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In this issue: A study of braking performance of passenger cars, trucks, and truck combinations.

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IN THIS ISSUE

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Stopping Ability of Motor Vehicles Selected From the General Traffic

DIVISION OF HIGHWAY TRANSPORT RESEARCH

BUREAU OF PUBLIC ROADS

Reported[1] by F. WILLIAM PETRING, Highway Transport Research Engineer

This article presents the results of tests conducted during 1955 on more than 1,200 vehicles selected at random from the general traffic. It compares past and present levels of brake performance, and shows that improvements in the brake performance of most vehicle types since 1949 have been small. Current performance levels are reported according to vehicle type, gross weight, vehicle capacity, and axle load.

The improvement in general levels of brake performance was smaller between 1949 and 1955 than it was in the earlier period, 1942–49. Only the 3-axle truck-tractors with 2-axle semitrailers and the truck-tractor-semitrailer and full-trailer combinations showed substantially better braking in both periods. The small amount of improvement made by most vehicle types since 1949 indicates that the wide range in stopping abilities which exists among the various types will not be appreciably reduced in the near future. Consequently, this range must be taken into account in highway design, vehicle regulation, and driver training.

The observed levels of performance in stops from 20 miles per hour for commercial vehicles operating in the general traffic stream with normal loads averaged about 25 feet for 2-axle trucks with a manufacturer's gross vehicle weight rating of 10,000 pounds or less. The average levels generally ranged from 35 to 45 feet for other 2-axle trucks, from 40 to 50 feet for the 3-axle trucks, from 45 to 55 feet for truck-tractor-semitrailer combinations, and from 55 to 65 feet for trucks with full trailers and truck-tractor-semitrailer and full-trailer combinations.

The tests also revealed that many commercial vehicles, except for the very light 2-axle trucks, were inadequately braked in proportion to the loads carried on individual axles. However, individual tests proved that vehicles with axle loads as high as 22,000 pounds can be adequately braked.

The percentages of vehicles tested which met the Uniform Vehicle Code specifications for brake-system application and braking distance present a little brighter picture. Some 92 percent of the passenger cars and 84 percent of each of two classifications of 2-axle trucks were able to meet their respective distance specifications of 25, 30, and 40 feet, respectively. About 80 percent of the 3- and 4-axle truck-tractor-semitrailer combinations and 3-axle trucks, and 38 to 64 percent of the largest vehicle combinations complied with their code specification of 50 feet.

Also of interest is the degree of compliance with the deceleration requirement of the Uniform Vehicle Code. Well over 99 percent of the passenger cars met the deceleration specification of 17 feet per second per second. At the same time, all very light 2-axle trucks and 94 percent of other 2-axle trucks met the 14 feet per second per second requirement. So did 76 to 85 percent of the truck-tractor-semitrailer combinations and 3-axle single-unit trucks, 51 percent of the trucks with full trailers, and 69 percent of the truck-tractors with semitrailers and full trailers.

AT THE request of representatives of both Government and industry, the Bureau of Public Roads in 1941 initiated a rather broad program of research on motor-vehicle brakes. Although the program was halted by World War II, one important phase of the work—tests of motor vehicles selected from the everyday traffic—was completed in 1944. In 1947, the program was reinstituted and field work was performed from November 1948 to September 1951. A comprehensive report[2] on the findings of the postwar research was published in 1954.

As a result of the information published by the Bureau of Public Roads, the National Committee on Uniform Traffic Laws and Ordinances revised its Uniform Vehicle Code[3] to provide a more realistic brake performance requirement. Since that time seven States have revised their brake performance requirements, patterning them after the Uniform Vehicle Code.

This article, which covers tests conducted during 1955, provides current information on the braking ability of various types of motor vehicles in the general traffic. It brings up to date similar information presented in earlier reports and compares present levels of brake performance with those determined by earlier tests.

As in previous brake studies, the Bureau of Public Roads was responsible for collection and analysis of the data, but each State in which tests were conducted provided assistance with the field work. Personnel for weighing the vehicles and recording data were furnished by the Maryland State Roads Commission, the California Division of Highways, and the Michigan State Highway Department. Uniformed personnel, who stopped the vehicles to be tested and kept traffic moving smoothly at the test sites, were provided by Maryland State Roads Commission Truck Patrol, California Highway Patrol, and Michigan State Police. Test apparatus used in the field work was furnished by General Motors Proving Ground, McCormick Engineering Co., and the Institute of Transportation and Traffic Engineering of the University of California.

Purposes of Study

The primary purposes of the study were as follows: (1) To show the levels of brake performance that prevail for the various types of vehicles currently found on the highways; (2) to bring up to date, information used as a basis for formulating brake performance regulations for such vehicles; (3) to provide current motor-vehicle brake performance data which may be used in establishing highway design standards; (4) to show the trend in levels of brake performance of the various types of vehicles using the highways; and (5) to focus attention on the existing brake performance situation, particularly with respect to the effect of load and vehicle type.

[1] This article was presented at the National Transportation Meeting of the Society of Automotive Engineers, New York City, October 10, 1956.

[2] *Braking performance of motor vehicles*, by Carl C. Saal and F. William Petring. Published by the Bureau of Public Roads, 1954.

[3] *Uniform vehicle code*, revised 1954. National Committee on Uniform Traffic Laws and Ordinances, Washington, D. C.

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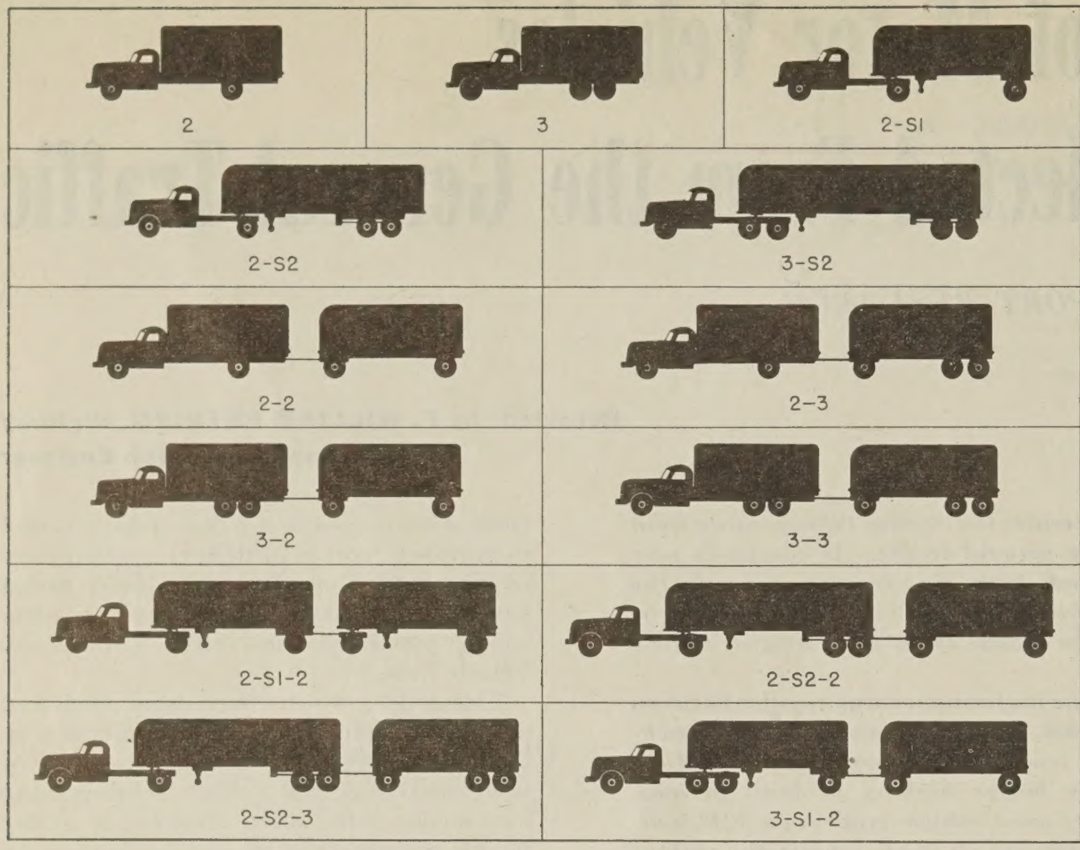


Figure 1.—Commercial vehicle types as designated by code based on axle arrangement.

Terminology

Certain terms used in this article must be thoroughly understood in order to have a clear conception of the results. Definitions of these terms follow:

Brake-system application time or distance.—The time elapsed or distance traveled between the instant or point at which the driver starts to move the braking controls and the instant or point of first retardation by the brakes.

Braking time or distance.—The time elapsed or distance traveled between the instant or point of first retardation by the brakes and the instant or point at which the vehicle comes to rest.

