of the 12.5 percentile.

For the 12.5 percentile of trucks with trailers (figure 3c) and of doubles and triples (figure 3d), current guidelines may be a good guide. However, the sample sizes used to develop these estimates were somewhat limited.

The final climbing speeds for the 12.5 percentile of each truck type and the final climbing speeds used in the current design guidelines are summarized in table 1.

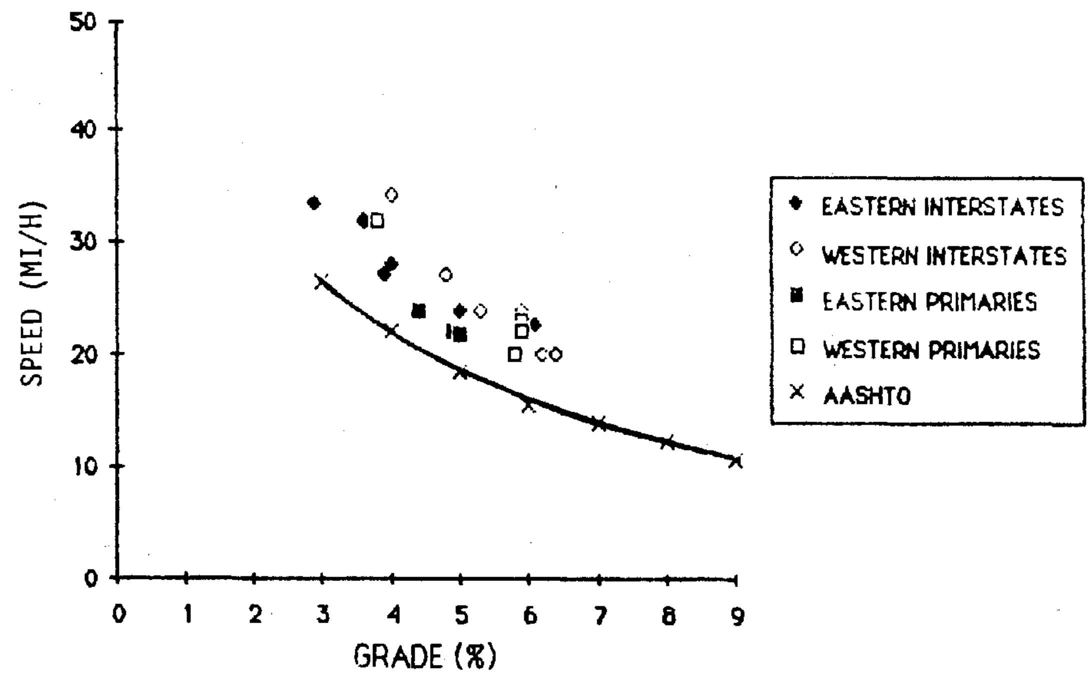

Figure 3c. Final climbing speeds for the 12.5 percentile of single-unit trucks pulling trailers.[1]

