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SEVEN EXPERIMENT DESIGNS ADDRESSING PROBLEMS OF SAFETY AND CAPACITY ON TWO-LANE RURAL HIGHWAYS
Volume V: Experimental Design for Vehicle Equivalency and Capacity Including Effects of Commercial and Recreational Vehicles on Rural Non-Controlled Access Highways

G. F. King
P. Abramson
J. W. Cohen
M. R. Wilkinson

KLD Associates, Inc.
300 Broadway
Huntington Station NY 11746

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16. Abstract

Two methods are proposed to measure equivalency and capacity: the Walker Method, used to compute the tables in the Highway Capacity Manual, and the mean cluster size method developed in Australia.

The object of the experiment is to update and extend Chapter 10 of the Highway Capacity Manual. This Technical Report consists of seven other volumes:

Vol.	pp.	Title
I	38	Introduction, Description of Experiments and Common Elements
II	70	Develop and Evaluate Dynamic Aids for Narrow Bridges
III	72	Evaluation of MUTCD and Other Traffic Controls for Highway Construction and Maintenance Operations on Two-Lane Highways
IV	58	Develop and Evaluate Remedial Aids to Warn Drivers of Slow Moving Vehicles on a Grade
VI	54	Comparative Evaluation of Warning-Advisory and Regulatory Traffic Control Devices
VII	50	Develop and Evaluate Measures for Reducing Effects of Roadside Friction
VIII	70	Remedial Aids for Intersections with Inadequate Sight Distance

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1. INTRODUCTION

This report contains the Experimental Design entitled "Vehicle Equivalency and Capacity Including Effects of Commercial and Recreational Vehicles on Rural Non-Controlled Access Highways." This is Volume V of an eight-volume report. Volume I contains background information and summaries of the seven experiments. Volume I also includes a discussion of elements common to all seven experiments. The present volume includes the following:

- Background and Objectives;
- State-of-the-Art Review;
- Experimental Design;
- Bibliography.

1.1 Background

The Highway Capacity Manual (1) and the research literature contain a variety of definitions of capacity and other means such as vehicle equivalency for assessing the ability of a roadway to carry traffic. The most recent previous update of these definitions and concepts was made in 1965. There has always been a recognized need to test these notions experimentally, particularly for rural roads. In addition, the increased current use of lower performance vehicles such as trucks, campers and mobile homes and other varieties of towed recreational vehicles has created a significantly new traffic environment having significant impact on roadway capacity. These factors have contributed to the need for further experimental results related to vehicle equivalency and capacity.

1.2 Objective of Experiment

The objective of this experiment is to establish the influence of various types of trucks, buses and recreational vehicles on traffic flow on rural non-controlled access highways. This influence is due primarily to the low speeds which are common for these types of vehicles, particularly when negotiating grades. The results of this experiment can also be used to update and extend Chapter 10 of the Highway Capacity Manual.

- Lane width;
- Lateral clearance
- Combination of lane width and lateral clearance;
- Shoulders;
- Auxiliary lanes;
- Surface Condition;
- Horizontal Alignment;
- Grades.

As the width of a lane is reduced from the ideal 12 feet (3.6 m), the capacity of the lane is reduced. The HCM states that if the lane size of a two-lane road is reduced from 12 feet (3.6 m) to 9 feet (2.7 m), capacity is reduced by one-fourth. Similarly, with lateral clearance, the closer restrictions are to the roadway, the greater the reduction in capacity. In general, these effects are interrelated. This is recognized by the HCM since the effects of the two factors are consolidated into a single adjustment factor.

Shoulders are the portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles for emergency use and for lateral support of the road surface.

Adequate shoulders are necessary as a refuge for disabled vehicles which would otherwise be forced to park in the traveled lane. On a two-lane road, this creates a situation where the traffic in the blocked lane would have to pass the disabled vehicle in the lane used by opposing traffic. This, in turn, causes congestion in the opposing lane. On multi-lane rural highways, a vehicle parked in a travel lane would force traffic in that lane to merge with an adjoining lane. The friction between the two lanes is further increased as the speed differential between the two lanes increases. Solomon (2) has shown that accident rates increase dramatically as speed differentials increase.

In addition to providing a disabled vehicle refuge; paved, adequately sized shoulders may increase the effective width of the traffic lanes. The HCM states that a shoulder, paved four feet (1.2 m) or wider, increases the effective width of the adjoining lane by one foot (.3 m).

Auxiliary lanes often serve to prevent the development of bottlenecks on roadways by removing slow moving or stopped vehicles from the normal travel lanes. Of particular interest are lanes added to a section of roadway that contains a grade. Truck climbing lanes provide a means for improving capacity on long steep upgrades by reducing the effects of slow trucks on the traffic stream and providing passing opportunities. Truck performance and the effects of grades on trucks will be discussed in the section on grades.

Horizontal alignment has an important effect on the abilities of a roadway to carry traffic. In addition to the possible slowing of vehicles negotiating the curve, sight distance may be restricted so that passing is prohibited, restricting the free flow of traffic.