Brake-system application and braking time or distance.—The time elapsed or distance traveled between the instant or point at which the driver starts to move the braking controls and the instant or point at which the vehicle comes to rest. (This definition is identical to the one for "vehicle stopping time or distance" which appears both in the Bureau of Public Roads 1954 report, Braking Performance of Motor Vehicles, and in the 1956 Society of Automotive Engineers Handbook.)

Brake force buildup time or distance.—The time elapsed or distance traveled between the instant or point of first retardation by the brakes and the instant or point maximum braking force is attained.

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

Swerving.—An uncontrollable lateral movement of the vehicle when the brakes are applied, which is involuntary on the part of the driver.

Deceleration.—The rate of reduction of the vehicle speed in feet per second per second.

Maximum deceleration.—The greatest deceleration measured during the stop regardless of the length of time it is sustained.

Manufacturer's gross vehicle weight rating.—The weight, in pounds, of the truck chassis with lubricants, water, and full tank or tanks of fuel, plus the weights of cab or driver's compartment, body, special chassis and body equipment, and payload as authorized by the chassis manufacturer.

Vehicle capacity.—In the case of single-unit trucks, vehicle capacity is the maximum gross vehicle weight rating; for combination units, it is the gross combination weight recommended by the vehicle chassis manufacturer for a given truck-tractor or truck to be used in combination with semitrailers or trailers.

Brake system types

Hydraulic.—Brake shoes are actuated by hydraulic brake cylinders operated with hydraulic line pressure developed by a pedal-operated hydraulic brake master cylinder.

Mechanical.—Brake shoes are actuated by a cam or wedge operated by a cable or rod linked to the brake pedal.

Vacuum-booster hydraulic.—Brake shoes are actuated by a hydraulic brake wheel cylinder operated with hydraulic line pressure developed by a vacuum-powered master cylinder or a vacuum hydraulic power unit.

Air-booster hydraulic.—Brake shoes are actuated by a hydraulic brake wheel cylinder operated with hydraulic line pressure developed by an air-powered master cylinder or an air hydraulic power unit.

Vacuum-mechanical.—Brake shoes are actuated by a cam or wedge operated by a vacuum brake chamber through a mechanical linkage.

Air-mechanical.—Brake shoes are actuated by a cam or wedge operated by an air brake chamber through a mechanical linkage.

Scope of Study

Tests to determine the brake-system application and braking distances of a representative number of vehicles were conducted on passenger cars and commercial vehicles selected at random from the general traffic. The vehicles were stopped on the highway by a uniformed policeman, weighed and de-

Table 1.—Number of vehicles tested by State, type, and axle arrangement in 1955 and in 1949

Type of vehicle [1]	Number of vehicles tested							
	1955				1949			
	Maryland	Michigan	California	Total	Maryland	Michigan	California	Total
Passenger cars	104	101	105	310	99	112	100	311
Single-unit trucks:								
2-axle	134	138	128	400	132	148	87	367
3-axle	20	28	25	73	19	4	23	46
Subtotal	154	166	153	473	151	152	110	413
Truck-tractors with semitrailers:								
2-S1	69	39	21	129	132	89	25	246
2-S2	93	43	17	153	17	44	37	98
3-S2	2	29	35	66	------	2	55	57
Subtotal	164	111	73	348	149	135	117	401
Trucks with trailers:								
2-2	------	9	7	16	------	6	3	9
2-3	------	------	1	1	------	------	2	2
3-2	------	13	33	46	------	4	12	16
3-3	------	------	7	7	------	------	27	27
Subtotal	------	22	48	70	------	10	44	54
Truck-tractors with semitrailers and trailers:								
2-S1-2	------	9	35	44	------	18	32	50
2-S2-2	------	5	2	7	------	6	3	9
2-S2-3	------	2	------	2	------	1	------	1
3-S1-2	------	------	1	1	------	------	------	------
Subtotal	------	16	38	54	------	25	35	60
Other vehicle combinations:								
Passenger-car driveaway-towaway	------	3	------	3	------	------	------	------
Housetrailer factory towaway	------	5	------	5	------	------	------	------
Subtotal	------	8	------	8	------	------	------	------
Grand total	422	424	417	1,263	399	434	406	1,239

[1] For an explanation of the code used, see p. 179.

scribed, and then subjected to emergency stops from a speed of 20 miles per hour. The test was not compulsory, and each driver clearly understood that punitive action would not be taken. The tests were conducted during 1955 on heavily traveled highways in Maryland and Michigan at the same sites used in a similar study in 1949, and in California at a site in the same general area as that used in 1949.

Table 1 shows the number of vehicles, by type and axle arrangement, tested in each State in 1949 and 1955. A similar series of tests, conducted during 1941 and 1942, included 907 passenger cars, 1,403 single-unit trucks, 1,597 truck-tractors with semitrailers, 216 trucks with full trailers, and 36 truck-tractors with semitrailers and full trailers. This early study was conducted at 11 locations in 10 States of wide geographical distribution. In order to maintain a continuing record of the levels of brake performance of the various types of vehicles in use on the highways, it is planned to conduct similar tests about every 5 years at locations as near as practicable to the three used in the 1949 and 1955 tests.

Conclusions

The following conclusions are based on the type and number of vehicles tested, and on the test procedures employed:

1. Except for two vehicle types, the improvement in the general levels of brake performance of motor vehicles selected from the general traffic was considerably smaller between 1949 and 1955 than it was between 1942 and 1949. The 3-axle truck-tractor with 2-axle semitrailer combinations and the truck-tractor-semitrailer and full-trailer combinations each showed a perceptible improvement of about the same magnitude in both periods. In contrast, for all other vehicle types, the improvement was appreciable in the earlier period while it was negligible in the later period.

2. In view of the small magnitude of improvement in brake-system application and braking distance made by most vehicle types since 1949, it appears that the wide range in stopping ability of the various vehicle types will not be significantly reduced in the near future. It follows that this wide range must be recognized in highway design, vehicle regulation, and driver training activities.

3. From 38 to 64 percent of the largest combination vehicle types and about 80 percent of the 3- and 4-axle truck-tractor-semitrailer combinations and 3-axle trucks were capable of complying with the Uniform Vehicle Code specification of a 50-foot stop from 20 miles per hour; 84 percent of each of the two classifications of 2-axle trucks and 92 percent of the passenger cars were able to comply with their respective distance specifications of 40, 30, and 25 feet.

4. Almost all passenger cars and 2-axle trucks, 76 to 85 percent of the 3-axle trucks and truck-tractor-semitrailer combinations, 69 percent of the truck-tractors with semitrailers and full trailers, and 51 percent of the trucks with full trailers were capable of meeting their respective Uniform Vehicle Code specifications for deceleration when tested with a pendulum-type decelerometer.

