VOL. 34, NO. 4

OCTOBER 1966

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

PUBLISHED
BIMONTHLY
BY THE BUREAU
OF PUBLIC ROADS,
U.S. DEPARTMENT
OF COMMERCE,
WASHINGTON

Types of some of the vehicles tested in the research reported in this magazine on *Braking Performance of Motor Vehicles* and the *Relation of Gross Weights and Horsepowers of Commercial Vehicles.* The third article, *Offtracking Calculations for Trailer Combinations*, refers to some of the vehicle types shown.

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Vol. 34, No. 4 *October 19*

Published Bimonthly

Muriel P. Worth, *Editor*

IN THIS ISSUE

NATIONAL BUREAU OF STANDARDS DEDICATION

Dedication ceremonies for new facilities of the National Bureau of Standards, Gaithersburg, Md., November 15 will be presided over by John T. Connor, Secretary of Commerce, and Dr. Allen V. Astin, Director, National Bureau of Standards. Dignitaries from Government, science, and industry also will participate in the ceremonies. To celebrate the construction and dedication of this new standards and testing complex, Secretary Connor is sponsoring an International Symposium of Technology and World Trade on November 16 and 17 at Gaithersburg.

The new $120 million NBS laboratory complex consists of 15 major buildings constructed on a 565-acre site. New laboratories and supporting facilities enable the Bureau of Standards to update its research programs in a rural environment removed from urban mechanical, electrical, and atmospheric disturbances. Expanded facilities include a nuclear research reactor and a linear electron accelerator for the establishment of measurements and standards. An Engineering Mechanics Laboratory was also added to the relocated facilities for work such as the calibration of rocket thrust measuring devices.

At the International Symposium of Technology and World Trade on November 16 and 17, experts from all over the world will examine and forecast the impact of technology upon the patterns and conduct of international trade and investment; consider the international environment needed for the wider generation and utilization of technology; and explore prospects for evolving policies and institutions that promote economic developemnt through technology and trade.

U.S. DEPARTMENT OF COMMERCE
JOHN T. CONNOR, Secretary

BUREAU OF PUBLIC ROADS
REX M. WHITTON, Administrator

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Public Roads, A Journal of Highway Research, is sold by the Su intendent of Documents, Government Printing Office, Washing D.C. 20402, at $1.50 per year (50 cents additional for foreign mail or 25 cents per single copy. Subscriptions are available for 1-, 2 3-year periods. Free distribution is limited to public officials a ally engaged in planning or constructing highways and to instruc of highway engineering. There are no vacancies in the free lis present.

Use of funds for printing this publication has been approved by Director of the Bureau of the Budget, March 16, 1966.

Braking Performance of Motor Vehicles

Y THE OFFICE OF
ESEARCH AND DEVELOPMENT
UREAU OF PUBLIC ROADS

Reported by [1,2,3] SAMUEL C. TIGNOR,
Highway Research Engineer,
Traffic Systems Division

Introduction

BECAUSE IT is well known that adequate brake performance is necessary for the se operation of motor vehicles, the Bureau o Public Roads in 1941 undertook a research pgram to determine at periodic intervals the bke performance levels of motor vehicles oerating on the highway systems of the Uited States. Studies also were made in 149 and 1955. The most recent series of tts was made beginning in July 1963; results o these tests are discussed in this article. Te 1963 field testing was done as nearly as pssible in the same locations in Maryland, Mchigan, and California used for the 1949 ad 1955 tests. The information obtained fm this series of braking studies is expected t be used to:

- Promote improvement in the general level o brake performance.

Since 1941, the Bureau of Public Roads periodically has conducted a research program to determine the braking performance levels of motor vehicles operating on public highways. The research results are used to promote improvement in the general level of brake performance for all types of vehicles, provide information that may be used in establishing highway design standards, and serve as a basis for revising brake performance standards. The most recent braking performance study, completed in November 1963, is discussed in this article.

- Serve as a basis for revising brake performance standards.
- Provide current motor-vehicle brake performance data that can be used to establish highway design standards, such as standards for stopping sight distance.
- Show the levels of brake performance for the different types of vehicles using the highways.

Scope of Research

Tests to determine braking performance of motor vehicles operating on the highways were made on foreign, compact, and other (referred to here as standard size) passenger cars; single-unit trucks; and trailer combinations. Vehicles were selected at random from general highway traffic. All vehicles were stopped by a uniformed policeman; they were weighed; the weight and a desciiption were recorded; and three emergency stops were

EDITORIAL INTRODUCTION

In the three articles, *Braking Performace of Motor Vehicles*, the *Relation of oss Weights and Horsepowers of Comrcial Vehicles*, and *Offtracking Calculatns for Trailer Combinations*, printed in tis issue of the magazine, some common thnical terminology is used. For the cnvenience of the reader, these terms are eplained in the following paragraphs. Secific terms are defined in each article.

Single-unit trucks and trailer combinatns have been designated by numerical ad letter combination codes based on the rmber of axles and their arrangement. The codes for these commercial vehicles are cfined in the following list.

2 =2-axle single-unit truck.
3 =3-axle single-unit truck.
2 1 =2-axle truck-tractor with 1-axle semitrailer.
2 2 =2-axle truck-tractor with 2-axle semitrailer.
3 2 =3-axle truck-tractor with 2-axle semitrailer.
2 =2-axle truck with 1-axle trailer.
2 =2-axle truck with 2-axle trailer.
3 =3-axle truck with 2-axle trailer.
4 =4-axle truck-tractor with 6-axle trailer.
2–3 =2-axle truck with 3-axle trailer.
2–S1–2=2-axle truck-tractor with 1-axle semitrailer and 2-axle trailer.
2–S2–2=2-axle truck-tractor with 2-axle semitrailer and 2-axle trailer.
2–S2–3=2-axle truck-tractor with 2-axle semitrailer and 3-axle trailer.
3–S1–2=3-axle truck-tractor with 2-axle semitrailer and 2-axle trailer.
3–S2–2=3-axle truck-tractor with 2-axle semitrailer and 2-axle trailer.
3–S2–4=3-axle truck-tractor with a 2-axle semitrailer and 4-axle full trailer. Also called a double trailer combination.
3–S3–5=3-axle truck-tractor with 3-axle semitrailer and 5-axle trailer.

Other technical terms used in the articles are defined in the following statements.

Gross vehicle weight.—Gross vehicle weight (GVW) is the empty weight, in pounds, including the weight of accessories and fuel, of a passenger car, truck, truck-tractor-semitrailer, or truck-tractor-semitrailer-full trailer combination, plus the weight of the cargo or payload carried at the time the vehicle was tested.

Brake system application and braking distance.—Brake system application and braking distance (BSABD) is the distance, in feet, traveled between the point at which the driver starts to move the braking controls and the point at which the passenger car or commercial vehicle is stopped.

Maximum deceleration.—Maximum deceleration is the peak deceleration measured in percent gravity (1 g.) that occurred during the stopping.

Pedal reserve.—Pedal reserve is the distance, in inches, between the floorboard or mat and the back of the pedal at the completion of a stop.

Brake system air pressure.—The brake system air pressure is air pressure, in pounds per square inch, indicated on the gage in the cab immediately after completion of a stop. This applies to vehicles equipped with some form of an air-actuated brake system. Before any stops were made during this research, the air reservoir was filled by the air compressor.

Manufacturers maximum gross vehicle weight rating.—The manufacturers maximum gross vehicle weight rating is the empty weight, in pounds, of the truck chassis and lubricants, water, fuel tank or tanks of fuel, plus the weight of cab, body, special chassis and body equipment, and the payload recommended by the chassis manufacturer.

Vehicle capacity.—Vehicle capacity for single-unit trucks is the same as the maximum gross vehicle weight rating; for trailer combinations it is the gross combination weight (GCW) recommended by the vehicle chassis manufacturer for a truck-tractor or truck used in combination with semitrailers or full trailers.

Mean.—The mean is a number that represents a set of numbers obtained by dividing the sum of all the numbers or elements in the set by the total number of elements in the set—expressed as: $\overline{X}=\frac{\Sigma X}{N}$

Median.—The median refers to the middle number in a series of test data.

Mode.—The mode is the number in a set of data that occurs most frequently.

Standard deviation.—Standard deviation (S.D.) is the square root of the arithmetic mean of the squares of the deviations from the mean (*1*).[4]

Standard error of the mean.—Standard error of the mean is an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean (*2*).

Gross horsepower.—The gross horsepower of a vehicle is the brake horsepower of the engine available at the clutch or its equivalent, when the engine is being operated but accessories such as fan, air compressor, generator, and muffler are not.

Net horsepower.—Net horsepower is the brake horsepower of the engine available at the clutch or its equivalent, when the engine is being operated with all the normal accessories. In other words, the net horsepower is the gross horsepower minus the horsepower absorbed by accessories such as fan, air compressor, generator, and muffler.

Weight-power ratio.—Weight-power ratio is the ratio of the gross weight of the vehicle or combination of vehicles to net horsepower of the powered unit. For example, if the gross weight of a trailer combination is 60,000 pounds and the net horsepower is 150, the weight-power ratio is 400 pounds per horsepower.

Presented at the October 1964 meeting of National Transptation, Powerplant, and Fuels and Lubricants Meeting, ohe Society of Automotive Engineers, Inc., Baltimore, Md.

Bureau of Public Roads personnel who contributed to the scess of the research project include F. William Petring (w with Ford Motor Co.), Harry H. Hill, Harry Krashen, Vlliam H. Oliver, John M. Wright, James LoJacono, Fhard C. Tennent, William J. Giacofci, Mrs. Madalene Fndall (now retired), John F. Lyons, and Mrs. Ruby Tice.

The Maryland State Roads Commission, the Michigan Ipartment of State Highways, and the California Division o Highways, and personnel from these State organizations asted in the field research. The Maryland Truck Patrol, t Michigan State Police, the California Highway Patrol, t Sacramento Police Department, and the city of Sacranto also contributed to the success of the project.

[4] References indicated by italic numbers in parentheses are listed on page 82.

made, each from a speed of 20 miles per hour (m.p.h.). Each driver was told that the tests were voluntary and that no punitive action would be taken regardless of the condition of the vehicles brakes. The braking performance was measured in terms of brake system application and braking distance—the distance traveled between the point at which the driver starts to move the braking controls and the point at which the vehicle stops—and in terms of deceleration.

Test sites

The tests were made at four locations: U.S. 40 near Elkton, Md., a 4-lane divided highway; U.S. 24 near Erie, Mich., also a 4-lane divided highway; U.S. 40 near Cordelia, Calif., an 8-lane divided highway; and Elvas Ave., Sacramento, Calif., an undivided city street carrying crosstown traffic. In California, the Cordelia site was used to obtain the commercial vehicle sample, and the Elvas Ave. site was used to obtain the passenger car sample. At each of the other sites, both commercial vehicles and passenger cars were tested. Out-of-State vehicles were tested at each site.

The test section used at each study site was a dry, single-level through lane approximately a half-mile long, separated from other through lanes by rubber traffic cones and/or barricades. Signs were erected that instructed through drivers to merge to a lane other than the test lane and notified them that braking tests were being conducted. Scales were located next to the test lane and were used to determine the gross vehicle weight before the testing. The scales at the sites in Michigan and Cordelia, Calif., were of the permanent pit type used by the States for enforcement of weight regulations. At the other test locations, portable scales were used.

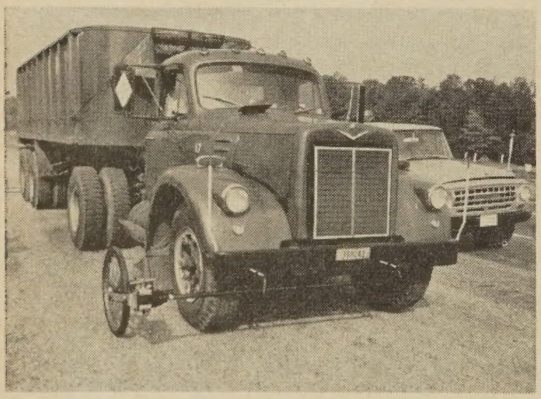

Figure 1.—Trailing fifth-wheel, distance-measuring device attached to a 2–S2.

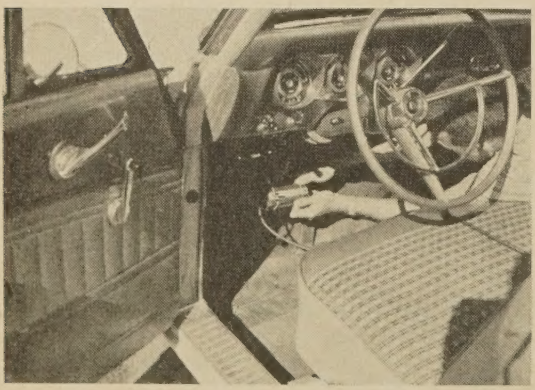

Figure 2.—Brake pedal switch for activating pavement marking and distance measuring devices.

Locked-wheel, passenger-car stops were made at each test section to determine the similarity of the coefficient of friction for the different test surfaces. The results of the locked-wheel stops showed that all of the surfaces had similar frictional characteristics, the average coefficient of sliding friction being 0.82.

Instrumentation

Instrumentation was primarily a test wheel, equipped with a distance measuring device and a portable decelerometer. The test wheel measured the speed of the test vehicle in miles per hour and the brake system application and braking distance in feet. The decelerometer measured the maximum deceleration occurring during the braking test in percent of 1 g. The instrumentation is shown in figures 1 through 4.

The test wheel (fig. 1), referred to as a fifth wheel, was equipped to start the distance-measuring device when the driver touched his foot to a switch attached to the brake pedal (fig. 2). When the driver's foot first touched the brake pedal switch, an electrical circuit was completed and it was maintained by a holding relay until released by the observer. An observer, who rode with the test driver, recorded the distance shown on the dial of the distance recording device, the speed, the deceleration, and the other information relevant to the stop.

Speed of the test vehicle was measured in miles per hour by a voltmeter wired to a belt-driven generator, which was mounted on the frame of the test wheel (fig. 3). The observer held the voltmeter (fig. 4) and when a speed of 20 m.p.h. was reached, he told the driver to stop. A pendulum-type decelerometer (fig. 4) was used. A moving scale, indicating percent of 1 g., was actuated by, and proportional to, the movement of a pendulum. When the test vehicle moved at a uniform speed, the pendulum assumed a vertical position; but when the speed was reduced by the application of brakes, the pendulum tended to move at the initial speed and thus swing forward. The tangent of the angle through which the pendulum moved from its vertical position was proportional to the deceleration. A scale reading of 80 percent thus would reflect a deceleration of 0.80×32.2, or 25.8 feet per second per second (ft./sec./sec.). The decelerations measured by a pendulum-type decelerometer are often larger than actual decelerations, which can be measured by more sophisticated equipment. The pendulum-type decelerometer, however, is effective for identifying vehicles that have improperly maintained brakes.

All equipment used for the braking performance tests was calibrated frequently during the tests to assure accuracy of test results. The speedometer or voltmeter was calibrated by measuring with the test wheel the time required to travel a measured mile at a constant speed. The accuracy of the distance-measuring device was verified by us of an electric detonator mounted on th bumper. The detonator ejected a chal capsule that marked the pavement at th instant the driver touched his foot to th brake switch pedal—the same switch tha activated the distance measuring devic The brake system application and brakin distance shown on the dial for the test whe was compared with the distance measure between the chalk mark on the pavement an a point below the detonator on the test vehicl To calibrate the moving scale on the decele ometer, the instrument was placed on a know slope and the tangent of the slope compare with the scale reading. These periodic tes of equipment showed a variation of 2 perce or less between the test and theoretic results.

Test procedures

When a vehicle was selected for testing, t driver was directed, by a uniformed office from the through lanes into an interview ar pit area adjacent to the test lane. The te procedures were explained to each driver ar those preferring not to participate in t tests were permitted to continue.

On one of two cards, both having the san test number, the vehicle characteristics we recorded. The information noted includ vehicle type, make, model, year, type transmission, tire size, type of cargo, man facturers maximum gross vehicle weig rating, type of brake system, and number

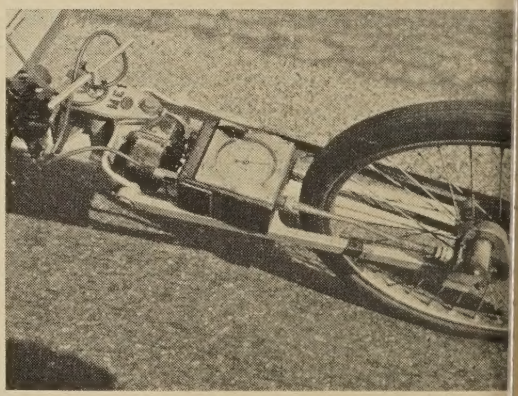

Figure 3.—Dial on fifth wheel for measuri brake system application and braki distance.

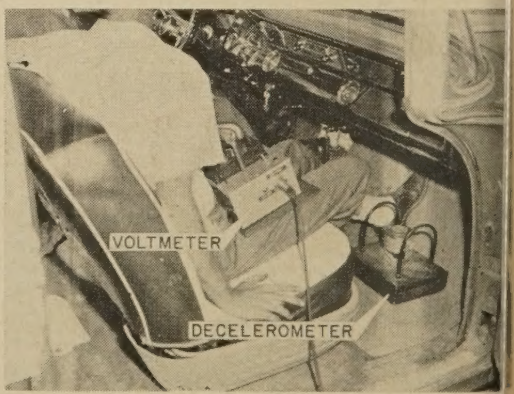

Figure 4.—Placement of test instrumen tion.

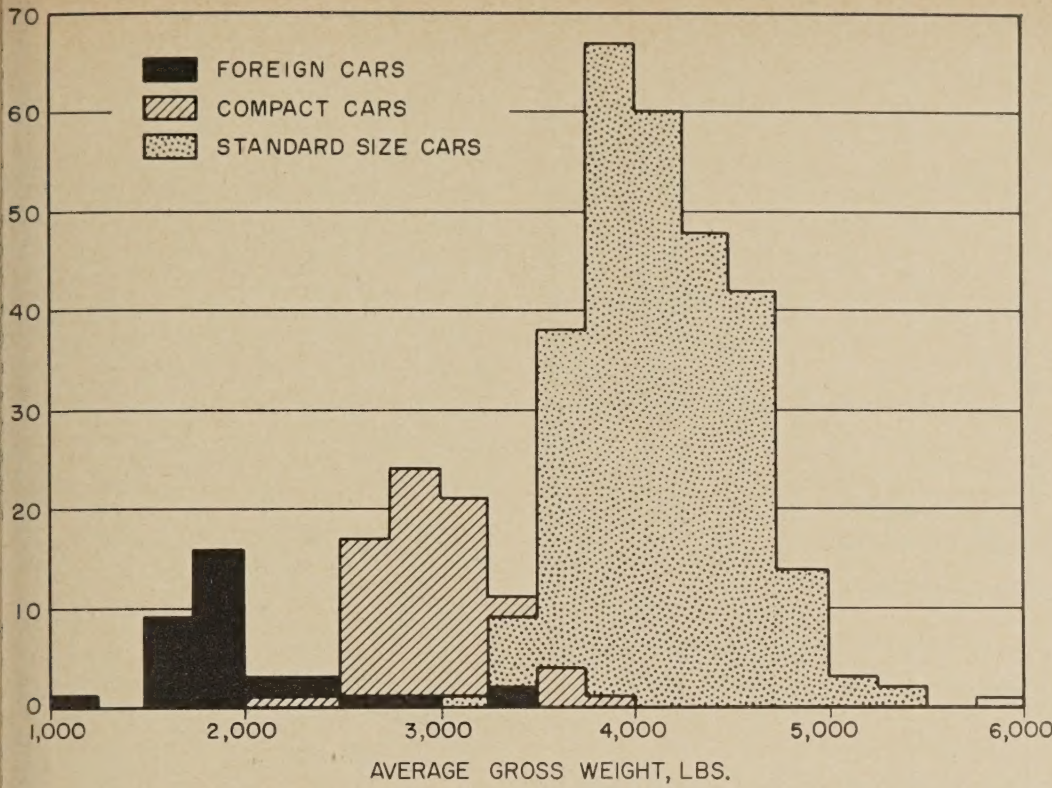

Figure 5.—Passenger car weight distributions.

braked axles; this card also had space for ording test data. On the other card, the icle weight by individual axle was re-ded. The equipment for measuring the ke performance then was installed.

An observer seated next to the driver di-ted him to the test lane. Before any ts were conducted, the driver was told disengage the clutch during the stop and, it were a commercial vehicle, to set the iting valve in the dry road position and t to use the hand control valve during tests. Approximately three emergency-e stops were made, each from a speed 20 m.p.h. Each stop was made upon observer's direction, when the test speed d been reached. The driver applied the kes and maintained the vehicles maximum king capacity. After each stop, the server recorded the brake system appli-ion and braking distance, the maximum deceleration, and the pedal reserve or brake system air pressure.

As the test lane was separated from all through traffic by rubber cones, barricades, or both, an unobstructed lane was available for each test vehicle. Thus the 20 m.p.h. speed could be stabilized for the braking stops. To prevent interference from a vehicle inadvertently entering the test lane, a project vehicle—equipped with a flashing red light on top and a large sign mounted on the rear that stated DANGER–BRAKE TESTS–SUDDEN STOP— followed the test vehicle. An observer also was in the project vehicle; he measured the lengths of any skid marks that were left by the test vehicle and entered these lengths on the weight data card. When the braking tests had been completed, the test equipment was removed from the vehicle and the driver was thanked for his cooperation. The equipment then was returned to the pit area for use on the next test vehicle.

Analyses

In the analyses of test data, vehicles were classified according to vehicle type; capacity, based on manufacturers maximum vehicle weight ratings; test gross weights; and brake type. The braking performance results from the 1963 study were compared with the performance requirements of the *Uniform Vehicle Code* (*5*) and with the results of the previous studies. Statistical tests were performed at different points in the analyses to determine whether the difference in observed means was statistically significant and to obtain insight into the meaning of the results. Separate analyses were made for the passenger car and commercial vehicle test results; these analyses are presented separately. For both analyses, a 40K7010 IBM computer was used in different phases. The computer arranged the vehicles by State, vehicle type, brake type, manufacturers capacity weight rating groups, and test gross weight. In general, its use expedited the computation of statistics such as means, standard deviations, and confidence intervals.

Passenger Cars

Passenger cars tested were classified as foreign, compact, and standard size. Because of the increase in popularity of the foreign and compact passenger cars and the frequency of their operation on the highways, an analysis of the braking performance of such vehicles was considered desirable. Also data for the foreign, compact, and standard size cars were combined and analyzed for comparison with the results of previous studies.

Any passenger car produced in a country outside the United States was placed in the foreign car category. Passenger cars not included in either the foreign or compact categories were classified as standard size cars. The criteria used to classify compact cars included primarily, the make of vehicle, year of production, gross weight, wheelbase, overall length, and horsepower, according to the method described by Cope and Liston (*3*). Automobile insurance company guides also were consulted.

The weight distributions for the foreign, compact, and standard size cars are shown in figure 5. Although some overlap of classi-

Table 1.—Passenger cars tested and results of analyses of data by classification from 1963 braking study

Data analyses	Foreign	Compact	Standard	Total
Gross weight:				
Number of cars	37	80	285	402
Mean, pounds	2,040	2,996	4,164	3,736
S.D., do	477	319	409	815
Mode, do	1,875	2,875	3,875	3,875
Deceleration:				
Number of cars [1]	37	80	283	400
Mean, feet/second/second	28.6	29.7	29.3	29.3
S.D., do	2.73	2.45	2.76	2.70
Mode, do	30.6	32.2	32.2	32.2
Distance:				
Number of cars	37	80	285	402
Mean, feet	19.3	19.0	20.0	19.7
S.D., do	2.65	1.16	2.09	2.04
Mode, do	19	20	19	19

[1] Number of cars shown does not always agree with number in weight and brake system application and braking distance columns as some of the cars did not have enough room for installation of the decelerometer.

Table 2.—Confidence interval for passenger cars classifications in which population means would be expected 95 percent of the time

Data analyses	Foreign	Compact	Standard	Total
Gross weight:				
Standard error of mean, lbs	78.45	35.68	24.23	40.65
95 pct. confidence interval, do	1,890–2,190	2,930–3,070	4,120–4,210	3,660–3,820
Deceleration:				
Standard error of mean, feet/second/second	0.449	0.274	0.164	0.135
95 pct. confidence interval, do	27.7–29.5	29.2–30.2	29.0–29.6	29.0–29.6
Distance:				
Standard error of mean, feet	0.436	0.130	0.124	0.102
95 pct. confidence interval, do	18.4–20.2	18.7–19.3	19.8–20.2	19.5–19.9

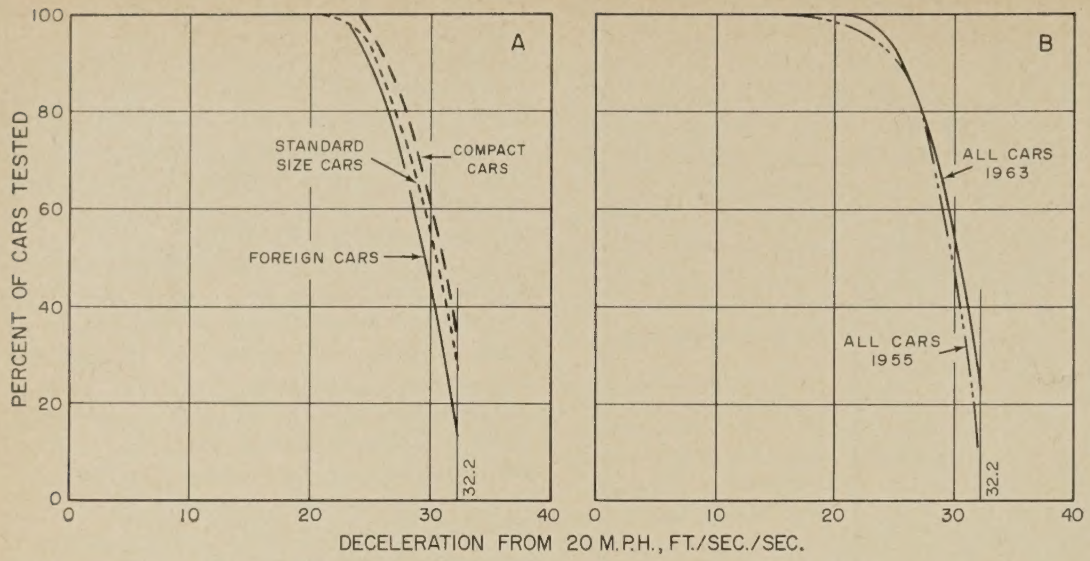

Figure 6.—Passenger cars decelerations.

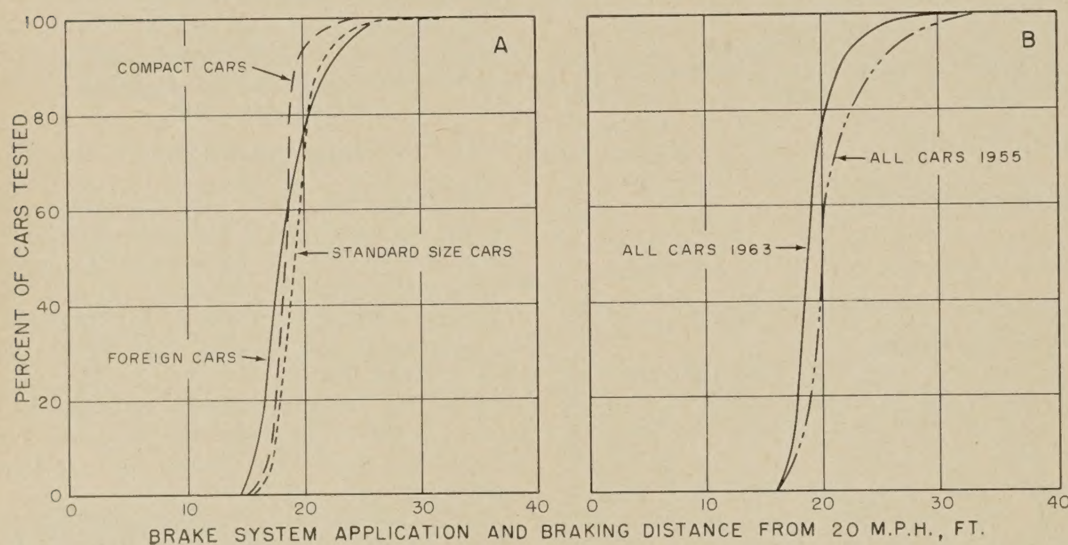

Figure 7.—Frequency distribution of brake system application and braking distances for passenger cars.

fications existed, it constituted less than 5 percent of the 402 passenger cars tested. To determine whether the passenger car classifications were significantly different, an analysis of variance was performed. The null hypothesis was formulated that no difference existed between the average test weight for the foreign, compact, and standard size passenger car classifications. A level of significance of 0.05 was used; in other words, about 5 chances in 100 existed that the hypothesis would be rejected when it should be accepted. The mean test weights were determined to have been unequal and sufficiently different to require individual analysis for each classification: each passenger car classification, the number of vehicles tested, the average or mean value, the standard deviation, and the mode for the gross vehicle test weight, deceleration, and brake system application and braking distance are listed in table 1.

Braking Performance

Use of cumulative frequency distribution curves is a convenient method for comparing the relative performance of the different classifications of passenger cars. Frequency distributions for deceleration and for brake system application and braking distances for each passenger car classification are shown in figures 6 and 7.

The frequency distribution for passenger car deceleration is shown in figure 6. In part B little change is shown to have occurred in the deceleration performance of all passenger cars since 1955 (*4*), however, in the 1963 tests nearly 16 percent more cars than in the 1955 study reached a peak deceleration of 1 g. The average deceleration for each passenger car classification was compared at the 0.05 level to determine whether the differences in means were statistically significant Only the foreign car comparison with the compact car showed significantly different decelerations.

The frequency distribution curve in figure 7 indicates the percentage of passenger cars capable of stopping in a given brake system application and braking distance from a speed of 20 m.p.h. In general the 1963 test results were better than those obtained in 1955, particularly above the 50th percentile level, as shown in part B. In part A of figure 7, data show a larger variability in the distances for the foreign cars than for the compact cars.

This difference in variability is also show in table 1; the standard deviation of the bra system application and braking distance f the foreign car classification exceeds that f the compact car.

An analysis of the average of test data the brake system application and braking d tance for each passenger car classification w made and compared with the average for ea of the other classifications. The means the compact cars and standard size c differed significantly at the 0.05 level. T analysis of the data for foreign cars compa with that for compact cars and of the d for foreign cars compared with that for sta ard size cars showed no significant differen at the 0.05 level; thus no real difference exis between the means of brake system appli tion and braking distance tests for these t passenger car classifications.

The braking performance of passenger c had improved since the first series of te were made in 1942 (*5*). The test data sho general reduction in the variability of brake system application and braking dista between 1942 and 1963; the results from 1963 tests had one-fifth the variability of 1942 results, although the 1942 results cluded data for some passenger cars equip with mechanical-type braking systems. general reduction in braking performance sults at the 85th, 50th, and 15th percent are shown in figure 8 for the studies mad 1942, 1949, 1955, and 1963.