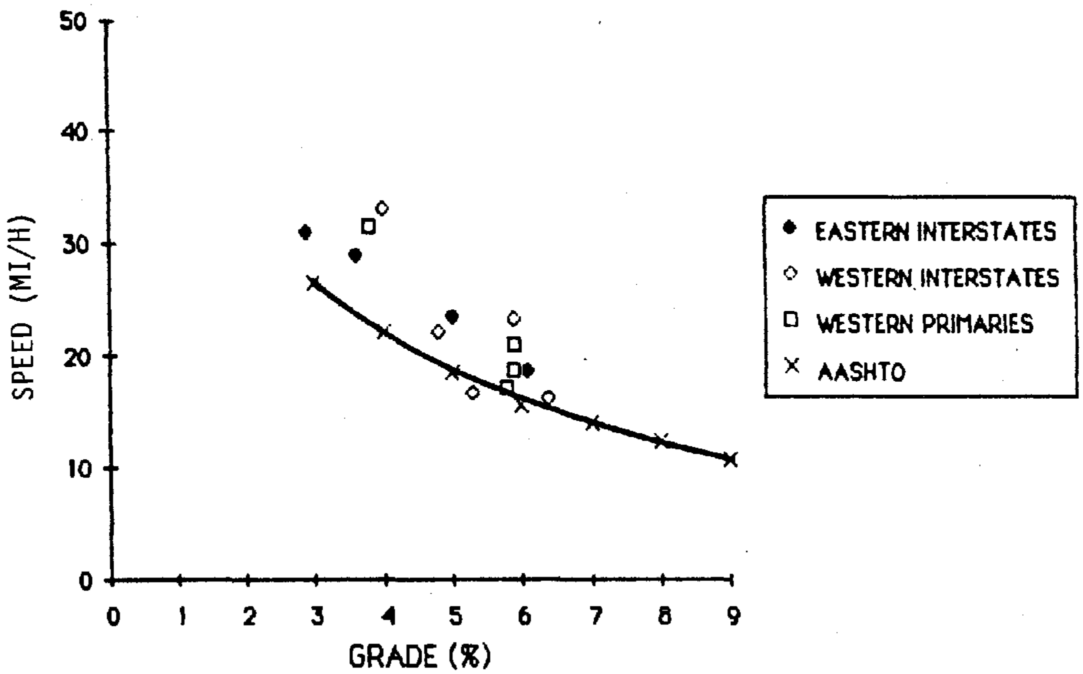

Figure 3d. Final climbing speeds for the 12.5 percentile of doubles and triples.[1]

Table 1. Final climbing speeds (mi/h).[1]

	12.5 Percentile Speed				
Grade %	Current Design Guidelines	Straight Trucks	Trucks with Semitrailers	Tractor-Semitrailers	65-foot Doubles
1.5	40.0	47.5	42.3	47.5	39.9
2	34.0	40.3	33.7	40.3	33.8
3	26.5	30.9	24.0	30.9	25.9
4	22.0	25.0	18.6	25.0	21.0
5	18.4	21.0	15.2	21.0	17.7
6	15.5	18.1	12.8	18.1	15.2
7	13.8	15.9	11.1	15.9	13.4
8	12.2	14.2	9.8	14.2	12.0
9	10.6	12.8	8.8	12.8	10.8

CHAPTER IV
TRUCK DECELERATION RATE

The performance of trucks climbing uphill was found to be related to the weight-to-available power or drive power (W/P_3) ratio. Drive power is the power available from the engine at the drive wheel. It is a function of the effective power available at the engine, the power loss due to rolling resistance, and the power loss from aerodynamic forces.

A good approximation of W/P_3 was obtained over a limited range of speeds by matching the higher order function at two speeds and assuming a linear relationship between the two values. For the hill-climbing characterization, the speeds of 25 mi/h (40 km/h) and 50 mi/h (80 km/h) were selected. A good match at 25 mi/h (40 km/h) ensures that the final hill-climbing speed is accurate; a good match at 50 mi/h (80 km/h) ensures that high-speed decelerations are accurate. Table 2 presents the W/P_3 values at 25 mi/h (40 km/h), as derived from the field data for the 12.5 percentile. Table 3 presents the W/P_3 values at 50 miles (80 km) per hour for the 12.5 percentile derived from the field data. The lower the W/P_3 value, the better the performance.

Tables 4 and 5 present the W/P_3 values for the 50 percentile derived from the field data at 25 and 50 mi/h (40 and 80 km/h), respectively.

Table 2. Weight-to-available power ratios in lbs/hp for 12.5 percentile trucks at 25 mi/h.[1]

Truck Class	Interstate Highways East	Interstate Highways West	Primary Highways East	Primary Highways West
Single-Unit Trucks	375	290	350	350
Single-Unit Trucks Pulling Trailers	*	525	*	525
Tractor-Semitrailers	375	375	375	375
Doubles	475	475	*	475

* Data not available

Table 3. Weight-to-available power ratios in lbs/hp for 12.5 percentile trucks at 50 mi/h.[1]

Truck Class	Interstate Highways East	Interstate Highways West	Primary Highways East	Primary Highways West
Single-Unit Trucks	550	500	500	500
Single-Unit Trucks Pulling Trailers	*	625	*	625
Tractor-Semitrailers	550	550	550	550
Doubles	800	800	*	800

* Data not available

Table 4. Weight-to-available power ratios in lbs/hp for 50 percentile trucks at 25 mi/h.[1]

Truck Class	Interstate Highways East	Interstate Highways West	Primary Highways East	Primary Highways West
Straight Trucks	250	200	150	150
Straight Trucks Pulling Trailers	350	325	350	325
Tractor-Semitrailers	250	250	250	250
Doubles	350	350	*	350

* Data not available

Table 5. Weight-to-available power ratios in lbs/hp for 50 percentile trucks at 50 mi/h.[1]