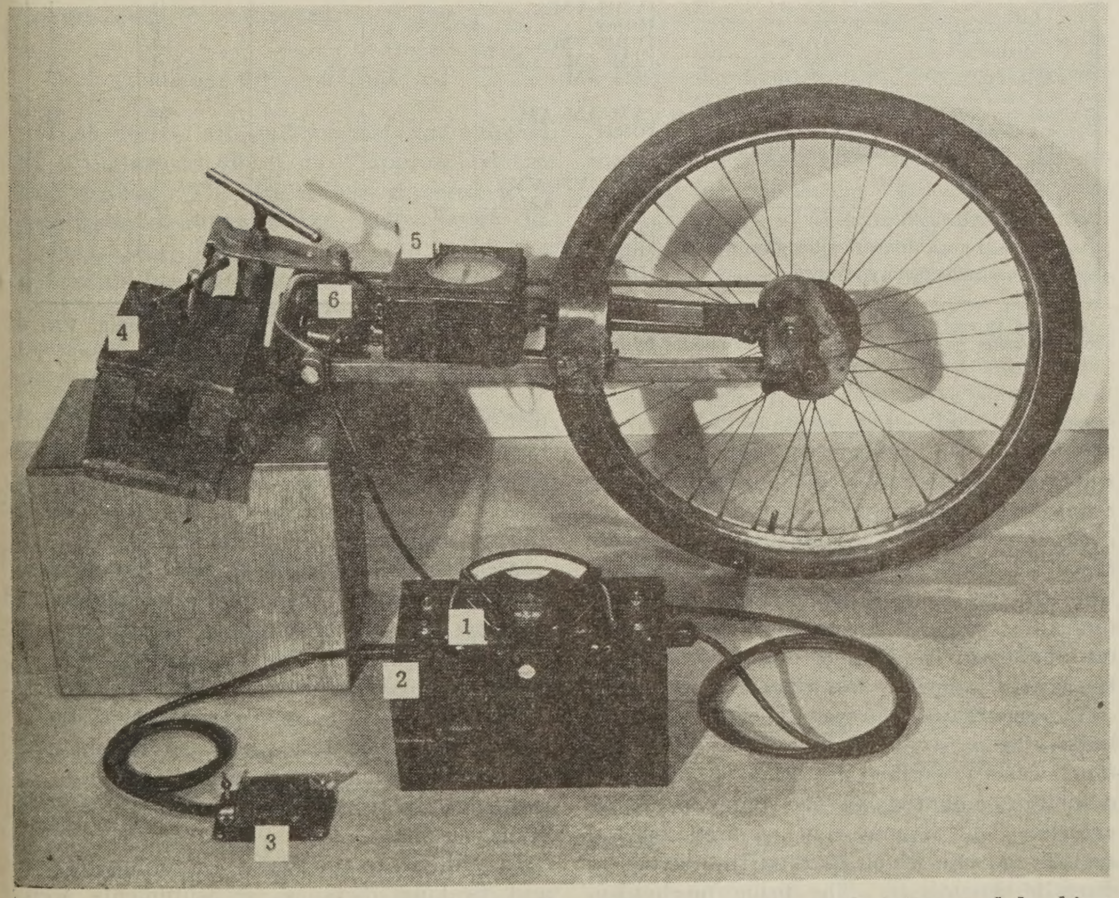


Figure 2.—Apparatus for measuring speed and brake-system application and braking distance: speedometer (1), control box (2), pedal switch (3), running-board clamp (4), odometer (5), and generator (6).

5. The observed average levels of brake performance in stops from 20 miles per hour for commercial vehicles, operating in the general traffic with normal loads, were about 25 feet for 2-axle trucks with a manufacturer's gross vehicle weight rating of 10,000 pounds or less, and ranged generally from 35 to 45 feet for other 2-axle trucks, from 40 to 50 feet for 3-axle trucks, from 45 to 55 feet for 3-, 4-, and 5-axle truck-tractor-semitrailer combinations, and from 55 to 65 feet for trucks with full trailers and truck-tractor-semitrailer and full-trailer combinations.

6. Many of the commercial vehicles, except very light 2-axle trucks, were found to be inadequately braked in proportion to the loads carried on individual axles. This condition may result from inadequate maintenance, axle loads heavier than those for which the brake components were designed, and/or poor selection of brake components. However, individual tests proved that vehicles with axle loads as high as 22,000 pounds can be adequately braked.

7. A substantial percentage of passenger cars and single-unit trucks selected from the general traffic showed a tendency to swerve—a condition that may be very dangerous in making emergency stops from normal speeds.

Vehicle Type Code

For convenience in reference, commercial vehicle types were assigned a code. Each digit represents the number of axles of a vehicle or of one unit of a vehicle combination. A combination symbol consisting of 2 or 3 parts separated by hyphens indicates a vehicle combination. The first digit of a combination symbol represents the power unit. An "S" in the second part of a combination symbol indicates a semitrailer, and the power unit, of course, is a truck-tractor. A digit appearing without an "S" in either the second or third position in a combination symbol represents a full trailer.

2 = 2-axle single-unit truck
3 = 3-axle single-unit truck
2–S1 = 2-axle truck-tractor with 1-axle semitrailer
2–S2 = 2-axle truck-tractor with 2-axle semitrailer
3–S2 = 3-axle truck-tractor with 2-axle semitrailer
2–2 = 2-axle truck with 2-axle trailer
2–3 = 2-axle truck with 3-axle trailer
3–2 = 3-axle truck with 2-axle trailer
3–3 = 3-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 1-axle semitrailer and 2-axle trailer

Illustrations of the various types of commercial vehicles tested and their respective code designations appear in figure 1.

The Test Sites

All of the tests were conducted on dry, smooth pavement, and each test section was approximately level and located on a tangent. The pavements at the Michigan and California test sites were portland cement concrete, and that at the Maryland site was a bituminous mat over portland cement concrete. In order to determine whether results obtained on the bituminous surface would be comparable with those obtained on portland cement concrete

Table 2.—Classification of vehicles tested by vehicle type, capacity, and brake type

Vehicle type and capacity	Brake type [1]	Number of vehicles tested in—			
		Maryland	Michigan	California	Total
Passenger cars	H	92	82	98	272
	VBH	11	19	6	36
	M	1	—	1	2
2-axle trucks:					
Very light	H	40	23	40	103
	VBH	—	3	—	3
	M	—	—	1	1
Light	H	6	13	5	24
	VBH	50	68	59	177
	ABH	—	—	1	1
	M	—	—	1	1
Medium	H	—	1	—	1
	VBH	21	25	15	61
	ABH	3	—	—	3
	AM	9	1	2	12
	M	—	1	—	1
Heavy	VBH	1	1	1	3
	ABH	1	—	—	1
	AM	4	1	3	8
3-axle trucks:					
Light	VBH	4	—	1	5
	ABH	—	5	—	5
	Other	2	1	1	4
Medium	VBH	2	7	9	18
	ABH	1	2	—	3
	AM	3	3	1	7
	Other	1	—	—	1
Heavy	VBH	—	—	3	3
	AM	7	10	10	27
2-axle truck-tractors with 1-axle semitrailers:					
Light	VBH-VM	5	13	2	20
	ABH-VM	4	—	1	5
	AM-AM	—	—	1	1
Medium	VBH-VM	2	13	7	22
	ABH-AM	4	1	—	5
	AM-AM	20	5	5	30
	Other	6	1	1	8
Heavy	AM-AM	25	5	4	34
	AM-VM	3	1	—	4
2-axle truck-tractors with 2-axle semitrailers:					
Light	VBH-VM	—	—	1	1
	Other	1	—	1	2
Medium	VBH-VM	—	3	1	4
	ABH-AM	—	3	—	3
	AM-AM	21	13	1	35
	Other	—	5	—	5
Heavy	AM-AM	71	18	12	101
	AM-VM	—	1	1	2
3-axle truck-tractors with 2-axle semitrailers:					
Medium	AM-AM	2	9	2	13
	ABH-AM	—	1	—	1
Heavy	AM-AM	—	19	32	51
	VBH-VM	—	—	1	1
3-axle trucks with 2-axle trailers:					
Medium	AM-AM	—	2	—	2
Heavy	AM-AM	—	11	33	44
Other trucks with trailers:					
Light	VBH-VM	—	—	1	1
	Other	—	—	2	2
Medium	VBH-VM	—	—	1	1
	AM-AM	—	—	1	1
Heavy	AM-AM	—	9	10	19
2-axle truck-tractors with 1-axle semitrailers and 2-axle trailers (heavy)	AM-AM-AM	—	9	34	43
	Other	—	—	1	1
Other truck-tractors with semitrailers and trailers:					
Medium	VBH-VM-VM	—	—	1	1
Heavy	AM-AM-AM	—	7	2	9
Other vehicle combinations:					
Passenger-car driveaway-towaway	H	—	2	—	2
	VBH	—	1	—	1
Housetrailer factory towaway	H-E	—	5	—	5

[1] Brake types: *H*=hydraulic, *M*=mechanical, *E*=electric, *VM*=vacuum-mechanical, *AM*=air-mechanical, *VBH*=vacuum-booster hydraulic, and *ABH*=air-booster hydraulic.

surfaces, a few preliminary tests were run before final selection of the Maryland test site. Locked-wheel stops were made with a passenger car on the bituminous-covered section of pavement, later selected for the brake tests, and on a section of the same highway having a good portland cement concrete surface. Results of these tests showed that the sliding coefficient of friction for stops made from 20 miles per hour was almost identical at the two sites and within the range of values normal for good portland cement concrete pavement surfaces. The site with the bituminous surfacing was selected for this study because it was the one used for the 1949 study, and also because of certain safety features. In the earlier study, the concrete pavement had not been resurfaced.

Each of the three test sites was located on a section of 4-lane divided highway. The lane in which tests were conducted was closed off with rubber traffic cones placed at approximately 75-foot intervals for a distance of about one-half mile. All through-traffic was diverted to the other lane. Advance signs warned drivers to slow down, indicated that brake tests were in progress, and directed through-traffic into the open lane. A patrolman stationed at the approach to the test lane directed vehicles to be tested into the weighing area and kept other traffic moving smoothly through the open lane.

The Instrumentation

The key measurement in the study was brake-system application and braking distance.[4] A test wheel, shown in figure 2, was used to measure this distance in feet and to indicate vehicle speed in miles per hour. The apparatus was so arranged that the instant the driver put his foot on a switch, which was securely fastened to the face of the brake pedal on the test vehicle, an electrical circuit was completed which started the distance-measuring device. The circuit was maintained by a holding relay until released by the observer after the vehicle had come to rest. Thus, the distance was measured from the point at which the driver started to move the braking control to the point at which the vehicle came to rest. Whenever a hand control valve was to be used during the brake test, a small fingerlike switch was attached to the valve control handle and included in the circuit in conjunction with the pedal switch. Distance was thereby measured from the point of first contact with a braking control.

