

Passenger-Car Equivalents for Rural Highways

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The objective was to determine the passenger-car-equivalent (PCE) value for 14 different vehicle types under varying conditions of traffic and roadway geometry. This was accomplished by analyzing field data collected in several states on both two-lane and four-lane highways. Data included headways, speeds, and travel times by vehicle type, traffic-volume condition, and roadway-section type. An analytical model was developed to estimate PCE values based on speed distributions, traffic volumes, and vehicle types. The calibrated model was used to estimate PCE values for 14 vehicle types under specified typical conditions for two-lane and four-lane rural highways. Composite PCE values for a range of geometric, volume, and percentage-of-truck values are presented and compared with values from other research.

The utility of a rural highway in serving traffic is a function not only of the geometric characteristics of the highway but also of the composition of the traffic. The presence of large and/or low-performance vehicles in the traffic stream reduces the total number of vehicles that can use the highway. The effects of trucks and other low-performance vehicles may be equated to an equivalent number of passenger cars added to the traffic stream if appropriate analytical models of traffic flow, vehicle-operating characteristics, and field validation of data are available. Passenger-car equivalents (PCEs) may be based on a consideration of passing, speed, occupancy, or capacity impacts.

This paper describes the methodology and results of a study done for the U.S. Department of Transportation (1). The results of this study were submitted for use in the Cost-Allocation Study of the Federal Highway Administration (FHWA), which has proposed an adjustment in the allocation of highway costs among the several classes of vehicles. Rural two-lane two-way highways and two-lane one-way (i.e., four-lane) facilities were studied in Texas, North Carolina, Pennsylvania, Colorado, and West Virginia. Flat, moderate, and steep grade geometrics were studied for both types of highways. An attempt was made to collect traffic speed and headway data at all volume levels. PCE values for 14 vehicle types were determined both empirically and theoretically by using an analytical model developed in this research.

BACKGROUND

PCE values have been used primarily in the framework of traffic-capacity procedures. PCE values are employed as a device to convert a traffic stream composed of a mix of vehicle types into an equivalent traffic stream composed exclusively of passenger cars. The availability of such values permits the specification of capacity in terms of PCEs exclusively and provides the basis for development of procedures to express any traffic-stream composition in terms of PCEs. By applying such procedures, an analyst can directly convert an existing (or projected) traffic volume composed of a mix of vehicle types into an equivalent PCE volume, which can then be compared with specified PCE (capacity) service volumes. These methods, whether applied to two-lane two-way highways or two-lane one-way (i.e., four-lane) highways, have generally been those described in the 1965 Highway Capacity Manual (HCM) (2).

The HCM gives both generalized and specific values of PCEs. Average generalized PCEs of trucks are given in the HCM as related to generalized terrain conditions and levels of service. PCEs are also provided for trucks on specific individual

highway grades. The generalized PCEs range in value from 2 to 12. The specific-grade PCEs range from 2 to 108.

The literature review carried out as a part of this research showed consistent agreement that the PCEs presented in the 1965 HCM for specific grades on two-lane highways are too high, especially for large percentages of trucks on steep grades. There was less than unanimous agreement on the issue of whether the incremental negative impact of adding trucks to the traffic stream decreases as the percentage of trucks in the traffic stream increases. The PCEs in the multilane section of the HCM vary greatly and in a complex manner.

The two-lane and four-lane PCE values will be addressed separately in the following sections.

TWO-LANE HIGHWAYS

The basic HCM (2) equation for the conversion of a mixed-traffic-stream volume to an all-passenger-car volume for two-lane highways is as follows:

$$SV_L = 2000 \cdot (v/c)_L \cdot W_L \cdot T_L \cdot B_L \quad (1)$$

where

SV_L = maximum volume for a given level of service (LOS) L (total for both directions),

$(v/c)_L$ = volume-to-capacity ratio at LOS L,

W_L = adjustment factor for lane width and lateral clearance at LOS L,

T_L = truck adjustment factor at LOS L, and

B_L = bus adjustment factor at LOS L.

The truck adjustment factor (T_L) is calculated from the following equation:

$$T_L = 1/[1 + P_T(E_L - 1)] \quad (2)$$

where P_T is the decimal fraction of trucks in the traffic stream and E_L is the PCE for trucks at LOS L.

The PCE values for trucks operating on grades of a given length and percent are calculated in the HCM (2) from separate speed distributions of passenger cars and trucks at a given volume level. The criterion used is the relative number of passings of trucks by passenger cars in relation to the number of passings of passenger cars by passenger cars. The specific method is known as the Walker method. It had been mentioned earlier by both Normann (3) and Wardrop (4) but is named for the man who applied it in the 1965 HCM.

The Walker method is used to calculate PCEs for trucks operating on grades. The separate speed distributions of passenger cars and trucks at a given traffic volume are used to compute the relative number of passings that would have been performed per mile of highway if each vehicle continued at its normal speed for the conditions under consideration. A gradability (speed versus distance up a sustained grade) curve for a weight/horsepower ratio of approximately 325 lb/hp, considered typical of conditions on two-lane highways carrying a variety of trucks [Figure 1 (2)], was used to develop an average speed over grades of varying steepness and length as shown in Figure 2 (2). When this average

Figure 1. Effect of length and steepness of grade on speed of average truck on two-lane highway.