Vertical curves, or grades, present one of the most serious bottlenecks to traffic flows on two-lane roads. In addition to the possible sight distance restrictions limiting passing opportunities, grades present an obstacle to high-weight-to-horsepower ratio vehicles. Passenger cars can usually negotiate upgrades as steep as seven or eight percent without appreciable loss of speed. A three percent upgrade has only slight effect on passenger car free speeds. As the grades become steeper, speeds decrease progressively.

One of the key elements contributing to the adverse effect of grades on capacity is truck performance. In the late 1930's, extensive tests were conducted to determine the ability of trucks to climb a given grade. Early studies by Saal (8) established methods of comparison between field, theoretical and dynamometer tests. In later tests (9), Saal sampled a large number of trucks to determine relationships between weight-to-horsepower ratio and performance. Recent studies (10) have essentially reconfirmed past performance studies. The Highway Capacity Manual states that although the horsepower of trucks has tripled in the past 25 years, performance has not increased radically. This is due to the increasing weight that is now carried by trucks (11). Figure 1 shows grade performance of 200, 300 and 400 lb/hp (121, 182, 243 kg/kw) trucks.

The length of the grade is another important consideration in truck hill climbing abilities. Studies by Taragin (13) represented one of the first systematic efforts to find the effect of grade length on truck grade climbing. Taragin also derived an equation to calculate speed changes for any vehicle weight class, load or grade. More recent studies by Firey and Peterson (14) devised methods for calculating speed versus distance trajectories of large trucks on a variety of vertical curves.

The effect of grades on truck performance is one of the major factors contributing to the frequency of truck involvement in rear-end collisions. Firey and Peterson (14) studied the ability of trucks to maintain speeds on measured grades. The authors found that trucks with a weight-to-horsepower ratio of 400 to 1 (243 kg/kw) entering a 2 percent grade with initial velocity of 50 mph (80 km/h) had their speed reduced to 38 mph (61 km/h) after 2500 feet (760 m) and to 32 mph (51 km/h) after 4500 feet (1372 m). With steeper grades, velocity drop off is sharper. A 5 percent grade was found to reduce speeds from 50 mph (80 kph) to 16 mph (26 km/h) in 1900 feet (580 m). Results of road tests by Huff and Scrivner (15) showed an even lower final speed than did the Firey study. Huff found that a truck with about a 400-to-1 weight-to-horsepower ratio (243 kg/kw) with an entry speed of 47 mph (75 kph) would slow to 32 mph (51 km/h) in 2500 feet (762 m) on a 2 percent grade and to 25 mph (k0 km/h) in 4500 feet (1372 m). A 5 percent grade would slow a truck to crawl speed (8-10 mph) (13-16 km/h) in 2000 (610 m) feet.

In a study on vehicle rear lighting systems, Mortimer (16) extensively examined the available literature on truck accidents. He found that the rear-end collision is more likely to occur on an upgrade than on a corresponding downgrade. In a study quoted by Mortimer, 28 percent of a total of 1284 rear-end collisions were on upgrades and only 5 percent on downgrades. It is interesting to note that the maximum grade studied was only 2 percent.

The speeds of passenger cars is not greatly affected by grades. Williston (17) in a study of grade effects on

Level of service is a term which denotes differing combinations of operating conditions which occur in a roadway. It is a qualitative measure of the effects of a number of factors:

1. Speed and travel time,
2. Traffic interruptions,
3. Freedom to maneuver,
4. Driver comfort and convenience,
5. Safety,
6. Vehicle operating costs.

Although it would be desirable to include all of the above factors in defining the various levels of service and associated service volumes, it is not possible to do so within the present state-of-the-art. In general, operating speeds and volume to capacity ratios are the parameters most frequently used because of relative ease of measurement and analysis. Operating speed is the highest overall speed, exclusive of stops, at which a motorist can drive on a given roadway under prevailing conditions without exceeding the design speed at any time.

Six levels of service have been established designated by the letters A thru F providing best to worst service in terms of driver satisfaction. The levels of service each represent a range of conditions, the extreme of which is defined by the upper volume limit and the lower limit of speed. Figure 2 shows conceptually the relationships between speed, density, volume/capacity and level of service.

For largely uninterrupted flow (level of service A, B, C, and D) two conditions must be met to consider a roadway to be operating at or above a given level of service. They are:

- Operating speed equal to or greater than the standard value for the level considered,

- The volume/capacity ratio of any subsection does not exceed the standard value for that level.

Level of Service E describes traffic flow conditions that approach or are at the capacity of the roadway. Level F describes forced flow traffic. These conditions are characterized by high density conditions when speeds are low and variable and volumes are below capacity. Both speed and volume may drop to zero in stoppages.

A more complete description of the levels of service may be found in the HCM (1).

2.2 Equivalency

The Highway Capacity Manual defines the passenger car equivalent (PCE) as the number of passenger cars displaced in the traffic flow by a truck, or a bus under prevailing roadway conditions. The manual also states*

"On two-lane highways, passenger car equivalents of trucks are obtained relatively easily. They can be directly determined by obtaining detailed information on the speeds and headways of vehicles during various rates of flow on highways with different alignments and profiles. An average passenger car equivalent is obtained for trucks under each condition."