Since brake-system application and braking distance varies with speed at a significant rate, an accurate determination of speed also was essential. The vehicle speed was indicated directly by a voltmeter calibrated in miles per hour. The voltmeter, which was held in the lap of the observer, was wired to a belt-driven generator mounted on the frame of the test wheel.

In order to insure accuracy of the data, the test wheel was calibrated at frequent intervals. To calibrate the speedometer, the time required to travel a measured mile at a constant speed of 20 miles per hour, as indicated by the test wheel, was measured with a stopwatch and compared with the computed time required to travel a mile at that speed. In every instance the actual time required to travel the mile varied from the computed time by less than 1 percent. The distance indicated by the test wheel was also checked on the measured mile and found to vary from the true distance by less than 0.2 percent.

The accuracy of the test wheel in measuring brake-system application and braking distance was also verified by means of an electric detonator mounted on the bumper of the vehicle. The detonator, when fired, ejected a chalk capsule which marked the pavement directly beneath it. The firing mechanism was wired to the same pedal switch used to actuate the distance-measuring device on the test wheel. The instant the driver started to move the braking control the gun fired causing the chalk capsule to mark the pavement, and simultaneously the test wheel started to measure the distance traveled.

After the vehicle came to rest, the distance was measured from a point on the pavement directly below the detonator to the point where the gun was fired, which was clearly indicated by the mark on the pavement. This distance was compared with the distance indicated by the test wheel. Periodic tests made in this manner showed a variation of less than 2 percent between the two methods of measurement.

In addition to the brake-system application and braking distance, measurements were made of the maximum deceleration as indicated by a portable decelerometer. The de-

[4] See definition, p. 178

celerometer used was a popular make of the pendulum type. A moving scale on the instrument is graduated to read percent braking efficiency, which is actually the percentage of one-G deceleration. For example, a reading of 80 percent on the instrument would be a deceleration of 0.80×32.2 feet per second per second or 25.8 feet per second per second. Movement of the scale is actuated by and is proportional to movement of a damped pendulum. When the vehicle is moving at a uniform speed, the pendulum will assume a vertical position. However, if the vehicle speed is reduced, as by the application of brakes, the pendulum tending to move on at the same speed will swing forward. The tangent of the angle through which the pendulum moves forward away from the vertical is directly proportional to the deceleration. The instrument holds the moving scale at the maximum value attained until released by the observer.

Vehicle Sample

At the test location in each of the three States, approximately 300 commercial vehicles and 100 passenger cars were selected from traffic and tested. The commercial vehicles were selected to produce a sample about equally distributed between single-unit trucks and combination vehicles. Selectivity was exercised also to provide a wide range of vehicle makes, gross weights, capacities, and brake types. The passenger cars were chosen to represent a wide range of makes and year models. Vehicles loaded in an unsafe manner, and those whose drivers objected to participating in the test, were not included. However, only a very small percentage of the drivers asked to be excused.

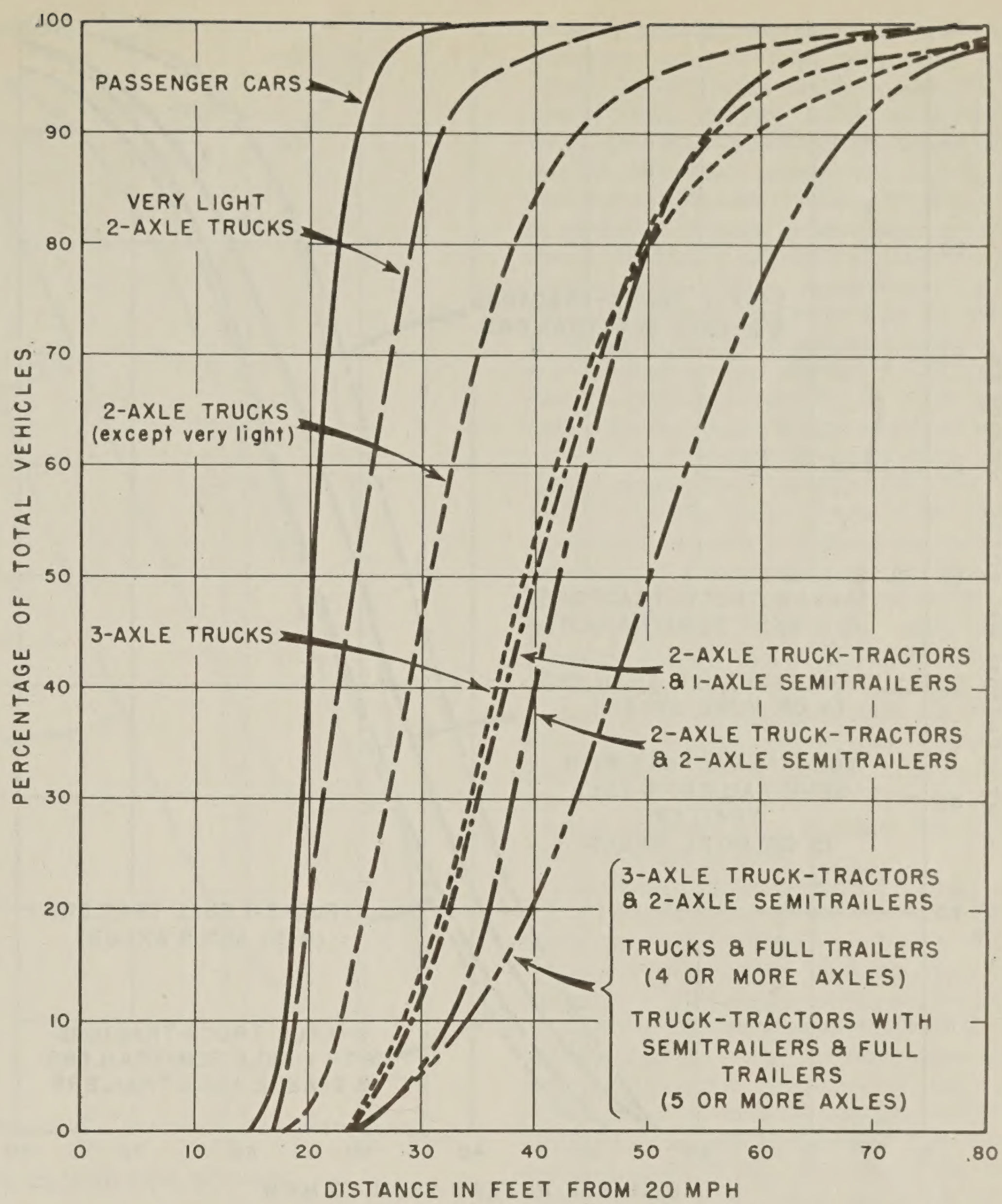


Figure 3.—Cumulative frequency distribution of minimum brake-system application and braking distances of motor vehicles selected from the general traffic.

Test Operations

Each vehicle selected for test was stopped by a uniformed officer as it approached the test section. The driver was directed to a spot where a crew was stationed to weigh the vehicle, record pertinent data, and install the apparatus for measuring brake performance. Each axle of the vehicle to be tested, including passenger cars, was weighed. In Maryland the vehicles were weighed on loadometers set in pits in a parking area adjacent to the highway; in California and Michigan, they were weighed on State-owned platform scales located adjacent to the test section.

Each vehicle tested was assigned a test number for use in coordinating the field data. Four separate forms were used to tabulate the following information: (1) axle weights, (2) vehicle characteristics, (3) skid data, and (4) brake performance and incidental data observed during the road tests.

Vehicle characteristics were recorded during the weighing operation. This description included the vehicle make, model, year model, type, manufacturer's gross weight rating, brake type, number of axles without brakes, total number of axles, and whether the vehicle was loaded or empty. When the weighing of the vehicle and the recording of vehicle characteristics had been completed, the apparatus for measuring brake performance was installed and the road tests were conducted. The regular driver of the vehicle, under the direction of an observer who rode beside him, made the emergency stops.

The road tests for each vehicle consisted of at least three emergency stops from a speed of 20 miles per hour. The observer noted, in the case of a commercial vehicle, whether there was a hand control valve and if it was used in making the stops. He also noted whether there was a valve for limiting the pressure applied to the front wheel brakes and, if so, the valve setting used in making the stops. After each stop the observer recorded the brake-system application and braking distance as indicated by the test wheel, the decelerometer reading, the brake pedal reserve, whether the vehicle swerved, and whether the clutch was engaged or disengaged during the stop.