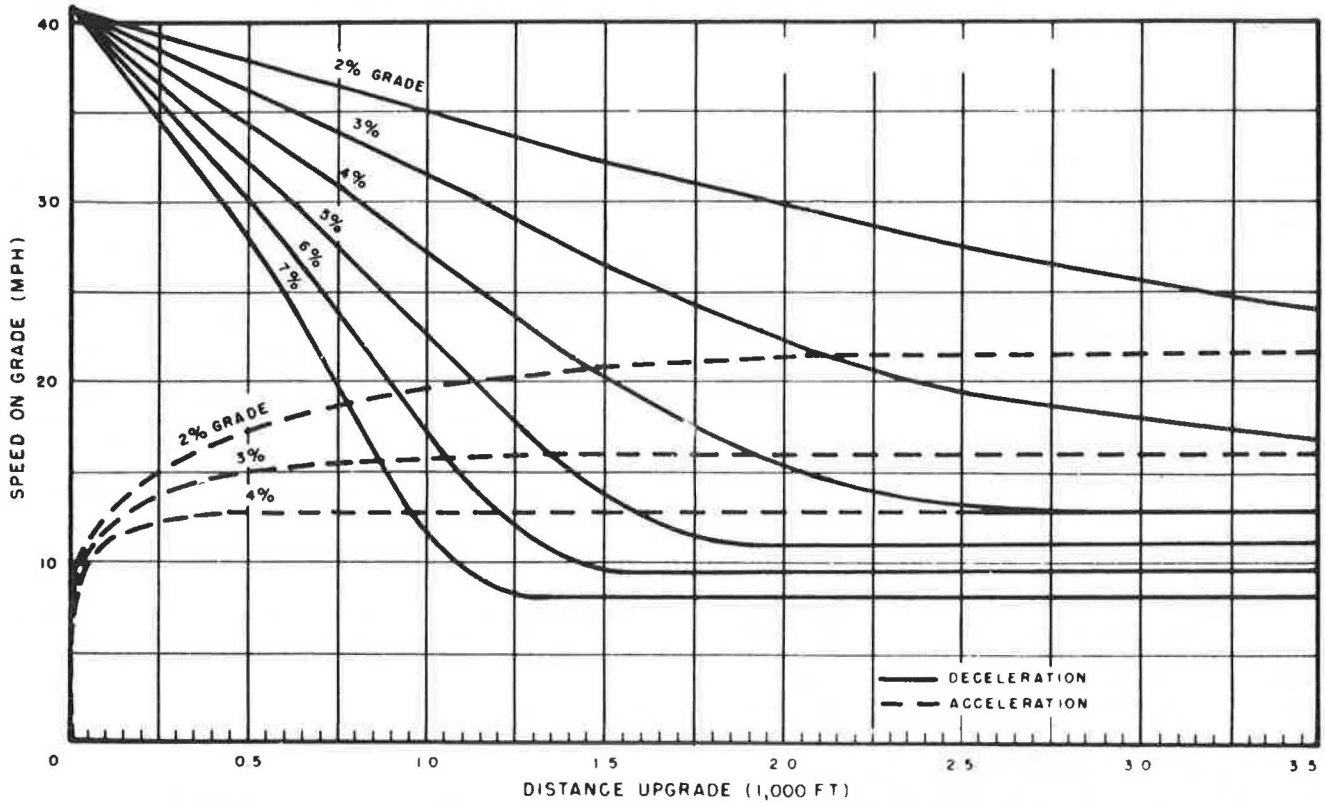


Figure 2. Mean speed of average truck over entire length of grade on two-lane highway.

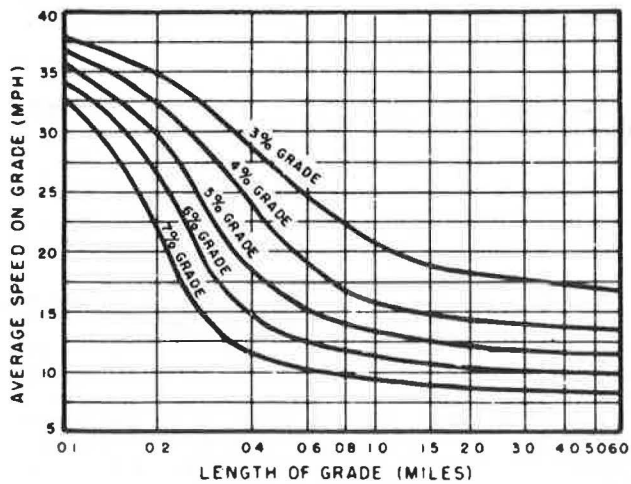
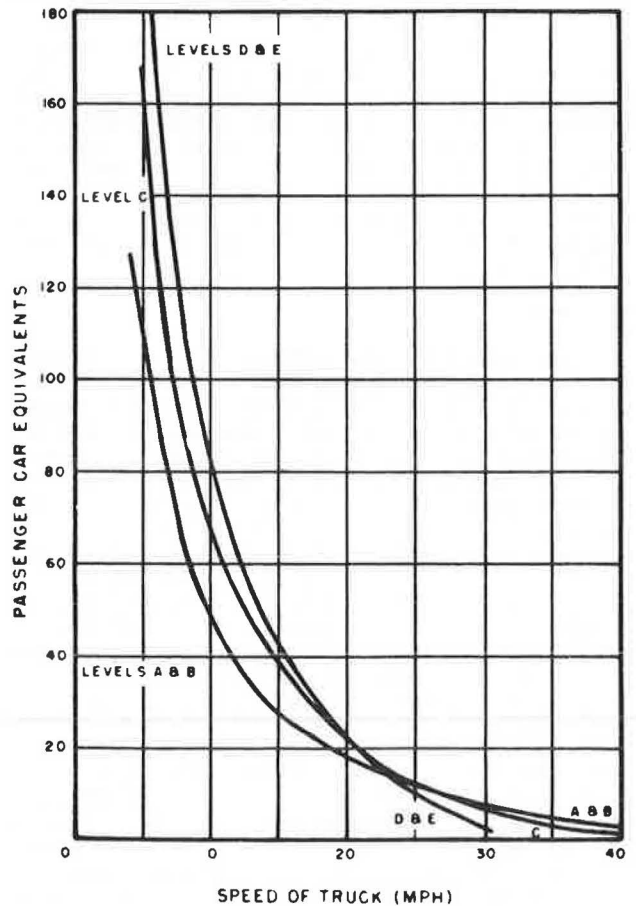