The Manual states further that:

"Passenger car equivalents can also be calculated with a high degree of accuracy from the separate speed distributions of passenger cars and trucks at any given volume level. The criterion used is the relative number of passings that would be performed per mile of highway if each vehicle continued at its normal speed for the conditions under consideration."

The above statements in the HCM originated in the Schwender-Normann-Granum study, "New Methods of Capacity Determination for Rural Roads in Mountainous Terrain" (26) However, this study does not explain the procedures to follow in order to calculate the equivalents.

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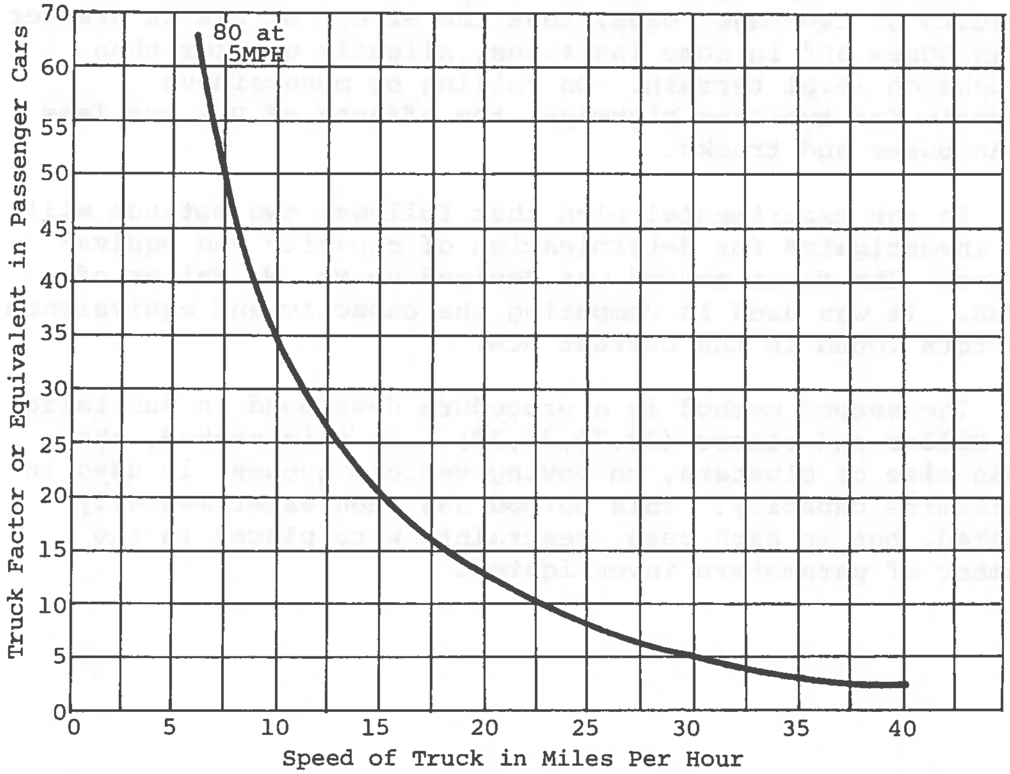
*HCM, Page 101



Source (26)

1 MPH = 1.6 Km/H

Figure 3: Truck Factor for Various Average Truck Speeds

3. EXPERIMENTAL DESIGN

The objective of this experiment is to establish the influence of various types of trucks, buses and recreational vehicles on traffic flow on rural non-controlled access highways. This influence is due to the low speeds which are common for these types of vehicles particularly when negotiating grades. In the first experiment, the measure of influence will be equivalent passenger cars, whereas in the second experiment, if feasible, a function of mean cluster size will serve as a measure. This project can also be used to update and extend Chapter 10 of the Highway Capacity Manual.

Unfortunately, the experimental facility rarely experiences conditions that would approach Level of Service E over extended periods of time. For the greater part of the time, conditions are such that Level of Service B is experienced by the traffic stream. It is, therefore, necessary to design an experiment which can provide an estimate of capacity even though traffic volumes may maintain Level of Service B. In addition, the experiment must estimate the sensitivity of roadway capacity to various intensities and mixes of heavy vehicles* for each roadway section.

The literature search has revealed that few experiments of this type have been undertaken. For the most part, attention has been focused on the determination of Passenger Car Equivalents of Trucks which are then applied to compute a Truck Adjustment Factor used in the calculation of capacity. This approach has been adopted for the Highway Capacity Manual (HCM); see Chapter 10 of the HCM (1) for details.

While this approach is certainly a viable one, and has gained wide acceptance, the low volume levels on the Maine Facility may not provide the necessary data base for estimating capacity for all Levels of Service. Another potential problem is that the assumptions implied by this approach may not be satisfied under actual field conditions. Hence, it is suggested that two independent

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*In this context, "heavy vehicles" defines a category of vehicle types which includes trucks, buses, recreational vehicles.