As previously mentioned, all traffic was excluded from the lane in which the tests were being conducted. However, as an added precaution in case some vehicle should enter the test lane, each vehicle being tested was followed by an observer in another vehicle. The space between the two vehicles was held to the distance necessary to prevent other traffic from entering. A large sign reading DANGER—BRAKE TESTS—SUDDEN STOPS was attached to the rear of the observer's vehicle, as shown on the cover page, and a flashing red warning light was mounted on top. After each stop the second observer measured and recorded the lengths of any skid marks left by the test vehicle.

Classification of Vehicles

One of the first steps in the analysis of the test results was the classification of data: first by vehicle type, second by vehicle capacity groups for each vehicle type, and finally by brake types for each vehicle capacity group. Table 1 shows the number of vehicles tested in each State, both in 1949 and 1955, by vehicle type and axle arrangement. Table 2 shows by capacity groups and by brake types, the number of vehicles of each type tested in 1955.

All commercial vehicles were segregated into vehicle capacity groups on the basis of the chassis manufacturer's gross vehicle weight or gross combination weight rating.

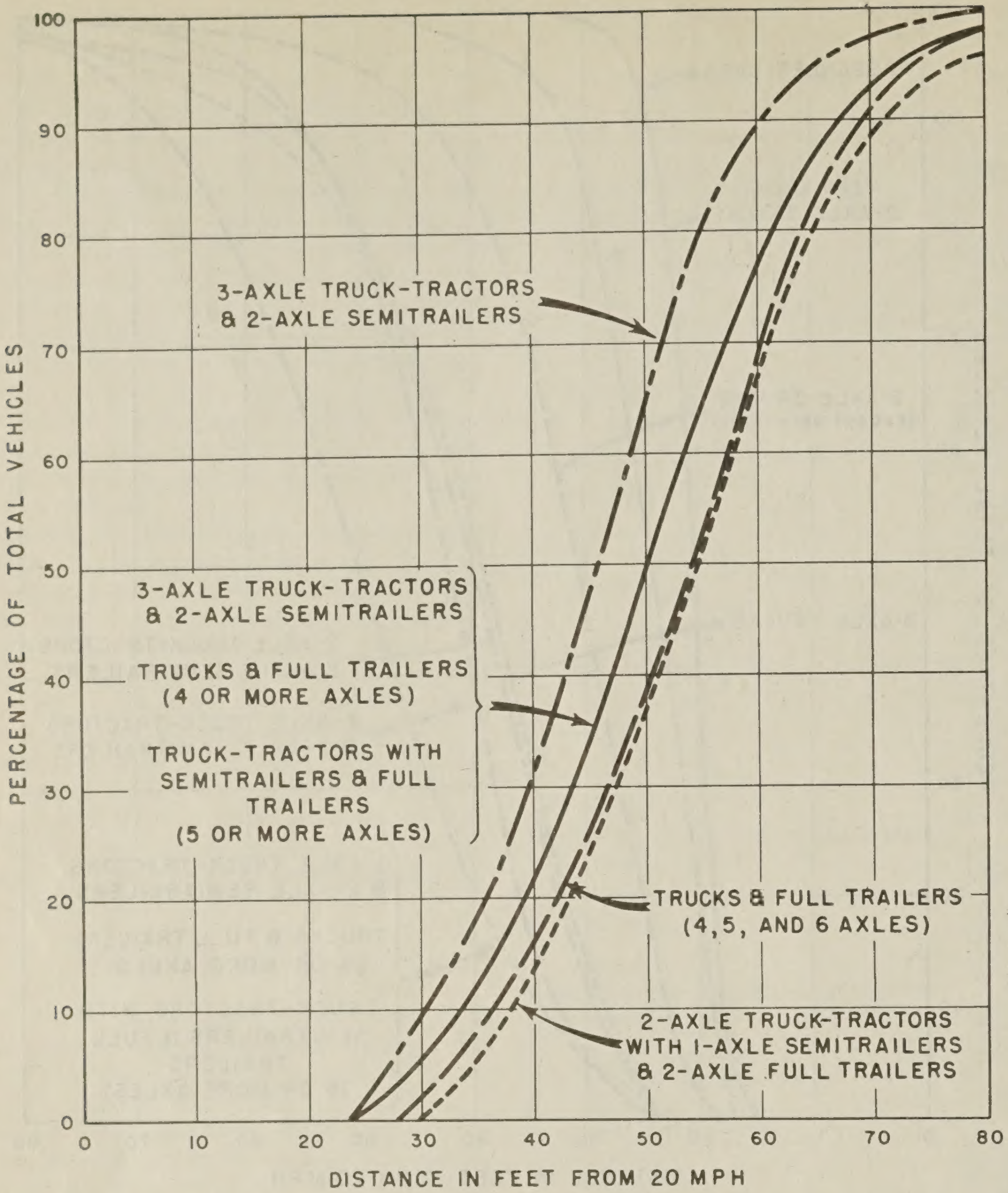


Figure 4.—Cumulative frequency distribution of minimum brake-system application and braking distances of the larger combination vehicles.

Table 3.—Classification of vehicles by capacity groups

Vehicle capacity group	Manufacturer's gross weight rating for—	
	Single-unit vehicles	Combination vehicles
	Pounds	*Pounds*
Very light	10,000 and under	----------------
Light	10,001–16,000	27,000 and under.
Medium	16,001–24,000	27,001–44,000.
Heavy	Over 24,000	Over 44,000.

truck and full-trailer combinations and truck-tractor-semitrailer and full-trailer combinations were generally equipped with air-mechanical brakes on all units. As in the the 1949 study, air-mechanical brakes predominated on the heavy capacity commercial vehicles.

The greatest percentage of the passenger cars were equipped with hydraulic brakes. However, the increasing popularity of power brakes was evident in that approximately 12 percent of the passenger cars tested were equipped with vacuum-booster hydraulic brakes. The percentage of passenger cars observed in the study equipped with mechanical brakes indicates that very few cars so equipped remain on the highways. Out of the total sample of 310 passenger cars, only 2 were equipped with mechanical brakes. One of the two was a postwar vehicle of foreign manufacture and the other a prewar American make.

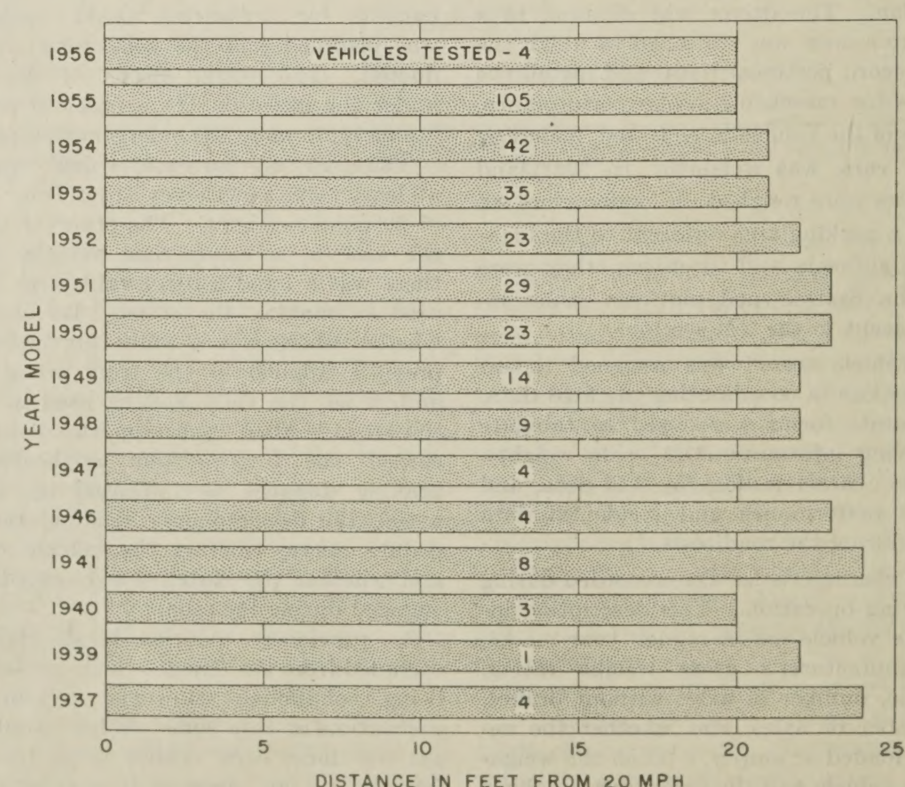
It is apparent from table 2 that the limited size of the sample and the nature of its distribution by vehicle type, capacity group, and brake type precludes comprehensive comparisons of brake performance by brake types. However, the sample was adequate to compare the performance of the two predominating brake types observed on passenger cars, light single-unit trucks, and medium 2-axle truck-tractors with 1-axle semitrailers.

Single-unit trucks were classified into four groups (very light, light, medium, and heavy); and the combination vehicles, three groups (light, medium, and heavy). The range of gross weight ratings for single-unit and combination vehicles is shown in table 3.