Truck Class	Interstate Highways East	Interstate Highways West	Primary Highways East	Primary Highways West
Straight Trucks	475	400	300	300
Straight Trucks Pulling Trailers	1,200	550	1,200	550
Tractor-Semitrailers	475	475	475	475
Doubles	700	700	*	700

* Data not available

Rate of Truck Speed Loss

As trucks travel uphill, their speeds drop and they lose effective power. The rate of speed loss can be calculated using the following equation:

$$dU/dX = .465\ [375/((W/P_3)\ (U)) - G_r]\ g/U \qquad (1)$$

where

dU/dX	=	the rate of change in truck speed with respect to distance in mi/hr/ft
W/P_3	=	weight-to-available power ratio in lbs/hp
G_r	=	constant grade, expressed as a percent/100
U	=	speed in mi/h
g	=	gravitational constant = 32.2 ft/s^2

Since W/P_3 depends on speed, the rate of change increases as trucks travel uphill until the trucks reach their final climbing speed.

Figure 4 presents speed as a function of grade and distance for the 12.5 percentile of single-unit trucks and tractor-semitrailers as derived from the experimental data. Figures 5 and 6 present the derived relationships between speed, grade, and distance for the 12.5 percentile of single-unit trucks pulling trailers and doubles, respectively. Comparing these relationships with figure 1, which served as the basis for current design guidelines, reveals that the rate of speed loss for single-unit trucks and tractor-semitrailers is less than the values used as the basis for current guidelines.

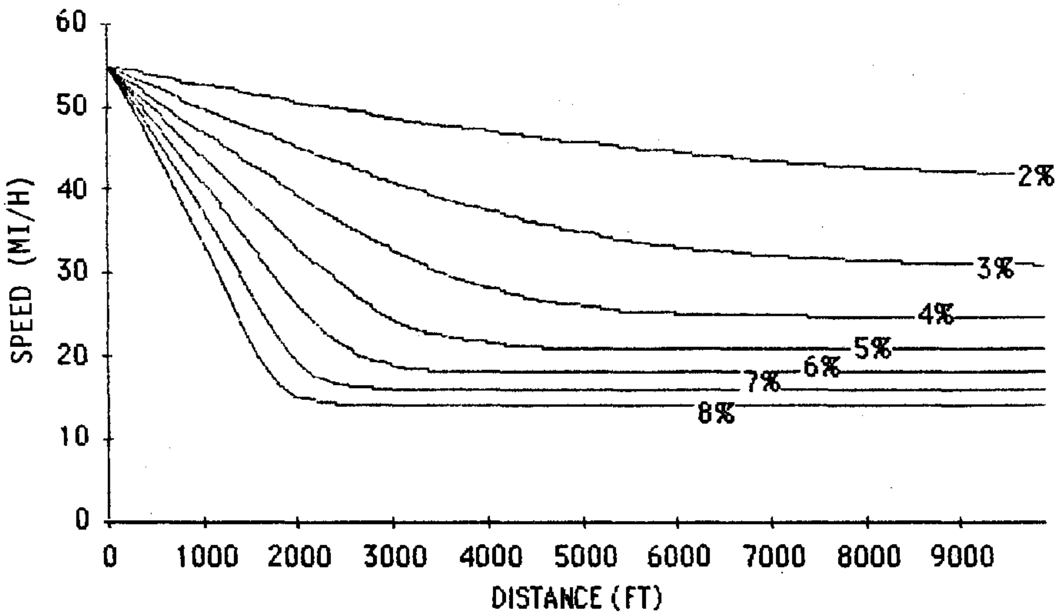

Figure 4. Speed loss for 12.5 percentile tractor-semitrailers and single-unit trucks.[1]