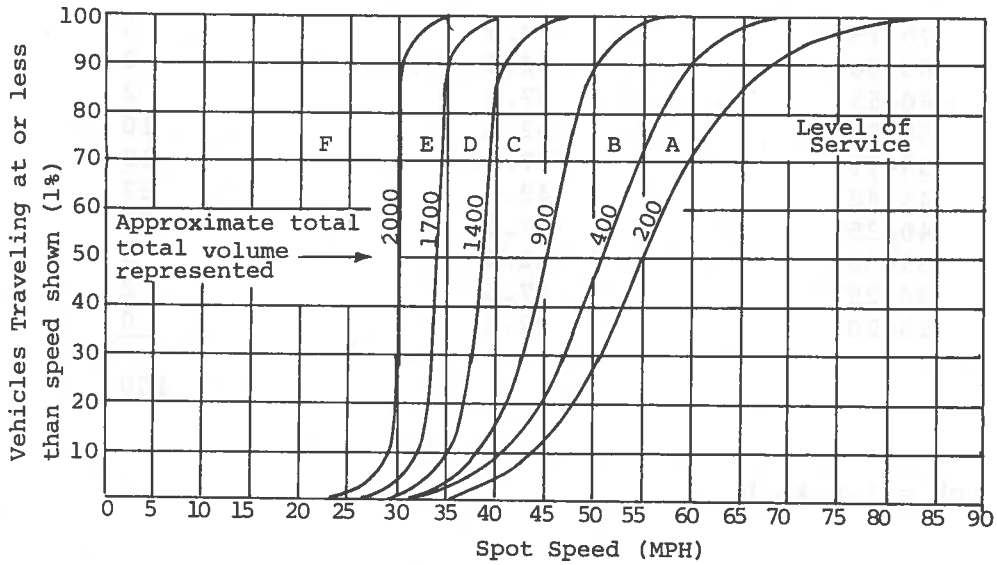


Figure 4: Typical Distribution of Passenger Car Speeds for Both Directions of Travel Under Ideal Uninterrupted Flow Conditions on Two-Lane Rural Highways.

Source: HCM 1 mph = 1.6 km/h

Here, X represents the number of vehicles per hour traveling at speed S_2 and Y represents the number of vehicles per hour traveling at speed, S_1. The units of N are in terms of

$$\frac{\text{fast vehicles}}{\text{mile}} \times \frac{\text{slow vehicles}}{\text{hour}}$$

Table 2 shows the results of using Equation 1 with the frequency distribution of Table 1. For example, for eight vehicles traveling between 30 and 34 mph (average of 32.5 mph) (48 and 56 km/h - average of 52 km/h) and ten vehicles traveling between 50 and 55 mph (average of 52.5 mph) (80-88 km/h - average of 84 km/h), the number of overtakings, N, is

$$N = 8 \times 10 \quad \frac{1}{32.5} - \frac{1}{52.5} \quad = 80(.0301-.0190)$$

$$= 80(.0111) = .8880.$$

The grand total of 19.0311 represents the total number of overtakings of slow passenger cars, by faster ones, which will occur for this speed distribution, for a volume of 100 passenger cars per hour.

The values in Table 3 are computed using (1), when x = 1 and slow vehicle speeds of S_2 = 15, 20 and 25 mph (24, 32 and 40 km/h). These represent a range of truck or other slow moving vehicle speeds, for which passenger car equivalents are desired. The total values at the right, 4.2657, 2.6057 and 1.6057, represent the total number of overtakings of a truck, by passenger cars having this speed distribution, when the truck volume is one truck per hour and the uniform truck speed is 15, 20 or 25 mph (24, 32 or 40 km/h), respectively.

The passenger car equivalent (PCE) is then defined as the ratio of overtakings of trucks, to overtakings of (slow) passenger cars per hour. Thus, for a truck traveling 15 mph,

$$\text{PCE} = \frac{4.27/1}{19.03/100} = 22.4 \text{ truck overtakings/passenger car overtakings.}$$

If these PCE values are computed for different levels of service speed distributions and for a range of truck speeds, then graphs such as those shown in Figure 5 can be constructed.

In addition to the underlying assumption (see footnote, p. 15) associated with the derivation of equation (1), it is necessary to recognize still another assumption. This assumption states that all "fast" vehicles which "catch up" to a slow-moving vehicle (either a passenger car or a truck) are able to overtake it without delay. That is, equation (1) is strictly valid only if no moving queue forms behind the slow moving vehicle.

In actual fact, such moving queues, or "clusters", do form even though overtaking is possible, due to oncoming traffic. Over those sections where passing is not permitted, or for those traffic conditions where passing is permitted, but not possible, due to heavy volumes (Level of Service E), the above assumption is not at all acceptable.

Yet, the resulting Truck Factors, derived from this method, are employed to estimate capacity at Level of Service E, when overtaking is not considered possible. Hence, this method may not be generally applicable over all traffic conditions and highway geometries.

The objective of this proposed experiment is two-fold:

- Study the impact of these real-world violations of the methods' underlying assumptions.
- Determine, when volume conditions permit, whether predicted capacities obtained by this method, agree with empirical values.