Of the passenger cars tested, only a fev the compact and foreign classifications vacuum power brakes, but 93 of the standard size passenger cars tested had va um power brakes. The average brake sys application and braking distance for cars t had vacuum power brakes was 20.1 feet c pared with 19.9 feet for cars that had reg hydraulic systems. Comparison at the level, showed no real or significant statis differences in the mean braking perform of the two systems.

Uniform Vehicle Code

The National Committee on Unif Traffic Laws and Ordinances presently rec mends in its *Uniform Vehicle Code* (*5*) all passenger cars stop in 25 feet or less f a speed of 20 m.p.h. As computed, nearl percent of the passenger cars tested in stopped in 25 feet or less. At the 95th perc ile level the passenger cars stopped in feet and at the 85th percentile level passe cars stopped in approximately 22 feet. committee also recommends that all passe cars decelerate from a speed of 20 m.p. not less than 17 ft./sec./sec. As indicate the pendulum-type decelerometer the sma peak deceleration was 17.7 ft./sec./sec. computed in the analysis, 95 percent o passenger cars could stop with a peak dece tion of more than 24.1 ft./sec./sec. the results of the 1963 brake perform test, the *Uniform Vehicle Code* (*5*) seen be liberal. Perhaps the code requiren should be updated to encourage addit improvement in the overall braking perf ance of passenger cars.

e of vehicle

\n analysis was conducted on 285 standard e passenger cars equipped with either uum power brakes or regular hydraulic kes to determine whether the average ke system application and braking dis-ice varied with the age of the car. To ermine whether the brake system appli-ion and braking distances means were nificantly different, an analysis of variance s performed. The null hypothesis was mulated that no difference existed between mean braking distance regardless of the e of the vehicle. A level of significance of 1 was used, and the mean brake system plication and braking distances for the ferent years were significantly different that level.

A linear regression equation that best fit e data was computed by the method of st squares. This linear regression is shown figure 9. The coefficients of correlation d the coefficients of determination were also mputed. The coefficient of correlation (r) a measure of the goodness of fit of the re-ession equation to the data; 1.00 indicates perfect fit and 0.00 indicates no fit (*6*). e coefficient of determination (r^2), the uare of the coefficient of correlation, repre-nts the part of the total variance that can accounted for by the independent variable, ich here is the age of vehicle (*6*).

The coefficient of correlation of 0.28 indi-ted that the regression curve did not fit the ta as well as it might have. The coefficient determination indicated that only 8 percent the total variation in the brake system plication and braking distance can be tributed to the age of the passenger car. he remaining or unexplained variation must attributed to other factors such as inade-uate brake system maintenance and/or poor ake adjustment.

The fact that a large percentage of the riability in brake system application and raking distance is unexplained, also is illus-ated in figure 9. The 95 percent confidence terval is shown in figure 9 by parallel lines .94 feet above and below the regression line $=0.149x+19.44$. For example, if the brake stem application and braking distance is to e estimated on the basis of age, for standard ze passenger cars 5 years old; the distance ould be expected to fall within the interval f 16.25 to 24.13 feet, 95 percent of the time. his large interval emphasizes that the age of passenger car is not by itself a good param-ter for estimating braking performance.

onfidence intervals

The classification of passenger cars, as previously explained, represents samples of he passenger cars operating on the public ighways. In evaluating the braking per-ormance of the entire population of cars vithin each classification, the means for each ample classification were used to determine he interval in which the population mean ould be expected to fall with some degree of onfidence. The confidence interval selected was 95 percent; meaning if 100 samples were taken from the population, 95 of the sample

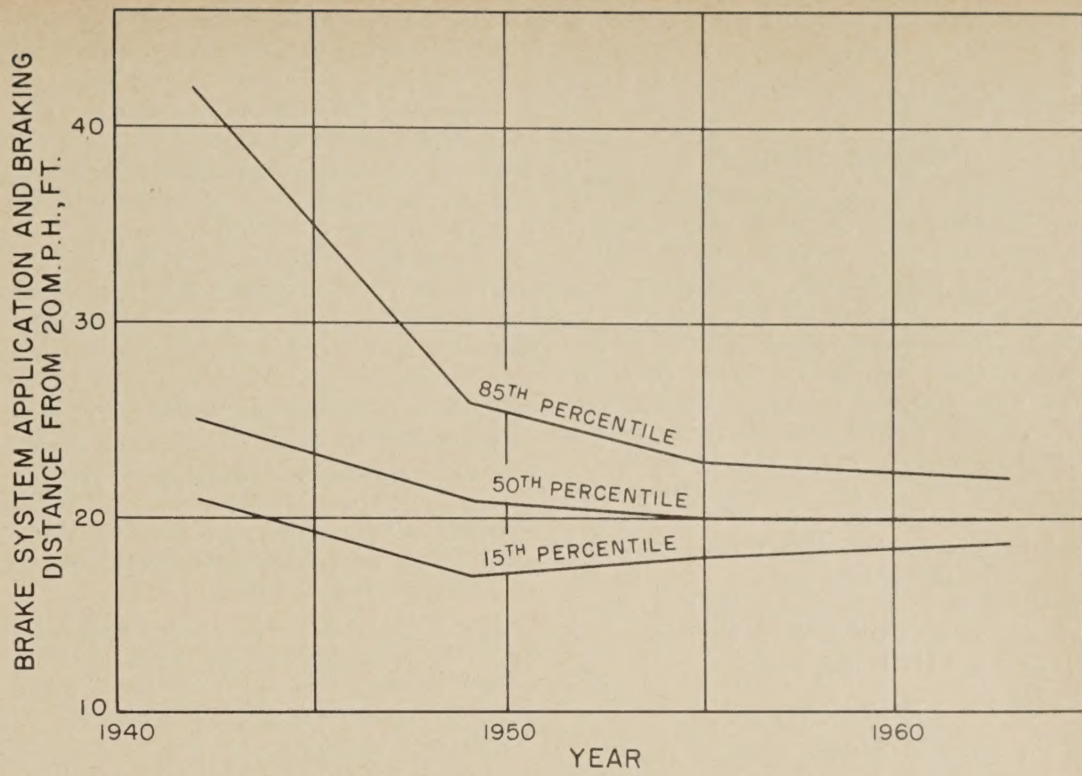

Figure 8.—Percentile levels of brake system application and braking distances for passenger cars.

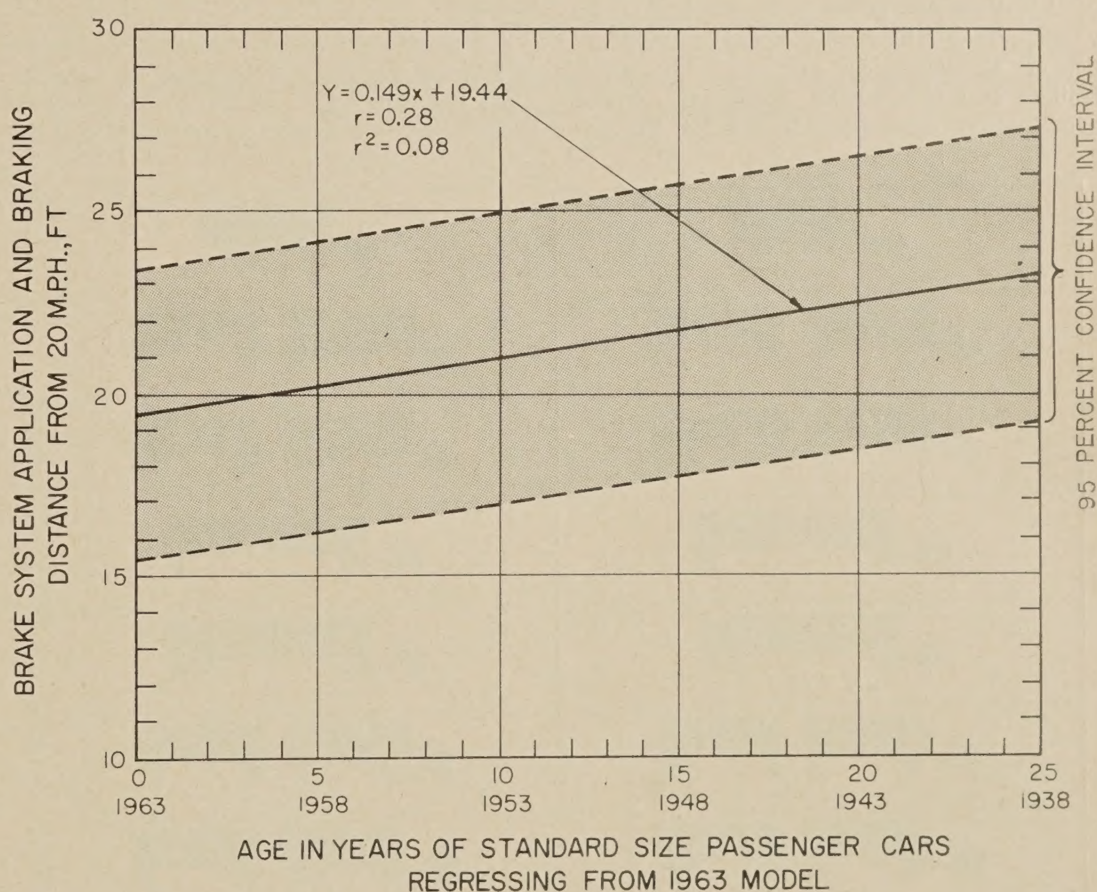

Figure 9.—Mean brake system application and braking distances by age of passenger car.

means would be within the computed interval. In computing the confidence interval, the standard error of the mean was adjusted for a probability of 0.95. The equation used for determining the confidence interval for the population mean was:

95 percent confidence interval = sample mean $\pm$ 1.96 $\times$ standard error of the mean

The interval in which the population mean for gross weight, deceleration and the brake system application and braking distance could be expected 95 percent of the time for the different classifications of passenger cars is shown in table 2.

Commercial Vehicle Test Results

The commercial vehicles tested were grouped according to vehicle type, capacity group, and brake type. Results from tests made with similar or like vehicles could then be considered together and the braking performance determined for the respective groupings. Types of commercial vehicles are shown in figure 10.

Capacity Groups

All commercial vehicles were classified by capacity groups on the basis of the chassis manufacturers gross vehicle weight or gross combination weight rating as marked on the rating plate attached to the test vehicle. Single-unit trucks were classified as very light, light, medium, and heavy; trailer combinations were classified as light, medium, and heavy. The distribution of gross weight ratings by capacity groups is shown in table 3. Sometimes the chassis manufacturers maximum gross weight for truck or truck-tractor used in combination with trailers was not available on the vehicles tested. These trailer combinations were classified as light, medium, or heavy on the basis of the power unit when it is used as a single-unit truck.

Brake Types

Four types of braking systems are commonly used on single-unit vehicles: hydraulic, vacuum-booster hydraulic, air-booster hydraulic, or air-mechanical systems. On trailer combinations the power units are braked by vacuum-booster hydraulic, air-booster hydraulic, or air-mechanical systems. The semitrailers and full trailers within the trailer combination generally are braked by air-mechanical or vacuum-mechanical systems. The brake types used on the vehicles tested are defined as:

Hydraulic (*H*).—Hydraulic brakes have brake shoes that are actuated by hydraulic-brake cylinders operated with hydraulic-line pressure developed by a pedal-operated hydraulic brake master cylinder.

Vacuum-booster hydraulic (*VBH*).—Vacuum-booster hydraulic brakes have brake shoes that are actuated by hydraulic brake wheel cylinders operated with hydraulic-line pressure developed by a vacuum-powered master cylinder or a vacuum-hydraulic power unit.

Air-booster hydraulic (*ABH*).—Air-booster hydraulic brakes have brake shoes that are actuated by hydraulic brake wheel cylinders operated with hydraulic-line pressure developed by an air-powered master cylinder or an air-hydraulic power unit.

Air mechanical (*AM*).—Air mechanical brakes have brake shoes that are actuated by a cam or wedge operated by an air-brake chamber through a mechanical linkage.

Vacuum-mechanical (*VM*).—Vacuum-mechanical brakes have brake shoes that are actuated by a cam or wedge operated by a vacuum-brake chamber through a mechanical linkage.

A code also was used to represent the system or systems employed in braking the vehicles. Each individual part of the code represents the braking system used in a single-unit truck or in one unit of a trailer combination. combination code consisting of two or th parts separated by hyphens indicates braking system used in each unit of the tra combination. For example, a truck-tract semitrailer, and full trailer combination hav a braking code of VBH–VM–VM would h vacuum-booster hydraulic brakes on the tru tractor and vacuum-mechanical brakes both the semitrailer and full trailer.

Vehicle Sample Size

Approximately 300 commercial vehi were tested in each of the three States. each State the sample was composed of ne 50 percent single-unit vehicles and 50 perc combination vehicles. Test vehicles w chosen at each test site so as to obtai sample in which gross vehicle or gross c bination weights were distributed as evenl possible from the lightest to heaviest weig In table 4, the number of vehicles tested each State are shown by type, capacity gro and brake type. No truck-tractors w semitrailers and full trailers were tested Maryland because none came along during testing period.

Weight, Deceleration, and Distan Observations

Tables 5 and 6 show for each commer vehicle grouping the number of vehicles test the mean, the standard deviation, and minimum and maximum test results for g vehicle weight, deceleration, and the br system application and braking distan Both tables present the results by vehicle t and capacity group: table 5 shows the res by type of brake system and table 6 by wei groups. For example, the mean brake syst application and braking distance for the he capacity, 2-axle, single-unit trucks bra by air-mechanical systems (AM) was 31.7 f and the mean distance—without regard to type of brake system—for the heavy capac 2-axle, single-unit trucks having a gross veh weight between 10,000 and 20,000 pou was 29.7 feet.

The minimum and maximum results for gross weight, deceleration, and brak distance in the two tables should not specifically associated with each other. Th results only indicate the spread of the d for each individual parameter; they are extremes and define the low and high lin Minimum and maximum results for one rameter, such as deceleration, cannot be sociated with the corresponding results

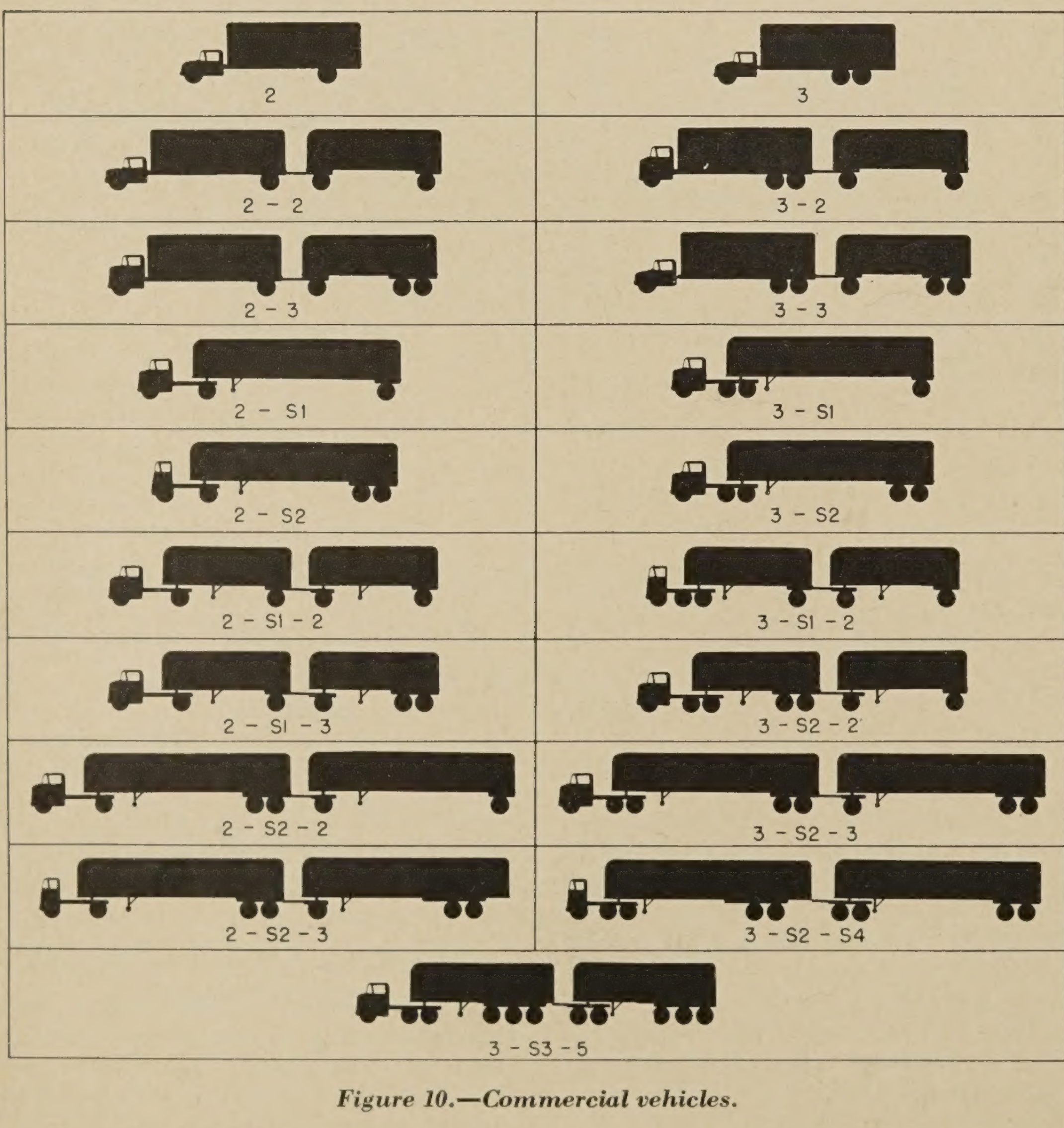

Figure 10.—Commercial vehicles.

Table 3.—Capacity group classifications of commercial vehicles by manufactu ratings

Capacity group	Manufacturers gross weight ratin	
	Single-unit trucks	Trailer combinations
	Pounds	*Pounds*
Very light	10,000 and less	
Light	10,001–16,000	27,000 and less
Medium	16,001–24,000	27,001–44,000
Heavy	24,000 and more	44,000 and mor

able 4.—Classification of vehicles tested by type, capacity group, and brake type

Commercial vehicles and capacity group	Brake type	Number of vehicles tested in— Md.	Mich.	Calif.	Total
Single-unit trucks:					
2-axle:					
Very light	H	46	37	33	116
	VBH	1	2	----	3
Light	H	4	7	3	14
	VBH	17	26	21	64
Medium	H	2	4	----	6
	VBH	55	65	51	171
	ABH	---	2	2	4
	AM	1	7	2	10
Heavy	VBH	7	4	----	11
	AM	12	2	2	16
3-axle:					
Light	VBH	---	----	1	1
Medium	VBH	---	2	2	4
	AM	---	1	1	2
Heavy	VBH	1	2	2	5
	AM	11	6	14	31
Truck-tractors with semi-trailers:					
2-S1:					
Medium	VBH-VM	6	11	1	18
	ABH-AM	---	1	1	2
	AM-AM	5	8	8	21
	ABH-VM	---	1	----	1
	AM-VM	---	1	----	1
Heavy	VBH-VM	2	1	----	3
	ABH-AM	3	----	----	3
	AM-AM	15	15	22	52
	AM-VM	1	----	1	2
2-S2:					
Medium	VBH-VM	---	1	----	1
	ABH-AM	---	1	3	4
	AM-AM	7	6	----	13
Heavy	ABH-AM	---	1	1	2
	AM-AM	104	64	10	178
2-S3:					
Medium	AM-AM	---	1	----	1
Heavy	AM-AM	---	1	----	1
3-S2:					
Medium	AM-AM	---	1	----	1
Heavy	ABH-AM	---	1	----	1
	AM-AM	22	45	31	98
Trucks with full trailers:					
2-2:					
Heavy	AM-AM	---	2	----	2
3-2:					
Heavy	AM-AM	---	1	25	26
Truck-tractors with semitrailers and full trailers:					
2-S1-2:					
Medium	VBH-VM-VM.	---	----	1	1
Heavy	AM-AM-AM.	---	8	40	48
2-S2-2:					
Medium	AM-AM-AM.	---	1	----	1
Heavy	AM-AM-AM.	---	4	----	4
2-S2-3:					
Heavy	AM-AM-AM.	-----	4	------	4
3-S1-2:					
Heavy	AM-AM-AM.	-----	------	1	1
3-S2-2:					
Heavy	AM-AM-AM.	-----	2	------	2
3-S3-5:					
Heavy	AM-AM-AM.	---	2	----	2
Other combinations:					
Truck driveaway-towaway:					
Heavy	VBH	---	1	----	1
	AM	---	1	----	1
Housetrailer factory towaway:					
Medium	VBH-E	2	1	1	4
Single-unit trucks with unbraked utility trailer:					
Medium	VBH	---	3	----	3
TOTAL		324	357	280	961

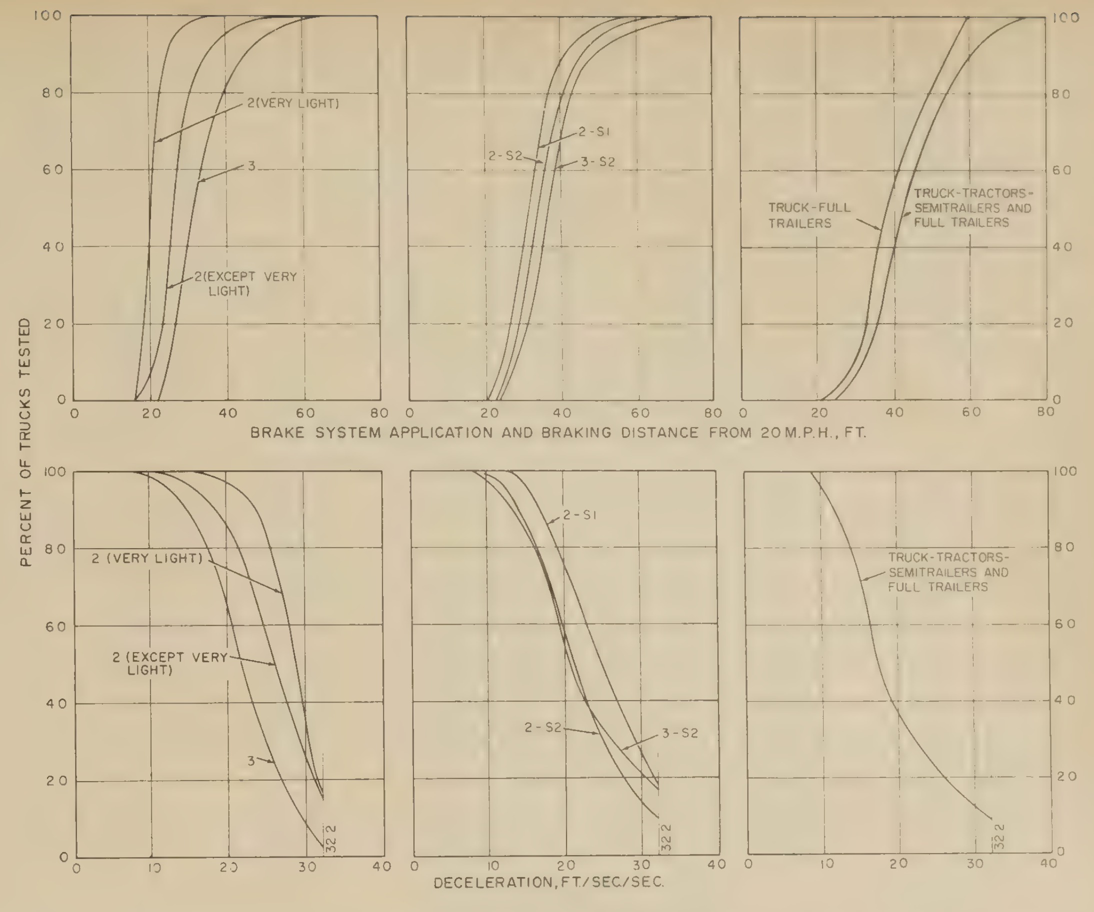

Figure 11.—Cumulative frequency distributions of minimum brake system application and braking distances and decelerations.

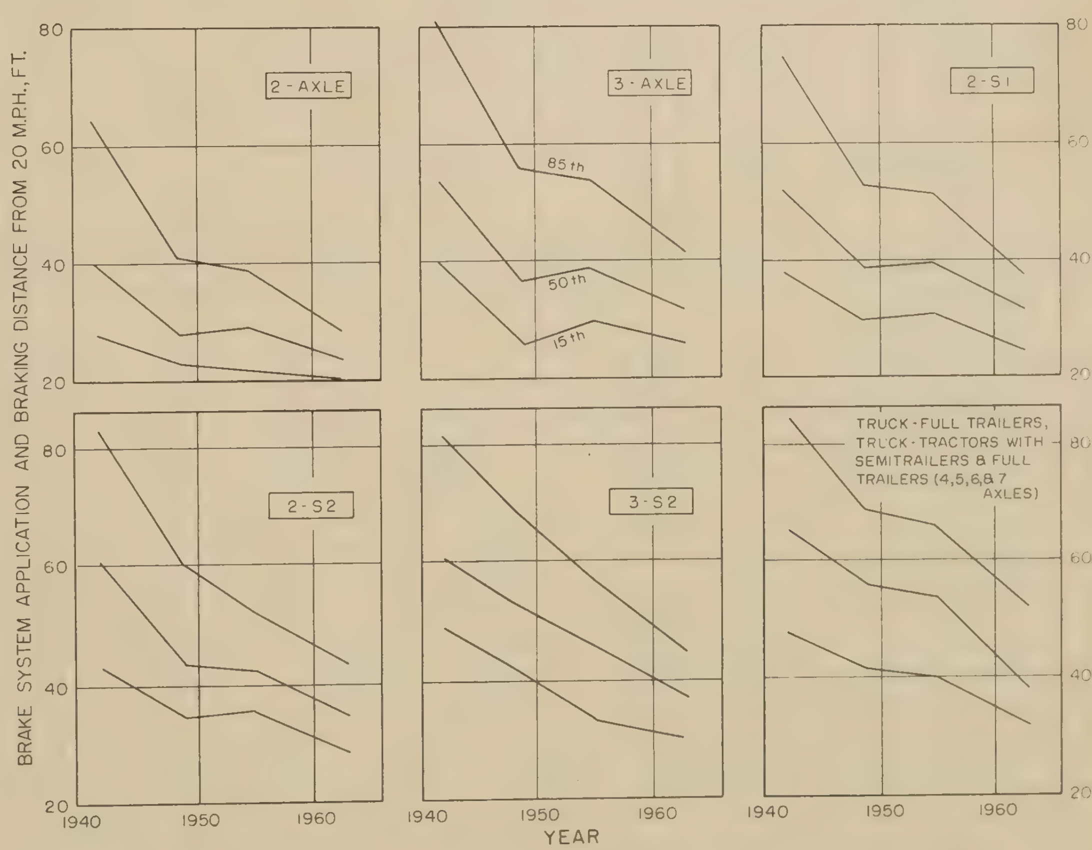

Figure 12.—Percentile levels of brake system application and braking distances for vehicles by year.