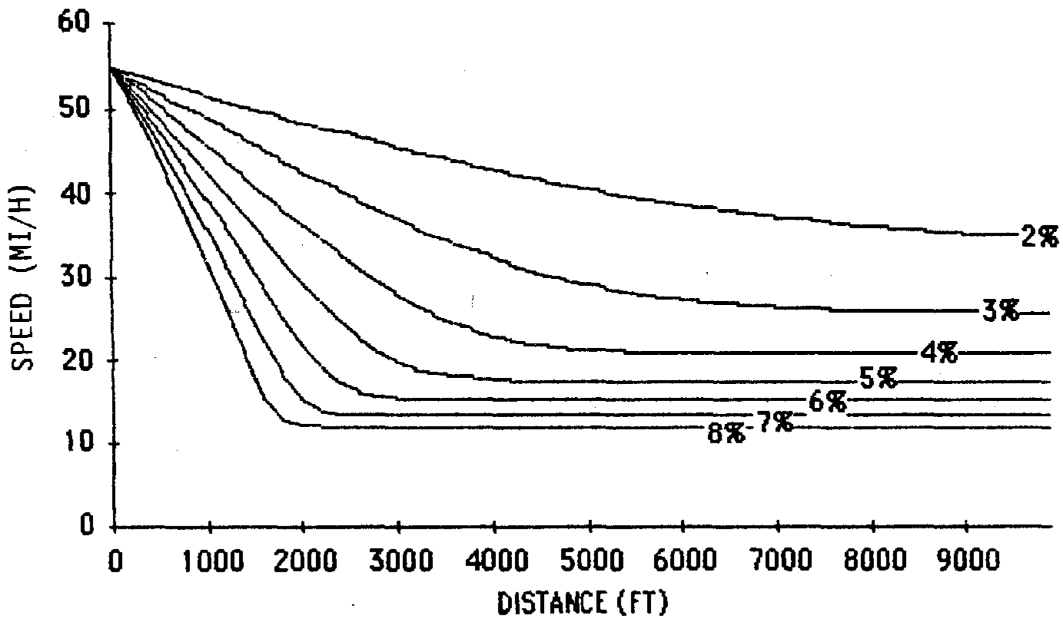

Figure 5. Speed loss for 12.5 percentile trucks with trailers.[1]

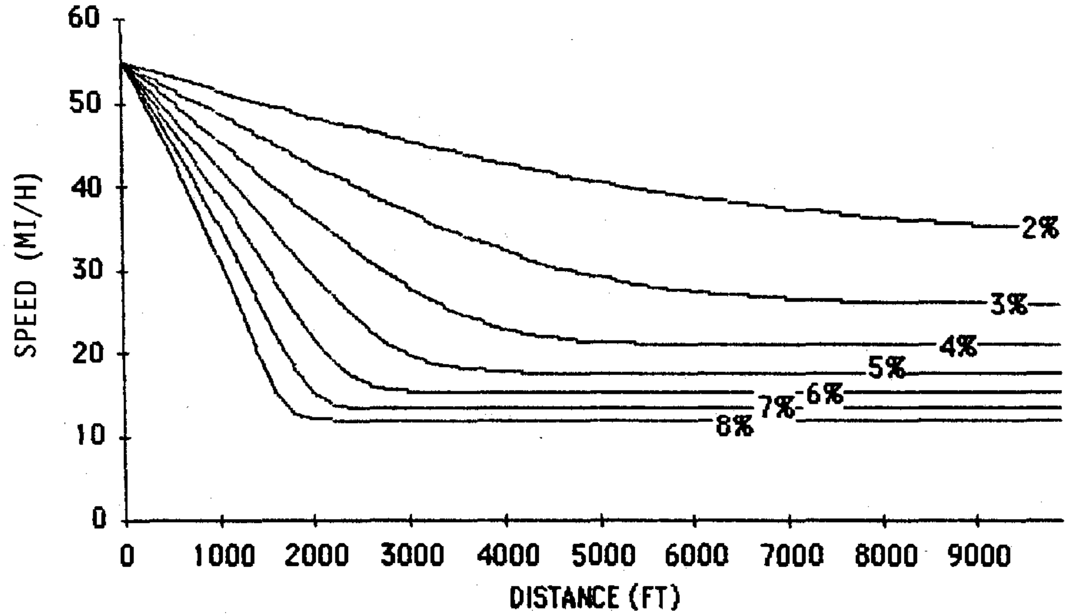

Figure 6. Speed loss for 12.5 percentile doubles and triples.[1]

Critical Length of Grade

A Policy on Geometric Design of Highways and Streets defines critical length of grade as the term "used to indicate the maximum length of a designated upgrade on which a loaded truck can operate without an unreasonable reduction in speed. For a given grade, lengths less than critical ones result in acceptable operation in the desired range of speeds." The common basis for determining critical length of grade is a 10 mi/h (16 km/h) reduction in speed of trucks below the average running speed. Figure 7 presents the current guidelines, which were based on a 300-lb/hp truck.

Table 6 compares the critical lengths of grade derived from this study with the values used in current design practice. On steep grades, the differences for the 12.5 percentile of single-unit trucks and tractor-semitrailers were fairly small. For instance, the critical length of grade on a 6 percent grade is about 600 ft (183 m), based on current guidelines for an entry speed of 55 mi/h (89 km/h). This study found these trucks travel about 700 ft (213 m) before speed drops more than 10 mi/h (16 km/h).