Figure 3. PCEs for various average truck speeds on two-lane highway.



speed was known, Walker's method was used to calculate PCEs as may be seen in Figure 3 (2). Table 1 contains the HCM PCEs calculated from this methodology for specific terrain conditions. The generalized HCM PCEs are shown below. No PCE values were given for recreational vehicles.

Equivalent	Level of Service	PCE for		
		Level Terrain	Rolling Terrain	Mountainous Terrain
E_T (truck)	A	3	4	7
	B and C	2.5	5	10
	D and E	2	5	12
	All	2	4	6
E_B (bus)	All	2	4	6

Table 1. PCEs of trucks on two-lane highways on specific individual subsections or grades.

Grade (%)	Length of Grade (miles)	PCE for All Percentages of Trucks (E _T) by Level of Service		
		A and B	C	D and E (Capacity)
0-2	All	2	2	2
3	0.25	5	3	2
	0.50	10	10	7
	0.75	14	16	14
	1	17	21	20
	1.50	19	25	26
	2	21	27	29
	3	22	29	31
	4	23	31	32
4	0.25	7	6	3
	0.50	16	20	20
	0.75	22	30	32
	1	26	35	39
	1.50	28	39	44
	2	30	42	47
	3	31	44	50
	4	32	46	52
5	0.25	10	10	7
	0.50	24	33	37
	0.75	29	42	47
	1	33	47	54
	1.50	35	51	59
	2	37	54	63
	3	39	56	66
	4	40	57	68
6	0.25	14	17	16
	0.50	33	47	54
	0.75	39	56	65
	1	41	59	70
	1.50	44	62	75
	2	46	65	80
	3	48	68	84
	4	50	71	87
7	0.25	24	32	35
	0.50	44	63	75
	0.75	50	71	84
	1	53	74	90
	1.50	56	79	95
	2	58	82	100
	3	60	85	104
	4	62	87	108

The spatial-headway method uses the relative amount of space "consumed" by a vehicle to determine its PCE. This method was recently applied by the Institute for Research (IFR) to obtain PCE values on urban freeways (5).

The equivalent-delay method uses the ratio of the delay experienced by a passenger car due to nonpassenger cars to the delay experienced by a passenger car due to other passenger cars. The delay caused to standard passenger cars due to lower-performance passenger cars is explicitly considered.

Craus (6) used the equivalent-delay concept to determine PCE values on two-lane highways based on both the Walker method and the delay to vehicles due to opposing traffic. Craus suggests that the PCE values given in the 1965 HCM are 34 percent too high for 10-mph trucks at LOS A, 40 percent too high at LOS C, and 46 percent too high at LOS E. Craus' model also predicts that PCEs will increase with increasing volume.

FOUR-LANE HIGHWAYS

The basic equation for the conversion of mixed-traffic-stream volume on a multilane rural highway to an all-passenger-car volume is as follows:

$$SV_L = 2000 \cdot N \cdot (v/c)_L \cdot W_L \cdot T_L \quad (3)$$

Table 2. PCEs of trucks on ordinary multilane highways on specific individual subsections or grades.