The experiment to be implemented will utilize Walker's Method to obtain PCEs for specified roadway sections over a range of traffic volumes and composition. These computed values of PCE will be compared with experimentally obtained values of overtakings and of catch-ups.

In addition, when heavy volumes occur over the sections being monitored, these values will be compared with the values of computed capacity, obtained via Walker's Method. Whether, in fact, such "heavy" volumes ever reach capacity level on the Maine Facility, remains to be seen. (see Volume I).

3.1.2 Assumptions

As noted in the above model description, several assumptions are implied by the Walker Method. These are summarized as follows:

- Each vehicle is assumed to continue at its normal speed for the conditions under study.
- Vehicles in the traffic stream are assumed to have equal time-headway separations.
- All "fast" vehicles which "catch up" to a slow moving vehicle are assumed able to overtake it without delay.
- It is assumed that no moving queue forms behind the slow moving vehicle.
- Passing is permitted throughout the test sections.
- Traffic conditions and highway geometrics do not seriously affect passing opportunities.

One of the purposes of this experiment is to determine the sensitivity of the model to violations of these assumptions. This will be accomplished by comparing the number of predicted overtakings with the number of observed overtakings.

Table 4: Section Geometrics on Maine Facility

Number of Sections of Indicated Geometrics

Lengths (ft)	Grades (percent) >6	3-6	0-3
Up to 500	2	14	30
501-1000	4	15	25
Greater than 1000	2	6	14

1 ft. = .3048 m

The high volume level will be defined as periods when volume exceeds 300 vph. This will only be possible during the summer months. The medium volume range will be from 200 to 300 vph. If it is not possible to collect adequate sample sizes in the high volume range, the high and medium ranges should be combined into one range.

Truck Speeds

Two levels of truck speeds will be considered. The first will be less than 30 mph. The second level will be 30 to 45 mph (48 to 72 km/h).

Traffic Stream Composition

In order for the experiment to be meaningful, the effects of different percentages of truck and RV traffic must be determined. To hold the number of cells in the design down to a reasonable level, the following levels of truck and RV percentages will be considered:

% Trucks	% RV
0-2%	0-3%
2-4%	3-6%
6-8%	6-9%
8-10%	9-12%
10-12%	>12%
> 12%	

3.1.4 Dependent Variables

For each volume level, truck speeds will be divided into two speed categories:

- Truck speeds less than 30 mph (48 km/h);
- Truck speeds between 30 and 45 (48 and 72 km/h).

Table 5

Sample Sizes and Data Stratifications

<table>
<tr><td colspan="5">Volume Levels</td></tr>
<tr><td colspan="3">High
$q_1 > 300$ vph
1. Obtain speed distribution
2. Obtain traffic mix - percent trucks by speed category
3. Sample size=400 vehicles</td><td colspan="2">Low
95 vph$<q_2<$200 vph
1. Obtain speed distribution
2. Obtain traffic mix - percent trucks by speed category
3. Sample size=400 vehicles</td></tr>
<tr><td colspan="2">Truck Speed</td><td rowspan="2">Recreational Vehicles</td><td colspan="2">Truck Speed</td></tr>
<tr><td>< 30 mph</td><td>30-45 mph</td><td>< 30 mph</td><td>30-45 mph</td></tr>
<tr><td>Min. Sample Size = 100 Trucks</td><td>Min. Sample Size = 100 Trucks</td><td>Min. Sample Size = 100 Recreational Vehicles</td><td>Min. Sample Size = 100 Trucks</td><td>Min. Sample Size = 100 Trucks</td></tr>
</table>

1 mph = 1.6 km/h

3.1.7 Data Collection

For each vehicle at each sampling station, that is, at each detector trap, the following data is to be recorded:

- Spot speed,
- Wheel base,
- Time headway to lead vehicle,
- Direction of travel,
- Vehicle type.

The data is to be taken only during daytime hours during clear, dry weather. This data will permit determination of the following information for each direction of travel at all traps:

- Volume,
- Percent trucks, recreational vehicles,
- Speed distribution, by vehicle type,
- Number of overtakings,
- Mean speeds, by vehicle type.

Clearly, the spot speed data will permit computation of volume, speed distributions and mean speeds at each trap. The Maine Facility sensors will automatically record all data except for vehicle type which will be observed in the field. Although the sensor system can possibly detect trucks versus passenger vehicles, the presence of recreational vehicles as distinct from trucks will require field observation. If the acquisition of adequate sample sizes for recreation vehicles proves to be impractical, the need for field observation will no longer exist.

Data collected should be aggregated by 15-minute periods. If the volumes fall below the lower volume limit (see volume section), the data should be ignored. The 15-minute period should assist in filling the cells for the various truck and RV percentages. The data is to be stratified into three volume levels--high, medium and low volume periods. An approximate speed distribution is to be obtained for each volume level at each detector station.

where $\bar{x}_1$, $\bar{x}_2$ represent the respective means, s^2 is the pooled sample variance of the mean, and n_1 and n_2 are the respective sample sizes used for computing the two means. This computed value can then be compared with the tabulated value at, say, 95% confidence, using $n_1 + n_2 - 2$ degrees of freedom.