Table 5.—Analysis results for gross vehicle weight, braking system application and braking distance, and deceleration, by type of braking system

Commercial vehicles and capacity groups	Brake system[1]	Test vehicles, GVW and BSABD	Gross vehicle weight: Mean	Gross vehicle weight: Standard deviation	Gross vehicle weight: Minimum	Gross vehicle weight: Maximum	BSABD: Mean	BSABD: Standard deviation	BSABD: Minimum	BSABD: Maximum	Deceleration (pendulum-type decelerometer): Test vehicles	Deceleration: Mean	Deceleration: Standard deviation	Deceleration: Minimum	Deceleration: Maximum
	Type	*No.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Feet*	*Feet*	*Feet*	*Feet*	*No.*	*Ft./sec./sec.*	*Ft./sec./sec.*	*Ft./sec./sec.*	*Ft./sec./sec.*
Single-unit trucks:															
2-axle: Very light	H	116	4,687	1,110	2,545	8,700	21.6	3.65	16	41	116	27.6	3.81	15.1	32.2
	VBH	3	7,918	------	6,320	11,050	21.0	------	19	23	3	29.8	------	28.3	32.2
	All	119	4,768	1,259	2,545	11,050	21.6	3.62	16	41	119	27.7	3.78	15.1	32.2
Light	H	14	10,126	4,164	5,700	18,530	29.4	7.31	18	40	14	21.9	5.17	14.5	30.6
	VBH	64	10,668	4,466	5,900	23,840	26.4	5.82	19	51	63	26.5	5.68	11.9	32.2
	All	78	10,571	4,392	5,700	23,840	27.0	6.17	18	51	77	25.7	5.84	11.9	32.2
Medium	H	6	12,239	------	10,205	15,660	28.5	------	26	31	5	25.2	------	20.9	32.2
	VBH	171	13,635	4,809	6,710	27,400	27.4	5.49	17	46	167	25.5	4.87	12.2	32.2
	ABH	4	12,155	------	8,900	18,570	34.7	------	26	46	4	24.3	------	15.1	27.4
	AM	10	17,544	6,382	8,100	26,800	37.8	16.82	24	75	10	18.8	7.53	6.4	29.0
	All	191	13,765	4,892	6,710	27,400	28.1	6.95	17	75	186	25.1	5.23	6.4	32.2
Heavy	VBH	11	15,777	5,292	10,605	28,480	30.4	5.79	24	44	11	27.6	4.72	18.0	32.2
	AM	16	17,936	5,249	12,410	31,410	31.7	5.40	25	46	15	22.0	3.54	14.5	30.6
	All	27	17,056	5,276	10,605	31,410	31.2	5.49	24	46	26	24.3	4.91	14.5	32.2
All capacity groups	H	136	5,580	2,768	2,545	18,530	22.7	4.87	16	41	135	26.9	4.33	14.5	32.2
	VBH	249	12,898	4,943	5,900	28,480	27.2	5.64	17	51	244	25.9	5.09	11.9	32.2
	AM	26	17,785	5,589	8,100	31,410	34.2	11.33	24	75	25	20.7	5.57	6.4	30.6
	All	415	10,799	5,818	2,545	31,410	26.2	6.66	16	75	408	25.9	5.68	6.4	32.2
3-axle: Light	VBH	1	25,400	------	25,400	25,400	28.0	------	28	28	1	23.2	------	23.2	23.2
Medium	VBH	4	15,808	------	11,000	23,400	28.7	------	27	30	4	24.5	------	22.5	27.4
	AM	2	26,725	------	17,500	35,950	45.0	------	28	62	2	18.5	------	11.3	25.8
	All	6	19,447	------	11,000	35,950	34.1	------	27	62	6	22.5	------	11.3	27.4
Heavy	VBH	5	15,491	------	12,925	17,900	25.4	------	23	29	5	27.4	------	22.5	32.2
	AM	31	25,566	11,120	12,300	53,200	35.9	9.56	24	68	31	19.8	4.61	8.0	30.6
	All	36	24,166	10,900	12,300	53,200	34.5	9.63	23	68	36	20.8	5.26	8.0	32.2
All capacity groups	VBH	10	16,609	4,702	11,000	23,400	27.0	2.45	23	30	10	25.8	3.74	22.5	32.2
	AM	33	25,636	11,014	12,300	53,200	36.5	10.42	24	68	33	19.7	4.83	8.0	30.6
	All	43	23,537	10,586	11,000	53,200	34.3	10.03	23	68	43	21.1	5.25	8.0	32.2
Truck-tractors with semitrailers:															
2-S1: Medium	VBH-VM	18	22,602	7,503	13,000	37,000	34.0	8.20	24	56	18	24.3	5.69	12.2	32.2
	ABH-AM	2	16,850	------	16,800	16,900	26.5	------	25	28	2	27.4	------	25.8	29.0
	AM-AM	21	22,822	6,310	15,300	33,980	31.1	6.07	24	53	19	26.8	5.89	17.4	32.2
	ABH-VM	1	21,610	------	21,610	21,610	29.0	------	29	29	1	22.5	------	22.5	22.5
	AM-VM	1	32,840	------	32,840	32,840	37.0	------	37	37	1	22.5	------	22.5	22.5
	All	43	22,657	6,772	13,000	33,980	32.2	7.01	24	56	41	25.4	5.64	12.2	32.2
Heavy	VBH-VM	3	38,848	------	34,680	41,455	40.0	------	35	46	3	17.4	------	14.5	19.3
	ABH-AM	3	19,800	------	19,490	20,170	27.0	------	24	29	2	27.7	------	25.8	29.6
	AM-AM	52	25,748	7,524	14,500	45,400	33.2	6.76	21	51	52	23.6	6.13	12.2	32.2
	AM-VM	2	18,753	------	17,400	20,105	32.5	------	32	33	2	27.4	------	22.5	32.2
	All	60	25,872	7,850	14,500	45,400	33.2	6.72	21	51	59	23.5	6.11	12.2	32.2
All capacity groups	VBH-VM	21	24,923	9,117	13,000	41,455	34.9	8.05	24	56	21	23.3	5.85	12.2	32.2
	ABH-AM	5	18,620	------	16,800	20,170	26.8	------	24	29	4	27.5	------	25.8	29.6
	AM-AM	73	24,906	7,276	14,500	45,400	32.6	6.59	21	53	71	24.4	6.19	12.2	32.2
	AM-VM	3	23,448	------	17,400	32,840	34.0	------	32	37	3	25.2	------	20.9	32.2
	All	103	24,530	7,554	13,000	45,400	32.8	6.82	21	56	100	24.3	5.97	12.2	32.2
2-S2: Medium	VBH-VM	1	42,080	------	42,080	42,080	48.0	------	48	48	1	12.9	------	12.9	12.9
	ABH-AM	3	29,783	------	15,900	49,950	33.6	------	26	40	3	22.0	------	17.7	27.4
	AM-AM	14	38,409	16,588	17,840	63,390	34.2	7.18	25	45	14	22.2	6.16	14.5	30.6
	All	18	37,175	16,134	15,900	63,390	34.8	7.49	25	48	18	21.7	6.06	12.9	30.6
Heavy	ABH-AM	2	22,445	------	21,200	23,690	25.0	------	24	26	2	29.8	------	27.4	32.2
	AM-AM	178	39,473	13,008	18,500	64,805	36.1	7.66	23	67	177	21.4	6.04	8.7	32.2
	All	180	39,283	13,059	18,500	64,805	36.0	7.70	23	67	179	21.5	6.08	8.7	32.2
All capacity groups	ABH-AM	5	26,848	------	15,900	49,900	30.2	------	24	40	5	25.1	------	17.7	32.2
	AM-AM	192	39,395	13,252	17,840	64,805	36.0	7.62	23	67	191	21.5	6.04	8.7	32.2
	All	198	39,092	13,334	15,900	64,805	35.9	7.67	23	67	197	21.5	6.06	8.7	32.2
2-S3: Medium	AM-AM	1	22,680	------	22,680	22,680	38.0	------	38	38	1	20.0	------	20.0	20.0
Heavy	AM-AM	1	42,480	------	42,480	42,480	45.0	------	45	45	1	17.1	------	17.1	17.1
All capacity groups	AM-AM	2	32,580	------	32,580	32,580	41.5	------	41	41	2	18.5	------	18.5	18.5
3-S2: Medium	AM-AM	1	72,480	------	72,480	72,480	68.0	------	68	68	1	9.7	------	9.7	9.7
Heavy	ABH-AM	1	24,090	------	24,090	24,090	38.0	------	38	38	1	32.2	------	32.2	32.2
	AM-AM	98	50,345	18,769	22,010	94,650	37.9	9.27	24	79	97	21.7	6.94	8.7	32.2
	All	99	50,079	18,858	22,010	94,650	37.9	9.22	24	79	98	21.8	6.98	8.7	32.2
All capacity groups	AM-AM	99	50,568	18,805	22,010	94,650	38.2	9.70	24	79	98	21.6	7.01	8.7	32.2
	All	100	50,303	18,896	22,010	94,650	38.2	9.65	24	79	99	21.7	7.06	8.7	32.2
Trucks with full trailers:															
2-2: Heavy	AM-AM	2	42,795	------	24,310	61,280	41.5	------	35	48	2	18.2	------	12.9	23.5
3-2: Heavy	AM-AM	26	48,969	23,793	22,400	78,200	41.3	9.48	23	60	26	23.1	8.95	11.3	32.2
Truck-tractors with semitrailers and full trailers:															
2-S1-2: Medium	VBH-VM-VM	1	25,600	------	25,600	25,600	49.0	------	49	49	1	17.7	------	17.7	17.7
Heavy	AM-AM-AM	48	60,551	21,871	24,500	82,700	46.5	11.71	27	75	48	19.1	6.79	9.3	32.2
All capacity groups	All	49	59,837	22,211	24,500	82,700	46.5	11.59	27	75	49	19.1	6.73	9.3	32.2
2-S2-2: Medium	AM-AM-AM	1	77,430	------	77,430	77,430	53.0	------	53	53	1	12.9	------	12.9	12.9
Heavy	AM-AM-AM	4	74,853	------	35,010	96,260	49.8	------	30	64	4	18.7	------	10.6	29.0
All capacity groups	AM-AM-AM	5	75,368	------	35,010	96,260	50.4	------	30	64	5	17.5	------	10.6	29.0
2-S2-3, Heavy	AM-AM-AM	4	88,768	------	38,440	113,460	40.5	------	37	49	4	21.3	------	17.7	25.8
3-S1-2, Heavy	AM-AM-AM	1	52,200	------	52,200	52,200	31.0	------	31	31	1	17.4	------	17.4	17.4
3-S2-2, Heavy	AM-AM-AM	2	37,010	------	34,970	39,030	37.0	------	37	37	2	29.9	------	27.4	32.2
3-S3-5, Heavy	AM-AM-AM	2	132,535	------	132,500	132,570	58.5	------	48	69	2	13.8	------	11.6	16.1
All other than 2-S1-2: Medium	AM-AM-AM	1	77,430	------	77,430	77,430	53.0	------	53	53	1	12.9	------	12.9	12.9
Heavy	AM-AM-AM	13	80,442	36,952	34,970	132,570	44.8	12.27	30	69	13	20.3	6.55	10.6	32.2
All capacity groups	AM-AM-AM	14	80,227	35,511	34,970	132,570	45.4	11.99	30	69	14	19.8	6.60	10.6	32.2

[1] All refers to the total number of vehicles tested in each category, regardless of brake system type or capacity group.

ne other two. For example, in the classi- cation under truck-tractors with semitrailers nd full trailers and for all other than 2–S1–2, e heavy capacity group, maximum decelera- on of 32.2 feet per second should not be sociated with the maximum gross weight of 32,570 pounds. It would be more appro- iate to associate the maximum deceleration vehicles in this classification with the inimum weight and the minimum decelera- on with the maximum weight. However, e fact that the distance required to stop creases with an increase in gross weight ust be considered.

All vehicles tested did not have decelerations 32.2 feet per second per second, or 1 g. he deceleration results shown in the tables e sometimes higher than the actual decel- ations that would be measured by more phisticated equipment. Some, but not all, the vehicles within the different classi- cations had indicated maximum decelerations 1 g.; the particularly heavily loaded vehicles d decelerations less than 1 g. The pen- ulum-type decelerometer used often in- icated decelerations of 1 g. when the vehicle ounced, hopped, or jumped during brake pplication. This was particularly evident hen the vehicles tested were carrying rel- tively light loads in comparison to design ads. The test results do show the relative eceleration performance relations between e different vehicle classifications.

raking Performance by Vehicle Type

The differences in braking performance ttributed to different types of vehicles are own by the frequency distribution curves figure 11 for the brake system application nd braking distances and deceleration. The urves show the braking performance in ercent of vehicles tested by vehicle type, hich stopped in a given distance or less, which reached a deceleration of a given or rger value when simulating an emergency op from 20 m.p.h. The decelerations easured were not sustained throughout the ops but were the maximum decelerations corded during the stops. The brake system pplication and braking distance and the eceleration frequency distributions are evi- ence that the smaller vehicles are capable f better braking performance.

The improvement in braking performance or different types of commercial vehicles om 1942 to 1963 is shown in figure 12 by e 15th, 50th, and 85th percentile levels (*4*). n general, braking performance has improved uring the years in a reduction in the distance equired to stop and a decrease in the vari- bility of brake system application and raking distance. This trend in continu- g improvement in braking performance was vident in the results of the 1963 brake tests.

The relative effect that different capacity roups and weight groups have on the braking erformance of vehicle types is shown by the ata in figure 13. The average brake system pplication and braking distance for each articular grouping was computed and is hown in the figure as a bar of a length in roportion to the respective distance. In

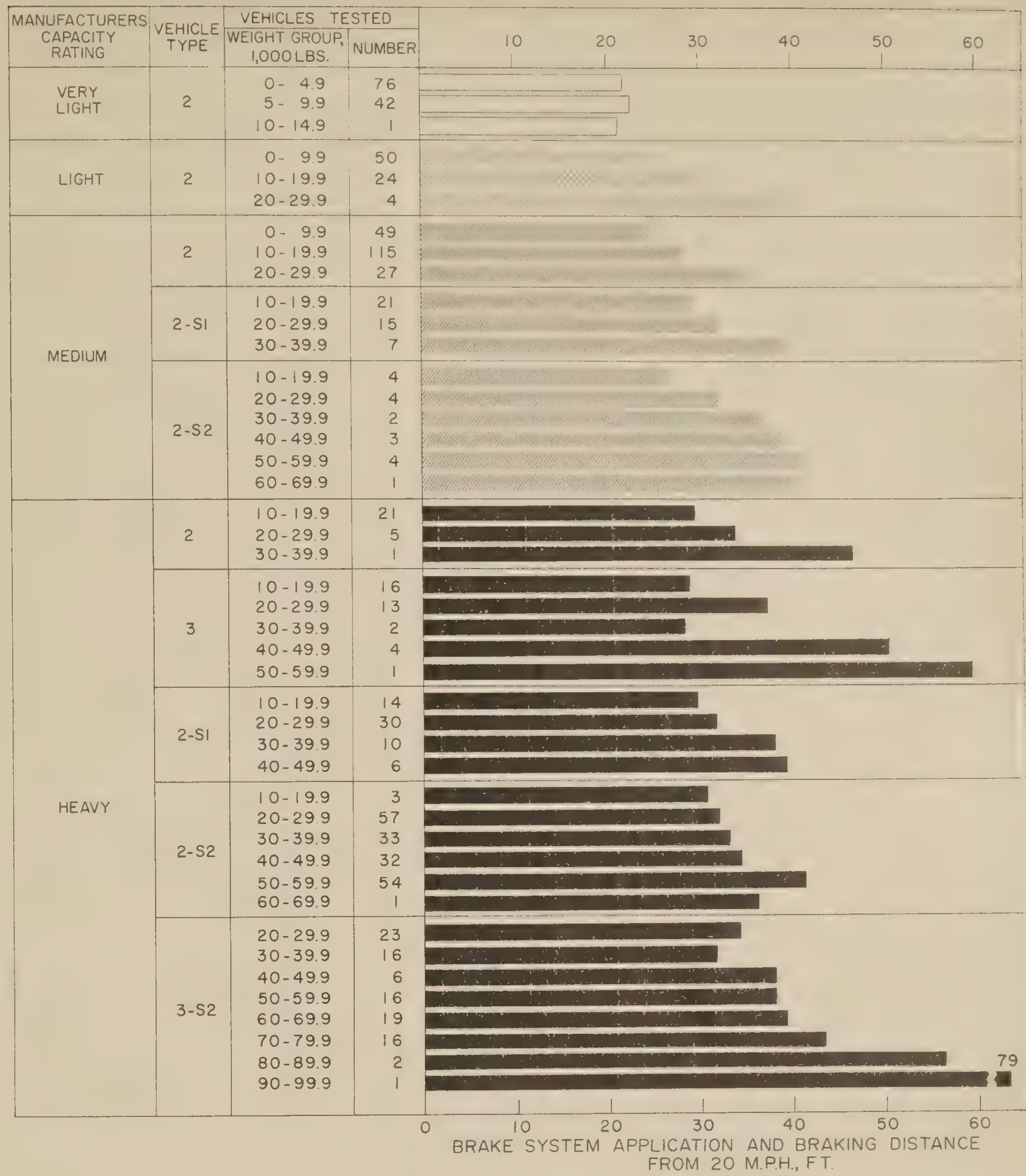

Figure 13.—Braking performance by vehicle types, capacity groups, and weight groups.

normal highway operation, brake system application and braking distance increases with weight for a given type of vehicle and this fact is confirmed by the test data shown (fig. 13).

Braking Performance in 1955 and 1963

The average weight and the average brake system application and braking distance is given in table 7 by type of vehicle for the vehicles studied in 1955 and 1963. For some types the average weight varied little from 1955 results, but the average weight for others varied considerably (*4*). Part of the variation in average weight can be explained by the chance selection of vehicles to be tested. However, part of the variation in weight also can be attributed to operators of commercial vehicles changing from use of one type of vehicle to another for economic reasons. For example, the 2–S1 vehicles currently are being used to carry lighter loads than previously, although no reduction has been made in the permissible legal weight limits.

The National Committee on Unifrom Traffic Laws and Ordinances specified, in *Uniform Vehicle Code* (*5*), the minimum deceleration and maximum brake system application and braking distances that motor vehicles operating on the highways shou'd obtain when simulating emergency stops from 20 m.p.h. A large percentage of vehicles in the 1963 study met the code requirements; these data are given in table 8. The vehicle types that did not meet the braking require- ments of the code were the truck-full trailer and the truck-tractor-semitrailer-full trailer combinations. However, when the brakes on these large vehicle combinations are adjusted properly, they can meet the code require- ments. For example, two 3–S3–5 trailer combinations, weighing approximately 133,000 pounds each, were tested. The two truck- tractors were the same make, model, and year, and an air-mechanical brake system was used in each. One trailer combination stopped in 69 feet from 20 m.p.h. and the other stopped in 48 feet, 2 feet less than the code requirement. No maintenance had been

Table 6.—Analysis results for gross vehicle weight, braking system application and braking distance, and deceleration by gross vehicl weight group

Commercial vehicles and capacity groups	Gross vehicle weight group	Test vehicles, GVW and BSABD	Gross vehicle weight: Mean	Gross vehicle weight: Standard deviation	Gross vehicle weight: Minimum	Gross vehicle weight: Maximum	BSABD: Mean	BSABD: Standard deviation	BSABD: Minimum	BSABD: Maximum	Test vehicle	Deceleration (pendulum-type decelerometer): Mean	Deceleration: Standard deviation	Deceleration: Minimum	Deceleration: Maximum
	1,000 lbs.	*Number*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Feet*	*Feet*	*Feet*	*Feet*	*Number*	*Ft./sec./sec.*	*Ft./sec./sec.*	*Ft./sec./sec.*	*Ft./sec./sec.*
Single-unit trucks:															
2-axle: Very light	0-4.9	76	4,053	471	2,545	4,995	21.3	3.9	16	41	76	27.0	3.9	15.1	32.2
	5-9.9	42	5,914	949	5,000	8,700	22.4	3.1	17	29	42	27.3	3.5	20.3	32.2
	10-14.9	1	11,050	----------	11,050	11,050	21.0	----------	21.0	21.0	1	28.3	----------	28.3	28.3
Light	0-9.9	50	7,955	1,192	5,700	9,960	24.5	3.8	8	39	50	27.4	5.0	15.1	32.2
	10-19.9	24	14,037	3,045	10,200	19,110	30.2	5.0	20	45	23	23.7	5.8	14.5	32.2
	20-29.9	4	22,466	----------	20,900	23,840	39.5	----------	32	51	4	15.7	----------	11.9	18.4
Medium	0-9.9	49	8,732	685	6,710	9,790	24.5	4.5	17	40	48	28.0	4.0	17.7	32.2
	10-19.9	115	13,780	2,848	10,050	19,995	28.1	6.3	18	75	111	25.3	4.7	6.4	32.2
	20-29.9	27	22,833	2,297	20,000	27,400	35.3	7.8	26	56	27	19.2	4.8	10.9	29.0
Heavy	10-19.9	21	14,769	2,453	10,605	18,975	29.7	3.9	24	40	20	25.1	4.4	19.3	32.2
	20-29.9	5	23,792	----------	20,185	28,480	34.8	----------	30	44	5	23.2	----------	17.7	30.6
	30-39.9	1	31,410	----------	31,410	31,410	46.0	----------	46.0	46.0	1	14.5	----------	14.5	14.5
All capacity groups	0-9.9	217	6,369	2,110	2,545	9,960	22.9	4.1	16	41	217	27.7	4.1	15.1	32.2
	10-19.9	161	13,930	2,833	10,050	19,995	28.5	6.1	18	75	155	25.1	4.8	6.4	32.2
	20-29.9	36	22,926	2,442	20,000	28,480	35.7	7.5	26	56	35	19.4	5.0	10.9	30.6
	30-39.9	1	31,410	----------	31,410	31,410	46.0	----------	46.0	46.0	1	14.5	----------	14.5	14.5
3-axle:															
Light	20-29.9	1	25,400	----------	25,400	25,400	28.0	----------	28.0	28.0	1	23.2	----------	23.2	23.2
Medium	10-19.9	4	14,332	----------	11,000	17,500	28.2	----------	27	30	4	24.5	----------	22.5	27.4
	20-29.9	1	23,400	----------	23,400	23,400	30.0	----------	30.0	30.0	1	25.8	----------	25.8	25.8
	30-39.9	1	35,950	----------	35,950	35,950	62.0	----------	62.0	62.0	1	11.3	----------	11.3	11.3
Heavy	10-19.9	16	16,389	2,173	12,300	19,300	28.4	4.3	23	41	16	23.6	4.4	17.7	32.2
	20-29.9	13	22,866	2,042	20,100	26,225	36.2	4.1	29	42	13	20.1	4.2	16.1	30.6
	30-39.9	2	37,350	----------	34,800	39,900	28.0	----------	27	29	2	21.7	----------	19.3	24.2
	40-49.9	4	45,651	----------	44,600	47,410	50.5	----------	43	68	4	13.5	----------	8.0	17.7
	50-59.9	1	53,200	----------	53,200	53,200	59.0	----------	59.0	59.0	1	13.5	----------	13.5	13.5
All capacity groups	10-19.9	20	15,978	2,461	11,000	19,300	28.4	4.0	23	41	20	23.8	4.1	17.7	32.2
	20-29.9	15	23,070	2,002	20,100	26,725	35.2	4.6	28	42	15	20.7	4.2	16.1	30.6
	30-39.9	3	36,883	2,675	34,800	39,900	39.3	----------	27	62	3	18.3	----------	8.0	17.7
	40-49.9	4	45,651	----------	44,600	47,410	50.5	----------	43	68	4	13.5	----------	8.0	17.7
	50-59.9	1	53,200	----------	53,200	53,200	59.0	----------	59.0	59.0	1	13.5	----------	13.5	13.5
Truck-tractors with semitrailers:															
2-S1: Medium	10-19.9	21	17,221	1,824	13,000	19,750	29.7	6.8	24	56	21	28.8	4.1	18.0	32.2
	20-29.9	15	24,752	3,515	20,100	29,510	32.6	4.0	26	40	14	22.9	5.1	17.4	32.2
	30-39.9	7	34,474	----------	32,100	37,000	39.1	----------	30	53	6	19.8	----------	12.2	24.2
Heavy	10-19.9	14	17,978	1,675	14,500	19,890	29.9	6.5	24	48	14	27.0	5.5	14.5	32.2
	20-29.9	30	23,628	2,925	20,105	29,800	32.0	6.4	21	51	29	25.1	5.4	12.6	32.2
	30-39.9	10	33,766	2,334	30,610	37,520	37.8	4.5	33	46	10	18.4	3.9	14.5	22.4
	40-49.9	6	42,358	----------	40,410	45,400	39.2	----------	34	47	6	16.9	----------	12.2	19.3
All capacity groups	10-19.9	35	17,524	1,781	13,000	19,890	29.8	6.6	24	56	35	28.1	4.7	14.5	32.2
	20-29.9	45	24,003	3,139	20,100	29,800	32.2	5.7	21	51	43	24.3	5.4	12.6	32.2
	30-39.9	17	34,057	2,151	30,610	37,520	38.4	6.3	30	53	12	18.9	3.9	12.2	27.4
	40-49.9	6	42,358	----------	40,410	45,400	39.2	----------	34	47	6	16.9	----------	12.2	19.3
2-S2: Medium	10-19.9	4	18,050	----------	15,900	19,270	26.3	----------	25	28	4	27.8	----------	22.5	30.6
	20-29.9	4	25,050	----------	23,500	27,130	32.3	----------	25	40	4	26.7	----------	20.9	30.6
	30-39.9	2	35,692	----------	34,985	36,400	36.5	----------	34	39	2	21.3	----------	20.6	21.9
	40-49.9	3	46,473	----------	42,080	49,950	38.3	----------	32	48	3	16.6	----------	12.9	19.3
	50-59.9	4	55,640	----------	53,555	58,345	41.3	----------	34	45	4	15.6	----------	14.5	16.1
	60-69.9	1	63,390	----------	63,390	63,390	41.0	----------	41.0	41.0	1	17.7	----------	17.7	17.7
Heavy	10-19.9	3	19,183	----------	18,500	19,915	31.0	----------	28	33	3	26.0	----------	16.7	32.2
	20-29.9	57	24,201	2,665	20,060	29,830	31.9	6.5	24	66	57	25.9	5.4	9.7	32.2
	30-39.9	33	35,649	3,016	30,140	39,670	34.4	5.3	23	51	32	22.1	4.1	11.9	32.2
	40-49.9	32	44,652	2,509	40,500	48,985	35.3	4.5	27	44	32	21.4	5.1	14.8	32.2
	50-59.9	54	54,888	2,402	50,660	58,800	42.1	8.1	29	67	54	16.5	4.2	8.7	29.3
	60-69.9	1	64,805	----------	64,805	64,805	36.0	----------	36.0	36.0	1	18.4	----------	18.4	18.4
All capacity groups	10-19.9	7	18,536	----------	15,900	19,915	28.3	----------	25	33	7	27.0	----------	16.7	32.2
	20-29.9	61	24,256	2,606	20,060	29,830	31.9	6.5	24	66	61	25.9	5.4	9.7	32.2
	30-39.9	35	35,651	2,931	30,140	39,670	34.5	5.2	23	51	34	22.0	4.0	11.9	32.2
	40-49.9	35	44,808	2,637	40,500	49,950	35.6	4.8	27	48	35	21.1	5.1	12.9	32.2
	50-59.9	58	54,940	2,368	50,600	58,800	42.1	7.9	29	67	58	16.4	4.1	8.7	29.3
	60-69.9	2	64,098	----------	63,390	64,805	38.5	----------	36	41	2	18.0	----------	17.7	18.4

performed on either trailer combination in preparation for the tests. It is almost certain that the trailer combination that stopped in 69 feet could have stopped in a considerably shorter distance if its brakes had been adjusted immediately before the test. It is also possible that a brake adjustment could have improved the braking performance of the other trailer combination.

Axle Loads

Not all vehicle types could be considered in the analyses because either too few vehicles of a given type were tested or weights carried on the principal load-carrying axles varied excessively. Axle loads could be analyzed for only the 2, 2–S1, 2–S2, and 3–S2 types of vehicles. The results from the analyses of the test data for 2, 2–S1, and 3–S2 vehicles were compared with the test results for similar vehicles from previous studies (*4*). Because of large variations in the weights carried on the principal load-carrying axles, previous 2–S2 test results could not be compared with the 1963 study results.

The performance of 2 and 2–S1 vehicles from the brake research studies of 1949, 1955, and 1963 are shown in figure 14. In general, the braking performance of these two types of vehicles improved from one study to the next. The weights on the steering axles were not considered in the data shown. For the type 2, single-unit vehicles, the rear axles were grouped in weight increments of 4,000 pounds and the braking performance was then computed for the groups and plotted at the midpoint of the weight group. The same analysis procedure was used for the 2–S1 vehicles, however, data were considered only for those trailer combinations for which the weights of the truck-tractor drive axle and the trailer axle were in the same 4,000-pound group.

Primarily because of difficulty encountered in establishing weight increments in which a sufficient number of observations could obtained for 2–S2 of trailer combinations, data were treated differently. The method least squares was used to compute the lin regression equation that best fit the data. the analysis of the data for 2–S2 trailer co binations information was used only on tra combinations for which the truck-trac drive axle weight equaled or exceeded 16,0 pounds. In the analysis of the data on 3–S2 combinations, test results were used o for trailer combinations in which both sets tandem axles were within 4,000 pounds of e other.

The braking performance for the 2–S2 3–S2 trailer combinations in relation to weight on the tandem axles is shown in fig 15. The regression curve determined for 2–S2 trailer combinations is approxima parallel to and 2 feet below the curve for 3–S2 trailer combinations. The coefficien

Table 6.—Analysis results for gross vehicle weight, braking system application and braking distance, and deceleration by gross vehicle weight group—Continued

Commercial vehicles and capacity groups	Gross vehicle weight group	Test vehicles, GVW and BSABD	Gross vehicle weight				BSABD				Test vehicle	Deceleration (pendulum-type decelerometer)			
			Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum		Mean	Standard deviation	Minimum	Maximum
Truck-tractors with semitrailers:	1,000 lbs.	Number	Pounds	Pounds	Pounds	Pounds	Feet	Feet	Feet	Feet	Number	Ft./sec./sec.	Ft./sec./sec.	Ft./sec./sec.	Ft./sec./sec.
3-S2:															
Medium	70-79.9	1	72,480	----------	72,480	72,480	68.0	----------	68	68	1	9.7	----------	9.7	9.7
Heavy	20-29.9	23	26,804	2,385	23,100	29,755	34.4	6.0	25	50	22	27.6	6.4	13.9	32.2
	30-39.9	16	33,575	2,849	30,230	39,700	31.7	4.5	24	39	16	27.8	4.6	17.7	32.2
	40-49.9	6	42,112	----------	40,400	44,540	37.7	----------	33	42	6	22.0	----------	16.1	32.2
	50-59.9	16	56,039	2,953	50,900	59,350	37.7	7.8	25	50	16	20.9	4.7	13.8	28.0
	60-69.9	19	64,709	2,947	60,090	69,200	38.7	4.6	26	44	19	17.8	3.7	12.9	25.1
	70-79.9	16	73,110	3,113	70,300	79,680	43.9	9.5	32	60	16	15.5	4.0	9.7	22.5
	80-89.9	2	80,495	----------	80,890	80,590	56.0	----------	38	74	2	15.1	----------	9.7	20.6
	90-99.9	1	94,650	----------	94,650	94,650	79.0	----------	79	79	1	8.7	----------	8.7	8.7
All capacity groups	20-29.9	23	26,804	2,385	23,100	29,755	34.4	6.0	25	50	22	27.6	6.4	13.8	32.2
	30-39.9	16	33,575	2,849	30,230	39,700	31.7	4.5	24	39	16	27.8	4.6	17.7	32.2
	40-49.9	6	42,112	----------	40,400	44,540	37.7	----------	33	42	6	22.0	----------	16.1	32.2
	50-59.9	16	56,039	2,953	50,900	59,350	37.7	7.8	25	50	16	20.9	4.7	13.8	28.0
	60-69.9	19	64,709	2,947	60,090	69,200	38.7	4.6	26	44	19	17.8	3.7	12.9	25.1
	70-79.9	17	73,073	3,018	70,300	79,680	45.4	10.9	32	68	17	15.2	4.2	9.7	22.5
	80-89.9	2	80,495	----------	80,400	80,590	56.0	----------	38	74	2	15.1	----------	9.7	20.6
	90-99.9	1	94,650	----------	94,650	94,650	79.0	----------	79	79	1	8.7	----------	8.7	8.7
Trucks with full trailers:															
3-2:															
Heavy	20-29.9	11	25,582	2,548	22,400	29,600	33.9	4.4	23	40	11	31.2	2.8	24.2	32.2
	30-39.9	2	36,800	----------	36,400	37,200	33.5	----------	33	34	2	29.0	----------	24.2	32.2
	40-49.9	2	45,000	----------	40,400	49,600	43.0	----------	36	50	2	16.3	----------	12.9	19.6
	50-59.9	0	----------	----------	----------	----------	----------	----------	----------	----------	0	----------	----------	----------	----------
	60-69.9	1	67,290	----------	67,290	67,290	57.0	----------	57	57	1	11.3	----------	11.3	11.3
	70-79.9	10	76,090	1,066	74,900	78,200	49.2	6.3	43	60	10	15.6	5.5	11.3	30.6
Truck-tractors with semitrailers and full trailers:															
2-S1-2:															
Heavy	20-29.9	7	26,313	----------	24,500	27,700	35.7	----------	32	----------	7	29.7	----------	22.5	32.2
	30-39.9	8	32,275	----------	30,200	36,600	34.5	----------	27	43	8	26.2	----------	20.9	32.2
	40-49.9	0	----------	----------	----------	----------	----------	----------	----------	----------	0	----------	----------	----------	----------
	50-59.9	1	51,200	----------	51,200	51,200	44.0	----------	44	44	1	17.7	----------	17.7	17.7
	60-69.9	3	62,900	----------	60,800	66,300	49.0	----------	44	52	3	17.0	----------	14.5	19.3
	70-79.9	27	76,284	1,971	70,300	79,000	52.7	10.8	40	75	27	14.9	2.9	9.3	20.9
	80-89.9	2	82,235	----------	81,700	82,770	47.5	----------	45	50	2	14.0	----------	11.9	16.1
Trucks with full trailers and truck-tractors with semitrailers and full trailers:															
Heavy	20-29.9	19	25,784	2,054	22,400	29,600	34.6	4.2	23	48	19	30.2	3.6	22.5	32.2
	30-39.9	14	34,232	2,954	30,200	39,030	34.6	4.6	27	40	14	27.3	3.1	20.9	32.2
	40-49.9	2	45,000	----------	40,400	49,600	43.0	----------	36	50	2	16.3	----------	12.9	19.6
	50-59.9	2	51,700	----------	51,200	52,200	37.5	----------	31	44	2	17.5	----------	17.4	17.7
	60-69.9	5	63,454	----------	60,800	67,290	50.4	----------	44	57	5	15.0	----------	11.3	19.3
	70-79.9	38	76,173	1,774	70,300	79,000	51.7	9.7	40	75	38	15.2	3.6	10.3	30.6
	80-89.9	2	82,235	----------	81,700	82,770	47.5	----------	45	50	2	14.0	----------	11.9	16.1
	90-99.9	3	95,153	----------	94,150	96,260	56.0	----------	49	64	3	15.4	----------	10.6	17.7
	100-109.9	1	108,120	----------	108,120	108,120	38.0	----------	38	38	1	20.3	----------	20.3	20.3
	110-119.9	1	113,460	----------	113,460	113,460	38.0	----------	38	38	1	20.9	----------	20.9	20.9
	120-129.9	0	----------	----------	----------	----------	----------	----------	----------	----------	0	----------	----------	----------	----------
	130-139.9	2	132,535	----------	132,500	132,570	58.5	14.8	48	69	2	13.8	----------	11.6	16.1

correlation for the 2–S2 and 3–S2 trailer combinations of 0.41 and 0.60, respectively, indicates that the regression curves did not fit the data as well as might be hoped for. A large amount of scatter about the regression line, caused by a large variation in the brake system application and braking distance, was responsible for the small coefficients. The coefficients of determination indicate that 17 and 36 percent of the total variation in brake system application and braking distance for the 2–S2 and 3–S2 trailer combinations, respectively, can be attributed to the tandem axle weights and the remaining or unexplained variation must be attributed to other factors. Such factors include inadequate brake system maintenance and/or poor brake adjustment. The linear regression curve for the 3–S2 trailer combinations tested in 1955 is also shown in figure 15. This curve indicates that the braking performance in relation to tandem axle loadings was poorer in the 1955 study than in the 1963 study. A larger percentage of the variation in brake system application and braking distance in the 1955 study could be explained by tandem-axle weight.