Grade (%)	Length of Grade (miles)	PCE (E _T)													
		LOS A Through C by Percentage of Trucks					LOS D and E (Capacity) by Percentage of Trucks								
		3	5	10	15	20	3	5	10	15	20				
0-1	All	2	2	2	2	2	2	2	2	2	2	2	2	2	
2	0.25-0.50	5	4	4	3	3	5	4	4	3	3	5	4	3	
	0.75-1	7	5	5	4	4	7	5	5	4	4	7	5	4	
	1.50-2	7	6	6	6	6	7	6	6	6	6	7	6	6	
	3-4	7	7	8	8	8	7	7	8	8	8	7	7	8	
	3	0.25	10	8	5	4	3	10	8	5	4	3	10	8	5
3	0.50	10	8	5	4	4	10	8	5	4	4	10	8	5	
	0.75	10	8	6	5	5	10	8	5	4	5	10	8	5	
	1	10	8	6	5	6	10	8	6	5	6	10	8	6	
	1.50	10	9	7	7	7	10	9	7	7	7	10	9	7	
	2	10	9	8	8	8	10	9	8	8	8	10	9	8	
	3	10	10	10	10	10	10	10	10	10	10	10	10	10	
	4	10	10	11	11	11	10	10	11	11	11	10	10	11	
	4	0.25	12	9	5	4	3	13	9	5	4	3	13	9	5
4	0.50	12	9	5	5	5	13	9	5	5	5	13	9	5	
	0.75	12	9	7	7	7	13	9	7	7	7	13	9	7	
	1	12	10	8	8	8	13	10	8	8	8	13	10	8	
	1.50	12	11	10	10	10	13	11	10	10	10	13	11	10	
	2	12	11	11	11	11	13	12	11	11	11	13	12	11	
	3	12	12	13	13	13	13	13	14	14	14	13	14	14	
	4	12	13	15	15	14	13	14	16	16	15	13	16	16	
	5	0.25	13	10	6	4	3	14	10	6	4	3	14	10	6
	5	0.50	13	11	7	7	7	14	11	7	7	7	14	11	7
		0.75	13	11	9	8	8	14	11	9	8	8	14	11	9
1		13	12	10	10	10	14	13	10	10	10	14	13	10	
1.50		13	13	12	12	12	14	14	13	13	13	14	14	13	
2		13	14	14	14	14	14	15	15	15	15	15	15	15	
3		13	15	16	16	15	14	17	17	17	17	17	17	17	
4		15	17	19	19	17	16	19	22	21	19	19	22	21	
6		0.25	14	10	6	4	3	15	10	6	4	3	15	10	6
6	0.50	14	11	8	8	8	15	11	8	8	8	15	11	8	
	0.75	14	12	10	10	10	15	12	10	10	10	15	12	10	
	1	14	13	12	12	11	15	14	13	13	11	15	14	13	
	1.50	14	14	14	14	13	15	16	15	15	14	15	16	15	
	2	14	15	16	16	15	15	18	18	18	16	18	18	16	
	3	14	16	18	18	17	15	20	20	20	19	20	20	19	
	4	19	19	20	20	20	20	23	23	23	23	23	23	23	

in which SV_L is the service volume (mixed vehicles per hour, total for one direction) for LOS L.

The PCE values for multilane highways in the 1965 HCM were based on the relative delay due to trucks, which was determined by the Walker method in conjunction with gradability curves.

The generalized PCEs for multilane highways suggested by the 1965 HCM are shown below. (Separate consideration of E_B (buses) is not warranted in most problems; E_B is used only where bus volumes are significant.)

Level of Service	PCE for		
	Terrain	Rolling Terrain	Mountainous Terrain
A	Widely variable; one or more trucks have same total effect, causing other traffic to shift to other lanes; use equivalent for remaining levels in problems		
B through E	2	4	8
	1.6	3	5

The PCEs for specific terrain and traffic-volume conditions are shown in Table 2. The PCE values in Table 2 generally decrease for increasing percentages of trucks.

Researchers at the Polytechnic Institute of New York (PINY) used simulation data from a model developed by the Midwest Research Institute (MRI) (7) to develop truck equivalents for varying percentages of trucks on any severity of sustained grade (8). IFR

recently completed a study to determine PCEs by the spatial-headway method for trucks and other nonpassenger cars on urban freeways (5).

The equivalent-delay method was applied in this research. On four-lane highways, overtaking vehicles are inhibited only by concurrent-flow traffic. Faster vehicles may pass at will except when obstructed by slower vehicles passing still slower vehicles. This concept was used by Newman and Moskowitz in a study for the California Department of Transportation and formed the basis for the PCE values used in the 1965 HCM (2,9). In this research,

$$PCE_{ij} = (D_{ij} - D_{base})/D_{base} \quad (4)$$

where

- PCE_{ij} = PCE of vehicle type i under condition j ,
 D_{ij} = delay to passenger cars due to vehicle type i under condition j , and
 D_{base} = delay to standard passenger cars due to slower passenger cars.

MAJOR FACTORS INFLUENCING PCEs

Determination of PCEs in this study included the following factors: roadway geometrics (up and down roadway grades, the length of grade, and the number of lanes), vehicle performance characteristics (length of vehicle, weight, and horsepower), and traffic flows (volume demand, directional split on two-way two-lane roads, percentage of vehicle types, and vehicle speeds).

Geometric Factors

The range of grades considered extends from 0 to 7 percent. Three levels of grades were defined:

1. Level (0-1 percent),
2. Moderate (2-4 percent), and
3. Steep (5-7 percent).

The 1965 HCM terrain descriptions (flat, rolling, mountainous) were purposely avoided since the terrain descriptions are generalizations of average conditions.

Two grade conditions were studied at each data-collection site. At each site, measurements were taken on a level section of the road and on a moderate or steep grade in the immediate vicinity.