In many instances the vehicle chassis manufacturer's recommended maximum weight for a truck or truck-tractor, used in combination with trailers, was not available. When this occurred the combination was classified as light, medium, or heavy on the basis of the power unit when used as a single-unit truck.

The most common brake types for the single-unit trucks were hydraulic and vacuum-booster hydraulic. The truck-tractor-semitrailer combinations were most commonly equipped with vacuum-booster hydraulic brakes on the tractor and vacuum-mechanical on the semitrailer or air-mechanical brakes on both units of the combination. The

Figure 5 (Right).—*Variation of average brake-system application and braking distances with year model for passenger cars equipped with hydraulic brakes and vacuum booster hydraulic brakes.*



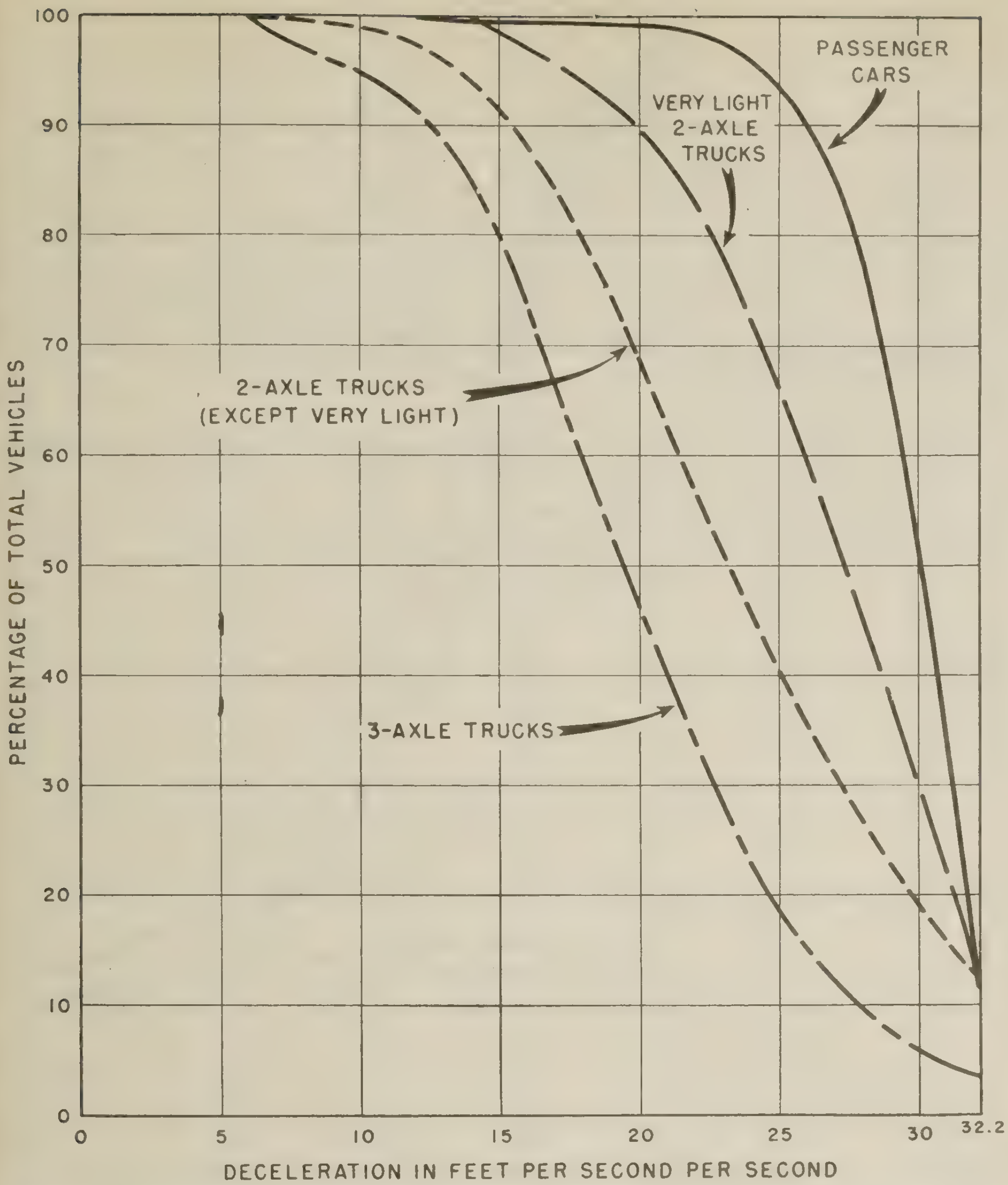


Figure 6.—Percentage of single-unit vehicles capable of a given or greater deceleration.

Consistency of Distance Data

As previously mentioned, the road tests of each vehicle consisted of three emergency stops from 20 miles per hour. In many instances, the first stop and sometimes the second did not represent the best possible braking performance of the vehicle, as frequently the driver was at first hesitant in making a true emergency stop, or did not understand that the shortest possible stop was desired. Since the length of the level test section was usually too short to make additional runs and it was not practical to turn vehicles around on the highway, the tests were not repeated.

In view of the fact that each of the three runs did not always represent the best brake performance of the vehicle being tested, an average of the three runs would not correctly reflect the true level of performance. Therefore, the minimum brake-system application and braking distance recorded for each vehicle was used in the analysis of the test results. This procedure also was followed in analyzing the results of the two previous studies. On the average there was a variation of slightly over 4 percent between the minimum or the maximum and the average brake-system application and braking distance observed for the three stops.

General Levels of Performance

The levels of brake performance of the various types of vehicles selected from the general traffic in 1955 are indicated in figures 3–8. In figures 3–5, where brake-system application and braking distance is the criterion of performance, the best performance is indicated by the shortest distance. But in figures 6–8, where deceleration is the criterion, the best performance is indicated by the highest deceleration. In studying the general results presented in the illustrations, it must be kept in mind that the sample of vehicles of each type is made up of various gross weights, capacities, brake types, and conditions of maintenance.

Brake-system application and braking distance

Figures 3 and 4 reveal quite clearly the differences in stopping ability of the various types of vehicles. The curves indicate the percentage of vehicles of each type that can stop in a given distance or less from a speed of 20 miles per hour. For example, figure 3 shows that the 50-percentile values for the various types of vehicles were as follows: Passenger cars, 20 feet; very light 2-axle trucks, 24 feet; other 2-axle trucks, 31 feet; 3-axle trucks, 39 feet; 2-axle truck-tractors with 1-axle semitrailers, 40 feet; 2-axle truck-tractors with 2-axle semitrailers, 42 feet; and all other combination vehicles, 50 feet. It is of particular interest to note that the curves shown in figure 3 converge at the lower percentile values. Thus, improvement in the levels of braking performance of all vehicle types will bring the performance levels of the individual types closer together. It is obvious that the greatest possibilities for improvement exist with the larger commercial vehicles.

In figure 4 the performance of the group of larger combination vehicles, which had the poorest stopping ability of any of the groups represented in figure 3, is shown for the three major types of combinations. For purposes of comparison, a composite curve (solid line) is included for the entire group. It is readily apparent that the 3-axle truck-tractors with 2-axle semitrailers, as a group, performed better than either the trucks with full trailers or the 2-axle truck-tractors with 1-axle semitrailers and 2-axle full trailers. Figure 4 also shows that there was little difference in the braking performance of the latter two groups of combination vehicles.

The average performance of passenger cars equipped with hydraulic and vacuum-booster hydraulic brakes is shown by year model in figure 5. It is evident that age had little influence on the stopping ability of this group of vehicles. On the average the 1955 and 1956 model cars were the best performers, requiring 20 feet to stop from 20 miles per hour. Also, the average stopping ability of the three 1940 model passenger cars tested equalled that of the 1955 and 1956 cars. Although the 1947, 1941, and 1937 model passenger cars were the poorest performers, they required, on the average, only 24 feet to stop. Since the sample was quite small for passenger cars of 1948 vintage and older, the results may not precisely reflect the stopping ability of each individual year model of the vehicles in this group. However, the total sample of these older vehicles was large enough to produce reliable results when considered as a group. The average brake-system application and braking distance for the 1948 model and older passenger cars was 23 feet from 20 miles per hour.

Deceleration

Although measurement of brake-system application and braking distance from a known speed provides the most reliable indication of braking ability, it is also significant to consider maximum deceleration, since brake performance enforcement in many jurisdictions is based entirely on measurement of deceleration. The curves shown in figures 6–8 indicate the decelerating abilities of the various types of vehicles tested. It should be kept in mind that the decelerations measured were not sustained throughout the stops, but were the maximum decelerations indicated during the stops.