In addition to comparison of mean values of PCE for specific average truck speeds, curves of theoretical and observed PCE will be plotted, as in Figure 2, for a range of truck speeds. For this purpose observed overtakings must be recorded as truck specific so that a range of observed PCE values as a function of truck speed can be obtained. The standard chi-square test can be used to determine whether the two curves differ significantly. As noted above, two approaches are recommended for determining observed PCE if sample sizes permit:

1. Observed PCE will reflect overtakings, as specified in the Walker Method,

2. Observed PCE will reflect catch-ups.

For the second part of the analysis, the computed values of PCE are converted to truck equivalence or adjustment factors. This can be accomplished in several ways, depending on the assumptions in effect. For example, in the Highway Capacity Manual, the combined adjustment factor, F, is computed using the formula:

$$F = \frac{100}{(100-P_1-P_2\cdots-P_x) + P_1E_1+P_1E_2+\cdots+P_xE_x)}$$

where P_x is the percentage of representation of vehicle type, x, in the traffic stream, having PCE E_x. Vehicle types include trucks having different average speeds or recreational vehicles versus trucks.

The calculation for capacity, C, then becomes:

$$C = 2000W_cF$$

as defined in the Highway Capacity Manual (9) where W_c is a correction factor for lane width.

where ν_i is a value associated with the i^{th} type of impeder vehicle which occurs with incremental percentage, δP_i.

It must be pointed out that ν (or the set of ν_i) are not equivalents. They are defined as equivalence kernels. That is, the kernel(s) must be assembled and subjected to a nonlinear process in [2] before equivalence in the usual sense is quantified.

Simulation results were used to construct Figure 6 for differing percentages of no passing zones. A least squares fit yields the following equation for equivalence kernels:

$$\nu = e^{[7.440436 - 0.08227925 V]} \qquad (3)$$

where

V = impeder speed (ft/sec).

Equation [3] is applicable for flows which are nearly balanced on highways where the percent no-passing is 46-80% and where the 85th percentile speed of passenger cars is about 65 mph in light, free flowing traffic. It is anticipated that the numerics in Equation [3] would change for highways with different design speeds or speed limits and for highways with percent no-passing outside the range 46 to 80%.

These two methods of computing F_T represent two different hypotheses and it is recommended that both computations be made. It is also possible that other relationships, for example, the exponential, exist between F_T and r. It is suggested that alternative relationships be investigated, to the extent possible, in the analysis in order to study the relationships between these parameters for different site conditions.

The analysis in this second part will attempt to determine significant differences in truck factor, capacity (or average PCE) for different grades, grade lengths, locations on grade, and volume levels. As noted in Ref. 28 , differences and similarities between truck and recreational vehicles as a function of grade and position on grade can be identified. Differences between means for the various hypotheses stated in Section 2.1.3 will be tested. This will yield information on the sensitivity of PCE and the resultant capacity to the independent variables which have been defined in Section 2.1.4.2. The ultimate result will be the evaluation of the effect of trucks on capacity on rural highways.