Vehicle Performance Factors

The terminology "vehicle performance" is used to describe the speed capabilities of individual vehicles operating along a road of given geometrics. The term "operations" is used to describe the collective behavior of a mix of vehicle types in the traffic stream. The vehicle performance capabilities of the following 14 vehicle types were considered:

1. Base automobile (standard and compact),
2. Small automobile (subcompact),
3. Motorcycle,
4. Bus (intercity, school, transit),
5. Single-unit truck with two axles and four wheels (pickups, vans, delivery),
6. Single-unit truck with two axles and six wheels (various weights),
7. Single-unit truck with three or more axles (various weights),
8. Three-axle truck combination (2S2, 2-1, various weights),

9. Four-axle truck combination (2S2, various weights),

10. Other four-axle truck combinations (3-1, 2-2, 3S1, 2S1, various weights),

11. Five-axle truck combination (3S2, various weights),

12. Other five-axle truck combinations (2S3, 3-2, 2S1, 2-3, various weights),

13. Truck combinations with six axles or more (3-3, 2S2-2, 3S2, various weights), and

14. Recreational vehicles--car and trailer, motorhome, pickup camper.

Except for the last category listed, these are the case-study visual categories for the FHWA Highway Performance Monitoring System.

Traffic Flow Factors

Volume levels were chosen to relate approximately to level of service. The following volume ranges correspond to the indicated levels of service for uninterrupted flow on two-lane one-way (four-lane) highways in the 1965 HCM:

Volume (vehicles/h)	Approximate Level of Service	Volume Level
0-600	A	1
601-1000	B	2
1001-1500	C	3
1501-1800	D	4
1801-2000	E	5
Over capacity	F	6

The maximum service volumes for two-lane two-way highways under uninterrupted flow conditions are given by the 1965 HCM in terms of the total traffic in both directions as follows:

Maximum Service Volume (both directions) (vehicles/h)	Approximate Level of Service	Volume Level
400	A	1
900	B	2
1400	C	3
1700	D	4
2000	E	5
Over capacity	F	6

By defining the volume ranges in terms of levels of service, five volume levels (1 through 5) were used.

PCE Matrix

A three-dimensional PCE matrix was constructed. The dimensions of the matrix are the 14 vehicle types listed previously, 6 rural highway section types (one or two lanes per direction times level, moderate, or steep grade), and 5 traffic-volume levels.

The 14 vehicle types, 6 rural highway section types, and 5 volume levels yield a matrix containing 420 cells. As might be expected, sufficient data could not be collected for all of the cells in the matrix. Volume levels above volume level 3 were not observed except at one two-lane one-way site with a moderate grade (Charlotte, North Carolina).

DATA COLLECTION

Data-collection sites were chosen to attempt to collect data that encompass the full range of vehicle types, volume levels, and rural highway section types (both by number of lanes and alignments) listed in the previous section.

Figure 4. Data-collection configuration.

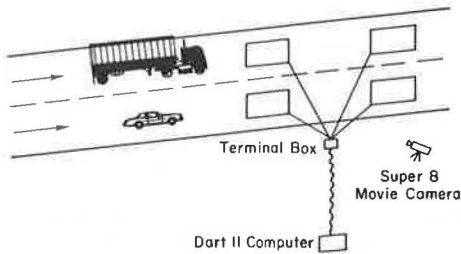
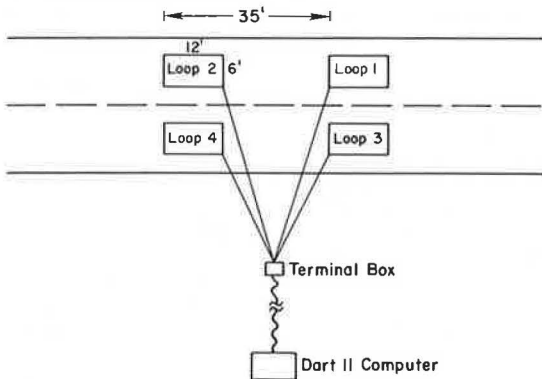


Figure 5. Loop configuration.



Site-Selection Criteria

Four sites were chosen on two-lane two-way highways and four on two-lane one-way highways. Operational data were collected at two locations per site. One location was on a level section of highway and the second was on a moderate or steep section of highway. Truck weight and horsepower data were collected concurrently with the traffic-flow data.

The eight sites (four two-lane and four four-lane) were located in five states, as follows:

1. Colorado: two-lane and four-lane,
2. Texas: two-lane and four-lane,
3. West Virginia: two-lane,
4. Pennsylvania: two-lane and four-lane, and
5. North Carolina: four-lane.

These states included sites where most, if not all, of the combinations of vehicle type, vehicle weight/horsepower ratio, volume level, and rural highway section type are available.

Data-Collection Techniques

Data were collected by using both an automatic data-collection system and a time-lapse camera, as shown in Figure 4. Headways, speeds, and occupancies were determined from data accumulated by the automatic data-collection system. Visual-classification data were collected by using Super-8 Timelapse Corporation cameras. Truck-characteristic data were collected concurrently.