Before the braking performance in relation to the manufacturers gross vehicle or combination weight rating could be evaluated, the manufacturers weight rating for the test vehicle had to be determined. The manufacturers gross vehicle weight ratings were used to evaluate the braking performance of single-unit trucks and the manufacturers gross combination weight ratings were used to evaluate braking performance of trailer combinations. Usually the weight rating appears on the manufacturers identification

Table 7.—Average weight and brake system application and braking distance for commercial vehicles tested in 1955 and 1963

Commercial vehicles	1955			1963		
	Vehicles	Average weight	Average BSABD from 20 m.p.h.	Vehicles	Average weight	Average BSABD from 20 m.p.h.
	Number	Pounds	Feet	Number	Pounds	Feet
Single-unit trucks:						
2-axle, very light	107	5,200	24	119	4,740	22
2-axle, other than very light	293	14,200	31	296	13,100	28
3-axle	73	28,400	39	43	23,500	34
Truck-tractors with semitrailers:						
2–S1	129	32,100	40	103	24,500	33
2–S2	153	40,400	42	199	39,000	36
2–S3	--------	--------	--------	2	32,600	42
3–S2	66	53,700	46	100	50,300	38
Trucks with full trailers:						
2–2	16	45,900	51	2	42,800	42
3–2	46	63,900	54	26	49,000	41
Truck-tractors with semitrailers and full trailers:						
2–S1–2	44	59,700	56	49	59,800	47
2–S2–2	7	62,200	54	5	75,400	50
2–S2–3	2	52,000	41	4	88,800	41
3–S1–2	1	78,600	43	1	52,200	31
3–S2–2	--------	--------	--------	2	37,000	37
3–S3–5	--------	--------	--------	2	132,500	58

Table 8.—Braking test results for 1955 and 1963 compared with *Uniform Vehicle Code* requirements

Commercial vehicles	Deceleration			BSABD		
	UVC requirements	Vehicles within requirements		UVC requirements	Vehicles within requirements	
		1955	1963		1955	1963
Single-unit trucks:	*Ft./sec./sec.*	*Percent*	*Percent*	*Feet*	*Percent*	*Percent*
2-axle, very light	14	100	100	30	84	97
2-axle, other than very light	14	94	98	40	84	95
3-axle	14	85	91	40	53	75
Truck-tractors with semitrailers:						
2-S1	14	83	97	50	81	97
2-S2	14	82	91	50	80	94
3-S2	14	76	89	50	64	92
Trucks with full trailers	14	51	80	50	38	86
Truck-tractors with semitrailers and full trailers	14	69	79	50	41	71

Table 9.—Mean, standard deviation, and minimum ratios of GVW to manufacturers weight rating

Commercial vehicles (all capacity groups)	Gross vehicle weight, 1,000 lbs.	Number	Ratio, gross vehicle weight / manufacturers weight rating			
			Mean	Standard deviation	Minimum	Maximum
Single-unit trucks:						
2-axle	0–9.9	217	0.65	0.192	0.37	1.12
	10–19.9	161	0.71	0.196	0.37	1.26
	20–29.9	36	1.11	0.208	0.65	1.49
	30–39.9	1	1.05	--------	1.05	1.05
3-axle	10–19.9	20	0.52	0.146	0.36	0.92
	20–29.9	15	0.73	0.316	0.45	1.59
	30–39.9	3	1.19	--------	0.93	1.63
	40–49.9	4	1.15	--------	1.06	1.36
Truck-tractors with semitrailers:						
2-S1	10–19.9	35	0.40	0.067	0.31	0.56
	20–29.9	45	0.51	0.161	0.27	0.81
	30–39.9	16	0.71	0.128	0.48	1.00
	40–49.9	6	0.80	--------	0.63	0.90
2-S2	10–19.9	7	0.43	--------	0.34	0.64
	20–29.9	62	0.47	0.130	0.30	0.97
	30–39.9	34	0.67	0.105	0.46	0.87
	40–49.9	35	0.81	0.200	0.53	1.45
	50.59.9	58	1.02	0.158	0.70	1.41
	60.69.9	2	1.25	--------	1.08	1.41
3-S2	20–29.9	22	0.42	0.055	0.31	0.54
	30–39.9	14	0.51	0.063	0.43	0.61
	40–49.9	4	0.68	--------	0.58	0.84
	50–59.9	11	0.81	0.084	0.69	0.93
	60–69.9	17	0.94	0.114	0.80	1.15
	70–79.9	13	1.09	0.164	0.90	1.45
	80–89.9	1	1.24	--------	1.24	1.24

Table 10.—Braking performance of trailer combinations with and without brakes on the steering axle

Commercial vehicles	Brakes on steering axle				No brakes on steering axle			
	Vehicles tested	Average weight	Average decelera-tion	Average BSABD	Vehicles tested	Average weight	Average decelera-tion	Average BSABD
Truck-tractors with semi-trailers:	*No.*	*Lbs.*	*Ft./sec./sec.*	*Ft.*	*No.*	*Lbs.*	*Ft./sec./sec.*	*Ft.*
3-S2	60	49,800	23	37	40	51,000	21	40
Truck-tractors with semi-trailers and full trailers:								
2-S1-2	28	56,400	18	46	21	64,400	19	48
3-S2-2	1	39,000	32	35	1	35,000	27	39

plate attached to the vehicle; however, often the manufacturers specifications had to be consulted. When the weight rating had been determined, a ratio was computed between the gross vehicle weight and the manufacturers weight rating for test vehicles. Sometimes the ratio could not be computed because the manufacturers weight rating could not be found on the vehicle or determined from the vehicle specifications; data for these vehicles were not used in the analysis.

The analysis of braking performance ratio by GVW and manufacturers weight rating was made for the 2- and 3-axle, single-unit trucks and for the 2-S1, 2-S2, and 3-S2 truck-tractor-semitrailer combinations. Because the manufacturers gross combination weight rating for many of the multicombination vehicles could not be determined, data for these vehicles were not included in the analysis. Results of the analysis of braking performance in relation to the ratio

Table 11.—Braking performance with al axles braked and without steering axle braked, in test by Committee on Winte Driving Hazards

Commercial vehicles	Weight	BSABD from 20 m.p.h.	
		All axles braked	Steering axles not braked
	Pounds	*Feet*	*Feet*
3-S2	24,830	24	30
3-2	22,300	21	25
2-S1-2	22,090	26	31

of gross weight and manufacturers weigh ratings are shown in table 9 by vehicle typ and weight group.

The effect of an increase in the gross weigh to the manufacturers weight rating on brakin performance is shown in figure 16. As th ratio of the gross vehicle weight to mar ufacturers weight rating increased, the brak system application and braking distanc also increased but the peak deceleratio decreased. Mean values for ratio, decelera tion, and distance are plotted in figure 1 at the mean weight for the different tes weight groups. All trailer combination except the 2-S1, had gross vehicle weight of more than the recommended manufacturer rating; this is indicated by a ratio of mor than 1. With one exception, when the rati was less than 1, the vehicles met the *Unifor Vehicle Code* (*5*) recommendations for brakir performance: the 3-axle, single-unit truck required approximately 2 feet more than th recommended distance of 40 feet from speed of 20 m.p.h. In an evaluation of th braking performance of the types of comme cial vehicles tested in this research, the fac must be recognized that braking systen can be designed to meet given performan requirements provided that the gross vehic weight does not exceed the manufacture suggested weight rating and that the brakin systems are properly maintained.

No Brakes on Steering Axle

Some States and the Interstate Commer Commission permit, in their motor-vehic regulations, certain vehicles to operate wit out any brakes on the steering axle. In t 1963 braking performance test, combinati vehicles were tested that did not have fro wheel brakes; these are listed in table 1 Except for the 3-S2 trailer combinations large difference existed in the mean gro weights between the trailer combinatio that did and those that did not have brak on the steering axle. Consequently, t longer distance required for stopping by t combinations without front wheel brak cannot be attributed entirely to the fact th one axle was not braked—the poorer pe formance also could have been attribut partially to the weight differential. T additional distance was approximately 2 to feet.

In 1958 the National Safety Counci Committee on Winter Driving Hazards co ducted tests on dry pavement for emp combination vehicles, both with and witho ie steering axles braked (6). The findings terms of the brake system application id braking distance when making emergency-pe stops from 20 m.p.h. for both braking onditions are shown in table 11. The brake stem application and braking distance creased 4 to 6 feet, when the steering axle as not braked.

Confidence Intervals

The commercial vehicles tested were rouped according to type, capacity, brake stem, and weight. Similar commercial ehicles were classified into groups, and then onsidered as samples from the group populaons. The standard errors of the means ere computed for the groups that had at ast 10 observations. Confidence intervals ien were computed for each commercial ehicle group having 10 or more observations. y using the confidence interval, the levels of raking performance for each individual roup could be estimated and the degree of liability of estimates known. For each roup, the 95 percent confidence intervals for he means of the gross weight, deceleration, nd brake system application and braking istance were determined; their confidence itervals were computed in the same manner s those for the passenger cars. The confience intervals by type of brake systems and y weight group are shown in table 12.

Findings of Analyses

'assenger cars

The following findings concerning passenger ars were obtained from analyses of the 1963 est data.

- The average weights of foreign cars, ompact cars, and standard size cars differed ignificantly from each other at the 0.05 level.
- Little change has occurred since 1955 in he deceleration performance of all passenger ars, when considered as a group. Comparion of decelerations of the foreign cars with he compact cars, however, showed that the ompact cars had significantly larger average lecelerations in the 1963 tests at the 0.05 evel.
- Some decrease since 1955 in the brake ystem application and braking distance was shown in the 1963 test results, particularly ibove the 50th percentile level. In the comparison of the average brake system applicaion and braking distances for the different passenger car classifications studied in 1963, mly results of the compact car comparison with the standard size car differed signifiantly at the 0.05 level.
- The variability in the brake system application and braking distances has continued to decrease since 1955.
- The mean brake system application and braking distances for the different test years were significantly different at the 0.01 level.
- According to 1963 test results, 95 percent of the time the mean brake system application and braking distances for the passenger car classifications can be expected to be within the following distance intervals: foreign, 18.4 to 20.2 feet; compact, 18.7 to 19.3 feet; and standard size, 19.8 to 20.2 feet.

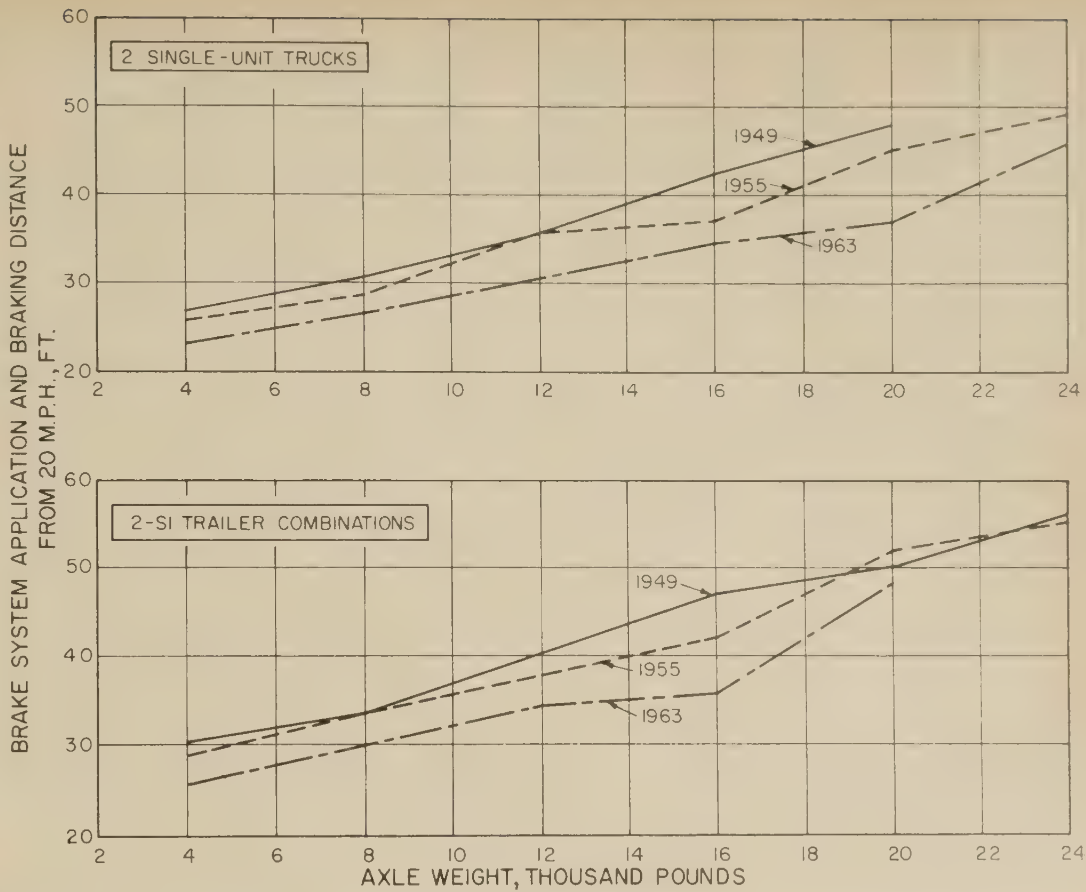

Figure 14.—Brake system application and braking distances by vehicle axle weights, by test years.

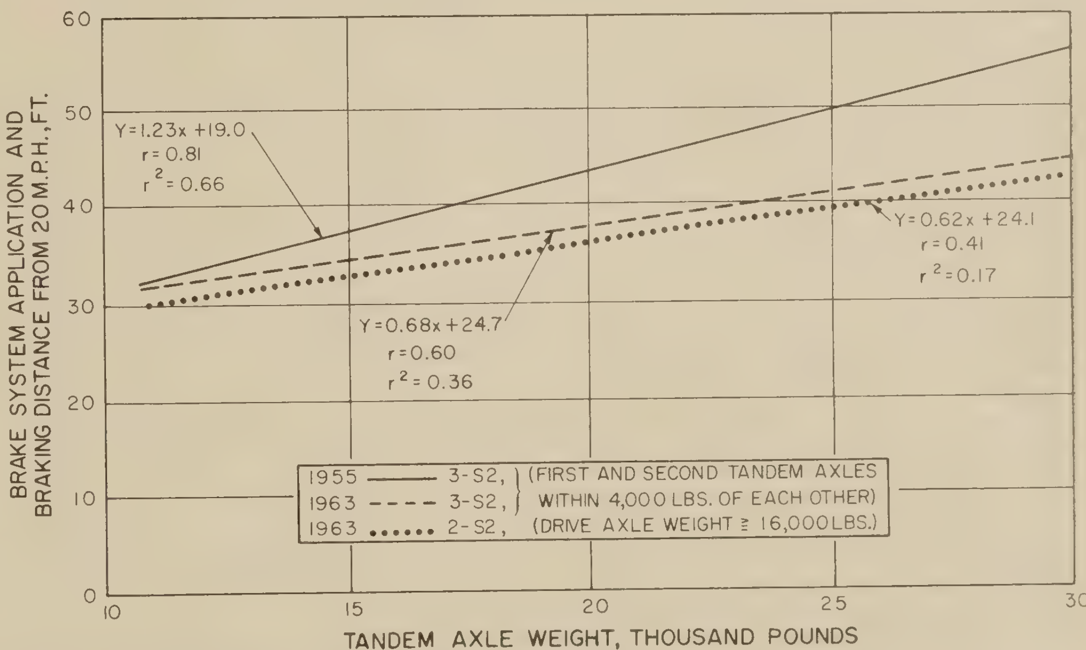

Figure 15.—Brake system application and braking distances by tandem axle weights for 2-S2 and 3-S2 vehicles.

Commercial vehicles

The following findings were obtained from the analyses of the 1963 test results for commercial vehicles.

- The average brake system application and braking distance since 1955 has decreased 2 to 3 feet for the very light 2-axle trucks to 10 feet or more for some of the heavier trailer combinations. Since the 1955 tests all the commercial vehicles had improved deceleration performance from approximately 5 percent for very light 2-axle trucks to 15 percent for heavier multitrailer combinations.
- The variability in the brake system application and braking distance for similar types of vehicles continued to decrease.
- The brake system application and braking distance generally has decreased since 1955 regardless of the vehicle type, weight group, or manufacturers capacity group.
- In the 1963 tests, a larger percentage than in the 1955 tests of commercial vehicles could meet the brake system application and braking distance and deceleration requirements recommended in the *Uniform Vehicle Code*.

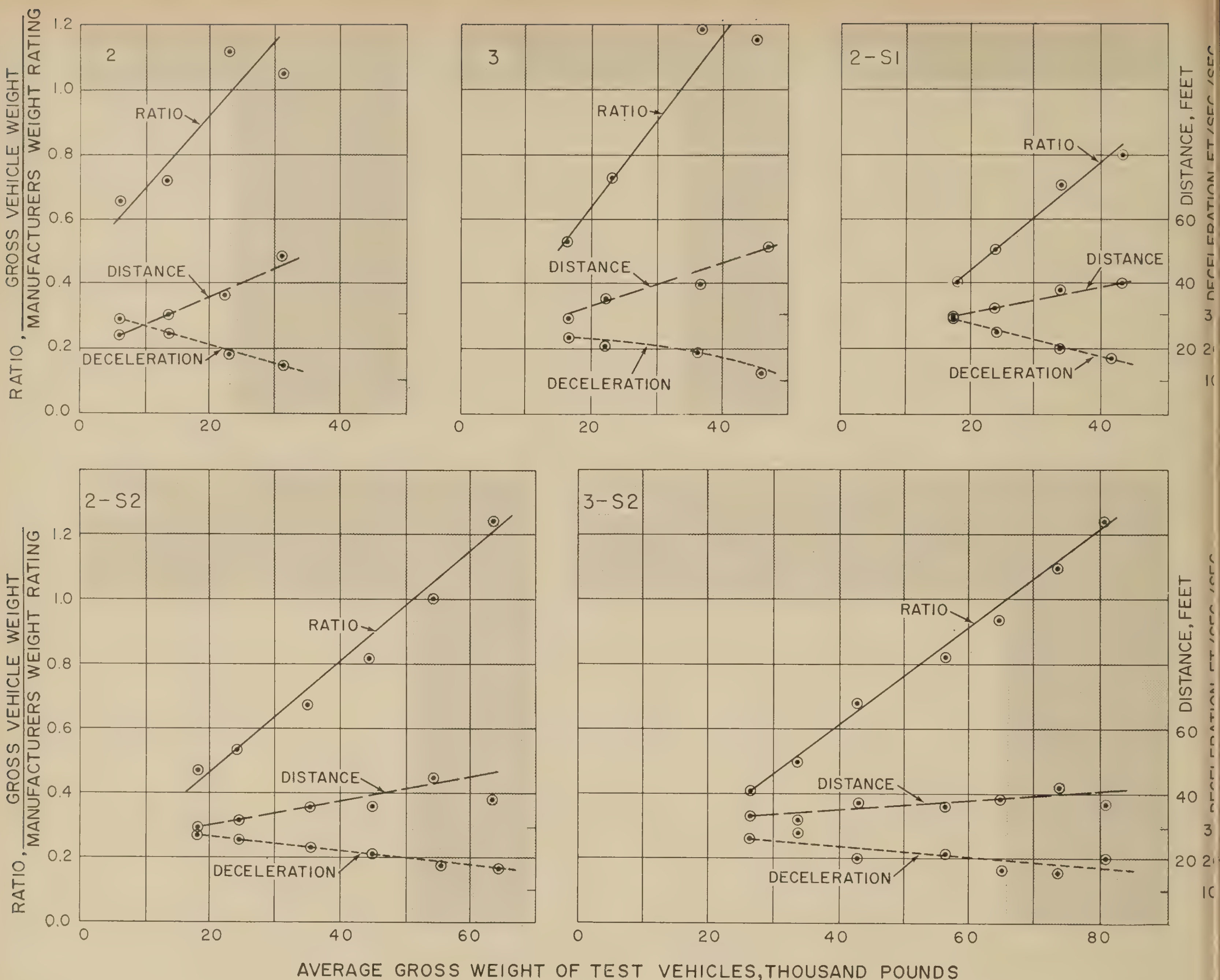

Figure 16.—Relation of GVW to manufacturers weight rating, distance, deceleration, and weight.

• Results of the axle load analysis showed that the brake system application and braking distances for similar axle loadings decreased approximately 3 feet from 1955 to 1963 for both 2-axle, single-unit trucks and 2–S1 trailer combinations.

• The relation between the distance required to stop and tandem axle weights of 2–S2 and 3–S2 trailer combinations could not be clearly defined in the analysis of test results. Only a small part of the total variation in the brake system application and braking distance could be explained by axle loading.

• When the ratio of gross vehicle weight to the manufacturers weight rating was less than 1, the vehicles met the *Uniform Vehicle Code* recommendations. However, the 3-axle, single-unit trucks required approximately 42 feet rather than the 40 feet to stop at 20 m.p.h.

• The 1963 test results and the National Safety Council Committee on Winter Driving Hazards studies showed that the brake system application and braking distance is several feet longer when the steering axle is not braked than when it is.

• According to the 1963 test results, the mean brake system application and braking distance for all commercial vehicles of a given type can be expected 95 percent of the time to be within the following distance intervals: 2-axle, single-unit trucks, 26 to 27 feet; 3-axle, single-unit trucks, 31 to 37 feet; 2–S1, 31 to 34 feet; 2–S2, 35 to 37 feet; 3–S2, 36 to 40 feet; 3–2, 38 to 45 feet; and 2–S1–2, 43 to 50 feet.

REFERENCES

(*1*) *Mathematics Dictionary*, edited by Glenn James and Robert C. James, The Digest Press, Van Nuys, Calif., 1943.

(*2*) *A Comprehensive Dictionary of Psychological and Psychoanalytical Terms*, edited by Horace B. English and Ava Champney English, David McKay Company, Inc., Ne York, N.Y., 1964.

(*3*) *A Discussion of Gasoline Tax Rates a Gasoline Consumption*, by Edwin M. Cope a Lawrence L. Liston, Highway Research Boa Proceedings, vol. 40, Jan. 1961, pp. 51–70.

(*4*) *Stopping Ability of Motor Vehic Selected From the General Traffic*, by William Petring, PUBLIC ROADS, A JOURN OF HIGHWAY RESEARCH, vol. 29, No. 8, Ju 1957, pp. 177–195.

(*5*) *Uniform Vehicle Code*, by Natio Committee on Uniform Traffic Laws a Ordinances, Washington, D.C., Revised 19

(*6*) *Methods of Statistical Analysis in E nomics and Business*, 2d ed., by Edward Lewis, Houghton Mifflin Company, Bost Mass., 1963.

(*7*) *The 1958 Winter Test Report*, by Co mittee on Winter Driving Hazards, Natio Safety Council, May 1962.

Table 12.—Confidence interval for commercial vehicles according to brake system and gross vehicle weight groups

By brake system

Commercial vehicles and capacity groups	Brake systems [1]	Standard error of mean: Gross weight	Standard error of mean: Deceleration [2]	Standard error of mean: BSABD	95 percent confidence intervals: Gross weight From	Gross weight To	Deceleration From	Deceleration To	BSABD From	BSABD To
	Types	*Pounds*	*Ft./sec./sec.*	*Feet*	*Pounds*	*Pounds*	*Ft./sec./sec.*	*Ft./sec./sec.*	*Feet*	*Feet*
Single-unit trucks:										
2-axle:										
Very light	H	103.1	0.35	0.34	4,480	4,890	26.9	28.3	20.9	22.3
	All	115.4	0.35	0.33	4,540	4,990	27.0	28.4	21.0	22.2
Light	H	1,113.4	1.38	1.95	7,940	12,310	19.2	24.6	25.6	33.2
	VBH	558.3	0.72	0.73	9,570	11,760	25.1	27.9	25.0	27.8
	All	497.4	0.67	0.70	9,600	11,550	24.4	27.0	25.6	28.4
Medium	VBH	367.7	0.38	0.42	12,910	14,360	24.8	26.2	26.6	28.2
	AM	2,019.6	2.38	5.32	13,590	21,500	14.1	23.5	27.4	48.2
	All	354.0	0.38	0.50	13,070	14,460	24.4	25.8	27.1	29.1
Heavy	VBH	1,594.0	1.42	1.74	12,650	18,900	24.8	30.4	27.0	33.8
	AM	1,312.3	0.91	1.35	15,360	20,500	20.2	23.8	29.1	34.3
	All	1,014.6	0.96	1.06	15,070	19,040	22.4	26.2	29.1	33.3
All capacity groups	H	237.2	0.37	0.42	5,110	6,040	26.2	27.6	21.9	23.5
	VBH	313.2	0.33	0.36	12,280	13,510	25.3	26.5	26.5	27.9
	AM	1,095.9	1.11	2.27	15,640	19,930	18.5	22.9	29.6	38.4
	All	285.6	0.25	0.33	10,240	11,360	25.4	26.4	25.6	26.8
3-axle:										
Heavy	AM	1,996.4	0.83	1.72	21,650	29,480	18.2	21.4	32.5	39.3
	All	1,818.2	0.88	1.61	20,600	27,730	19.1	22.5	31.3	37.7
All capacity groups	VBH	1,488.0	1.18	0.78	13,690	19,520	23.5	28.1	25.5	28.5
	AM	1,918.8	0.84	1.82	21,870	29,400	18.1	21.3	32.9	40.1
	All	1,613.7	0.80	1.53	20,370	26,700	19.5	22.7	31.3	37.3
Truck-tractors with semitrailers:										
2-S1:										
Medium	VBH-VM	1,769.6	1.34	1.93	19,130	26,070	21.7	26.9	30.2	37.8
	AM-AM	1,377.7	1.35	1.33	20,120	25,520	24.2	29.4	28.5	33.7
	All	1,032.3	0.88	1.07	20,630	24,680	23.7	27.1	30.1	34.3
Heavy	AM-AM	1,043.6	0.85	0.94	23,700	27,790	21.9	25.3	31.4	35.0
	All	1,012.9	0.80	0.87	23,890	27,860	21.9	25.1	31.5	34.9
All capacity groups	VBH-VM	1,990.6	1.28	1.76	21,020	28,820	20.8	25.8	31.5	38.3
	AM-AM	852.0	0.73	0.77	23,240	26,580	23.0	25.8	31.1	34.1
	All	744.2	0.60	0.67	23,070	25,990	23.1	25.5	31.5	34.1
2-S2:										
Medium	AM-AM	4,435.3	1.65	1.92	29,720	47,100	19.0	25.4	30.4	38.0
	All	3,805.2	1.43	1.77	29,720	44,630	18.9	24.5	31.3	38.3
Heavy	AM-AM	975.1	0.45	0.57	37,560	41,380	20.5	22.3	35.0	37.2
	All	973.1	0.45	0.57	37,380	41,190	20.6	22.4	34.9	37.1
All capacity groups	AM-AM	956.1	0.44	0.55	37,520	41,270	20.6	22.4	34.9	37.1
	All	947.7	0.43	0.55	37,230	40,950	20.7	22.3	34.8	37.0
3-S2:										
Heavy	AM-AM	1,895.9	0.70	0.94	46,630	54,060	20.3	23.1	36.1	39.7
	All	1,895.3	0.71	0.93	46,360	53,790	20.4	23.2	36.1	39.7
All capacity groups	AM-AM	1,889.9	0.71	0.97	46,860	54,270	20.2	23.0	36.5	40.1
	All	1,889.6	0.71	0.97	46,600	54,010	20.3	23.1	36.3	40.1
Trucks with full trailers:										
3-2:										
Heavy	AM-AM	4,66[illegible].3	1.75	1.86	39,820	58,110	19.7	26.5	37.7	44.9
Truck-tractors with semitrailers and full trailers:										
2-S1-2:										
Heavy	AM-AM-AM.	3,156.0	0.98	1.69	54,360	66,740	17.2	21.0	43.2	49.8
All capacity groups.	All	3,173.0	0.96	1.66	53,620	66,060	17.2	21.0	43.2	49.8
All other than 2-S1-2:										
Heavy	AM-AM-AM.	10,236.0	1.81	3.40	60,380	100,500	16.8	23.8	38.1	51.5
All capacity groups.	AM-AM-AM.	9,494.9	1.76	3.21	61,620	98,840	16.4	23.2	39.1	51.7
Trucks with full trailers and truck-tractors with semitrailers and full trailers:										
Heavy										