On shallow grades of 3 percent or less, however, the differences were substantial. Based on the current design guidelines, the critical length of a 3 percent grade for trucks is 1,400 ft (426.7 m); the study showed the distance to be over 2,100 ft (640.1 m). Thus, the current design guidelines for critical length of grade may be more than 700 ft (213 m) shorter than warranted for single-unit trucks and tractor-semitrailers.

In other words, hill-climbing lanes may be needed less often than current guidelines suggest.

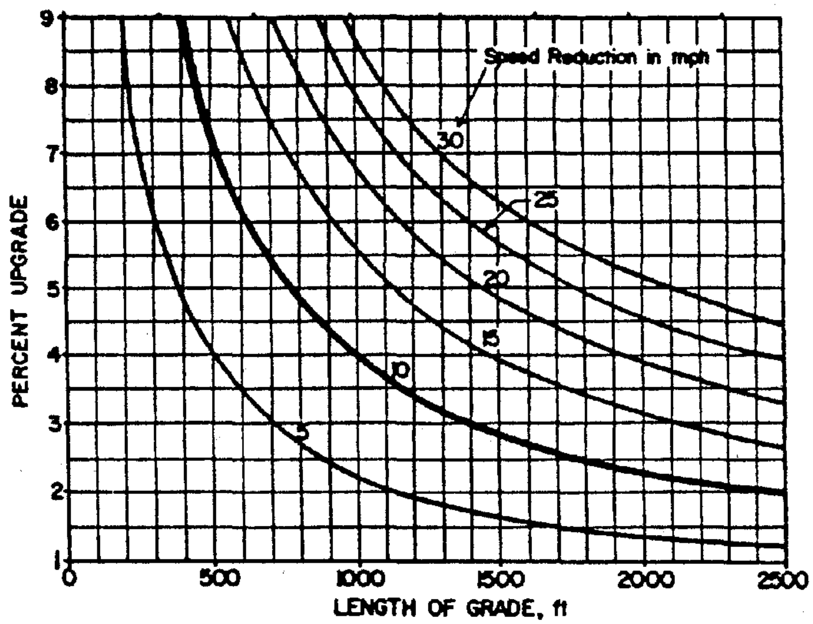

Figure 7. Current design guidelines for critical lengths of grade if entering speed is 55 mi/h.[2]

Table 6. Critical lengths of grade in ft for 55 mi/h entry speed.[1]

Grade	Current Design Guideline	Values Developed from This Study: Single Trucks and Tractor-Semitrailers	Single Trucks Pulling Trailers	Doubles
2	2,500	5,250	4,170	3,140
3	1,400	2,040	1,850	1,620
4	1,000	1,270	1,190	1,090
5	750	920	880	820
6	625	720	700	660
7	525	600	580	550
8	450	500	490	470
9	400	450	430	410

CHAPTER V
TOOLS FOR DESIGNING HILL-CLIMBING LANES

This study produced a method which can help highway designers analyze the effect of grades on truck speeds, assess the need for hill-climbing lanes, and design or maintain hill-climbing lanes. This chapter describes the method, gives examples to illustrate its application, and compares the results with values used in current design guidelines.

The general formula to calculate speed losses on grades for a particular type of truck is:

$$dU/dX = 0.465\ [375/((W/P_3)\ (U)) - G_r]\ 32.2/U \qquad (2)$$

where

U = speed, in mi/h
G_r = grade, in percent/100
W/P_3 = weight-to-available power ratio, in lbs/hp.

As described earlier, W/P_3 is speed dependent. The speed at which a specific type of truck climbs a hill can be computed through an iteration process:

$$U_i = U_{(i-1)} + (dU/dX)\ \Delta x \qquad (3)$$

where

U_i = speed in mi/h for the i^{th} iteration
Δx = a distance increment, e.g., 10 ft (3.0 m)

To assist designers, a computer program in the BASIC language was developed to calculate truck speed. Figure 8 lists this program.