The sensors for the automatic data-collection system were pairs of inductive loops connected to a roadside terminal box, shown in Figure 5. The loops were 6 ft laterally by 12 ft longitudinally in a rectangular shape, spaced 35 ft from leading edge to leading edge; there were two conductors in each loop. The loops were fixed to the pavement surface by using 3-in-wide gray duct tape. A coating of

rubber-based adhesive was then applied to both the tape and approximately 3 in of the adjacent roadway surface to provide a stronger bond. The material used was Miracle Construction Adhesive, and it dried to a firm state in approximately 30 min under dry, warm conditions.

The roadside terminal box contained a remote oscillator for each loop, tuned to different frequencies to minimize interference for transmission to the Radian Corporation DART II computer located approximately 100 ft from the edge of the highway. The Radian DART II is a microprocessor-based data-acquisition system that contained both the vehicle detector circuits and an IBM flexible disk drive for recording data. Traffic-flow data were collected as time of actuation and time of deactuation for each of the four inductive loops in the configuration shown in Figure 5. The date, time, loop identification number, and current loop status (on or off) were recorded for each input event.

Visual vehicle classification data were collected by using Super-8 Timelapse Corporation cameras. The cameras display time of day digitally, to the second, on the film image. The cameras were generally set to 1 frame/s, although in some instances 2 frames/s was used. The time of day for all cameras and computers was set daily prior to starting the study. The time-lapse cameras were aimed at the loops to enable identification of the vehicles actuating the detectors as well as to provide a means of match with the truck-weighing operation data.

Concurrent with the automatic data-collection and visual data-collection effort, trucks were weighed at a point remote from the loop locations. The truck weighing included a side variation in methods, which ranged from the portable "loadometer"-type scales used in Pennsylvania to the directional, double-sided platform scale station in North Carolina, which processed two queues of trucks simultaneously. Truck weight, horsepower, identifying features, and time of day were manually recorded for pairing with observed traffic-flow data. Photographs of the trucks were taken in most cases to confirm site identity.

After extensive communication with the highway departments in Texas, Colorado, Pennsylvania, North Carolina, and West Virginia and following a field inspection trip to each location, the sites were chosen and studied from May through August of 1981.

DATA REDUCTION

The data were stored by the Radian Corporation DART II automatic data-collection system on flexible diskettes. The format of each record was as follows:

1. Date,
2. Time (hour, minute, second, and ticks of a 240-h clock),
3. Detector number, and
4. Detector on or off indicator.

The data on the flexible diskettes were interpreted and transferred to an 800-bit/in magnetic tape in the form of 80 character records in the same general form shown above. These records were then analyzed to determine the actuation trajectory of each vehicle. Simultaneously, the vehicles were identified as one of the 14 types previously described. The resulting vehicle data were then coded in the following format:

1. Site number,
2. Lane number,
3. Vehicle type,

4. Date,
5. Time of first trap detector on,
6. Time of first trap detector off,
7. Time of second trap detector on, and
8. Time of second trap detector off.

Volume-level samples were obtained by expanding 5-min samples to 1-h volumes; 5-min samples of the same volume level were then concatenated. Headways and speeds by vehicle type within each volume level at each unique location were analyzed. Only volume levels 1, 2, and 3 were found at the sites studied, with the exception that the Charlotte, North Carolina, site had some traffic of volume level 5. A total of 13 991 vehicles were observed at the two-lane one-way (four-lane) sites, and 11 213 vehicles were observed at the two-lane two-way sites.

DATA ANALYSIS

The data were analyzed to produce a number of statistics to be applied in the PCE procedures. Spatial-headway and speed mean values were derived by lane, site, vehicle type, and volume level. The truck-weight data obtained concurrently with the traffic-stream data were also processed to provide insight into the effects of weight and horsepower on vehicle performance.

PCE values were determined by using the Walker, spatial-headway, and equivalent-delay methods. These could be computed directly for only those volumes and vehicle types sampled. Since very little data were available at volume levels 3, 4, and 5, models were developed to allow estimation of PCEs on the basis of the Walker method or the equivalent-delay method for varying volume levels and percentages of trucks and recreational vehicles. Vehicle speed estimates were based on the gradability curves developed by MRI (7) and weight/horsepower and traffic-stream data collected during this study.

The model for estimating the Walker-method PCEs used the following equation:

$$PCE_i = (OT_i/VOL_i)/(OT_{LPC}/VOL_{LPC}) \quad (5)$$

where

- PCE_i = PCE of vehicle type i ,
 OT_i = number of overtakings of vehicle type i by passenger cars per mile per hour,
 VOL_i = volume of vehicle type i per hour,
 OT_{LPC} = number of overtakings of lower-performance passenger cars by other passenger cars per mile per hour, and
 VOL_{LPC} = volume of lower-performance passenger cars per hour.

The model for estimating the equivalent-delay PCEs used the following equation:

$$PCE_i = (OT_i/VOL_i) [(1/TSSP) - (1/MPCSP)] \div (OT_{LPC}/VOL_{LPC}) [(1/AVCRSP) - (1/MPCSP)] \quad (6)$$

where

- TSSP = mean speed of mixed traffic stream,
MPCSP = mean speed of traffic stream with only higher-performance passenger cars, and
AVCRSP = mean speed of traffic stream when it contains only passenger cars.