Each curve shown in the graphs indicates the percentage of vehicles of a particular type which reached a maximum deceleration of a given or greater value. For example, figure 6 shows that 50 percent of each of the vehicle types represented by the four curves were capable of the following or greater decelerations, expressed in feet per second per second: passenger cars, 30.1; very light 2-axle trucks, 27.4; other 2 axle trucks, 23.2; and 3-axle trucks, 19.4. Similarly, figure 7 shows that 50 percent of each of three types of truck-tractor-semitrailer combinations were capable of the following or greater decelerations, expressed in feet per second per second: 2-axle truck-tractors with 1-axle semitrailers, 18.5; 2-axle truck-tractors with 2-axle semitrailers, 17.2; and 3-axle truck-tractors with 2-axle semitrailers, 16.8. Figure 8 shows that 50 percent of the trucks with full trailers and truck-tractors with semitrailers and full trailers were capable of decelerations of at least 14.2 and 17.1 feet per second per second, respectively. It is evident from figures 6–8 that there is a wide range in the decelerating ability of the various types of vehicles, just as it is evident from figures 3–4 that there is a wide range in their brake-system application and braking distances. Again, it is apparent that the smaller vehicles are capable of better performance.

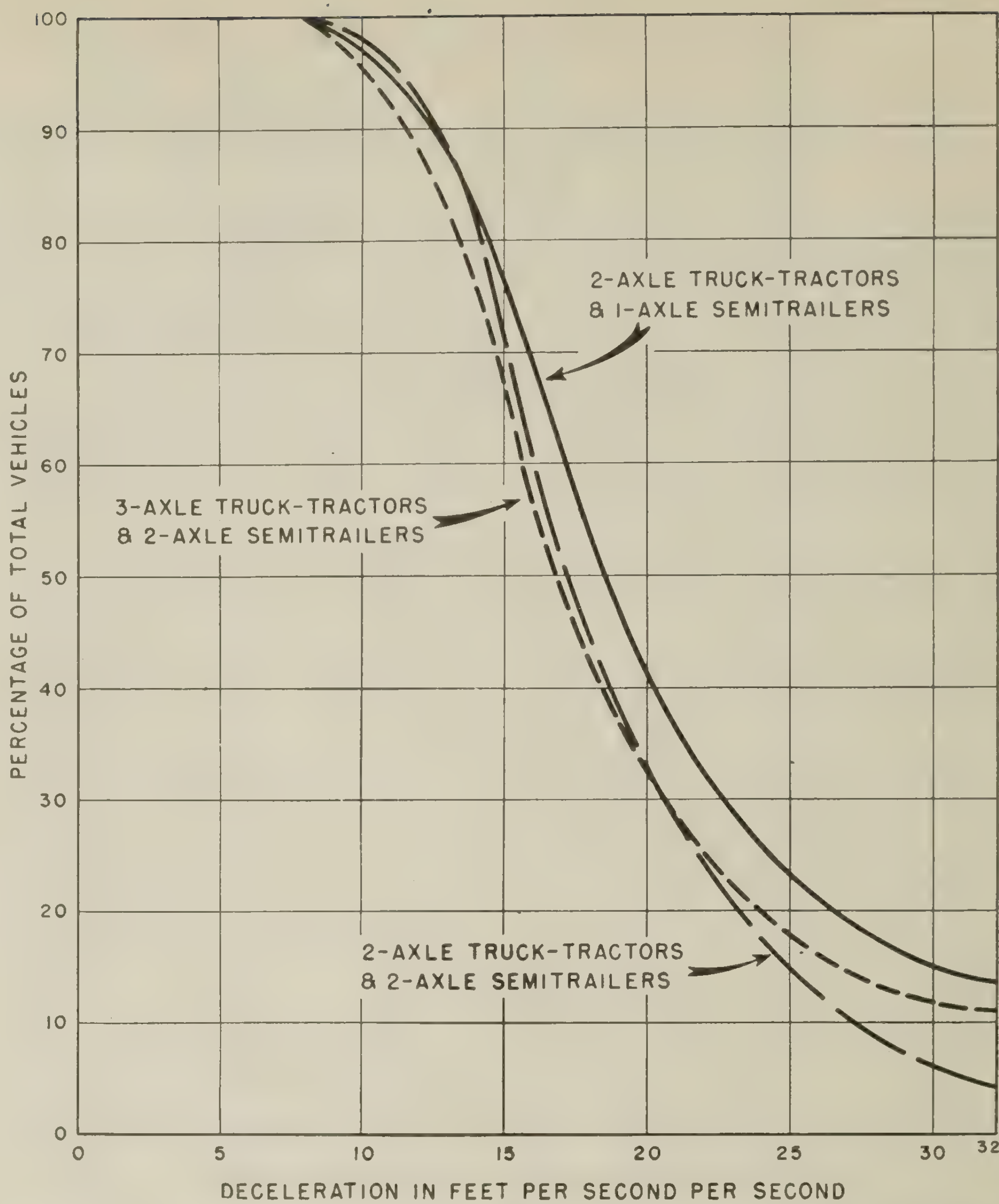


Figure 7.—Percentage of truck-tractor-semitrailer combinations capable of a given or greater deceleration.

Changes in Performance Levels Since 1942 and 1949

Between 1942 and 1949 there was considerable improvement in the brake performance of all types of motor vehicles selected from the general traffic. However, between 1949 and 1955 the improvement in brake performance of the various types of vehicles, with two exceptions, was quite small. Table 4 summarizes the 15-, 50-, and 85-percentile values of brake-system application and braking distance for stops made from 20 miles per hour by the various vehicle types tested in 1942, 1949, and 1955. This general summary again includes vehicles of various gross weights, capacities, brake types, and conditions of maintenance. It will be noted from the table that there was appreciable improvement between 1942 and 1949 in the braking performance at all three levels for each of the vehicle types tested. The greatest improvement, as would be expected, was at the 85-percentile level. Although the improvement at the 50- and 15-percentile levels was progressively smaller, it was still significant for most vehicle types.

Between 1949 and 1955 there was some improvement at the 85-percentile level in the brake performance of each vehicle type even though it was very small for some types. However, at the 50- and 15-percentile levels the performance of some vehicle types in 1955 was slightly below that of 1949. Only two vehicle types showed continuous improvement at all three performance levels. The truck-tractor-semitrailer with full-trailer combinations showed moderate improvement, and the 3-axle truck-tractors with 2-axle semitrailers showed substantial improvement at all three performance levels in both 1949 and 1955. Of course, it is evident that there was more room for improvement in these vehicles than there was for some of the other types.

The improvement in the 3-axle truck-tractors with 2-axle semitrailers is illustrated throughout the range of performance levels by comparing the cumulative frequency distribution curves, shown in figure 9, for the 1955 tests with similar curves plotted from data obtained from the tests conducted in 1949 and 1942. One of the most revealing observations to be made from these curves concerns the percentages of vehicles tested which could stop within 50 feet—the present standard of the Uniform Vehicle Code for combinations of commercial vehicles. In 1942, only 17 percent of these vehicles could stop within 50 feet; but in 1949, 36 percent could stop in 50 feet; and in 1955, 64 percent could stop within 50 feet or less. Between 1949 and 1955, 3-axle truck-tractors with 2-axle semitrailers showed a greater increase than any other type in the percentage of vehicles capable of complying

Table 4.—Comparison of brake-system application and braking distances from 20 miles per hour for various vehicle types tested in 1942, 1949, and 1955

Vehicle type	Brake-system application and braking distance in feet								
	15-percentile level			50-percentile level			85-percentile level		
	1942	1949	1955	1942	1949	1955	1942	1949	1955
Passenger cars	21	17	18	25	21	20	42	26	23
2-axle trucks	28	23	22	40	28	29	64	41	39
3-axle trucks	40	26	30	54	37	39	81	56	54
2-axle truck-tractors with 1-axle semitrailers	38	30	31	52	39	40	75	53	52
2-axle truck-tractors with 2-axle semitrailers	43	34	35	61	43	42	83	60	52
3-axle truck-tractors with 2-axle semitrailers	49	42	33	61	53	46	82	69	57
Trucks with full trailers (4, 5, and 6 axles)	48	39	39	65	52	54	87	70	66
Truck-tractors with semitrailers and full trailers (5, 6, and 7 axles)	47	45	41	62	59	53	82	73	67