By gross vehicle weight groups

Commercial vehicles and capacity groups	Gross vehicle weight groups	Standard error of mean: Gross weight	Standard error of mean: Deceleration [2]	Standard error of mean: BSABD	95 percent confidence intervals: Gross weight From	Gross weight To	Deceleration [2] From	Deceleration [2] To	BSABD From	BSABD To
	1,000 lbs.	*Pounds*	*Ft./sec./sec.*	*Feet*	*Pounds*	*Pounds*	*Ft./sec./sec.*	*Ft./sec./sec.*	*Feet*	*Feet*
Single-unit trucks:										
2-axle:										
Very light	0–4.9	54.0	0.45	0.45	3,950	4,160	27.0	28.8	20.4	22.2
	5–9.9	146.5	0.54	0.48	5,630	6,200	26.2	28.4	21.5	23.3
Light	0–9.9	168.6	0.71	0.54	7,620	8,280	26.0	28.8	23.4	25.6
	10–19.9	621.4	1.21	1.22	12,820	15,250	21.3	26.1	27.8	32.6
Medium	0–9.9	97.9	0.58	0.64	8,540	8,920	26.9	29.1	23.3	25.8
	10–19.9	265.7	0.45	0.59	13,260	14,300	24.4	26.2	26.9	29.3
	20–29.9	441.7	0.92	1.50	21,970	23,700	17.4	21.0	32.4	38.2
Heavy	10–19.9	535.6	0.98	0.85	13,720	15,820	23.2	27.0	28.0	31.4
All capacity groups	0–9.9	143.2	0.28	0.28	6,090	6,650	27.2	28.3	22.4	23.5
	10–19.9	223.2	0.39	0.48	13,490	14,370	24.3	25.9	27.6	29.4
	20–29.9	407.0	0.84	1.25	22,130	23,720	17.8	21.1	33.3	38.2
3-axle:										
Heavy	10–19.9	543.3	1.10	1.08	15,320	17,450	21.4	25.8	26.3	30.5
	20–29.9	565.7	1.16	1.14	21,760	23,970	17.8	22.4	34.0	38.4
All capacity groups	10–19.9	550.6	0.92	0.89	14,900	17,060	22.0	25.6	26.7	30.1
	20–29.9	517.3	1.09	1.19	22,060	24,080	18.6	22.8	32.9	37.5
Truck-tractors with semitrailers:										
2-S1:										
Medium	10–19.9	398.3	0.90	1.48	16,440	18,000	27.0	30.6	26.8	32.6
	20–29.9	908.3	1.36	1.03	22,970	26,530	20.2	25.6	30.6	34.6
Heavy	10–19.9	447.9	1.47	1.74	17,100	18,860	24.1	29.9	26.5	33.3
	20–29.9	533.8	1.00	1.17	22,580	24,670	23.1	27.1	29.7	34.3
	30–39.9	738.6	1.23	1.42	32,320	35,210	16.0	20.8	35.0	40.6
All capacity groups	10–19.9	300.8	0.79	1.11	16,930	18,110	26.6	29.7	27.6	32.0
	20–29.9	467.8	0.82	0.85	23,090	24,920	22.7	25.9	30.5	33.9
	30–39.9	522.1	0.98	1.53	33,030	35,080	17.0	20.8	35.4	41.4
2-S2:										
Medium										
Heavy	20–29.9	353.0	0.72	0.86	23,510	24,890	24.5	27.3	30.2	33.6
	30–39.9	525.4	0.72	0.92	34,620	36,680	20.7	23.5	32.6	36.2
	40–49.9	443.3	0.90	0.80	43,780	45,520	19.6	23.2	33.7	36.9
	50–59.9	326.8	0.57	1.10	54,250	55,530	15.4	17.6	39.9	44.3
All capacity groups	20–29.9	333.7	0.69	0.83	23,600	24,910	24.6	27.3	30.3	33.5
	30–39.9	495.1	0.69	0.88	34,680	36,620	20.7	23.4	32.8	36.2
	40–49.9	445.4	0.86	0.81	43,930	45,680	19.4	22.8	34.0	37.2
	50–59.9	310.8	0.54	1.04	54,330	55,550	15.3	17.5	40.1	44.1
3-S2:										
Heavy	20–29.9	496.9	1.36	1.25	25,830	27,780	24.9	30.3	32.0	36.9
	30–39.9	712.3	1.15	1.13	32,180	34,970	25.6	30.1	29.5	33.9
	50–59.9	738.3	1.18	1.95	54,590	57,490	18.6	23.2	33.9	41.5
	60–69.9	675.9	0.85	1.06	63,380	66,030	16.1	19.5	36.6	40.8
	70–79.9	778.3	1.00	2.38	71,580	74,630	13.5	17.5	39.2	48.6
All capacity groups	20–29.9	496.9	1.36	1.25	25,830	27,780	24.9	30.3	32.0	36.9
	30–39.9	712.3	1.15	1.13	32,180	34,970	25.6	30.1	29.5	33.9
	50–59.9	738.3	1.18	1.95	54,590	57,490	18.6	23.2	33.9	41.5
	60–69.9	675.9	0.85	1.06	63,380	66,030	16.1	19.5	36.6	40.8
	70–79.9	732.5	1.02	2.65	71,640	74,510	13.2	17.2	40.2	50.6
Trucks with full trailers:										
3-2:										
Heavy	20–29.9	767.5	0.84	1.33	24,080	27,090	29.6	32.9	31.3	36.5
	70–79.9	337.3	1.74	1.99	75,430	76,750	12.2	19.0	45.3	53.1
Truck-tractors with semitrailers and full trailers:										
2-S1-2:										
Heavy	70–79.9	379.0	0.56	2.08	75,540	77,030	13.8	16.0	48.6	56.8
All capacity groups.										
All other than 2-S1-2:										
Heavy										
All capacity groups.										
Trucks with full trailers and truck-tractors with semitrailers and full trailers:										
Heavy	20–29.9	471.1	0.83	0.96	24,860	26,710	28.6	31.8	32.7	36.5
	30–39.9	789.8	1.04	1.23	32,680	35,780	25.3	29.3	32.2	37.0
	70–79.9	288.0	0.58	1.57	75,610	76,740	14.1	16.3	48.6	54.8

[1] All refers to total number of vehicles tested in each category, as identified in table 5. [2] Measured by pendulum-type decelerometer.

Relations of Gross Weights and Horsepowers of Commercial Vehicle

BY THE OFFICE OF
RESEARCH AND DEVELOPMENT
BUREAU OF PUBLIC ROADS

Reported by [1] JOHN M. WRIGHT and SAMUEL C. TIGNO
Highway Research Enginee
Traffic Systems Divisi

Results of a study on the relation between gross weight and net engine horsepower of commercial vehicles are presented in this article. Data from the braking performance study were used to update current information on weight-power ratios of trucks and to investigate the trend in these ratios since 1949. A total of 1,026 commercial vehicles, in a large variety of types, weights, and horsepowers were sampled in three States from routes having a heavy concentration of commercial vehicles.

Data from the study were used to determine the effect of weight-power ratio requirements on the trucking industry and to determine the percentage of vehicles affected by a minimum performance requirement. The data collected in the study indicate that the dissimilarity in performance of passenger cars and commercial vehicles is lessening. There is a trend toward decreasing weight-power ratios and a performance requirement of 400 pounds per horsepower would affect only a small percentage of the commercial vehicles. However, a substantial reduction in the weight-power ratio is still necessary to put passenger and commercial vehicles on similar performance levels.

Introduction

THE BUREAU of Public Roads periodic braking performance study made in 1963 also provided information for determining the ratios of commercial vehicle gross weight to net engine horsepower. An engine net horsepower rating for each truck or trailer combination tested was also recorded. Field observations were made in Maryland, Michigan, and California on routes having a heavy concentration of commercial vehicles. A total sample of 1,026 commercial vehicles in a large variety of types, weights, and horsepowers was investigated.

A study of weight-power ratios published in 1957(*1*)[2] included data collected in 1949, 1950, and 1955. The 1950 data, collected in conjunction with the annual truck weight survey, contained information on 10,726 trucks in 39 States. The 1949 and 1955 data, were obtained from brake tests on 782 and 862 commercial vehicles, respectively, in the same States as the 1963 brake study. The 1963 brake test data have been used to update the weight-power ratio information published in 1957 and to indicate the trend in the ratios.

It is believed that a performance requirement of 400 pounds per horsepower for commercial vehicle operation would improve the weight-power ratios, but a substantial reduction in this ratio will be required before the two types of vehicles attain similar performance levels. For example, large horsepowers are required for trucks to maintain a high speed on grades. A trailer combination having a gross weight of 100,000 pounds and powered by a 250-net-horsepower engine can maintain a speed of 50 m.p.h. on the level, but up a 3-percent grade only 20 m.p.h. To maintain the 50 m.p.h. speed up the 3-percent grade, this vehicle would require an engine capable of producing a net horsepower of 700.

Although production of highway commercial vehicles equipped with 700-horsepower engines may be remote, the trend is toward larger engines and smaller weight-horsepower ratios. Furthermore, the authors believe industry is capable of producing engines larger than those now in use. In addition, information has been developed to show that an increase in the average road speeds is economically justifiable for owners who can use their equipment advantageously during the time saved (HRB Bulletin 301, *Line-Haul Trucking Costs in Relation to Vehicle Gross Weights*).

Conclusions

On the basis of information gathered in the study reported here, the authors conclude that commercial vehicles having larger horsepower engines soon may be operating on the highways. Use of these larger engines would n row the gap between the performance of p senger cars and commercial vehicles. Crite developed during earlier studies on vehi performance and still accepted in designi highways are: (1) operating characteristics commercial vehicles and passenger cars are r similar; (2) these two types of vehicles cann be designed any time soon to similar perfor ance standards without an injustice being do to one or both; (3) public interest requires th highways be adequately designed and co structed to serve both passenger vehicles a commercial vehicles; (4) by appropriate hig way design, the highways required for oper tion of both types of vehicles can be design so that these vehicles can operate without u due movement restrictions.

Analysis of the data collected during t study on the weight-horsepower ratios has pr vided information from which the autho concluded that the performance gap is bei narrowed. The weight-power ratios of co mercial vehicles decreased 12 percent fro 1949 to 1955 and 28 percent from 1955 to 196

Purpose of Study

The primary purpose of the study was update information on weight-power rati of commercial vehicles in order to analy traveltime, grade-climbing ability, and a celerating ability of trucks. Another purpo was to investigate the trend in weight-pow ratios, based on 1949 and 1955 brake tes and 1950 truck weight survey informatic Data from the 1963 study may also be us to determine the effect of minimum weigh power ratio requirements on the trucki industry. It can provide information the percentage of vehicles affected by minimum performance requirement. For e ample, a performance requirement of 4 pounds gross weight per net horsepower c be translated into grade-climbing ability b cause it is inversely proportional to the rat A weight-power ratio of 400 is approximate equal to 20 m.p.h. on a 3-percent grade.

Many believe that the result of a minimu performance requirement would be bett balance between the vehicle weight a the load for which its tires, brakes, a other components were designed. It doubtful that commercial vehicles cou

[1] Presented at the October 1964 meeting of National Transportation, Powerplant, and Fuels and Lubricants Meeting, of the Society of Automotive Engineers, Inc., Baltimore, Md.

[2] *Relation Between Gross Weights of Motor Trucks and Their Horsepower*, by Carl C. Saal. *Public Roads, A Journal of Highway Research*, vol. 29, No. 10, October 1957, pp.233–238.

ver be required to maintain the same speed n grades as passenger cars. Nevertheless minimum performance requirement may rovide the highway engineer with a level vehicle performance on which to base ighway design standards conducive to afer and more efficient movement of traffic.

Analysis Procedure

The first step in the analysis of the data ollected was to determine the net horse- ower of each truck in the sample. Whenever possible, this was obtained in the field om the vehicle manufacturers rating plate. he net horsepower for unrated vehicles as determined from the vehicle specifica- ons of individual manufacturers and the utomobile Manufacturers Association. hen only gross horsepower could be deter- ined, the net horsepower was assumed be 90 percent of that value. When two more horsepower options were available r a given model and it was not possible determine which was installed in the rticular vehicle, the net horsepower of e smaller engine was used for computing e ratio.

After computation of weight-power ratios, e ratios were grouped according to vehicle pe and gross weight. The average net rsepower, the average gross weight, and e average weight-power ratio for each vehicle pe were computed. The gross weights, t horsepowers, and weight-power ratios r each vehicle type were tabulated also. umulative frequency distributions of weight- ower ratios were made for each vehicle pe by grouping the weight-power ratios class intervals of 50 pounds gross weight r net horsepower. The 15th, 50th, and th percentiles of the frequency distributions r 1955 and 1963 were tabulated and mpared.

An analysis was made to determine the lation between the weight-power ratio d the gross weight of the vehicles regard- ss of vehicle type. The vehicles were ouped in intervals of 10,000 pounds gross ight and the average ratio was calculated r each interval group. These weight- wer ratios were plotted in relation to the oss weight and compared with similar rves derived from 1949 and 1955 data. A parate analysis was made for only loaded hicles in the 1963 braking study. Loaded hicles were those that carried any cargo payload. Of the 1,026 vehicles, 634 re loaded. The same procedure for anal- is of loaded vehicles was used as for the tal sample of empty and loaded vehicles.

Survey Results

A summary of the horsepowers, weights, d weight-power ratios for each vehicle pe is shown in figure 1 and table 1. Two ethods of listing the data were used in ure 1: average for all vehicles and average r loaded vehicles only. Gross weights, t horsepowers, and weight-power ratios creased as the number of axles increased

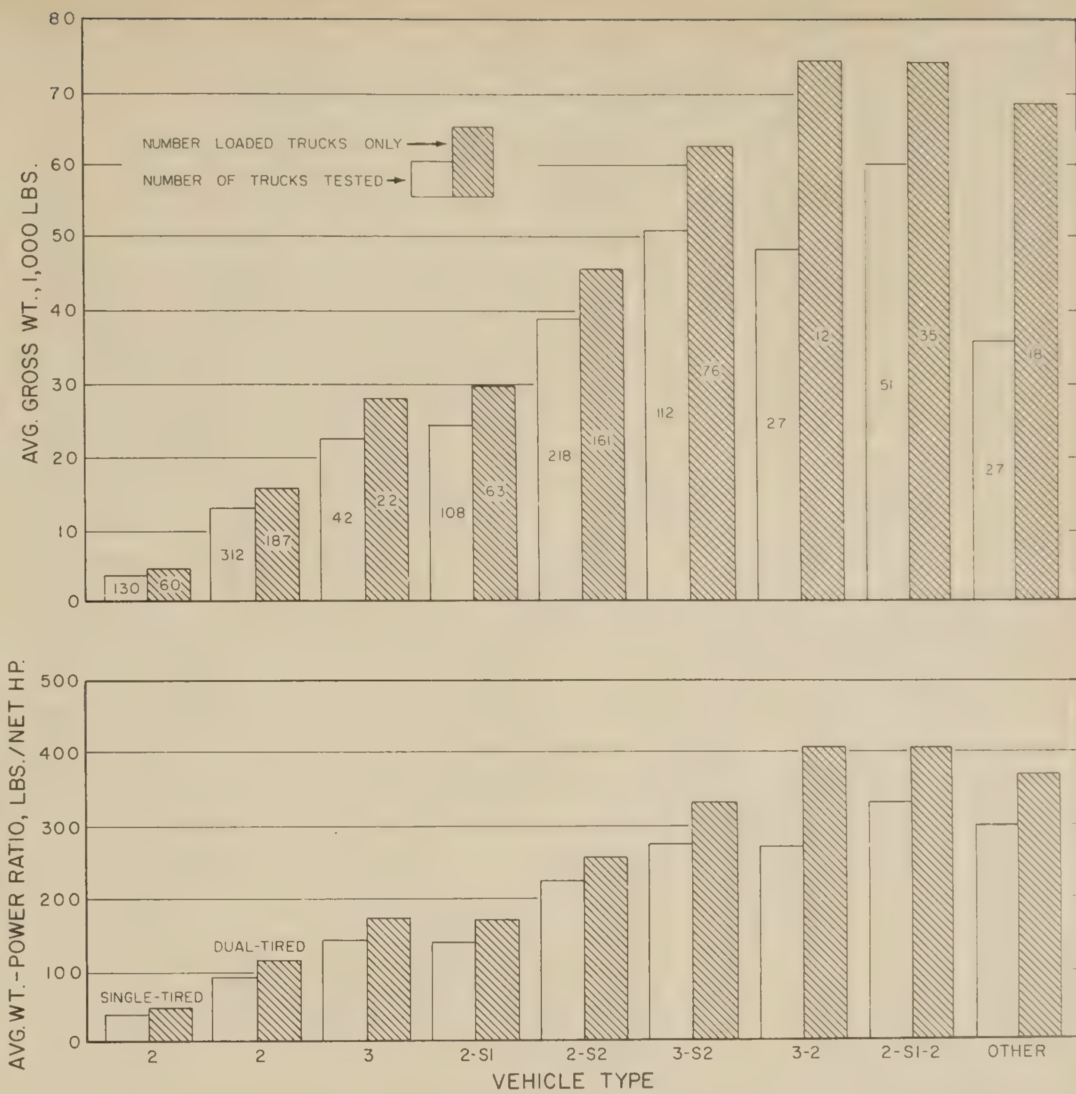

Figure 1.—Average weight-power ratios and gross weights for commercial vehicles, 1963 brake test.

Figure 2.—Cumulative frequency distributions of weight-power ratios for all commercial vehicles, 1955 brake test.

up to 5 axles, as shown in table 1. For vehicles having 5 or more axles, the measures remained fairly constant. Thus, a large variation in hill climbing and accelerating ability was indicated for the different vehicle types. The smaller weight-power ratios were generally computed for empty vehicles having large engines. For example, an empty 3–S2 trailer combination having a 310 net horsepower engine weighed 29,100 pounds and had the smallest weight-power ratio, 94, for any of the 3–S2 trailer combinations tested. The 310 net horsepower also was the largest horsepower for any vehicles tested in the 1963 braking performance study.

Data for the loaded vehicles only are shown in table 1. Although the average weight and the lowest limits of the weight range were larger for the loaded vehicles than for the total of all vehicles, net horsepower remained nearly constant for both loaded only and the total of all vehicles tested. Therefore, the average weight-power ratio and the lowest weight-power ratios were also larger for the loaded vehicle sample than for the total vehicle sample.

Larger weight-power ratios occurred when vehicles having small engines were heavily loaded. A 3–S2 trailer combination having a gross weight of 94,650 pounds and a net engine horsepower of 135 had a weight-power ratio of 701, the largest ratio for any vehicle in the 1963 brake study. This particular vehicle was operating under a special permit because it had tandem axle weights in excess of the legal limit for the State in which it was operating. However, it is possible to transport extremely heavy loads and remain within the legal weight limits of the State, as illustrated by a 3–S3–5 trailer combination having a gross weight of 132,570 pounds and a weight-power ratio of 567.

Cumulative frequency distributions for all vehicle types for 1955 and 1963 are shown in figures 2 and 3, respectively. The summary in table 2 of the cumulative frequency distributions at the 15th, 50th, and 85th percentiles shows a reduction in the ratios from the 1955 to the 1963 study for all vehicle types. The percentage change at the 50th percentile was 28 percent for 2-axle, single-tired trucks; 36 percent for 2-axle, dual-tired trucks; 45 percent for 3-axle trucks; 48 percent for 2–S1 trailer combinations; 27 percent for 2–S2 trailer combinations; and 31 percent for all other trailer combinations. The average reduction in ratios for all vehicle types was approximately 30 percent at the 15th and 50th percentiles and 25 percent at the 85th percentile.

Cumulative frequency distributions of weight-power ratios for trailer combinations 3–S2 and 2–S1–2 from the 1963 study are shown in figure 4. These curves show data separated from that shown by the curve labeled OTHER in figure 2. The sample size for the 1955 study was not large enough for such a breakdown. The irregularity in the curve for the 2–S1–2 trailer combinations (fig. 4) occurred because nearly all of these trailer combinations either were traveling empty or heavily loaded. The sample vehicles in the middle-weight range was small; only 5 of 51 had gross weights within the range of 35,000 to 70,000 pounds.

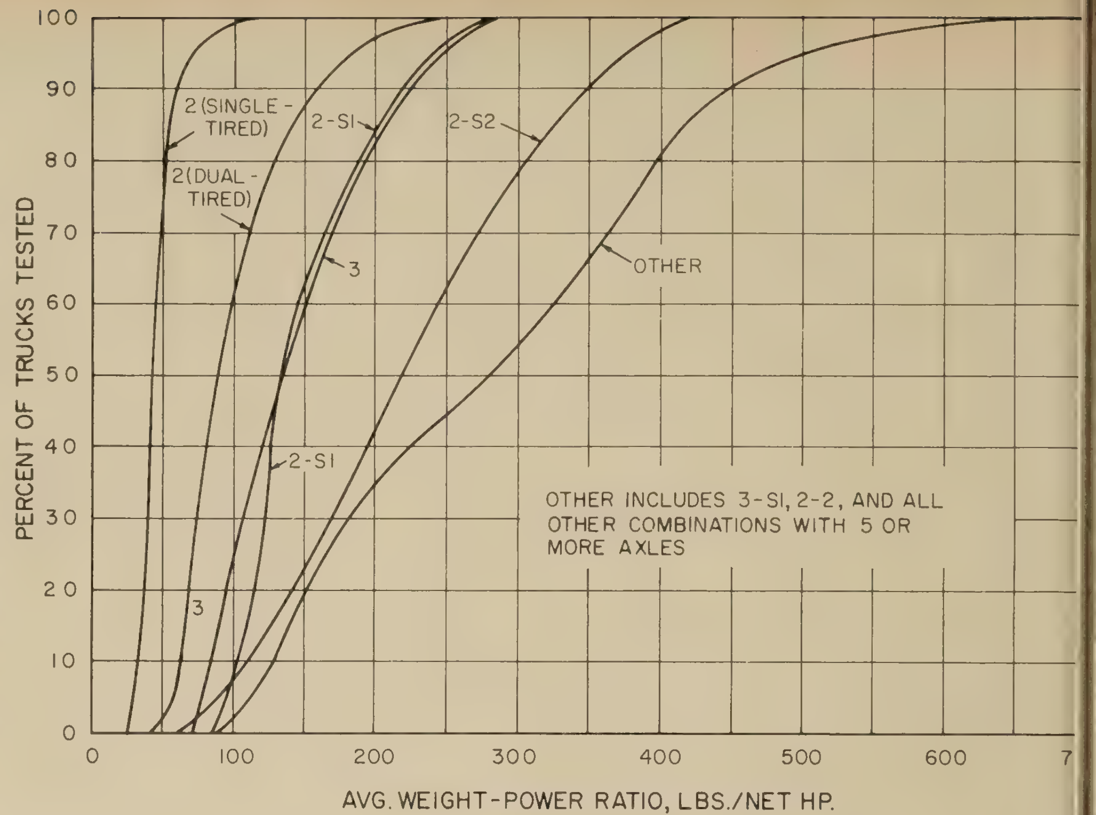

Figure 3.—Cumulative frequency distributions of weight-power ratios for all commercial vehicles, 1963 brake test.

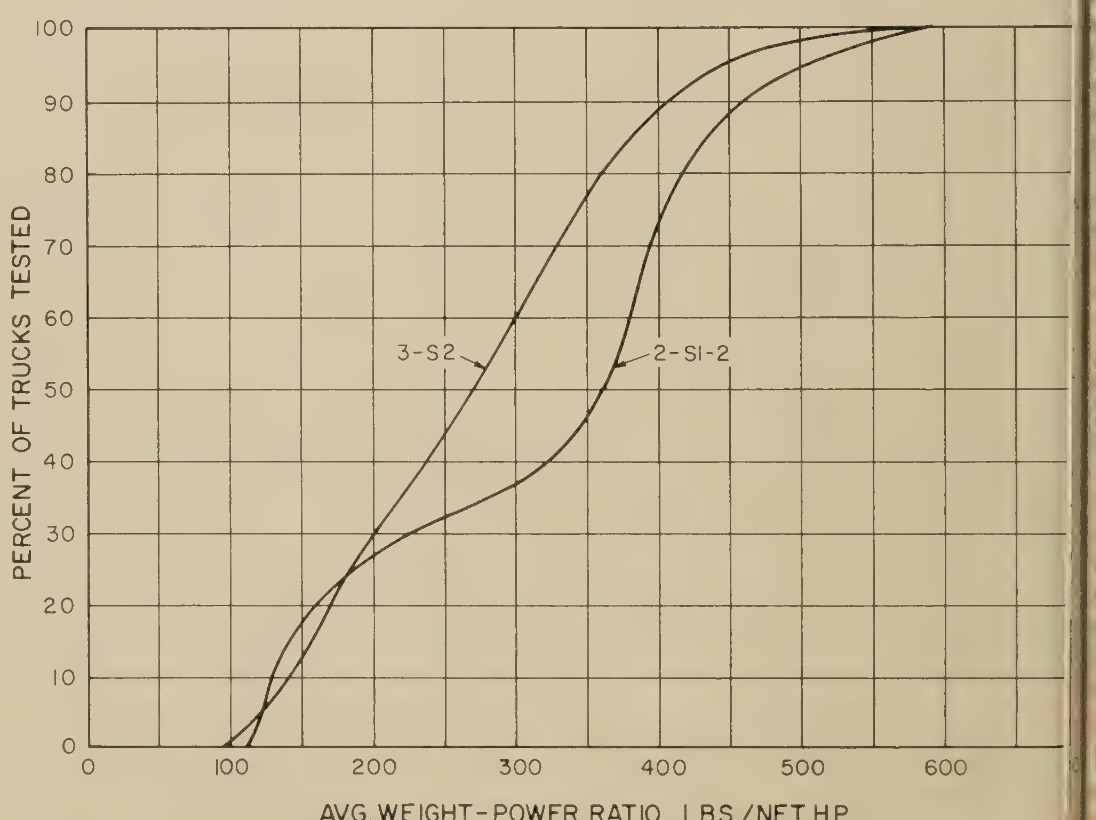

Figure 4.—Cumulative frequency distributions of weight-power ratios for a[ll] 3–S2 and 2–S1–2 trailer combinations, 1963 brake test.

Cumulative frequency distributions [o]f weight-power ratios for only loaded vehicl[es] [in] the 1963 study are shown in figure 5 by ve[hicle] type. The curve designated as OTHER incl[udes] 3–S1, 3–S2, 2–2, 2–S1–2, and all other tr[ailer]

Table 1.—Range and average of gross weights, net horsepowers, and weight-power ratios for commercial vehicles weighed in 1963 brake performance study

Commercial vehicles	All commercial vehicles tested in 1963 brake study						Loaded commercial vehicles tested in 1963 brake study					
	Gross weight		Net horsepower		Weight-power ratio		Gross weight		Net horsepower		Weight-power ratio	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
	Pounds	*Pounds*	*Horsepower*	*Horsepower*	*Ratio*	*Ratio*	*Pounds*	*Pounds*	*Horsepower*	*Horsepower*	*Ratio*	*Ratio*
2 (single-tired)	2, 545–11, 120	4, 795	50–165	109	24–128	44	3, 270–11, 120	5, 275	63–165	108	29–128	49
2 (dual-tired)	5, 700–31, 410	13, 230	80–198	136	42–267	97	6, 020–31, 410	15, 425	80–198	136	45–267	113
3	11, 000–47, 410	22, 785	95–222	157	71, 282	145	11, 000–47, 410	27, 460	95–222	157	82–282	175
2–S1	13, 000–45, 400	24, 630	118–230	165	84–304	149	14, 500–45, 400	28, 700	118–230	167	99–304	172
2–S2	15, 900–64, 805	39, 030	110–238	172	89–427	227	19, 270–64, 805	44, 625	110–235	172	120–427	259
3–S2	22, 010–94, 650	50, 625	128–310	184	94–701	275	27, 240–94, 650	60, 775	134–255	185	151–701	329
3–2	22, 400–78, 200	48, 070	128–250	184	93–511	261	49, 600–78, 200	73, 150	150–209	182	329–511	403
2–S1–2	24, 500–82, 770	59, 595	130–235	186	111–590	321	36, 600–82, 770	73, 685	134–235	185	203–590	398
Other trailer combinations [1]	16, 000–132, 570	54, 995	153–288	188	88–625	292	16, 000–132, 570	67, 285	133–234	187	88–625	359

[1] Includes 3–S2 and 2–S1–2 and other trailer combinations not listed specifically.

Table 2.—Comparison of weight-power ratios by percentiles from cumulative frequency distributions for 1955 and 1963

Commercial vehicles	Weight-power ratio, pounds per horsepower					
	15th percentile		50th percentile		85th percentile	
	1955	1963	1955	1963	1955	1963
2 (single-tired)	41	32	58	42	85	56
2 (dual-tired)	73	64	135	87	208	142
3	132	88	245	135	306	208
2–S1	161	108	256	133	376	204
2–S2	186	126	300	218	406	327
3–S2	---	157	---	272	---	377
2–S1–2	---	141	---	360	---	431
Other trailer combinations [1]	232	138	400	278	531	428

[1] Includes 3–S2 and 2–S1–2 and other trailer combinations not listed specifically.

Table 3.—Weight-power ratios for loaded vehicles from cumulative frequency distributions, by percentiles, 1963

Commercial vehicles	Weight-power ratio, pounds per horsepower		
	15 percentile	50 percentile	85 percentile
2 (single-tired)	37	45	60
2 (dual-tired)	75	106	157
3	110	125	243
2–S1	117	116	223
2–S2	180	252	346
3–S2	247	315	408
2–S1–2	338	388	454
Other trailer combinations [1]	251	354	452

[1] Includes 3–S2 and 2–S1–2 and other trailer combinations not listed specifically.

nbinations having 5 or more axles. The S2 and 2–S1–2 types are shown separately cause they are the largest groups for which a is contained in the curve labeled OTHER. e 15th, 50th, and 85th percentiles of the nulative frequency distributions for the ded vehicles tested in 1963 are summarized table 3. These ratios follow a pattern simr to that for the total of vehicles tested in 53, except that the ratios are larger when ly loaded vehicles are considered.

In figure 6 the trend in weight-power ratios m 1949 to 1963 is illustrated. The curves e based on average data for all commercial hicles weighed in the brake studies of 1949, 55, and 1963. The average ratios for all hicles sampled in the 1950 truck weight survy are indicated by the triangular symbols in ure 6. Average ratios for the 1950 truck ight survey closely follow the curve for the 149 brake test data; this indicates the validity the smaller sample of vehicles. The avere ratios for all vehicles sampled in a differt, but related, study conducted in 1964 near oodbridge, Va., also are shown in figure 6. ese data on 408 trucks are indicated by the cular symbols. Data collected at Woodidge closely approximate the 1963 brake test ta and, therefore, substantiate the results the 1963 brake test.

The reduction in the weight-horsepower tios from 1949 to 1955 amounted to about 15 rcent for vehicles having gross weights less an 40,000 pounds. Above that weight, the ange decreased to about 8 percent at 80,000 unds. From 1955 to 1963, the reduction nounted to about 25 percent for gross ights up to 40,000 pounds. The change adually decreased to about 16 percent at ,000 pounds gross weight.

The 1963 test data on loaded trucks also ere analyzed. The curve obtained closely proximated the curve for all trucks in the mple. At weights of less than 40,000 pounds, the difference in the two curves was 2 percent or less. For weights of more than 40,000 pounds, the two curves are identical. Therefore, only one curve is shown.