Unimpeded vehicle speeds were estimated for typical grade conditions for each of the 14 vehicle types on two-lane and four-lane highways by using typical weight/horsepower values for each vehicle type. Insufficient data were obtained for motor-

cycles to estimate PCEs. The typical grade conditions used for PCE computation were

1. Flat (0 percent grade);
2. Three percent grade, 1 mile long; and
3. Six percent grade, 1 mile long.

The models were calibrated for the grade conditions observed; then PCE values were computed for the above typical conditions.

A fundamental assumption in the Walker method is that faster vehicles are not impeded in passing as they overtake slower vehicles, so queues do not form. Conversely, in the equivalent-delay model, it is assumed that faster vehicles are always impeded by slower vehicles, which results in queues on the analysis section. It was assumed that the Walker method is appropriate for volume level 1, and the equivalent-delay method is appropriate at volume level 5. A linear combination of the Walker and equivalent-delay PCEs was computed for each intermediate volume level.

PCE values for each vehicle type, roadway condition, and volume level were derived. For the two-lane highways, up-grade PCEs were computed. For the four-lane highways, the median and outside lanes were considered separately. Due to space constraints, the individual-vehicle-type PCE values are not presented here. They may be found elsewhere (1).

Composite PCE values for all trucks and recreational vehicles, weighted and pooled by constituent proportion of the truck population, were considered. This mechanism supports continuation of the current percentage-of-truck input to the truck factor with a single truck PCE rather than use of a large number of truck types and PCE values. These composite values were computed and are shown in Table 3 for 5,

Table 3. Composite PCE values for two-lane and four-lane highways.

Roadway Type	Trucks (%)	Volume Level				
		1	2	3	4	5
Two-Lane Highway						
Two-lane flat	5	1.5	1.6	1.6	1.6	1.7
	10	1.5	1.6	1.6	1.7	1.8
	15	1.5	1.6	1.7	1.8	1.8
	20	1.5	1.6	1.8	1.8	1.9
	25	1.5	1.7	1.8	1.9	2.0
Two-lane moderate	5	3.0	3.2	3.5	3.7	4.0
	10	3.0	3.3	3.7	4.0	4.4
	15	3.0	3.4	3.8	4.3	4.8
	20	2.9	3.5	4.0	4.5	5.1
	25	2.9	3.5	4.2	4.8	5.4
Two-lane steep	5	5.5	7.3	9.6	12.0	15.5
	10	5.4	7.6	10.5	13.3	13.3
	15	5.3	8.9	11.1	12.1	12.6
	20	5.3	8.1	10.4	11.7	12.0
	25	5.3	8.2	10.1	11.7	11.1
Four-Lane Highway						
Four-lane flat	5	1.7	1.8	1.8	1.9	2.0
	10	1.7	1.8	1.9	2.0	2.1
	15	1.6	1.8	1.9	2.0	2.1
	20	1.6	1.8	1.9	2.1	2.2
	25	1.6	1.8	1.9	2.1	2.2
Four-lane moderate	5	2.9	3.3	3.7	4.1	4.5
	10	2.9	3.4	3.9	4.4	5.0
	15	2.9	3.5	4.0	4.6	5.3
	20	2.9	3.5	4.2	4.8	5.6
	25	2.9	3.6	4.3	5.1	5.8
Four-lane steep	5	6.8	9.3	14.6	19.8	25.6
	10	6.4	8.2	9.9	12.9	17.0
	15	6.0	7.1	7.1	10.0	13.1
	20	5.6	6.3	6.7	8.0	10.1
	25	5.3	5.6	5.7	6.5	7.8

Table 4. Comparison of PCE values for two-lane highways.

Roadway Type	Volume	PCE Value		
		HCM General	HCM Specific	TTI (25 percent trucks)
Two-lane flat	A	3	2	1.5
	B	2.5	2	1.6
	C	2.5	2	1.6
	D	2	2	1.6
	E	2	2	1.7
Two-lane moderate	A	4	17	2.9
	B	5	17	3.5
	C	5	21	4.2
	D	5	21	4.8
	E	5	20	5.4
Two-lane steep	A	7	41	5.1
	B	10	41	8.2
	C	10	59	10.1
	D	12	59	11.7
	E	12	70	11.1

Table 5. Comparison of PCE values for four-lane highways.

Volume	Trucks (%)	PCE Value				
		HCM General	HCM Specific	IFR	PINY	TTI
Four-Lane Flat						
A-C	5	2	2	1.2		1.8
A-C	10	2	2	1.2		1.8
A-C	15	2	2	1.2		1.8
A-C	20	2	2	1.2		1.8
DE	5	2	2	1.8		2.0
DE	10	2	2	1.8		2.1
DE	15	2	2	1.8		2.1
DE	20	2	2	1.8		2.2
Four-Lane Moderate (3 percent, 1 mile long)						
A-C	5	4	8		8.5	3.3
A-C	10	4	6		7	3.4
A-C	15	4	5		7	3.5
A-C	20	4	6		7	3.6
DE	5	4	8		8.5	4.3
DE	10	4	6		7	4.7
DE	15	4	5		7	5.0
DE	20	4	6		7	5.2
Four-Lane Steep (6 percent, 1 mile long)						
A-C	5	8	13		21.5	10.2
A-C	10	8	12		18	8.2
A-C	15	8	12		18	6.9
A-C	20	8	11		18	6.2
DE	5	8	14		21.5	22.7
DE	10	8	13		18	15.0
DE	15	8	13		18	11.6
DE	20	8	11		18	9.0

10, 15, 20, and 25 percent trucks. These values include all buses and recreational vehicles.