Although it is recommended that the W/P_3 values for the 12.5 percentile be used, this method can be applied using values for percentiles greater than 12.5. Moreover, the method can be applied to account for different truck mixes. The general procedure for applying this method is shown in figure 9.

```
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 8. Microcomputer program for computing speed-distance curves.[1]

1. Select/Determine entry speed.
2. Estimate/Determine distribution of trucks in terms of:
   - single-unit trucks and tractor-semitrailers
   - doubles
   - single-unit trucks pulling trailers.
3. Select design percentile; 12.5 percent recommended.
4. Determine W/P_3 at 25 and 50 mi/h (40 and 80 km/h) for design percentile truck.

5a. Compute critical length of grade.

    Or

5b. Determine speed for given uphill profile.

Figure 9. Procedure for applying method.

The following three examples are presented to show highway designers how to use this method to calculate critical lengths of grade.

Problem #1

Determine critical length of a 4 percent uphill grade for a proposed primary highway located in a Western State. Assume truck entry speed is 55 mi/h (89 km/h).

Solution Using Current Design Guidelines:

The critical length of grade for a speed reduction of 10 mi/h (16 km/h) as determined from figure 7 is a little less than 1,000 ft (304.8 m).

Solution Using New Method:

Assuming that the mix of trucks is 100 percent single-unit trucks and tractor-semitrailers and that the design percentile is 12.5 percent, then the critical length of grade can be determined in one of the following three ways:

1. Read from the plots developed in this study; in this case, see figure 4.

2. Use the BASIC program with entry speed equaling 55 mi/h (89 km/h) and WP25 and WP50 set at 375 and 550, respectively. (W/P_3 values are taken from tables 2 and 3.)

3. Calculate dU/dX for an average speed of 50 mi/h (80 km/h) (i.e., entry limited speed = 55 mi/h [89 km/h] and final speed = 45 mi/h [72 km/h]), an average W/P_3 of 550 lbs/hp (i.e., appropriate for 12.5 percentile at 50 mi/h [80 km/h]) and an uphill grade of 4 percent. Then calculate critical length of grade = (10 mi/h)/(dU/dX).

The critical length of grade would be calculated to be more than 1,200 ft (365.7 m), which is more than 200 ft (61.0 m) longer than the current design guidelines indicate.

Problem #2

Determine the critical length of grade if the truck mix is 80 percent tractor-semitrailers and 20 percent doubles.

Solution Using Current Design Guidelines:

Since the current methodology does not consider different truck types, the solution would be the same as that for Problem #1, which is 1,000 ft (304.8 m).

Solution Using New Method:

The solution can be obtained in two ways. For the first, estimate the W/P_3 values at 25 mi/h (40 km/h) and 50 mi/h (80 km/h) for the 12.5 percentile of the truck mix and then execute the BASIC program. Alternatively, estimate the dU/dX value for 50 mi/h (80 km/h) for the 12.5 percentile of the truck mix and calculate the Δx. The full solutions follow below:

1. First, based on proportions, the 12.5 percentile W/P_3 value for the specified truck mix is equivalent to the 62.5 percent W/P_3 value for doubles (i.e., 12.5%: x = 20% : 100%). Estimates for this W/P_3 value at 50 mi/h (80 km/h) can be extrapolated from the values in tables 2 through 5. The W/P_3 values were calculated to be 308 and 667 at 25 mi/h (40 km/h) and 50 mi/h (80 km/h), respectively. Using the BASIC program, the critical length of grade is computed to be 1,150 ft (305.5 m).

2. Using the W/P_3 values in tables 2 through 5, the dU/dX values at 50 mi/h (80 km/h) can be computed to be:

	dU/dX, in mi/h per 1,000 ft	
	12.5 Percentile	50.0 Percentile
Tractor-Semitrailer	-7.89	-7.25
Doubles	-9.17	-8.77

Plotting these points to reflect the 80/20 truck mix results in figure 10a. Combining the two curves to develop a distribution for the 80/20 truck mix yields figure 10b. Based on this curve, the dU/dX for the 12.5 percentile can be approximated to be -8.6 mi/h per 1,000 ft (-14 km/h per 304.8 m). Therefore

$$\Delta x = \frac{\Delta S}{dU/dX} = \frac{-10 \text{ mi/h}}{-8.6 \text{ mi/h per } 1000 \text{ ft}} = 1163 \text{ ft} \tag{4}$$

The critical length of grade is approximately 1,150 ft (350.5 m).

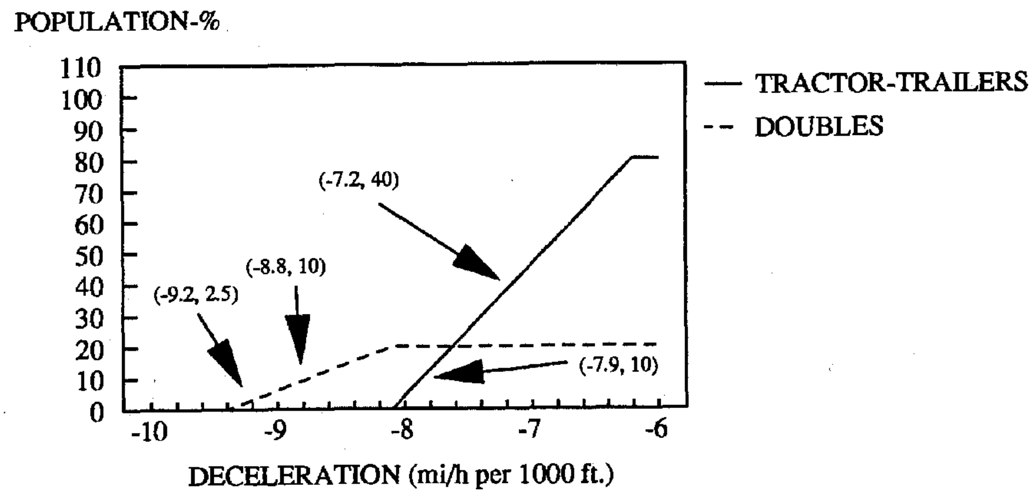

Figure 10a. Deceleration distributions for doubles and for tractor-semitrailers within a mixed truck population.[1]

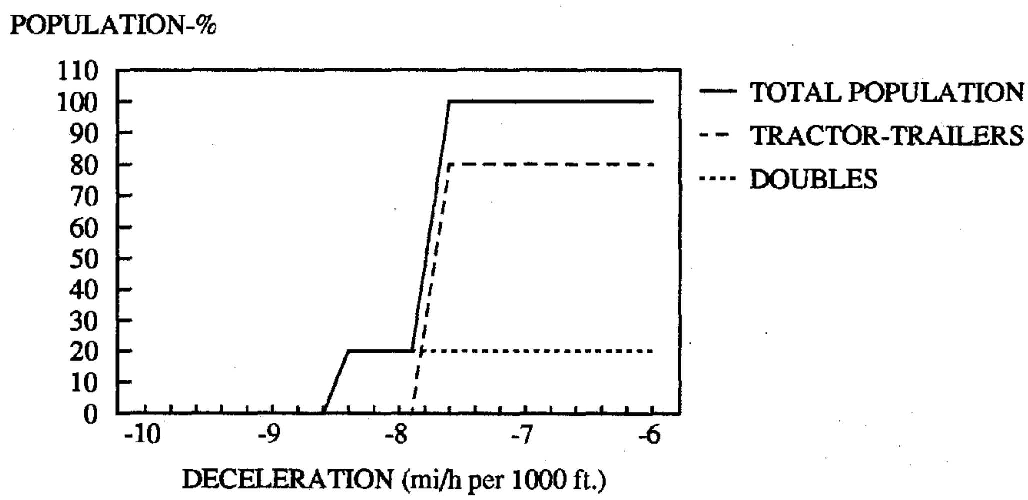

Figure 10b. Deceleration distribution for a mixed truck population.[1]

Problem #3

Determine the critical length of a 5 percent upgrade preceded by a 1,500 ft (457.2 m) length of 2 percent upgrade. Assume trucks enter the 2 percent upgrade at 55 mi/h (89 km/h) and that 100 percent of the trucks are tractor-semitrailers.

Solution Using Current Design Guidelines:

Figure 7 shows that after traveling 1,500 ft (457.2 m) up a 2 percent grade, the estimated drop in truck speed is 6 mi/h (10 km/h). Using this figure, it can be determined that the remaining allowable speed reduction of 4 mi/h (6 km/h) will be made on approximately 275 ft (83.8 m) of the 5 percent upgrade.

Solution Using New Method:

The critical length of grade could be computed using the BASIC program with the entry speed set to 55 mi/h (89 km/h), WP25 and WP50 set equal to 375 and 550, respectively, and distance and elevation data reflecting first the 1,500 ft (457.2 m), 2 percent upgrade and then a long (e.g., 2,000 ft), 5 percent upgrade. The output of the program indicates that truck speed drops below 45 mi/h (72 km/h) at a distance approximately equal to 2,100 ft (640.1 m). Therefore, 600 ft (183 m) up a 5 percent grade is acceptable.

Limitations of New Method