The trend in average weight-power ratios by vehicle type from 1949 to 1963 is shown in table 4. The variation in percentage change from 1949 to 1955 and from 1950 to 1955 was small, except when the sample size was small. The comparison of 1949 and 1955 data showed that the largest reductions in ratio occurred for 2-axle, single-tired trucks and 2–S2 and

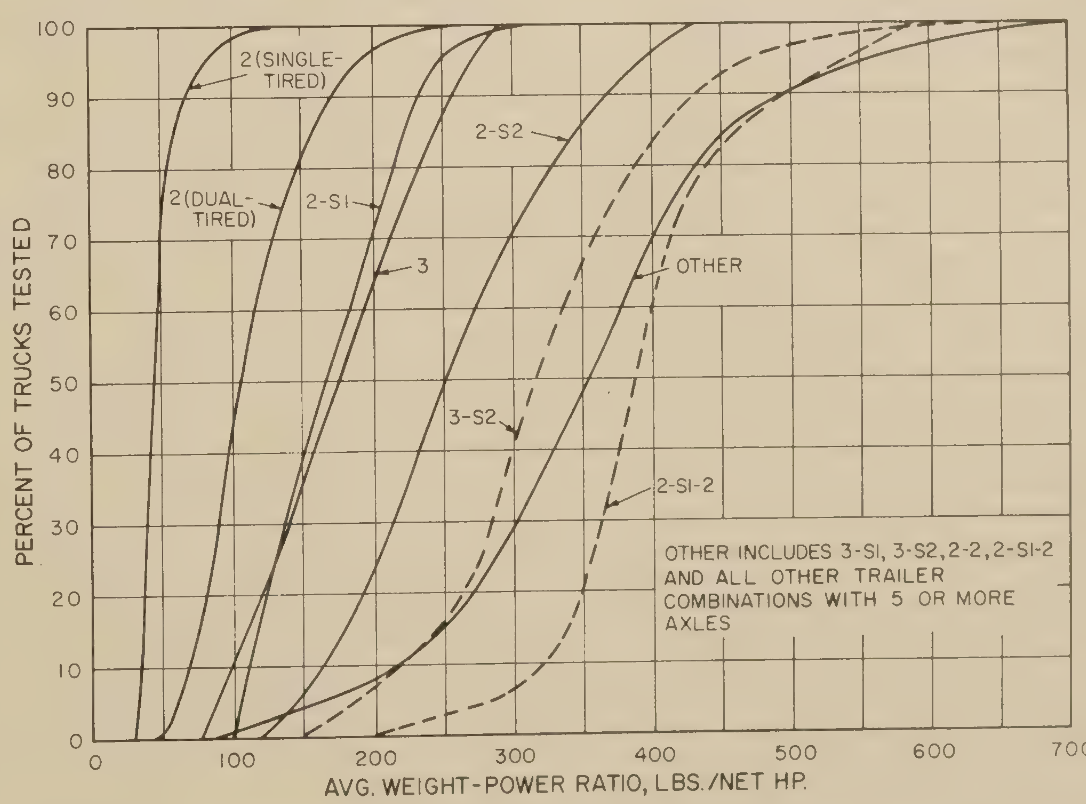

Figure 5.—Cumulative frequency distributions of weight-power ratios for loaded commercial vehicles, 1963 brake test.

3–S2 trailer combinations. The ratio increased from 1949 to 1955 for 3-axle trucks and 2–3, 3–2, and 2–S1–2 trailer combinations. The ratio for 2-axle, dual-tired trucks, did not change. A reduction in the ratio occurred for all vehicle types from 1955 to 1963, the largest percentage reductions were for the 2-axle, dual-tired, and 3-axle trucks, and 2–S1 trailer combinations. The overall reduction in the ratio from 1949 to 1955 was about 12 percent. The corresponding reduction from 1955 to 1963 was approximately 28 percent.

The percentages of vehicles sampled in 1955 and 1963 that could not meet performance requirements are listed in table 5. Comparison of these percentages shows considerable change. Percentages for 3–S2 and 2–S1–2 trailer combinations are not shown for 1955 because of inadequate samples. In 1955, 50 percent of the vehicles having 5 or more axles—14 percent of the total sample—had weight-power ratios of more than 400 pounds per horsepower. In 1963, only 20 percent of vehicles with 5 or more axles, and 5 percent of the total sample, had weight-power ratios of more than 400. The percentage of the loaded vehicles sampled in 1963 that could not meet the different performance requirements are shown in table 6. These percentages were taken from figure 5. In 1963, 30 percent of the loaded vehicles with 5 or more axles and 8 percent of the total sample of loaded vehicles had weight-power ratios of more than 400.

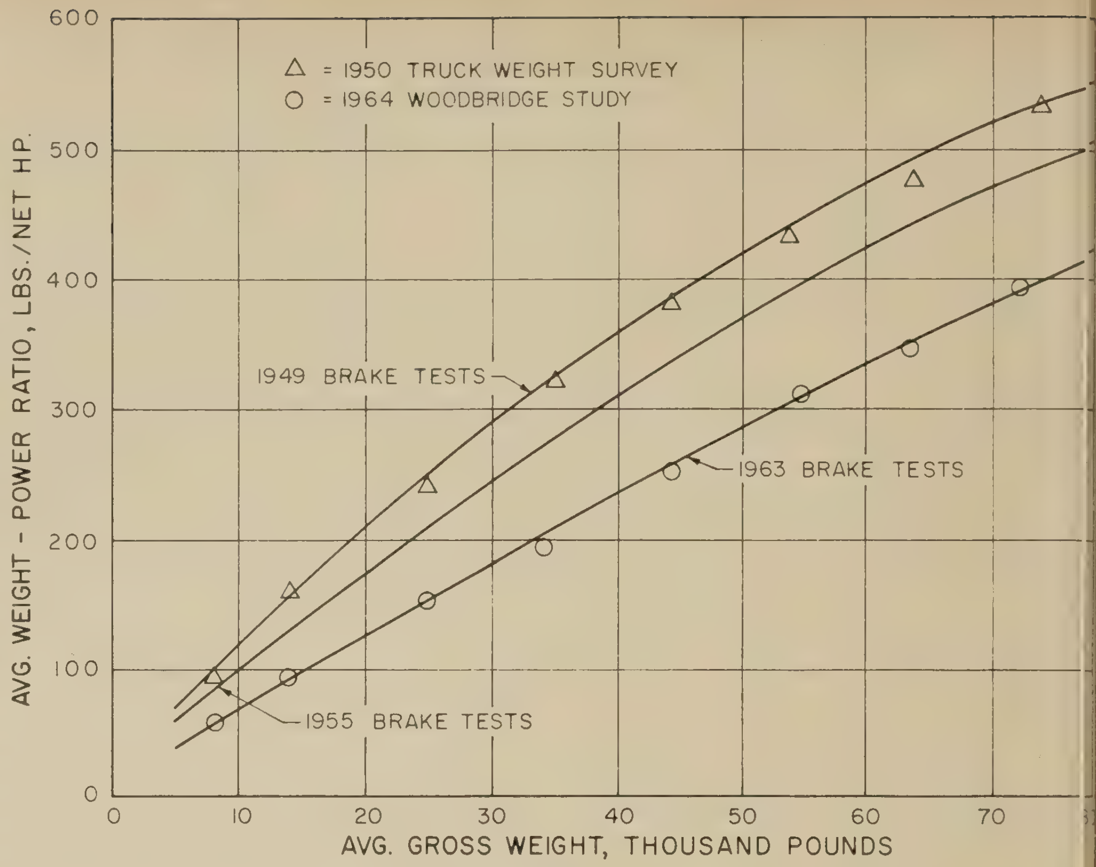

Figure 6.—Trend in weight-power ratios from 1949 to 1963 based on average dat for all types of commercial vehicles.

Table 4.—Average weight-power ratios for all vehicles by types for 1949, 1950, 1955, and 1963

Commercial vehicles	Number of vehicles				Average weight-power ratios				Percentage reduction of weight-power ratios		
	1949	1950	1955	1963	1949	1950	1955	1963	1949–55	1950–55	1955–63
2 (single-tired)	19	239	99	130	81	75	57	44	30	24	23
2 (dual-tired)	275	3,642	272	312	142	135	142	97	0	−5	32
3	38	263	67	42	227	244	231	145	−2	5	37
2–S1	228	3,900	117	108	291	294	264	149	9	10	44
2–S2	87	1,991	145	217	369	357	301	227	18	16	25
3–S2	46	483	57	112	422	411	348	275	18	15	21
2–3, 3–2, and 2–S1–2	51	136	71	78	394	384	418	300	−6	−9	28
Other trailer combinations [1]	38	72	34	27	428	421	374	292	13	11	22
TOTAL	782	10,726	862	1,026	----	----	----	----	----	----	----
WEIGHTED AVERAGES	----	------	----	-----	260	253	228	165	12	10	28

[1] Includes trailer combinations not listed specifically.

Table 5.—Percentage of all vehicles of given types weighed in the 1955 and 1963 brake tests that could not meet indicated performance levels

Commercial vehicles	Vehicles with weight-power ratios larger than—											
	250:1		300:1		350:1		400:1		450:1		500:1	
	1955	1963	1955	1963	1955	1963	1955	1963	1955	1963	1955	1963
2 (single-tired)	----	----	----	----	----	----	----	----	----	----	----	---
2 (dual-tired)	3	----	1	----	----	----	----	----	----	----	----	---
3	48	10	21	----	2	----	----	----	----	----	----	---
2–S1	53	2	34	1	20	----	10	----	2	----	----	---
2–S2	66	37	50	21	34	10	17	3	5	----	1	---
3–S2	----	57	----	38	----	23	----	12	----	5	----	6
2–S1–2	----	67	----	65	----	55	----	28	---	12	----	6
Other trailer combination [1]	82	55	73	46	62	34	50	20	35	10	22	7
TOTAL	38	20	29	14	20	9	14	5	8	2	4	1

[1] Includes 3–S2 and 2–S1–2 and other trailer combinations not listed specifically.

Table 6.—Percentage of loaded vehi[cles] weighed in the 1963 brake tests that co[uld] not meet indicated performance level[s]

Commercial vehicles	Loaded vehicles with weight-powe[r] ratios larger than—					
	250:1	300:1	350:1	400:1	450:1	50[0:1]
2 (single-tired)	----	----	----	----	----	--
2 (dual-tired)	----	----	----	----	----	--
3	12	----	----	----	----	--
2–S1	4	1	----	----	----	--
2–S2	51	29	14	4	----	--
3–S2	84	59	34	17	7	[illegible]
2–S1–2	97	94	80	40	18	[illegible]
Other trailer combinations [1]	85	71	52	30	15	[illegible]
TOTAL	33	23	15	8	3	[illegible]

[1] Includes 3–S2 and 2–S1–2 and other trailer com[bina]tions not listed specifically.

Offtracking Calculations For Trailer Combinations

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ESEARCH AND DEVELOPMENT
UREAU OF PUBLIC ROADS

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Traffic Systems Division

In this article the offtracking characteristics of single-unit trucks and trailer combinations are described. Offtracking results were obtained by use of scale models of vehicles making turns on radii ranging from 25 to 255 feet. Individual vehicle offtrackings are influenced by three variables: the degree of turn, the length of vehicle wheelbase, and the turning radius. It was determined that the offtracking measurements of a trailer combination may be calculated by adding the offtracking measurements of the individual vehicles in the combination. Also, the offtracking is greatest when the projection of the rear axle axis passes through the turning radius center, even though the projections of the other axles on the vehicle or trailer combination do not pass through the turning radius center at the same time.

The research reported here was planned to develop a more simple, quick, and comprehensive method for calculating offtracking. This method uses a series of figures constructed to allow for direct reading and calculation of offtracking for almost all practical highway vehicles and trailer combinations. The information is given for turns of 90 degrees and 270 degrees and for outer front-wheel turning radii from 25 to 225 feet. The range of turns and turning radii covers most of the vehicle turns made on city streets and turns made at rural intersections, including at-grade intersections, diamond interchanges, and separated cloverleaf interchange ramps.

Introduction

XPANSION of the National System of Interstate and Defense Highways and increasing use of the nation's highways has placed new demands on highway designers. Design emphasis is on highways that will permit good traffic flow, traveling ease and also provide maximum safety. Changes also are being made in the vehicles that use the highways. Size and weight regulations for commercial vehicles are being reevaluated and changed, and more and larger trailer combinations are using the highways. As a result more information is required on the handling characteristics of the larger vehicles.

The turning and offtracking characteristics of single-unit trucks and trailer combinations are of particular interest to the highway engineer as he must use this information in the design of highway curves, city street turns, and freeway entrance and exit ramps. Until recently only limited information on turns of different degrees and turning radii has been readily available. Data from the vehicle manufacturers have been sparse. Several studies have been made on vehicle steering performance but most of the material reported has provided information only on minimum radius turns on the operation of a few specific vehicles and trailer combinations. The data presented usually related only to resultant maximum offtracking without regard to the degrees of turn made by the vehicle before it exited onto a tangent.

Sketches, drawings, and detailed descriptions of the minimum turning paths of specific vehicles have also been provided. Although of value this information is inadequate because easy interpolation cannot be made of offtracking measurements between different types of vehicles and neither can comparisons be made of performance of vehicles of different wheelbases operated on turns of different radii. Even the SAE offtracking formulas (*1*) [2] require the use of specific vehicle dimensions, and then only maximum offtracking measurements are obtained for a particular combination. Thus, to make a comparison of the offtracking characteristics of different vehicles or to determine the offtracking limits for some particular turning radius, a long and tedious process of individually calculating the offtracking for each variation in vehicle dimensions is required.

Previously reported offtracking data have been based on measurements taken from the center of the axles of the vehicle. Although such data may be satisfactory for automotive engineering uses, the highway engineer must add or subtract other factors. In the study reported in this article all offtracking and turning radius measurements were made to the outside of the outer tire of an axle.

Conclusions

On the basis of findings from the research reported here, the authors have concluded that additional research may be required. Information on offtracking for turns of different degrees—only 90- and 270-degrees turns were studied—can be obtained by using similar models and procedures. They suggest that perhaps studies should be made of the maneuverings required for long trailer combinations on different types and sizes of cloverleaf intersections.

Although the research results reported here indicate that width over the tires has almost no effect on the offtracking characteristics of the outside of the outer tires of a trailer combination, additional studies may be required because of offtracking of certain units. It is believed that the width over the front tires of a power vehicle having Ackerman steering may have some limiting effect on the offtracking of the vehicle.

The authors also believe that additional research is needed to define more precisely the percentage relation between the turning radii and the wheelbase of different trailers. Knowledge gained from such a study would be useful to highway designers so that trailer backup and pivot motion on 180- and 270-degree turns could be prevented.

Basis of the Study

The fundamental premise made for the study was that: The sum of the offtracking of

[1] Presented at the 45th annual meeting of the Highway Research Board, Washington, D.C., Jan. 1966.

[2] References indicated by italic numbers in parentheses are listed on page 100.

the individual vehicles of a highway trailer combination closely approximates the total offtracking of the combination. The research plan included experiments with vehicle models that led to the establishment of patterns of vehicle offtracking behavior that are related to differences in wheelbase length, turning radius, and degree of turn. The final step in the research was the development of methods of plotting these data for rapid use and comparison.

Because sometimes two or more engineering organizations have defined the same terms differently and a few terms are used that have not been previously defined, the definitions in the following list and those at the front of this magazine should be considered carefully.

Angle of turn.—The angle of turn is the angle through which a vehicle travels in making a turn (2).

Axle.—For simplification, only the single term axle is used: it designates either a single axle or the centerline between tandem axles; this application depends on the vehicles being considered. The term axle can be used because the theoretical turning center of a tandem-axle assembly lies on the centerline between tandem axles.

Cramp angle.—The cramp angle is the limit of the turning ability of the front wheels of an Ackerman-type front axle and is limited by the construction of mechanical parts around the the front-axle, kingpin-pivot mechanisms. These constructions limit the degree to which the inner front wheel may be turned and also the turning of the outer front wheel.

Fifth wheel.—The fifth wheel is a lubricated bearing plate, mounted on a tractor chassis or on a trailer converter dolly chassis, arranged with an internal clutch device to engage and hold the kingpin of a trailer. The fifth wheel clutch engages and locks upon contact with the trailer kingpin; a manual release by the driver is required to separate the trailer kingpin and the fifth wheel. Primarily, the manual fifth wheel is being used. Previously an automatic fifth wheel was attached to the trailer and connected to this landing gear, and the kingpin was mounted on the towing vehicle. Few of these automatic fifth wheels are in use now, and these few are used only in local cartage service where the semitrailers are a captive fleet. In the article on braking performance the term fifth wheel refers to a trailing, fifth-wheel, distance-measuring device.

Kingpin.—The term kingpin has two different meanings in automotive design, and the precise meaning is determined by the context in which the term is used. A kinpgin of a front axle of a power vehicle is a vertical or near vertical shaft. The shaft is the pivot connecting each stub axle that carries a front wheel of a power vehicle to the rigid center of an Ackerman-type front axle. All Ackerman-type front axles have two kingpins, one at each end of the rigid center of the front axle.

A kingpin of a trailer is a vertical pivot shaft attached near the front of and on the centerline of the underside of a trailer chassis. This kingpin is surrounded by a lubricated bearing plate. It engages a fifth wheel on a towing tractor, a trailer converter dolly, or it is permanently connected to the center of an undetachable front axle of a full trailer. A trailer is pulled by and pivots around its kingpin.

Radius of inside curb.—The radius of the inside curb is the radial difference between the turning radius and the turning track width when the offtracking of the vehicle is at the maximum amount for a given turn. This shortest inside curb radius will occur at only one point (instantaneously) on a 90-degree turn. On a 270-degree turn, the shortest curb radius may remain constant for some distance before the exit tangent.

Minimum turning radius.—The minimum turning radius is the radius of the minimum turning path of the outside of the outer front tire. Vehicle manufacturers data books usually give minimum turning radius to the centerline of the outer front tire (2).

Negative offtracking.—Negative offtracking occurs during a turn in which the radius of the path of the outer rear corner of a vehicle becomes longer than the radius of the turning path of the outside of the vehicle's outer rear tire. For example, for a tractive truck or a trailer that has a cargo body extending back of the rear axle, negative offtracking occurs as the outer rear corner of the cargo body swings outside the path of the outside of the outer rear tire.

Offtracking.—Offtracking is the path of the outside of the outer tire on a rear or trailing axle that deviates inward toward the center of a turn from the circular path of the outside of the outer front tire, while the vehicle or trailer combination is making a turn.

Outside of tire.—The outside of a tire is the external side of a tire farthest away from the vehicle chassis.

Outside of outer tire.—The outside of the outer tire of a vehicle is the outside of the outermost tire on an axle on the outer side of a turn.

Outside of innermost rear tire.—The outside of the innermost rear tire of a vehicle is the outside of the rear tire nearest the turning radius center.

Overall length.—The overall length of a vehicle or trailer combination is the distance between the front bumper of the power vehicle and the rear bumper or guard on the rear vehicle.

Pintle hook.—A pintle hook is a vertical hook device attached to the rear of a tractive truck or to the rear of a leading (towing) semitrailer in a double trailer combination. The pintle hook engages the towing eye (ring eyelet) at the front end of the towbar of a trailer converter dolly or the towbar of a full trailer undetachable front-axle assembly.

Power vehicles.—Three general types of power vehicles are used:

- Single-unit trucks are power vehicles having Ackerman front-axle steering equipped with a cargo body but not equipped to pull a trailer.
- Tractive trucks are power vehicles with Ackerman front-axle steering equipped with a cargo body and a pintle hook that is attached to and recessed into the rear frame members so that a full trailer may be pulled.
- Tractors for commercial freight use are legally defined as truck-tractors to differentiate them from farm or industrial tractors. The single term tractor, however, is used in this article for a power vehicle of short wheelbase that is equipped with Ackerman front-wheel steering and a fifth wheel to engage and pull a semitrailer.

Rear axles of trailers.—Rear axles of trailers are attached primarily through springing suspensions and mechanisms to the trailer chassis so as to be in a fixed alinement with the longitudinal centerline of the trailer.

Rear overhang.—The rear overhang of a tractive truck, of a semitrailer, or of a full trailer is the distance between the centerline of the vehicle's rear axle and the centerline of its pintle hook.

Steering system.—One of two types of steering systems generally is used but related types are also used. The main ones are described in the following paragraphs.

- The Ackerman-steering system for front axles of power vehicles consists of a three-piece articulated axle with two front wheels that are mounted on short stub axles. The stub axles are attached to opposite ends of the rigid center section of the front axle by the front axle kingpins. The short stub axles are pivoted about the axle kingpins by steering arms and mechanisms connected to the driver's steering wheel.
- Fifth wheel pivot steering is similar to that used at the front ends of 2-axle, horse-drawn wagons. The front axle is a one-piece, rigid axle with the front wheels at each end of the axle. The rigid axle pivots about a kingpin located above the lateral center of the axle. Surrounding the kingpin are two lubricated bearing surfaces, the lower one is attached to the axle assembly. The upper bearing plate is attached to the underside of the vehicle chassis on its longitudinal centerline. These bearing plates give lateral and longitudinal stability to the cargo vehicle and make it possible for the trailer to be pulled by the kingpin. This type of steering is predominantly used at the front end of trailers.
- Pintle hook steering through a towbar is similar in action to fifth wheel pivot steering except that no vehicle weight rests on the pintle hook.

Trailers.—There are three types of trailers:

- A semitrailer is a cargo trailer equipped with one or more axles at or near its rear; it is constructed so that a substantial part of its tare weight and its cargo weight rests upon a tractor through the tractor fifth wheel.
- A full trailer is basically a semitrailer that has been converted into a full trailer by one of two methods. In one method the front axle and spring suspension are permanently connected to the chassis of the trailer. In the other method a semitrailer is combined with a trailer converter dolly.
- A trailer converter dolly is a very short wheelbase semitrailer. It consists of an axle attached through a spring suspension system to a platform (chassis) that carries a lower fifth-wheel plate. It has a towbar mechanism affixed at 90 degrees to its axle. The front end of the towbar is equipped with a towing eye that engages with a pintle hook on the rear of the towing vehicle.

Towbar.—A towbar is a bar, or a V-shaped assembly two bars, attached to the chassis of a trailer converter do or to the undetachable front axle assembly of a full trail and constructed so that it has a towing eye at its forwa end and exerts a pulling force in the middle of and at degrees to the axle of a trailer converter dolly or to a fı trailer undetachable front axle.

Turning path.—Turning path is the path of a designat point on a vehicle making a turn (2).

Turning radius.—The turning radius is the radius of t circular turning path of the outside of the outer front t from the turning radius center.

Turning radius center.—The turning radius center is t point that is the center of the circular turning path follow by the outside of the outer front tire of the power vehic

Turning track width.—The radial distance between t turning paths of the outside of the outer front tire and t outside of the rear tire nearest the center of the turn is t turning track width (2).

Wheelbase.—The several measures of wheelbase, whi depend on the type of vehicle, are defined in the followi paragraphs.

- The wheelbase of a single-unit power vehicle (tru or tractor) is the distance between the centerline of the fro axle and the centerline of the rear axle. The centerline b tween any tandem axles always is used as the reference poi for wheelbase measurements.
- On semitrailers, the wheelbase is the distance betwe the trailer kingpin and the centerline of the rear axle.
- On trailer converter dollies, which are in effect sho semitrailers, the wheelbase is the distance between the cent of the towing eye of the towbar and the centerline of t dolly's axle.
- The wheelbase of full trailers is measured the same w as for semitrailers and is the distance between the kingp of the trailer and the centerline of the rear axle.
- On complete trailer combinations, the overall wheelba is the distance between the front axle of the power vehic and the rearmost axle when the trailer combination is stru out in a straight line. This overall wheelbase may diff from the sum of the defined wheelbases.

Width over tires.—The width over tires is the outside-t outside distance over the tires on an axle.

SAE definitions.—The meanings of the two following SA terms are different from the definitions and measuremen of offtracking that are used in this article. To preve confusion the SAE definitions are given in the followi statements.

Turning center, SAE.—The turning center is the poi about which all parts of a vehicle or combination of vehicl revolve in describing a turn of constant radius and to whi all wheel spindles are normally radial. For 2-axled bogies tandems in which the axles are constrained to parallelis the interaxle trunnion or its equivalent is assumed to l radial from this point (3). The location of this turni center moves around as a trailer combination enters a cur from a tangent, proceeds around the curve, and leaves an exit tangent. This turning center should not be co fused with the outer front wheel turning radius cent referred to in this article.

Offtracking, SAE.—Offtracking is the difference in ra from the turning center to the vehicle centerlines at t foremost and rearmost axles of a vehicle or combinati and represents the increase beyond the tangent track caus by a turn (3).

Peak offtracking.—Peak offtracking is the offtracking r sult obtained from the data shown in figure 5 and 6. Tl peak offtracking may be equal to or less than the maximu offtracking calculated by use of SAE formulas.

Fundamentals of Offtracking

Offtracking is the phenomenon in whi the paths of the wheels of a rear axle of single-unit power vehicle or of a trailer con bination deviate inward toward the center a turn from the circular turning path of tl outside front wheel. When operating turns uniform in radius, individual vehicle whether in combinations or single-uni offtrack in similar patterns of turns. Tl front wheels of a power unit do not offtrac but all other axles on the vehicle or trail combinations do. Although, most highw vehicles have nonsteerable rear axles,

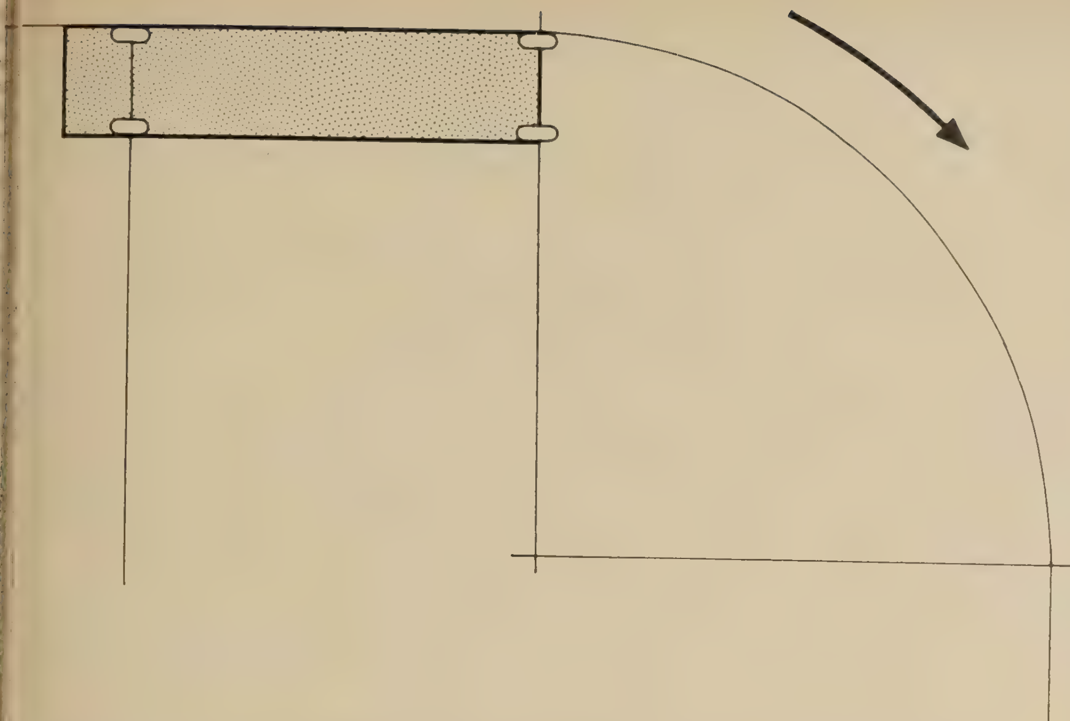


Figure 1.—A long wheelbase vehicle in tangent position about to enter turn.

all minority does have different methods r rear steering. In the study discussed in s article only vehicles with nonsteering r axles were studied.

For practical vehicle-highway geometrics, most important factor of offtracking is offtracking that occurs when a single-it vehicle or a trailer combination makes turn of 270 degrees. On short wheelbase, gle-unit vehicles, the peak offtracking may cur early in the first 90-degree segment of turn; but on very long trailer combinations, e full 270 degrees of turn may be used before e peak offtracking occurs. For the longer iler combinations, the offtracking during 90-degree turn will be substantially less an their offtracking on a 270-degree turn. so on 90-degree turns, the front wheels of the power vehicle of a long trailer combination will run for some distance on the exit tangent before the peak offtracking occurs. It is difficult to calculate the offtracking of trailer combinations having long wheelbases when the front wheels of the power vehicle travel on the exit tangent, but the solution can be obtained with scale models of vehicles. Of course, for very short wheelbase single-unit vehicles, which reach their maximum offtracking before 90-degrees of turn, any travel on the exit tangent does not increase the amount of offtracking.

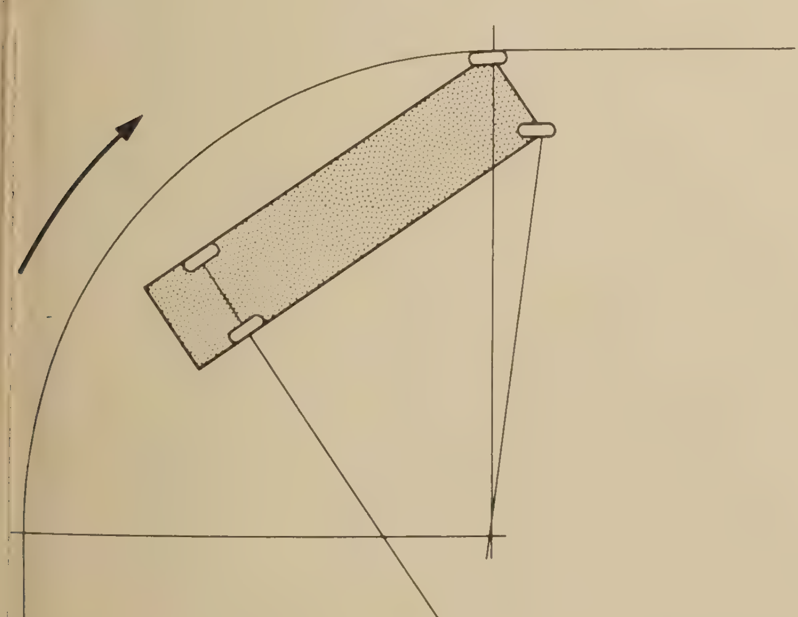
On turns, the offtracking characteristics of single-unit vehicles and the individual vehicles in trailer combinations are affected by several interlocking factors, such as: (1) the degree of a turn; (2) the wheelbase of each individual vehicle in a trailer combination; (3) the uniform turning radius of the outside of the outer front tire of the power vehicle—this turning path of the outside of the outer front tire usually is the outer pavement or curb radius on a specific turn; (4) the radius of the outside of the outer front tire on a trailer's virtual front axle with reference to the turning radius center, when the towing vehicle is at its point of peak offtracking on a specific turn; (5) in trailer combinations, the rear trailing axle of each leading vehicle acts as a virtual front axle of the trailing vehicle.

The virtual front axles of trailing vehicles are: (1) on semitrailers, the tractor rear axle is the semitrailer's virtual front axle; (2) on trailer converter dollies or undetachable front axle assemblies of full trailers, the virtual front axle of such semitrailer-type assemblies is located on the centerline of the towing vehicle's pintle hook, which is the same location as the center of the pintle hook eye of the towbar; (3) on full trailers the axle of the trailer converter dollies is the virtual front axle. However, on undetachable front-axle assemblies, such a front axle of a full trailer is its real front axle. Both types of front axles for full trailers perform similarly.

Turning and Offtracking

Single-unit vehicles

The principles of offtracking for single-unit vehicles are illustrated in figures 1 through 4, which show the action on turns of vehicles with Ackerman-steering. A long single-unit vehicle is shown in figure 1 at its entrance tangent position just before entering a curve; the projections of the two stub axles of the front wheels and of the rear axle are parallel and do not intersect. For long vehicles, the projections of the front wheel, stub axles, and the rear axle vary from parallel when on the entrance tangent to different intersecting positions during a turn (fig. 2). The projections reverse toward parallelism when the



igure 2.—A long wheelbase vehicle that has completed 90 degrees of turn but not reached peak offtracking.