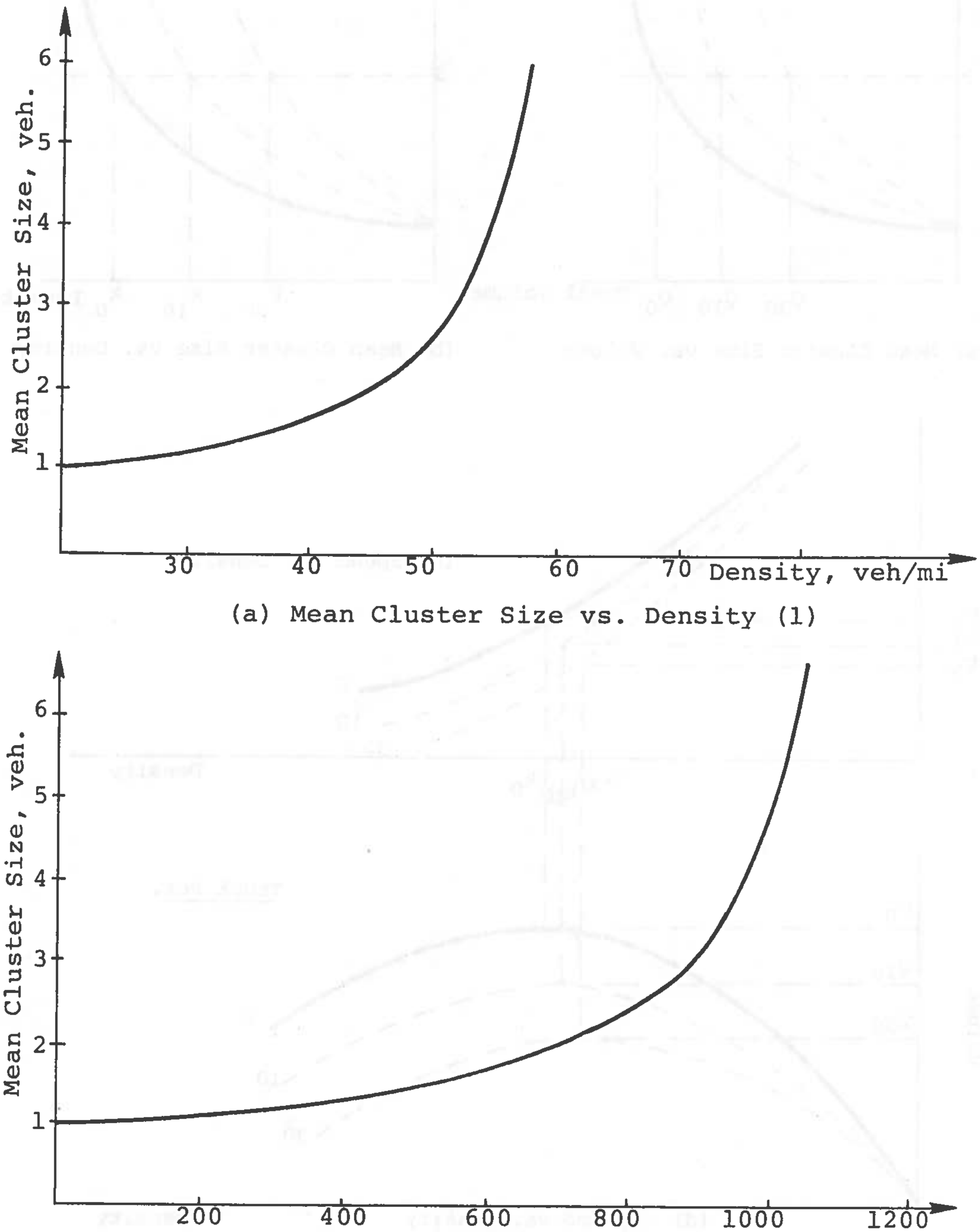
Capacity of a two-lane highway depends upon many factors:

- Speed of "slow" vehicles which creates clusters,
- Speed of faster trailing vehicles in cluster,
- Availability and extent of passing zones,
- Volume, speed and headway distribution of oncoming traffic,
- Lateral clearance,
- Number of slow vehicles in traffic stream (say, percent trucks),
- Gap acceptance distribution for overtaking maneuvers,
- Lane width.

The speed parameters depend upon such factors as grade and length of grade. The extent of passing zones depends upon sight distance considerations.

It would be extremely difficult to express capacity directly as a function of all these parameters using empirical data obtained from a field experiment. Indeed, considerable experimentation coupled with analytical efforts has already been conducted in Australia (31,33,34,35). In each experiment, it was necessary to restrict the number of parameters permitted in order to isolate a particular effect. For example, in order to obtain distributions of sight distances accepted by overtaking vehicles, it was necessary to conduct the experiment on a level, tangent section of roadway having no oncoming traffic (35). These experiments consisted of subjects driving a "slow" vehicle at steady speeds and recording the data of interest.

While these interactions are indeed complex, past research has revealed that several simplifications are possible on a more macroscopic level:



(a) Mean Cluster Size vs. Density (1)

(b) Mean Cluster Size vs. Total Volume (3)

Figure 7: Relationship between Mean Cluster Size, and Density and Total Volume

- Clusters are easily recognized and quantified by the software
- Short-term samples over, say, 15-minute aggregations will be sufficient to provide readings of MCS vs. Volume at a point.* Hence, it is not necessary for a facility to service sustained, high volumes in order to obtain an estimate of capacity.

3.2.2 Alternative Method for Light Volumes Only

In the event that traffic volumes are consistently light to the extent that 15-minute aggregations of data do not produce MCS values of 3 or greater (with adequate sample sizes), then the following alternative method is proposed. This method, based on a development in (33), provides the value of capacity in the vicinity of a slow-moving vehicle over a section of highway.

Define:

m = N/T, the overtaking (passing) rate of vehicles relative to the slow vehicle

N = Total number of (trailing) vehicles within the cluster behind a slow-moving vehicle that overtake this vehicle over the time period, T. During this period, T, the cluster must never empty; i.e., there must always be at least one vehicle trailing the slow lead vehicle

$\bar{V}$ = Mean free-flow speed of overtaking vehicles after they have passed the slow lead vehicles (as measured over at least three detectors immediately following completion of the passing maneuver)

$\bar{u}$ = Mean speed of slow lead vehicle (as measured over at least three detectors immediately preceding initiation of the passing maneuver)

*Very light volumes are of no interest. See details later.

The subsequent experimental design is presented as a contingency plan in the event that the necessary assumptions can be met.

3.2.4 Design Plan

This plan consists of two parts. The first design is intended to determine mean cluster size (MCS), traffic density and traffic volume from the existing traffic stream traversing the Maine Facility roadway. By plotting points in the MCS-Density plane and points in the MCS-volume plane (Figures 8a and 8b) and determining the location of the "knee", a value of practical capacity can be estimated. The techniques for locating the "knee" are described in the data reduction and analysis subsection. This experiment will be referred to as the MCS experiment.