A comparison among PCEs from the 1965 HCM (2), both general and specific; the IFR study (5) on urban freeways; the PINY study (8) from MRI design charts (7); and the values computed in this research at the Texas Transportation Institute (TTI) is shown in Tables 4 and 5. The PCE values found for trucks in this research generally agree with the 1965 HCM general values, as well as with the PCEs found by IFR on flat urban freeway sections. The specific values, however, found in the 1965 HCM for the two-lane moderate grade (3 percent, 1 mile long) and the two-lane steep grade (6 percent, 1 mile long) are seriously divergent. In the light of other recent research, for instance, that of McLean (10) and ours, which concludes that the PCE values for trucks

on long grades are much too high, serious consideration should be given to substantial reductions in the HCM specific-grade PCE values.

The four-lane PCE values for flat terrain are in virtual agreement for all of the values shown in Table 5. For four-lane PCE values for moderate grades, (3 percent, 1 mile long) the HCM specific values and the PINY values are both somewhat higher than the HCM general and the PCEs computed in this study. The PCE values for the four-lane steep grade are all of the same order of magnitude, although a lack of sensitivity to percentage of trucks is apparent in all sources except this research.

CONCLUSIONS

This research provided several significant findings for two-lane and four-lane rural highways, as listed below:

1. The generalized PCE values for two-lane and four-lane rural highways in the 1965 HCM are substantiated by the PCEs determined in this research for the composite stream of nonpassenger car types.
2. The PCE values for specific grades on two-lane rural highways are overly conservative for both moderate and steep grade conditions.
3. It is not necessary to increase the complexity of the truck-factor equation (Equation 2). E_L values may be used for a composite traffic stream consisting of buses, trucks, and recreational vehicles. E_L is shown in this research to be an explicit function of (a) percentage of trucks, (b) volume level (1, 2, 3, 4, 5), and (c) grade condition (flat, moderate, steep, and four-lane or two-lane).

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The contents of this paper reflect our views, and we are responsible for the facts and accuracy of the data presented herein.

The contents do not necessarily reflect the official view or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Discussion

Roger P. Roess

The subject of PCEs has received considerable attention in recent years for two different reasons. The federal government has supported a number of studies for the development of PCE values for various categories of trucks with the purpose of using these values in the allocation of the road-user tax burden among these categories of trucks as well as among other vehicles that use the nation's highways. The research reported by the authors results from one such study. The subject has also received attention in a variety of studies directed at producing methodologies for the third edition of the HCM.

Cunagin and Messer should be complimented on the thoroughness and quality of their work. Their paper points out, however, one of the hazards of working with PCE values: the lack of any general consensus of what PCE values are and how they ought to be calibrated.

Various researchers have used a variety of criteria for calibrating PCE values:

1. Relative numbers of passing maneuvers on two-lane highways,

2. Delay caused by trucks in the traffic stream (equivalent delay),
3. Relative spatial headways of trucks compared with those of passenger cars, and
4. Equivalent volume/capacity ratio.

Cunagin and Messer have used a combination of the first two criteria in calibrating PCE values for their study. This method is an adaptation of the methods used to develop the values of the 1965 HCM.

The authors compare the study results with PCE values calibrated at PINY for Transportation Research Circular 212 (11). In general, the study values are lower than the PINY values in Circular 212.

It should be noted that PINY values were calibrated to produce an equivalent volume in passenger cars per hour that used the same percentage of the roadway's capacity as the actual volume of mixed traffic, i.e., to keep the volume/capacity ratio constant. Thus, since the two studies started with different concepts of PCEs, it is not unusual that the results differ, even significantly.

The use of PCEs is a critical point. Messer has clearly recognized this in his recent draft report on the capacity of two-lane rural highways. In his formulation of new capacity-analysis procedures, he has not used the values resulting from the study reported in this paper, the focus of which was not capacity analysis. For capacity analysis, he suggests the use of factors based on producing an equivalent volume in passenger cars per hour that travels at the same average speed as the actual volume of mixed traffic. This is directly related to the use of average speed as a measure of effectiveness for level of service of two-lane rural highways.

For multilane highways, there is considerable evidence that the PCE values used in Circular 212 are too high, primarily because the standard truck selected for calibration was too heavy to reflect current conditions. These factors are now being revised as part of Project 3-28B of the National Cooperative Highway Research Program, which will produce the third edition of the HCM.

In summary, the paper presents a most comprehensive treatment of PCE calibration and use. The philosophical issue of whether or not PCE values are

an appropriate measure by which to evaluate the allocation of road-user taxation remains but is not one that can be addressed in the context of a study such as that reported here, since it was a given objective of the sponsor.

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