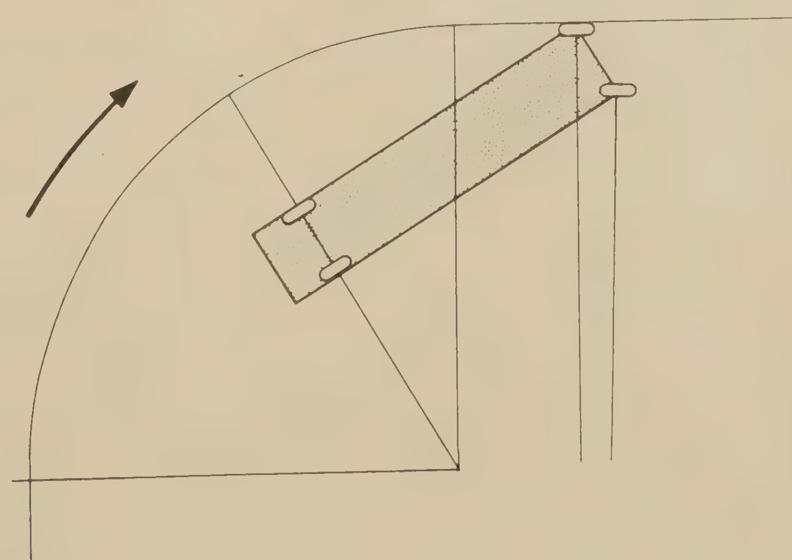


Figure 3.—A long wheelbase vehicle at its point of peak offtracking on an exit tangent.

front wheels leave the turn on an exit tangent (fig. 3). Thus, the offtracking rear wheels travel in a double spiral curve.

The vehicle shown in figure 2 has not attained its peak offtracking on a 90-degree turn; it is still in transition from its starting position even though the front wheels are at the exit tangent. Although, the projections of the stub axles of the front wheels pass through the turning radius center, the axis of the rear axle does not. In such situations, the peak offtracking will occur after the outer front tire of the vehicle is on its exit tangent (fig. 3). The front end of the vehicle has moved down the exit tangent until the projected axis of the rear axle passes through the turning radius center. This point of peak offtracking during a 90-degree turn was observed in the operation of the vehicle models. The axes of the front wheels no longer pass through the original turning radius center, but the axes of all axles will intersect at some distance behind the turning radius center. The amount of offtracking was measured with the vehicle models, but this offtracking cannot be calculated by use of the SAE equations.

For single-unit vehicles having short wheelbases, such as passenger cars and small trucks, maximum offtracking usually will occur during the first 90-degree segment of a turn (fig. 4). As shown, the axes of all axles intersect at the turning radius center. The offtracking of such vehicles was measured with the vehicle models and results are shown in figures 5 and 6. The offtracking of these short wheelbase vehicles also can be calculated by use of the SAE equations.

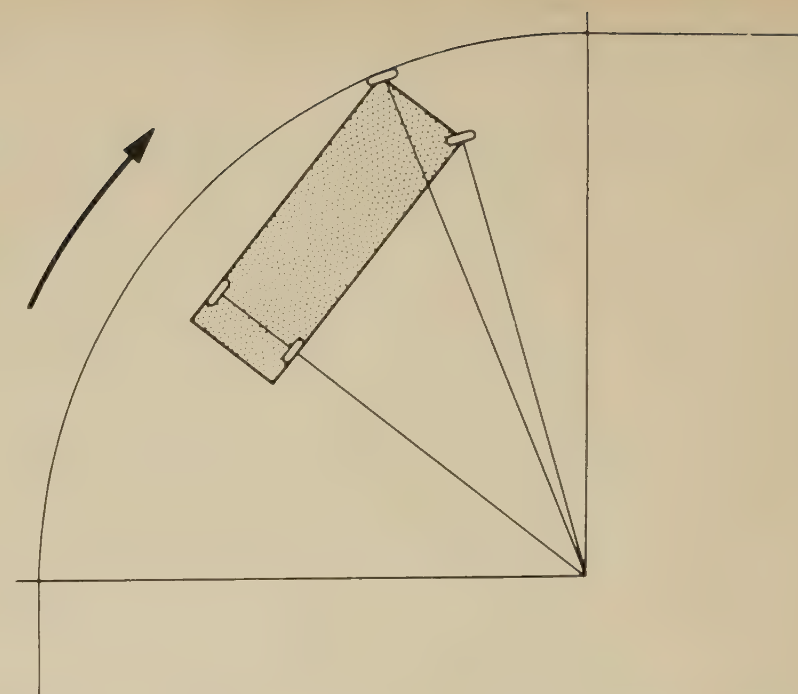


Figure 4.—A short wheelbase vehicle that has reached its point of maximum offtracking.

Trailer combinations

It is desirable that trailer combinations move continuously and progressively forward at a reasonably rapid speed when negotiating highway curves or at-grade intersections. Because of their jointed construction, trailer combinations may not travel in a continuous, smooth path when the turning radius is shorter than the trailer wheelbase. Such nonuniform type of travel is possible with trailer combinations because fifth-wheel, pivot-type steering permits a trailer to turn 90-degrees or more from the longitudinal axle of the towing vehicle. The angle through which the power vehicle can turn is limited by its steering cramp angle and its wheelbase.

An example of a trailer combination offtracking in a noncontinuous, irregular manner is illustrated in figure 7. As shown, when trailer combinations are negotiating 180-degree turns and the turning radius is less than the length of the trailer's wheelbase, the rear axle will pass behind the turning radius center and will pivot and travel backwards in an irregular path. The rear axle of long trailer combinations traveling on short radius, 270-degree turns also have similar backing and pivoting characteristics. Such reverse travel and pivoting of the rear axle can only be considered in very close quarters, for example, in buildings where the drivers carefully manipulate the trailer combinations at creep speeds. Data in figures 5 and 6 do not apply to this type of irregular offtracking.

Trailer combinations negotiating 90-degree turns, however, travel in a continuous and smooth path regardless of which side of the turning radius center the semitrailer passes. A long wheelbase trailer combination following a relatively short turning radius, a situation truck drivers encounter as typical of city streets, is shown in figure 8. Because the outer rear tire on the rear axle passes behind the turning radius center, the maximum offtracking cannot be calculated with the SAE equations but can be and was measured with the vehicle models. The peak offtracking on such a turn occurs when the projection of the rear axle, as shown in figure 8, passes through the turning radius center although the front wheels of the power vehicle are on the exit tangent. The problems associated with long trailer combinations negotiating curves having short turning radii are troublesome, particularly on city streets and diamond approaches to controlled-access highways. Such problems will be magnified if, in the future, longer single-trailer combinations are permitted. In general, double-trailer combinations offtrack less than long single-trailer combinations.

Factors in Offtracking Determinations

An important feature of vehicle offtracking is that the peak offtracking for any degree of smooth and continuous turn occurs when a projection of the axis of the rear axle of a vehicle is on a radial passing through the turning radius center. This was observed with the vehicle models, which were equipped with a scale that projected from the outer end of the trailing rear axle. The peak outer rear tire offtracking occurred wh the rear axle was parallel with a radial l passing through the turning radius cen on the model test pattern.

The different measurements of offtrack data of interest and use to the highway des engineer are: (1) Dimensions of vehic and trailer combinations; (2) turning rad of specified turn; (3) offtracking of trail rear axle; (4) turning track width; and inside curb radius, for zero clearance w tire.

Dimensions

The dimensions of vehicles and tra combinations are needed so that the des engineer will know the sizes of vehicles be considered in a specific turn situati Dimensions needed of the individual vehic in a trailer combination are: wheelbase each vehicle, width over the tires; and double cargo vehicle combinations, the r overhang of each towing vehicle and spacing between the vehicles.

The outer curb radius of a specific t usually is determined by the location terrain situation in the turning area. (tracking is the radial distance between outer front wheel turning radius of the o side of the outer front tire of a vehicle the radius of the outside of the outer r tire of a rear trailing axle, at the point peak offtracking. Offtracking for single-u vehicles and individual vehicles of tra combinations can be obtained from the tracking data in figures 5 and 6.

The turning width is the amount of tracking plus the width over the tires of dual tires on a rear axle or the width of cargo body, if it is significantly wider t the width over the dual tires. This dimens was assumed to be 8.0 feet in the st

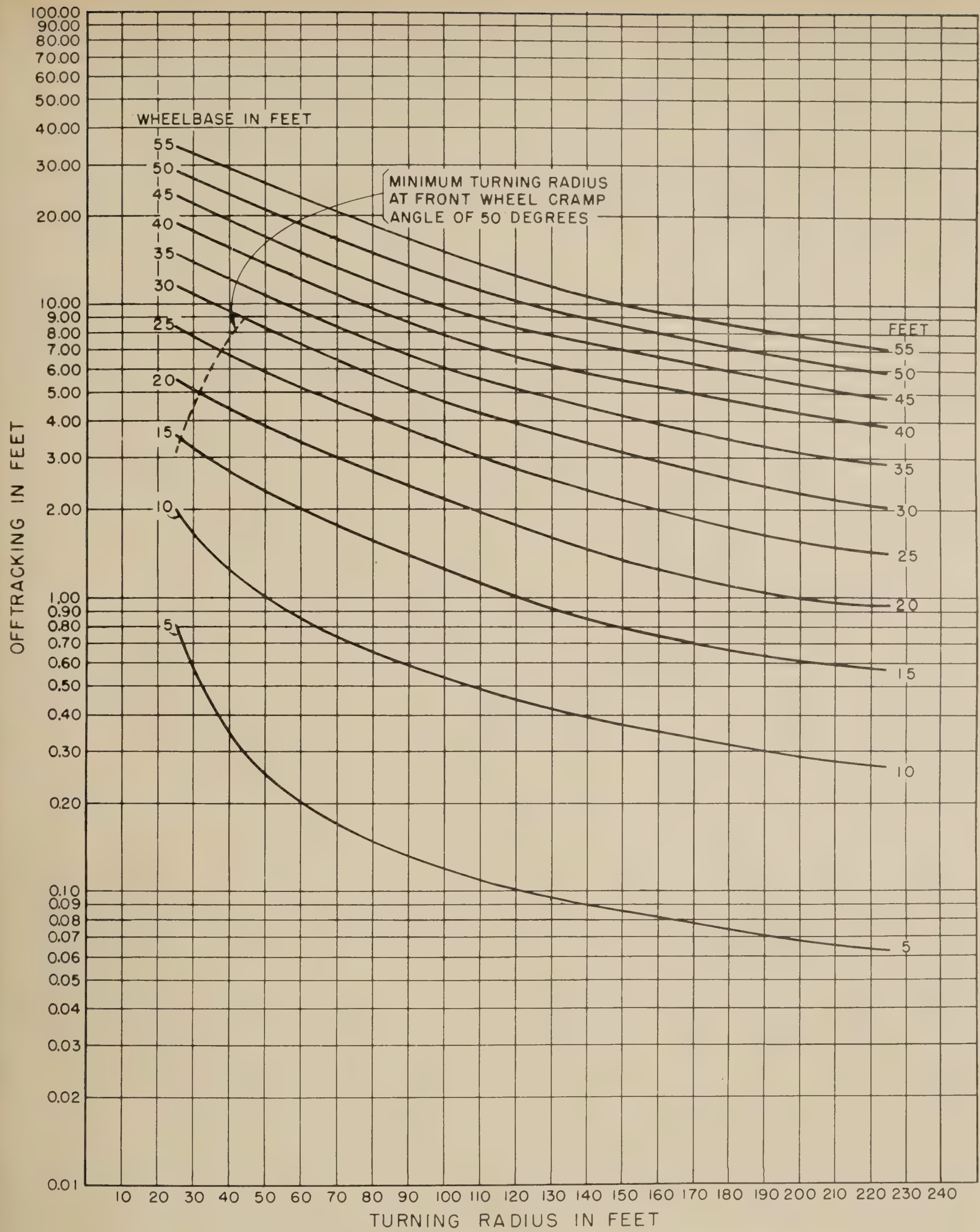


Figure 5.—Offtracking and turning radii for 90-degree turns and different wheelbases.

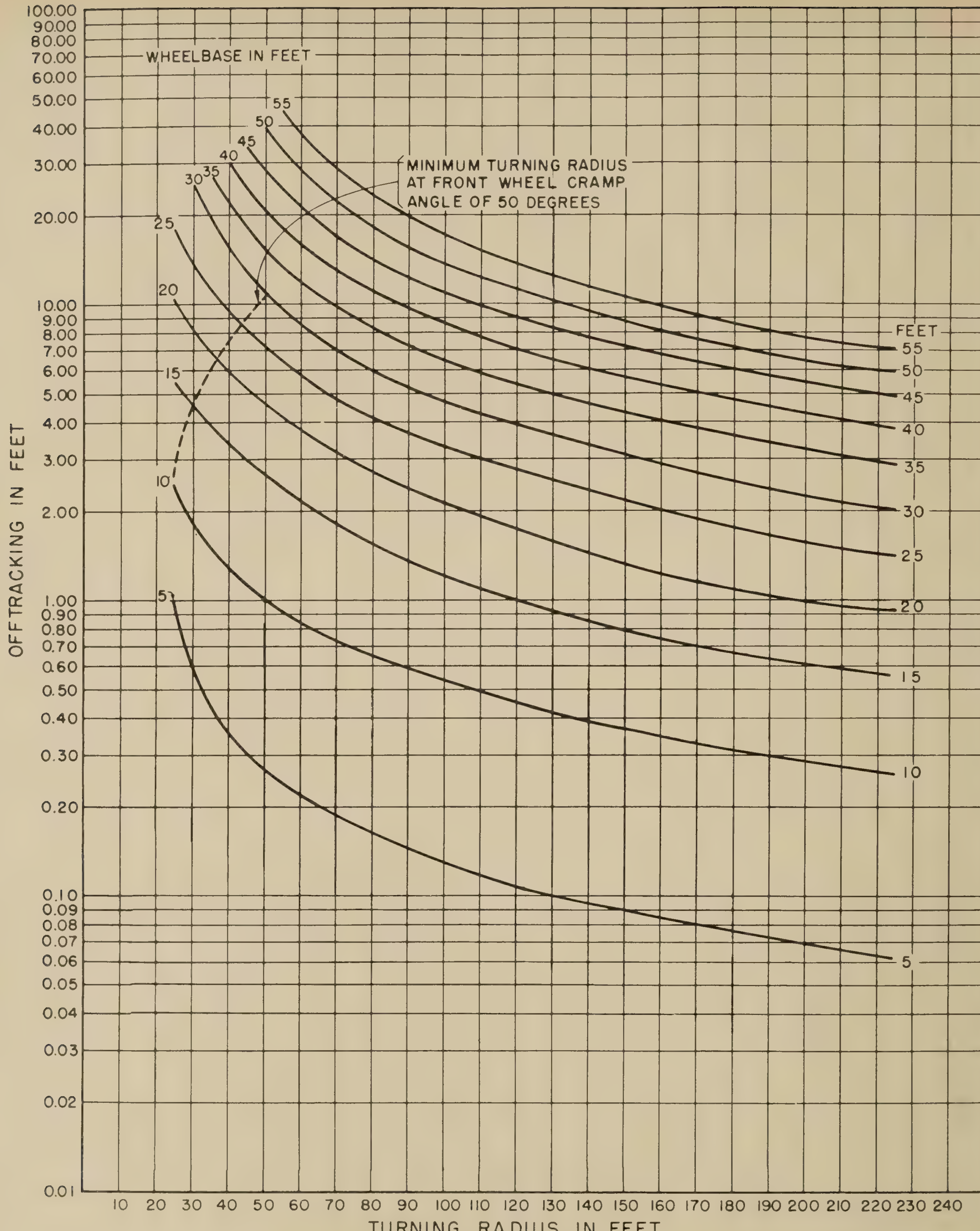


Figure 6.—Offtracking and turning radii for 270-degree turns and different wheelbases.

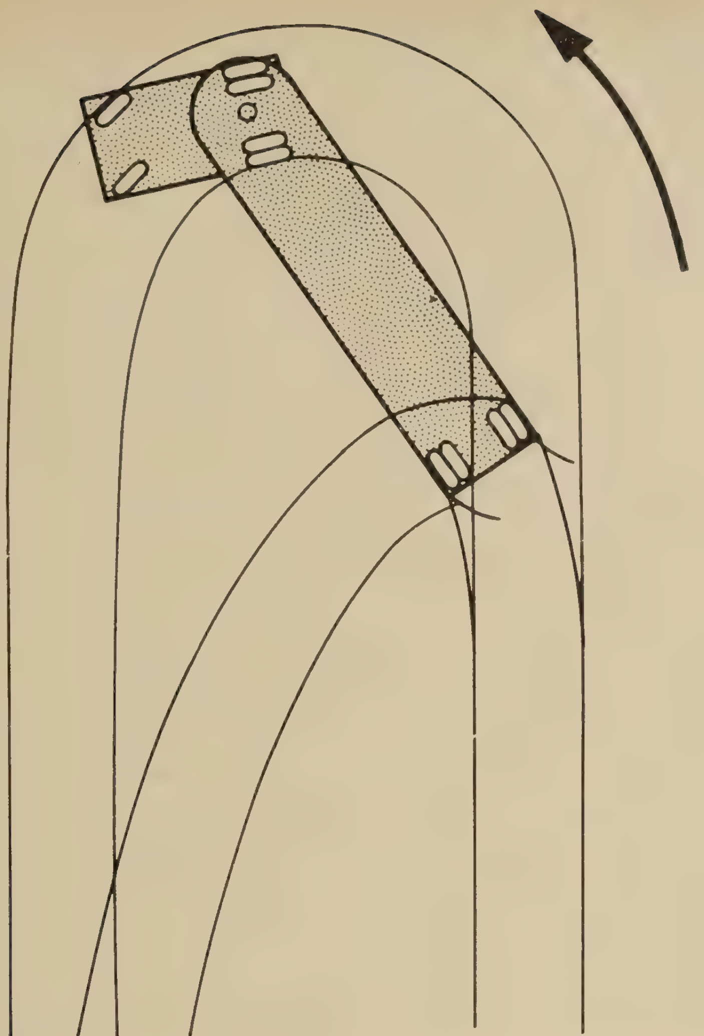


Figure 7.—A long wheelbase combination on a short radius turn, in which the semitrailer backs up and pivots behind the turning radius center.

ɪported here because it is the width presently ıost in use. However, the *1965 AASHO ɪze and Weight Recommendations* carry a ɪovision for over-the-tire widths of 8.5 feet.

The inside pavement or curb radius on a ɪrn is the radius from the turning radius ɪnter to the outside of the innermost rear ɪe on the rear axle at the point of its peak ɪftracking for a specific turn. The inside ɪrb radius equals the original front-wheel ɪrning radius minus the turning track width. ɪhis inside curb radius will permit a perfectly ɪiven trailer combination, following the ɪecified outer curb turning radius, to just ɪear the inner curb at its point of peak ɪftracking. The actual inner curb radius ɪould be shorter so as to permit variations ɪ driver manipulation. The offtracking of ɪdividual single-unit vehicles can be deɪrmined from the offtracking data in figures ɪ and 6 by a single reference to either the ɪ-degree or the 270-degree information.

ɪailer combination

The offtracking of a trailer combination on ɪ specific turn is a summation of the offɪacking of the individual vehicles in the ɪailer combination. Each vehicle in a trailer ɪmbination offtracks individually in accordance with its wheelbase and the radius from the turning radius center to the outside of the outer front tire on its virtual front axle. Determining the turning radius of the real or virtual outer front tire of each individual trailer vehicle in the train poses a problem. Because all trailing vehicles (semitrailers, trailer converter dollies, or undetachable full trailer, front-axle assemblies, and full trailers) offtrack and steer like semitrailers, a virtual or real front axle for each such semitrailer-like unit must be assumed. The point of peak offtracking for the rear axle of each towing vehicle on a specific turn will prescribe the turning radius of each following semitrailer-like unit. Proceeding from the front axle of a trailer combination, a progressive series of changed, usually reduced, turning radii occurs for the outer tire of the virtual front axle for each semitrailer-like unit. By analyzing each semitrailer-like unit in the order it appears in the trailer combination, using in sequence the turning radius of the outer front tire on each real or virtual front axle, it is possible to obtain a series of separate offtracking measurements for each vehicle. These measurements can be added to obtain the peak overall offtracking of the complete trailer combination.

When determining the offtracking of trailer combinations having full trailers, the phenomenon of negative offtracking must be considered. Negative offtracking occurs when the edge of the cargo body opposite the pintle hook swings outside the path of the outside of the outer rear tire on a turn, as shown in figure 9. In effect, negative offtracking increases the turning radius of the following semitrailer-like unit. The magnitude of negative offtracking depends upon the wheelbase of the towing vehicle, the length of rear overhang to the centerline of the pintle hook, turning radius, and the degree of turn. The negative offtracking measurements for practical power vehicles and towing semitrailers are given in tables 1 and 2.

Steering Systems

Ackerman steering

An understanding of different aspects of vehicle turning and offtracking requires information on the systems of steering used on most highway vehicles. Single-unit vehicles, automobiles, light trucks, tractive trucks, and tractors, are equipped with Ackerman-type steering. The Ackerman system was invented in Germany about 1817 and patented by an Englishman in 1818. It is the preferred steering system because it provides better stability to the front end of the vehicle during a turn. In the Ackerman system the two front wheels are mounted on short, stub axles that are connected to the steering kingpins. The kingpins are connected to the front-wheel spring suspension and are supported by the vehicle chassis or sometimes by a rigid beam-type front axle. During a turn, the front wheels are pivoted on the kingpins by the steering linkage and other mechanisms connected to the steering wheel.

Vehicles equipped with Ackerman steering are limited in their offtracking by the minimum turning radius curve that can be followed by the outer front wheel. This minimum turning radius usually is limited, because of mechanical obstructions, by the degree to which the inner front wheel may be turned. This limited turning capability of the inner front wheel is called the cramp angle. On most over-the-road trucks the maximum cramp angle is between 30 and 35 degrees. Recently, however, the manufacturers of city delivery trucks have been widening the distance between front wheels and are obtaining cramp angles of 45 to 50 degrees. Offtracking data for such vehicles are included in the figures in this article.

Fifth-wheel steering

Semitrailers, full trailers, and trailer converter dollies operate with a fifth-wheel, pivot-steering principle that is different from the Ackerman system. As trailers are not operated alone, they do not require the front-end stability required for power vehicles. In the fifth-wheel, pivot-type of steering system the front wheels are mounted at the ends of a rigid one-piece axle. This axle is pivoted about a kingpin mounted above the lateral center of the axle, where it is connected to the trailer body.

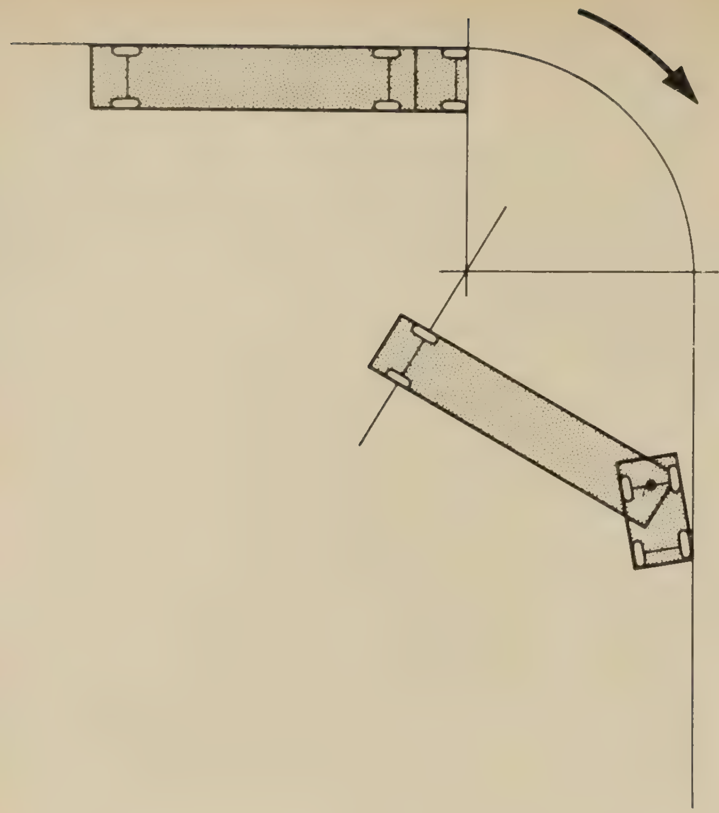


Figure 8.—A long wheelbase combination on a short radius turn, in which the semitrailer passes in back of the turning radius center.

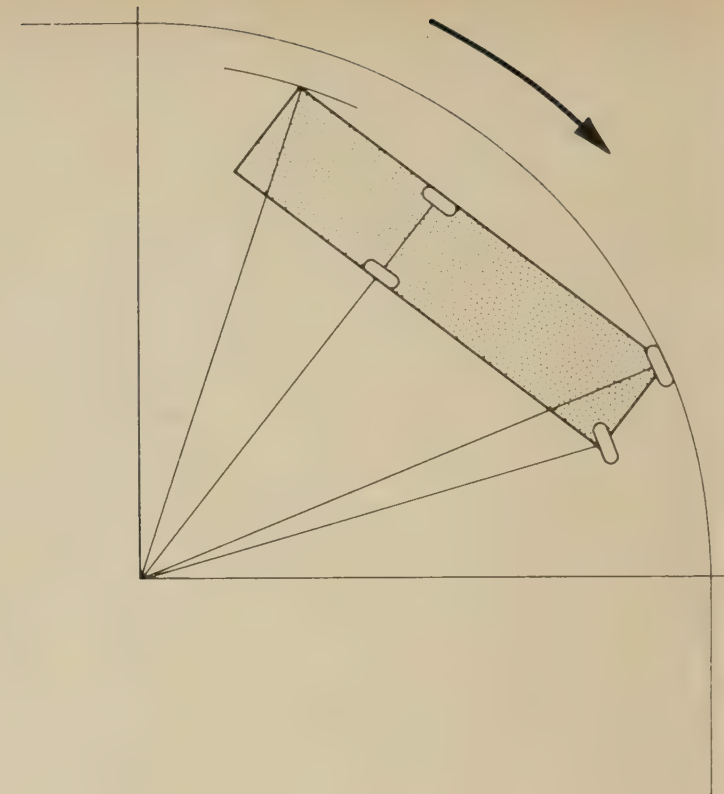


Figure 9.—Negative offtracking in which the path of the ou rear corner of the cargo body has a greater radius than the p of the outer rear wheel.

For semitrailers the rear axle of the tractor acts as the virtual front axle of the trailer. In most designs, the trailer kingpin, surrounded by a lubricated bearing plate, is attached to the underside of the semitrailer, usually about 3 feet back of the front end of the trailer. Another bearing plate, equipped with a kingpin locking device, is mounted on the tractor chassis over the rear axle. This fifth wheel engages and holds the trailer kingpin and allows the trailer to be pulled and steered by the tractor. This system permits easy coupling or uncoupling and the interchanging of trailers.

Full trailers are basically semitrailers that have one or two types of front-axle assemblies; the front axle is permanently attached to the trailer or is removable. The removable, front-axle assemblies are known as trailer converter dollies. They consist of one or more one-piece axles supported by a spring suspension system and have a fifth wheel mounted above the center of the axle. Both the trailer converter dollies and the permanently attached front-axle assemblies have towbars affixed at a 90-degree angle to the axle. The towbar has an eye that engages a vertical pintle hook on the rear of its towing vehicle. Once engaged, the towbar may pivot freely about its pintle hook. Such pivoting is limited only by interferences with rear frame parts of the towing vehicle. Because of the free pivoting action of the towbar, both types of front-axle assemblies of full trailers act as short wheelbase semitrailers in making a turn. Thus a full trailer turns and offtracks in the same manner as a semitrailer connected in tandem to another semitrailer, both of which have fifth-wheel pivot steering.

In the steering and offtracking behavior of full-trailer front-axle assemblies, their virtual front axle can be assumed to be located at the center of the pintle hook. The wheelbase of such devices, therefore, is measured from the center of the towbar eye to the center of the axle. With fifth-wheel-pivot steering no cramp-angle problem occurs and the angular relationship between the towing vehicle and the semitrailer is not restricted; it may be as much as or more than 90 degrees.

Vehicle Models and Instrumentation

The relations on offtracking contained in this article were obtained primarily through the use of scale models of highway vehicles. The models were designed to provide a good simulation of actual vehicle turning characteristics for many different types and lengths of single-unit vehicles and trailer combinations. To expedite the study, models were designed as detachable components that could be quickly assembled or disassembled. The models, equipped with an Ackerman steering mechanism, were constructed to a scale of 0.75 inch equals 1 foot and the width over the tires equals 8 model feet.

The models were operated on a smooth surface of 4-by-8-foot panels placed on a level concrete floor. The panels were assembled in 16-by-16-foot squares and circles were painted from the center to simulate highway curves ranging from a turning r of 25 to 100 model feet. Radial lines, 10-degree intervals, and tangents were su imposed upon the test layout, as shown figure 10. Turning radii of 165 and 225 m feet were obtained by placing 8 additi panels about the original 16-by-16-foot squ

Before each individual test, the ve and axle alinement of the model was chec on an 8-foot approach tangent. If the m followed the tangent without any per tible deviation, it was then guided so that outside of the outer front wheel followed circular curve selected for the test. Offtr ing tests were conducted with models re senting different types of single-unit vehicles trailer combinations. Included were mode power vehicles with wheel bases ranging f 5 to 30 model feet, tractive truck models considerable rear overhang, and semitr models with wheelbases ranging from 55 model feet. Full trailer model were not conducted as full trailers offt the same way as semitrailers.

In the semitrailer model tests the tr kingpin was positioned directly over the center of the front axle of a short w base tractor model, as shown in figure With the kingpin in this position any tracking of the tractor did not affect trailer offtracking; however, the tractor provide model stability. In all of the m tests the offtracking was measured at rear or trailing axle of a vehicle or tr combination. To ascertain the magni of negative offtracking on tractive tr ving long rear overhangs, an additional 'tracking measurement was taken at the ter rear corner of the model opposite the ntle hook centerline. To expedite the termination of the peak offtracking, a scale s mounted on the vehicle models as shown figure 11. Offtracking data were obtained the model assemblies for both 90- and 0-degree turns.

Offtracking Calculations

The results obtained from the tests on hicle models are shown in figures 5 and 6 r 90 degree turns. They were designed permit the rapid determination of off-acking for single-unit vehicles and trailer mbinations. For single-unit vehicles, the 'tracking can be determined directly. Determination of the offtracking for trailer mbinations can be obtained by adding together the offtracking of the individual units the combinations. Semilogarithmic graph per was used in the preparation of these gures. The ordinate in a logarithmic scale presents offtracking in feet. The logarithmic scale was selected to reduce the height of ie ordinates for publication. The abscissa presents the turning radius in feet and it has en presented on an equal interval scale. n each figure, the wheelbase curves were awn in 5-foot increments.