The second design is an alternative experiment in the event that traffic volumes are consistently light so that 15-minute aggregates produce MCS values smaller than three. In this case, capacity is computed using the formula for the light volume case described in the model description section.

3.2.4.1 Experimental Sites

The same site selection criteria used in the Walker Method will be used in both experiments proposed here. However, it is recommended that only one site of each of the four types be selected and two repetitions be implemented at each site. Of course, the same sites as those chosen for the Walker Method can be used here.

3.2.4.2 Independent Variables

The data is to be stratified into volume levels, truck speeds and truck percentages.

In order to obtain a minimal representation of the MCS-volume and MCS-density curves, at least five distinct points on each will be required. It is also assumed that the data will be sorted into at least two truck percentages and two truck average speeds. Table 6 summarizes the stratifications. Each succeeding strata applies to each level of the previous strata.

- The values of N and T over each section are to be noted by the recorder;

- The cluster size to be noted by the recorder and by the surveillance system;

- The free-flow speeds of overtaking vehicles, $\bar{v}$ and the oncoming volumes, Q, are to be accessed via the surveillance system.

Replications are to be made over a range of oncoming volumes, with truck speed invariant. These are then to be repeated with a new value of truck speed, $\bar{u}$. Truck speeds of $\bar{v}$ - 15 and $\bar{v}$ - 25 should be studied where $\bar{v}$, defined previously, is section specific. Table 7 summarizes the data stratifications.

Table 7

Stratifications - Light Volume Experiment

Volume Level i	Truck Speed j
i=1,...,5	j=1,2

3.2.4.3 Dependent Variables

For the MCS experiment, the following data is to be recorded for each vehicle over each of at least three detector traps per site:

- Spot speed;
- Wheel base;
- Time headway to lead vehicle;
- Direction of travel;
- Vehicle type.

3.2.4.5 Data Collection

For the MCS experiment, the data collected is at a point in space. Hence, the traffic in each direction of travel, over each section, must be described by aggregating the data collected at the various sampling points within each test section. It is also desired to determine the value of density associated with each value of MCS. The data at each sampling station (detector) may be used to obtain the necessary information as follows:

Flow Rate (Volume): $Q = \frac{N}{T}$

Density: $K = \frac{\sum_{i=1}^{N} V_i}{T}$

Mean Speed: $\bar{v} = \frac{N}{\sum_{i=1}^{N} \frac{1}{V_i}}$

where N = Total number of vehicles crossing the detector over a period of time, T

V_i = Spot speed of vehicle, i, over the detector.

These values are computed at each detector station, for each period, T, of 15 minutes. Also, the values of MCS, as well as the truck percentage, are determined. Hence, a point in the MCS-Density plane is defined, as well as a point in the MCS-Volume plane (Figures 7 and 8a, 8b). A sequence of such points, each reflecting data collected over one period, will define the curves shown in Figure 7a and 7b.

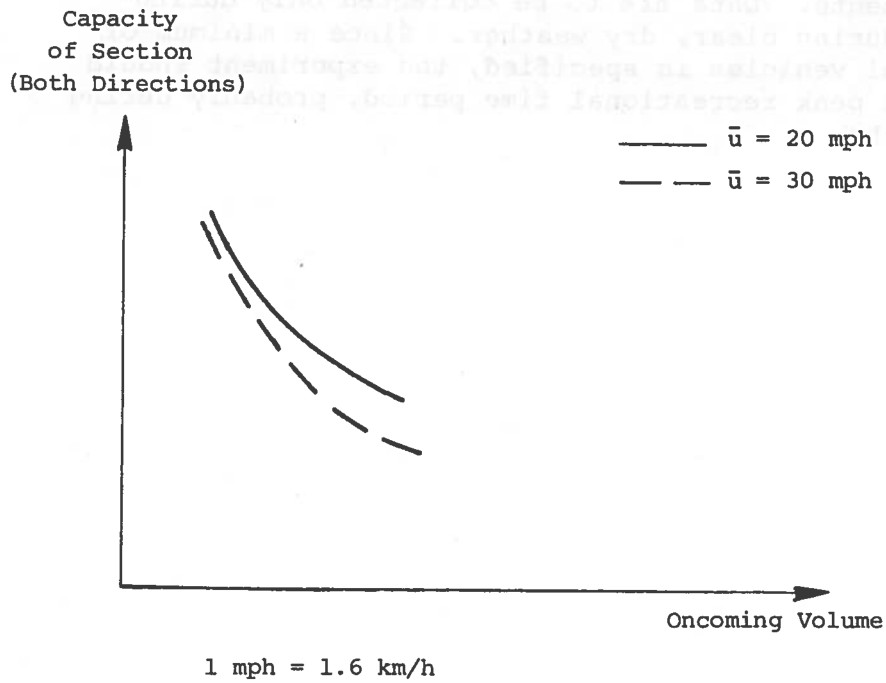


Figure 9: Capacity in Vicinity of Slow Truck Traveling at Speed, $\bar{u}$, vs. Oncoming Volume

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