While the method described in this study may yield better predictions of speed loss going uphill than current guidelines, the decision-making process for designing or maintaining hill-climbing lanes needs further improvements. This new method deals only with relative differences among four truck types. It does not consider the relative percentage of trucks compared to cars or the absolute number of trucks per day. From a safety perspective, a potentially dangerous situation occurs when trucks travel significantly more slowly than the traffic stream. Therefore, in determining the need for hill-climbing lanes, designers should try to minimize the frequency of times that this situation occurs. Thus the decision-making process should consider such factors as the probability that the event described above occurs, average daily truck traffic volumes, and trucks as a percentage of the total traffic stream.

In addition, this new method may require estimating trucks by truck class. Traffic engineers, transportation planners, and highway designers already have difficulty simply projecting the number of trucks that will travel daily on a given roadway in the future. For this method, they also will have to estimate the number of trucks for each of the following groups: doubles, single-unit trucks pulling trailers, tractor-semitrailers, and single-unit trucks. Accuracy is an issue.

The method also does not anticipate future improvements in truck design. As shown in figure 11, trends indicate that trucks are being designed with more horsepower per pound of gross weight.

Finally, since the relationships established for the weight-to-available power ratio for doubles and single-unit trucks pulling trailers are based on a rather limited sample, more data are needed to estimate these parameters better.

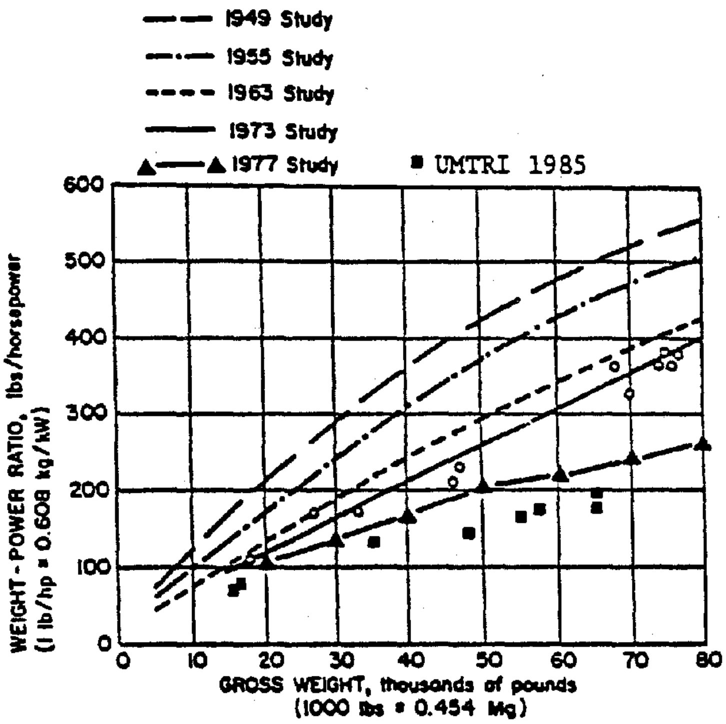

Figure 11. Trends in weight-to-power.[2]

CHAPTER VI
CONCLUSION

Summary

- Current design guidelines are conservative for single-unit trucks and tractor-semitrailers. As a result, the critical length of grade being used for these two types of trucks is shorter than warranted.

- Single-unit trucks with trailers and doubles do not perform as well as single-unit trucks and tractor-semitrailers.

- The weight-to-available power ratio should be used to determine critical length of grade.

- Highway designers need more comprehensive methods for deciding when hill-climbing lanes are warranted.

The Impact on Highway Safety

Trucks often have a difficult time traveling uphill. They can impede the flow of traffic, reduce the highway's capacity to carry traffic, and create possible hazards to other vehicles. For all of these reasons, highway designers consider constructing hill-climbing lanes to make travel safer.

This study, however, shows that the current design guidelines may be leading designers to construct and maintain more hill-climbing lanes than actually needed. This means that there is a low rate of return on precious dollars being spent to construct these lanes. These dollars could perhaps be used elsewhere to improve highway safety more effectively.

REFERENCES

(1) Thomas D. Gillespie, Methods for Predicting Truck Speed Loss on Grades, FHWA/RD-86/059, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1986.

(2) American Association of State Highway and Transportation Officials (AASHTO), A Policy on Geometric Design of Highways and Streets, Washington, DC, Copyright 1984. Figures used by permission.