Vehicle offtracking may be evaluated for urning radii of 25 to 225 feet and for wheelbase lengths of 5 to 55 feet. The 25-foot urning radius represents the shortest radius urn studied with the models. At more than 225-foot turning radius, the offtracking of ngle-unit vehicles and trailer combinations pproaches the maximum offtracking that an be calculated by the SAE equations (*1*). he approximate limits of the minimum radii f turns possible when an Ackerman-type eering system is employed and when the ont wheel cramp angle is 50 degrees are lso shown. The following examples explain how the data in these figures can be sed.

ingle-unit vehicles

The offtracking for single-unit vehicles can e determined directly. For example, the eak offtracking for a 2-axle truck negotiating turning radius of 70 feet on a 90-degree urn is shown in figure 5. If the 2-axle ruck had a wheelbase of 30 feet, the peak fftracking would be 6.4 feet. If the same -axle truck was negotiating a 70-foot radius urve through a 270-degree turn, the peak fftracking would be 7.0 feet (fig. 6). If he minimum turning radius for the 2-axle ruck is desired, it can be approximated by se of the dashed curve shown on the figure. f the front wheel cramp angle is 50 degrees, a 0-foot wheelbase, single-unit truck cannot egotiate a curve having a turning radius of ess than 45 feet (fig. 5).

If the offtracking is desired for a vehicle having a wheelbase between those represented by the wheelbase curves in either figure 5 or 6, figure 12 may be used to interpolate between the wheelbase curves. For example, if offtracking had been desired for a

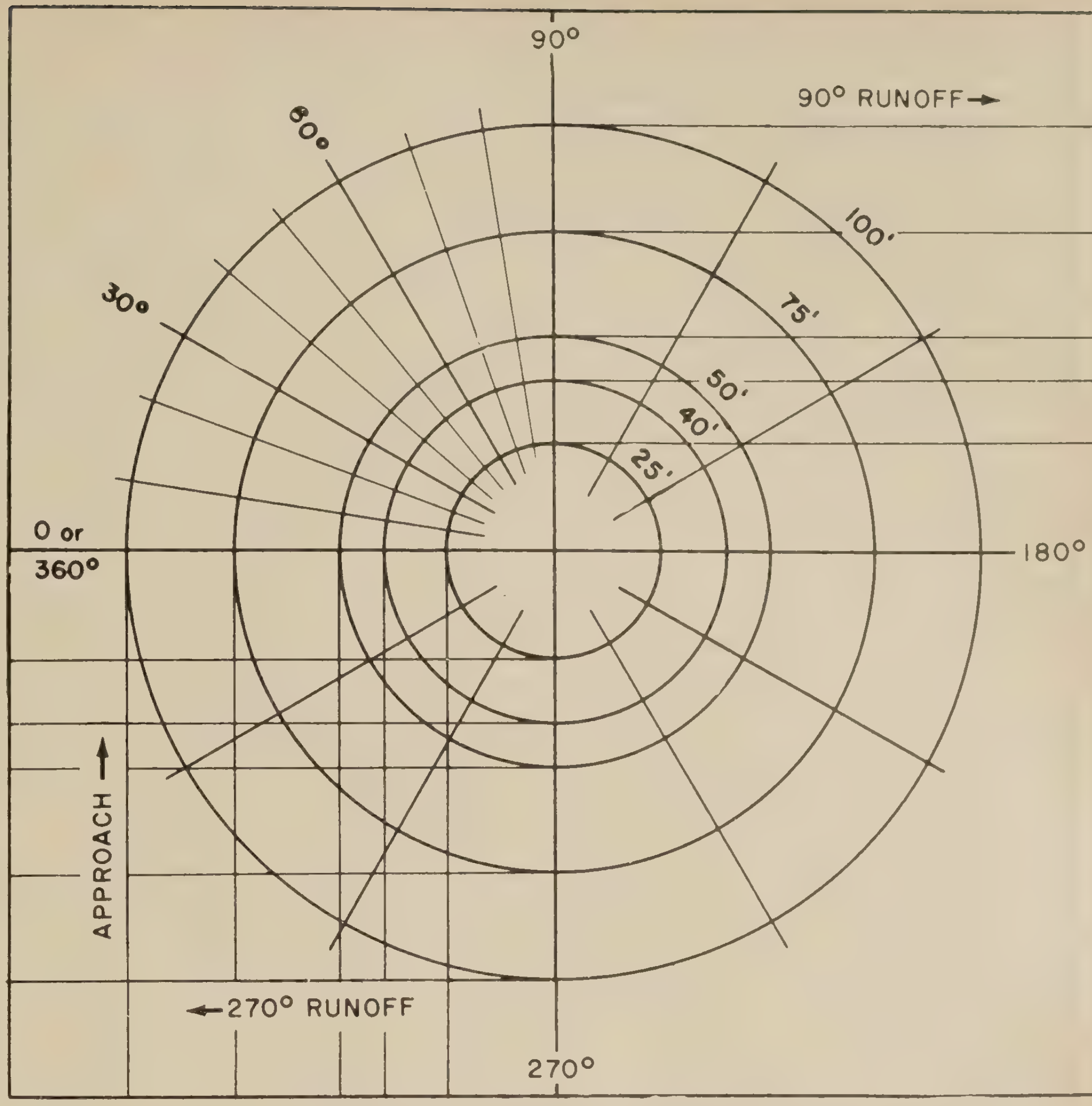


Figure 10.—Schematic arrangement of guidelines on floor panels.

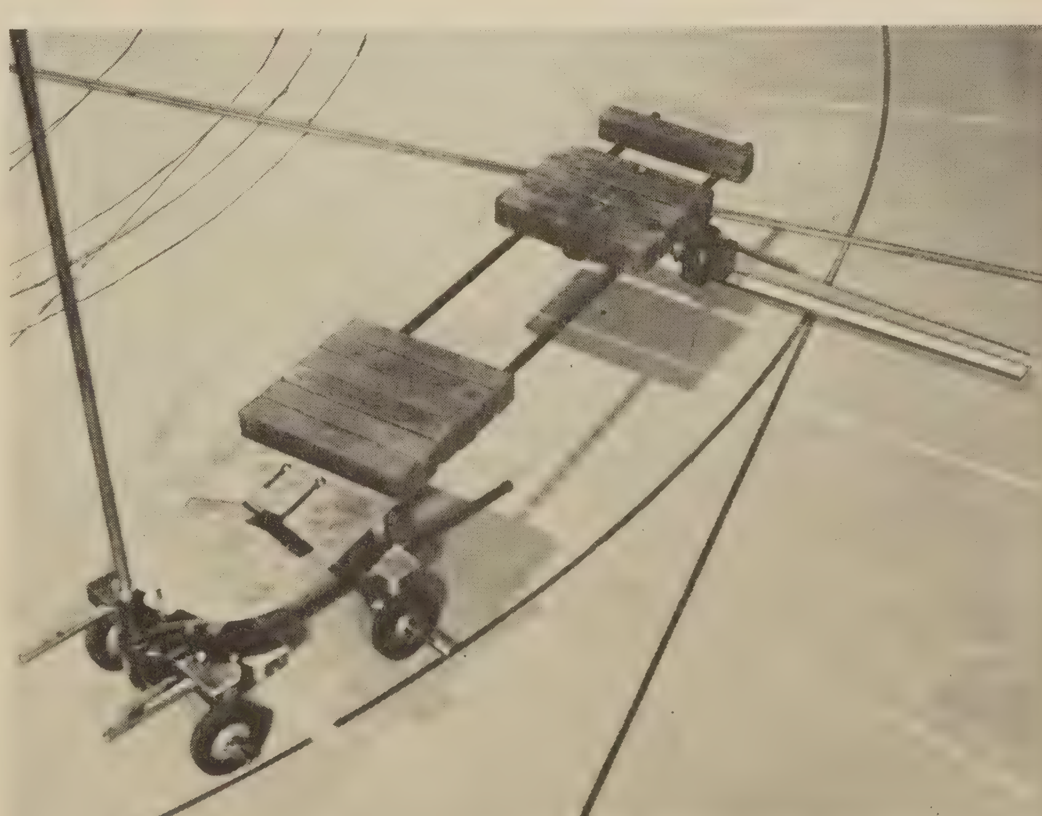


Figure 11.—Semitrailer model and fifth-wheel pivot steering.

Table 1.—Negative offtracking for 90-degree turns

Wheelbase	Turning radius of outside of outer front wheel	Offtracking of outside of outer rear wheel	Negative offtracking of outer rear corner opposite pintle hook for—				
			3-foot overhang	5-foot overhang	7-foot overhang	9-foot overhang	11-foot overhang
Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
10	25	2.00	0.19	0.54	1.04	1.70	------
	30	1.71	.16	.44	.85	1.40	------
	40	1.27	.12	.32	.63	1.03	------
	50	1.01	.00	.26	.50	.82	------
	60	.85	.00	.21	.41	.68	------
	70	.75	.00	.18	.35	.58	------
	80	.67	.00	.16	.31	.51	------
	90	.60	.00	.15	.27	.45	------
	100	.54	.00	.13	.25	.39	------
15	25	3.62	.20	.55	1.11	1.78	2.75
	30	3.24	.17	.46	.88	1.45	2.17
	40	2.70	.12	.33	.64	1.07	1.59
	50	2.30	.00	.26	.51	.84	1.25
	60	2.00	.90	.22	.42	.69	1.03
	70	1.75	.00	.18	.36	.59	.88
	80	1.55	.00	.16	.31	.51	.77
	90	1.38	.00	.14	.28	.46	.68
	100	1.23	.00	.13	.25	.41	.61
20	25	5.43	.22	.62	1.23	1.96	2.97
	30	5.05	.18	.51	.96	1.56	2.33
	40	4.40	.13	.35	.68	1.12	1.66
	50	3.89	.10	.27	.53	.87	1.29
	60	3.45	.00	.22	.43	.71	1.15
	70	3.08	.00	.19	.37	.60	.90
	80	2.72	.00	.16	.32	.52	.78
	90	2.41	.00	.14	.28	.46	.69
	100	2.17	.00	.13	.25	.41	.62
25	25	8.37	.27	.74	1.43	2.28	3.31
	30	7.80	.20	.58	1.08	1.75	2.58
	40	6.80	.14	.37	.73	1.20	1.77
	50	5.93	.10	.28	.55	.91	1.35
	60	5.28	.00	.23	.45	.74	1.09
	70	4.61	.00	.19	.37	.62	.92
	80	4.10	.00	.16	.32	.53	.79
	90	3.70	.00	.14	.28	.47	.70
	100	3.34	.00	.13	.25	.42	.62
30	25	11.71	.33	.92	1.76	2.73	3.96
	30	10.90	.23	.66	1.24	2.01	2.94
	40	9.50	.15	.41	.79	1.30	1.92
	50	8.30	.11	.30	.58	.96	1.43
	60	7.27	.00	.24	.46	.76	1.14
	70	6.41	.00	.20	.38	.63	.94
	80	5.70	.00	.17	.33	.55	.81
	90	5.11	.00	.15	.29	.48	.71
	100	4.62	.00	.13	.26	.42	.63
35	25	15.08	.44	1.19	2.22	3.47	4.89
	30	14.20	.28	.77	1.48	2.38	3.45
	40	12.55	.16	.46	.88	1.44	2.12
	50	11.10	.12	.32	.62	1.04	1.53
	60	9.60	.00	.25	.48	.80	1.19
	70	8.49	.00	.20	.40	.65	.98
	80	7.52	.00	.17	.38	.56	.83
	90	6.78	.00	.15	.29	.49	.72
	100	6.10	.00	.13	.26	.43	.64

Table 2.—Negative offtracking for 270-degree turns

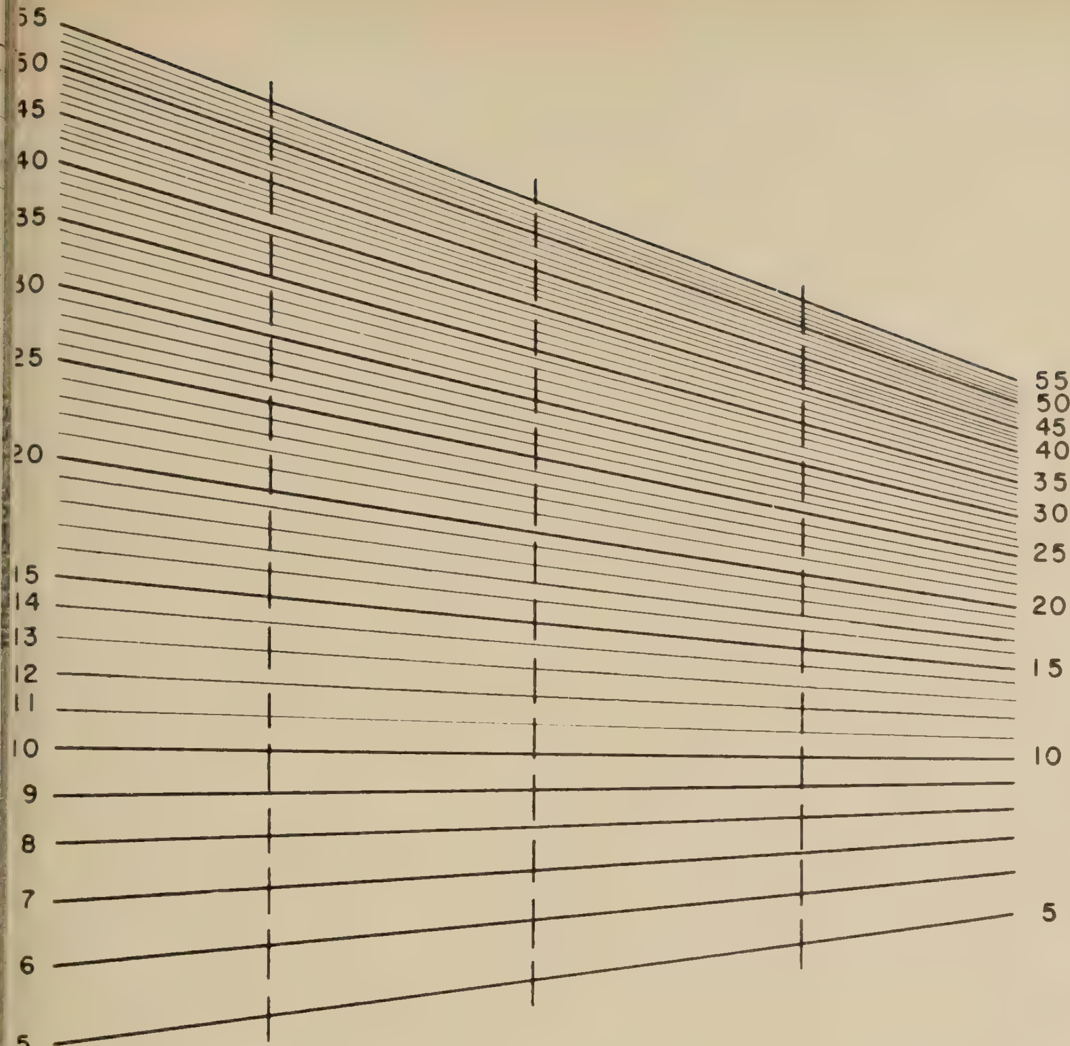
Wheelbase	Turning radius of outside of outer front wheel	Offtracking of outside of outer rear wheel	Negative offtracking of outer rear corner opposite pintle hook for—				
			3-foot overhang	5-foot overhang	7-foot overhang	9-foot overhang	11-foot overhang
Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
10	25	2.58	0.20	0.55	1.07	1.74	------
	30	1.90	.16	.44	.86	1.41	------
	40	1.27	.12	.32	.63	1.03	------
	50	1.01	.00	.25	.50	.82	------
	60	.85	.00	.21	.41	.68	------
	70	.75	.00	.18	.35	.58	------
	80	.67	.00	.16	.31	.51	------
	90	.60	.00	.14	.27	.45	------
	100	.54	.00	.13	.25	.41	------
15	25	10.40	.31	.83	1.59	2.55	3.68
	30	4.60	.18	.49	.95	1.55	2.28
	40	3.43	.12	.33	.67	1.09	1.63
	50	2.68	.00	.26	.51	.85	1.26
	60	2.18	.00	.22	.42	.70	1.03
	70	1.83	.00	.18	.36	.59	.88
	80	1.61	.00	.16	.31	.51	.77
	90	1.38	.00	.14	.28	.46	.68
	100	1.23	.00	.13	.25	.41	.61
20	25	18.93	.70	1.79	3.19	4.79	4.49
	30	8.70	.21	.58	1.12	1.82	2.67
	40	6.24	.13	.37	.72	1.18	1.75
	50	4.72	.10	.27	.54	.89	1.30
	60	3.71	.00	.22	.43	.71	1.06
	70	3.10	.00	.19	.37	.60	.90
	80	2.73	.00	.16	.32	.52	.78
	90	2.41	.00	.14	.28	.46	.69
	100	2.17	.00	.13	.25	.41	.62
25	25	--------	------	------	------	------	------
	30	14.25	.28	.77	1.55	2.39	3.46
	40	9.70	.15	.41	.80	1.31	1.93
	50	7.27	.11	.29	.57	.95	1.39
	60	5.80	.00	.23	.45	.74	1.10
	70	4.81	.00	.19	.37	.62	.92
	80	4.17	.00	.16	.32	.53	.79
	90	3.70	.00	.14	.28	.47	.70
	100	3.34	.00	.13	.25	.42	.62
30	25	--------	------	------	------	------	------
	30	26.01	1.00	1.80	4.07	5.85	7.71
	40	14.85	.18	.49	.88	1.52	2.20
	50	11.21	.12	.32	.63	1.03	1.53
	60	8.67	.00	.24	.48	.78	1.17
	70	7.18	.00	.20	.39	.64	.96
	80	6.07	.00	.17	.33	.55	.81
	90	5.26	.00	.15	.29	.48	.71
	100	4.70	.00	.13	.26	.42	.63
35	25	--------	------	------	------	------	------
	30	38.00	------	------	------	------	------
	40	18.80	.20	.58	1.13	1.83	2.68
	50	15.65	.13	.36	.71	1.16	1.72
	60	12.50	.00	.26	.51	.85	1.26
	70	10.15	.00	.21	.41	.67	1.00
	80	8.50	.00	.17	.34	.56	.84
	90	7.35	.00	.15	.30	.49	.73
	100	6.57	.00	.13	.26	.43	.65

single-unit truck having a 11-foot wheelbase the following procedure would be employed. Use the vertical distance from figure 5 or figure 6 between the 10- and 15-foot wheelbase curves and locate the same distance vertically on figure 12 between the 10- and 15-foot lines. At this location, the vertical distance between the 10- and 11-foot lines is then carried back to figure 5 or 6 and located vertically above the 10-foot wheelbase curve; the offtracking is then read on the ordinate horizontally opposite the point representing the 11-foot wheelbase. When negotiating a 90-degree turn, the peak offtracking for this single-unit vehicle would be 0.9 foot.

Tractor combinations

Offtracking is determined for tractor semitrailers by adding the offtracking data for the individual vehicles of the combinations. For example, the peak offtracking for a 2–S2 combination negotiating a turning radius of 100 feet through a 270-degree turn would be determined from figure 6. The dimensions of the sample 2–S2 trailer combination are given in figure 13. The peak offtracking is determined for the tractor having a 10-foot wheelbase (0.54 foot, fig. 6). To determine the semitrailer offtracking, its turning radius and wheelbase must be known. The assumption has been made that the kingpin is located directly above the centerline of the rear axle of the tractor (figs. 5 and 6). In effect, the rear axle of the tractor becomes the virtual front axle of the semitrailer. The semitrailer turning radius is computed by subtracting the tractor offtracking from the tracking turning radius; it is 99.5 feet. The semitrailer wheelbase is the distance from the kingpin to the centerline of the rear axle on the semitrailer. In this example, the semitrailer had a tandem rear axle, therefore, the wheelbase of 29 feet is the distance from its kingpin to the centerline between the tandem axles. Reference to figure 6 shows the semitrailers peak offtracking was 4.4 feet when the turning radius was 99.5 feet and the wheelbase was 29 feet. The offtracking f the tractor-semitrailer portion of the trail combination is the sum of the tractor of tracking and the semitrailer offtracking (0. plus 4.4 or 4.94 feet). As previously dete mined, the tractor semitrailers peak of tracking, in reference to the centerline betwe the tandem axles, was 4.94 feet when neg tiating a 100-foot turning radius through 2 degrees. But the offtracking for the trail converter dolly and the full trailer also mu be determined.

The trailer converter dolly is connected the semitrailer at a pintle hook, located 7 fe behind the centerline between the tande axles. Negative offtracking is present in th the path of the outer rear corner of the sem trailer swings outward from the turning radi center. The magnitude of negative offtrac ing can be determined from table 1 or With a wheelbase of approximately 30 fee a turning radius of nearly 100 feet, and 7-foot rear overhang to the pintle hook, th



gure 12.—Interpolation guide for wheelbase lengths between 5-foot interval wheelbase curves.

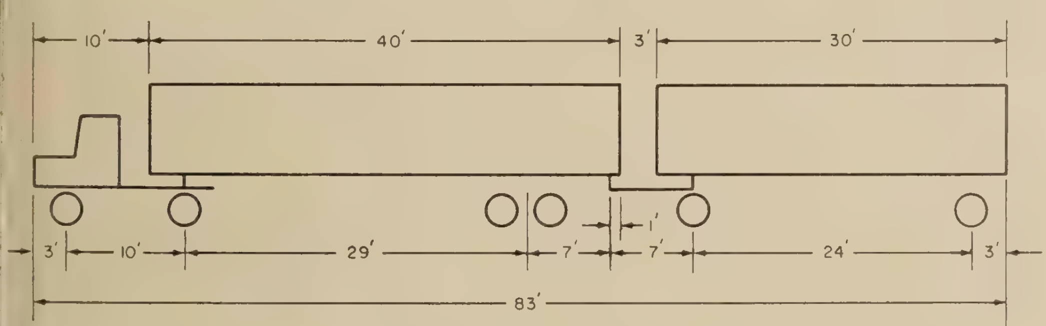


Figure 13.—Dimensions of trailer combination used to demonstrate calculations.

gative offtracking of the virtual front axle the dolly is 0.26 foot for a 270-degree turn. The pintle hook was assumed to be in the nter of the virtual front axle of the trailer nverter dolly. The trailer converter dolly rning radius is found by subtracting the actor semitrailer offtracking (4.94 feet) from e turning radius of the tractor and adding that the negative offtracking. Thus, the rning radius of the virtual front axle of the ailer converter dolly would be 95.32 feet 00.00 minus 4.94 plus 0.26). With the trailer nverter dolly having a wheelbase of 7 feet and a turning radius of 95.32 feet, the dolly offtracking of 0.28 foot, was determined from figure 6.

After the peak offtracking of the trailer converter dolly is obtained, the offtracking for the full trailer is determined. The turning radius for the full trailer is computed in the same way as for the semitrailer. Thus, the turning radius of the virtual front axle of the full trailer is 95.04 feet (95.32 minus 0.28). The kingpin on the full trailer is assumed to be directly above the centerline of the dolly axle. If a tandem axle dolly had been used, the kingpin would be located directly above the centerline between the tandem axles. In effect the dolly axle is the virtual front axle of the full trailer. For a full trailer having wheelbase of 24 feet and a turning radius of 95.04 feet, the full trailer offtracking is 3.2 feet (fig. 6).

The offtracking of the entire 2–S2–2 tractor semitrailer and full trailer with an overall length of 83 feet is the sum of the offtracking of the individual vehicles minus the negative offtracking. The peak offtracking for the 2–S2–2 combination example would be 8.16 feet (0.54+4.40+0.28+3.20−0.26) when negotiating a 100-foot turning radius curve through a 270-degree turn. The turning track width would be 16.16 feet (8.16+8.00). The inside curb radius is equal to the turning radius minus the turning track width or 83.84 feet (100−16.16). The computed SAE maximum offtracking for this vehicle is 8.42 feet.

Truck and full trailers

The peak offtracking for truck and full trailers also can be determined by use of data shown in figures 5 and 6. The same techniques are used for determining the offtracking of the individual vehicles of a truck and full trailer combination as are used for determining the offtracking of a tractor semitrailer and full trailer combination.

Offtracking Comparisons

To illustrate that different types and sizes of vehicle combinations offtrack differently, several representative long trailer combinations were selected for comparisons. Dimensions of the trailer combinations are listed in table 3 and offtracking characteristics are listed in table 4. In table 3, the 2–S1, 2–S2, and 3–S2 combinations have over-all lengths shorter than either of the 2–S1–2 combinations listed. However, the 65-foot, 2–S1–2 combination offtracks less than either of the tractor-semitrailer combinations and the 71-foot 2–S1–2 combination has approximately the same offtracking as the tractor semitrailers. Because vehicles do offtrack differently; highway design engineers use as guides the highway design vehicles recommended by the American Association of State Highway Officials. The offtracking characteristics given for vehicles in the 1965 proposed revision of the AASHO highway design vehicles also are shown in table 4. The dimensions proposed for these design vehicles are given in table 5.

Model and SAE Offtracking Comparisons

Offtracking results computed from tests with the models were compared to results obtained from the SAE offtracking equations. Comparisons were made for 90- and 270-degree turns on 50- and 150-foot turning radii, respectively. Most of the vehicle models obtained their maximum offtracking prior to reaching the 270-degree exit tangent, therefore, the results could be validated by com-

Table 3.—Dimensions of some of the trailer combinations listed in table 4

	2–S1	2–S2	3–S2	2–S1–2	2–S1–2	3–S2–4
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Length of each trailer	40	40	40	27	30	40
Front bumper to nose of first trailer	10	15	15	8	8	16
Space between trailers	----	----	----	3	3	3
Width over tires	8	8	8	8	8	8
Wheel base, tractor (to centerline of tandem axle)	10	15	15	8	8	16
Front bumper to front axle of tractor	3	3	3	3	3	3
Wheelbase, semitrailer	31	29	32	21	24	32
Rear pintle hook overhang of semitrailer	----	----	----	3	3	5
Wheelbase of trailer converter dolly	----	----	----	6	6	6
Wheelbase, full trailer	----	----	----	21	24	32
Rear overhang of trailer	3	8	5	3	3	5
Overall length of trailer combinations	50	55	55	65	71	99

Table 4.—Vehicle offtracking computations and AASHO propos

Vehicle types	Overall length	90-degree turn, 50-foot turning radius			270-degree turn, 150-foo turning radius		
		Off-tracking	Turning track width	Inside curb radius	Off-tracking	Turning track width	Insic curl radiu
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Fee*
Long trailer combinations:							
2–S1	50	11.3	19.3	30.7	4.5	12.5	137.
2–S2	55	10.3	18.3	31.7	3.7	11.7	138.
3–S2	55	11.7	19.7	30.3	4.3	12.3	137.
2–S1–2	65	9.4	17.4	32.6	3.3	11.3	138.
2–S1–2	71	12.5	20.5	30.5	4.4	12.4	137.
3–S2–4	99	22.0	30.0	20.0	8.1	16.1	133.
AASHO proposals: [1]							
Passenger cars	19	1.1	7.1	42.9	0.4	6.4	143.
Other vehicles:							
2	30	3.8	12.3	37.7	1.2	9.7	140.
2–S2	50	7.8	16.3	33.7	2.7	11.2	138.
3–S2	55	11.8	20.3	29.7	4.2	12.7	137.

[1] Proposed 1965 revision of AASHO highway design vehicles.

Table 5.—Dimensions in proposed 1965 revision of AASHO highway design vehicles listed in table 4

	Single-unit truck or bus	2–S2 trailer combinations, WB-40[1]	3–S2 trailer combinations, WB-50[1]
	Feet	*Feet*	*Feet*
Length of trailer	--------	36	37
Front bumper to nose of trailer	--------	14	18
Width over tires	8.5	8.5	8.5
Wheelbase, single-unit truck, or tractor	20	13	18
Front bumper to front axle	4	4	3
Wheelbase, semitrailer	--------	25	30
Rear overhang	6	8	4
Overall length of vehicles	30	50	55

[1] AASHO identification for trailer combinations by wheelbase.

Table 6.—Model and SAE offtracking test results

Trailer combinations	Trailer length	Overall length	Offtracking: 90-degree turn, 50-foot turning radius		Offtracking: 270-degree turn, 150-foot turning radius	
			Model	SAE	Model	SAE
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2–S1	40	50	11.30	16.62	4.47	4.36
2–S1	40	55	13.00	18.75	4.96	4.81
2–S2	40	50	8.90	11.69	3.28	3.26
2–S1	40	55	10.30	13.51	3.72	3.69
3–S2	40	50	10.00	14.46	3.87	3.90
3–S2	40	55	11.65	16.45	4.30	4.34
2–S1–2	2×27	65	9.38	-----	3.28	3.06
2–S1–2	2×30	71	12.48	-----	4.41	4.32
3–S2–4	2×40	99	21.97	-----	8.12	8.16

paring them with the maximum offtracking results computed by the SAE equations. Results of some of the comparisons are listed in table 6. As shown the tractor-semitrailer models negotiating the 90-degree turns on the 50-foot turning radius curve did not obtain SAE maximum offtracking. For the tractor-semitrailer and full trailer models negotiating the same turns, the SAE offtracking equation is not applicable because the trailing rear axle of the trailer combination passed behind the turning center.

REFERENCES

(1) *Turning Ability and Off Tracking—SAE J695*, by Society of Automotive Engineers, Inc., 1965 SAE Handbook, pp. 913–918.

(2) *AASHO Highway Definitions*, by American Association of State Highway Officials, 1962.

(3) *Commercial Motor Vehicle Nomenclature*—SAE J687a, by Society of Automotive Engineers, Inc., 1965 SAE Handbook, pp. 904–906.

(4) *Path of Vehicles on Curves and Minimum Width of Turning Lanes*, appendix to *Determining Widths of Pavements in Channelized Intersections*, by L. F. Heuperman, HRB Bulletin 72, Directional Channelization and Determination of Pavement Widths, 1953, pp. 23–49.

(5) *Truck Paths on Short Radius Turns*, by State of California Department of Public Works, Division of Highways, Aug. 1949.

(6) *Truck Turns*, by J. C. Young, Califor Highways and Public Roads, vol. 29, N 3, 4, March–April 1950, pp. 14–31.

(7) *Observations on the Turning Cha teristics of Western Type Trucks and C binations*, by Western Highway Institu Technical Bulletin No. 2, July 15, 1950.

(8) *Turning Radius and Swept Path Ch acteristics of 44 Seat and 51 Seat Urban T Transit Buses*, by B. H. Sexton a I. J. LoJacono, Capital Transit Co., Wa ington, D.C., Oct. 1952. (Processed)

(9) *Truck Widths of Vehicles on Curs* by Frederick Jindra, Traffic Engineer g vol. 32, No. 12, Sept. 1962, pp. 15–18.

(10) *Offtracking of Tractor-Trailer Com nations*, by Frederick Jindra, Automo Engineer, United Kingdom, March 19 pp. 96–101.

(11) *Determination of Oversized Vehi Tracking Patterns by Adjustable Scale Mo* by DeVere M. Foxworth, Highway e search Board Proceedings, vol. 39, Ja 1960, pp. 479–491.

(12) *Tracking Mechanisms and Couplin for a Combat Support Train Concept, Ph IIA, Off-tracking of Trailer Trains*, by Southwest Research Institute, TCREC Te nical Report 62–12, SwRI Report No. EE–43, March 1962.

(13) *Commercial Vehicle Maneuvers— Analysis of Vehicle Turning Paths and O Operation, at Existing Junctions, of the La Lorries now Permitted Under the Constr tion and Use Revisions*, by R. M. Newl d Roads and Road Construction, vol. 42, o. 501, Sept. 1964, pp. 278–284.

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