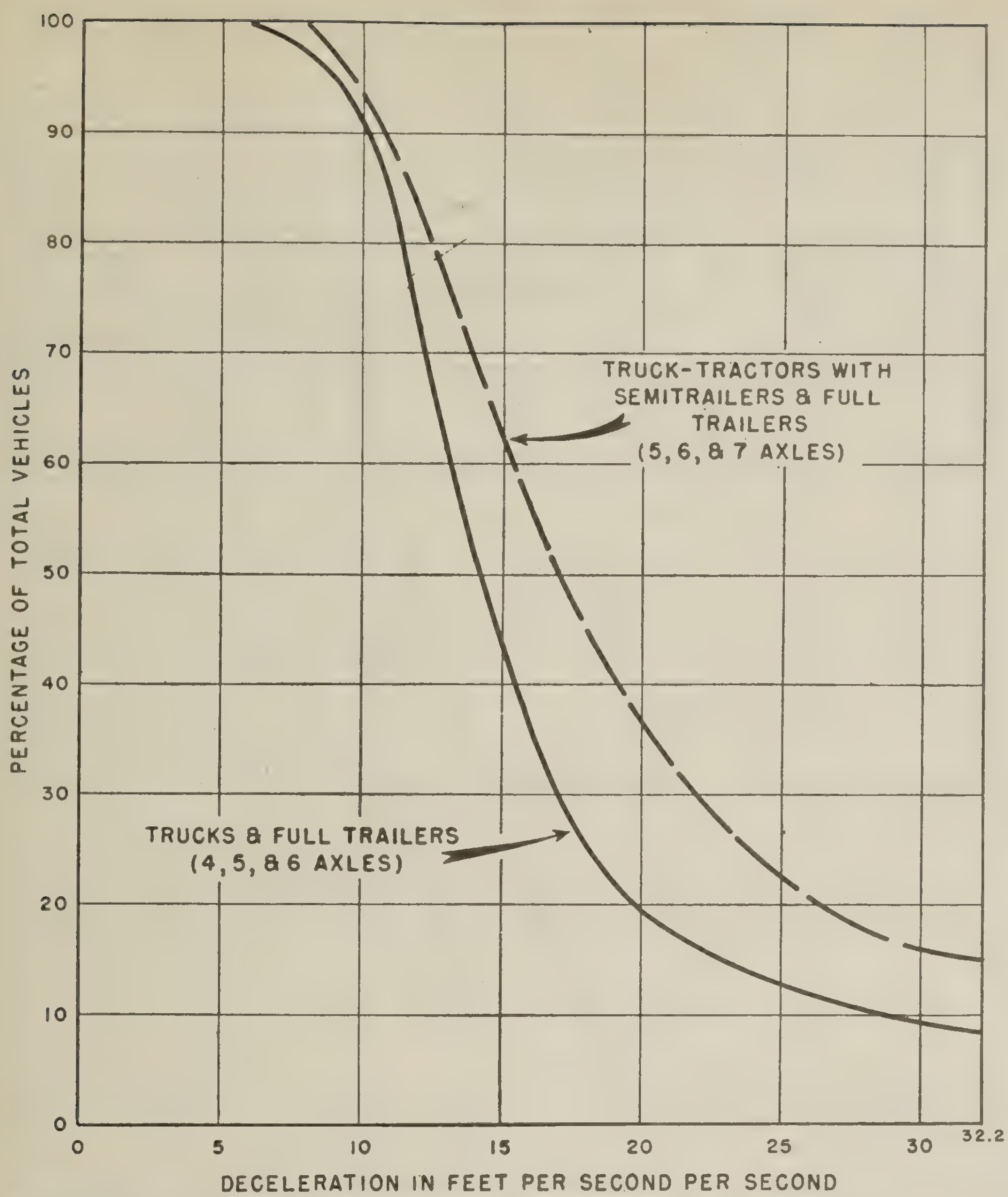


Figure 8.—Percentage of trucks with full trailers and truck-tractor-semitrailer and full-trailer combinations capable of a given or greater deceleration.

with the present requirement of the Uniform Vehicle Code. Such gains lead to the belief that there are excellent opportunities for considerable improvement in the braking performance of other commercial vehicle types.

If one considers the ability of the various vehicle types to comply with brake performance regulations, the improvements between 1949 and 1955 appear a little more encouraging than indicated by table 4. Table 5 shows by vehicle type the percentage of vehicles tested, both in 1949 and 1955, which could meet the present Uniform Vehicle Code requirement for brake-system application and braking distance for stops made from 20 miles per hour. In studying the results presented in table 5, it should be kept in mind that the requirement varies for the different vehicle types. For example, the requirement for very light 2-axle trucks (those having a manufacturer's gross vehicle weight rating of 10,000 pounds or less) is 30 feet; for 2-axle trucks other than very light, 40 feet; and for all other types of commercial vehicles, 50 feet.

Table 5.—Vehicles tested in 1949 and 1955 capable of meeting the Uniform Vehicle Code requirement, as revised in 1954, for brake-system application and braking distance from 20 miles per hour

Vehicle type	Requirement for brake-system application and braking distance	Vehicles capable of meeting requirement	
		1949	1955
	Feet	*Percent*	*Percent*
Passenger cars	25	83	92
Very light 2-axle trucks	30	76	84
Other 2-axle trucks	40	84	84
3-axle trucks	50	78	80
2-axle truck-tractors with 1-axle semitrailers	50	81	81
2-axle truck-tractors with 2-axle semitrailers	50	73	80
3-axle truck-tractors with 2-axle semitrailers	50	36	64
Trucks with full trailers (4, 5, and 6 axles)	50	44	38
Truck-tractors with semitrailers and full trailers (5, 6, and 7 axles)	50	22	41

As previously mentioned, the greatest percentage increase of vehicles capable of meeting the requirement between 1949 and 1955 was made by the 3-axle truck-tractors with 2-axle semitrailers; next in order were truck-tractors with semitrailers and full trailers. The latter type improved from 22 to 41 percent able to meet the requirement, an increase of 19 percent. Moderate increases in the percentage of vehicles able to comply with their respective requirements were made by passenger cars, very light 2-axle trucks, and the 2-axle truck-tractors with 2-axle semitrailers, which gained 9, 8, and 7 percent, respectively.

The 3-axle trucks showed a small improvement of 2 percent, whereas 2-axle trucks having a manufacturer's gross vehicle weight rating of over 10,000 pounds and the 2-axle truck-tractors with 1-axle semitrailers showed no change. The only vehicle type which lost ground with respect to its ability to meet the present Uniform Vehicle Code requirement for brake-system application and braking distance was the truck and full-trailer combination. In 1949, 44 percent of the sample of this vehicle type could comply, but in 1955, only 38 percent could meet the requirement.

It was not possible to compare the decelerating abilities of vehicles tested in 1949 and 1955, because deceleration was not measured in the 1949 studies of vehicles selected from the general traffic. However, it is of particular interest to view the results of deceleration studies made in 1955 with respect to Uniform Vehicle Code specifications. Table 6 shows the percentages of vehicles tested in 1955 which could meet their respective requirements for deceleration. The deceleration specified for passenger cars is 17 feet per second per second, whereas for all commercial vehicle types it is 14 feet per second per second.

Well over 99 percent of the passenger cars, all of the very light 2-axle trucks, and almost 94 percent of the other 2-axle trucks were able to meet the requirements for deceleration when measured with a commercially available portable decelerometer. From 76 to 85 percent of the truck-tractor-semitrailer combinations and 3-axle single-unit trucks, and 51 to 69 percent of the trucks with full trailers and truck-tractors with semitrailers and full trailers could comply with the 14 feet per second per second specification for deceleration.

A comparison of the results given in tables 5 and 6 shows that a greater percentage of vehicles of each type could comply with the Uniform Vehicle Code specification for deceleration than could comply with the corresponding specification for brake-system application and braking distance. However, in examining the two tables it should be kept in mind that the specifications for deceleration and for brake-system application and braking distance correspond to each

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other mathematically only for passenger cars and very light 2-axle trucks.

In making the foregoing comparisons of the performance of commercial vehicles tested in 1942, 1949, and 1955, the amount of improvement should be related to the weight of the vehicles in each sample of data. In other words, if the weights of the 3-axle truck-tractors with 2-axle semitrailers were considerably less in 1955 than in 1949, the improvement might be attributed to weight rather than to the braking system. From the tabulation of average gross weights given in table 7 for various types of vehicles, it is seen that average gross weights were generally higher in 1949 than in 1942, and similarly weights recorded in 1955 generally exceeded those in 1949. However, the reverse is true of the 2-axle trucks. The average weights of the 2-axle trucks tested were progressively lighter in 1949 and 1955.

The small decrease in average gross weights of the 3-axle truck-tractors with 2-axle semitrailers in 1955 may possibly account for a part of their improvement in stopping ability. However, since the weight decrease was relatively small, only 3,200 pounds and less than 6 percent, the greater part of the improvement may be attributed to more efficient braking systems.

The increases in the average gross weights of truck and full-trailer combinations, particularly those having 5 or 6 axles, can at least partly explain the poorer showing of these vehicles with respect to their ability to meet the present standard of the Uniform Vehicle Code. However, results of the controlled brake tests of commercial vehicles, which were reported in 1954,[5] indicate that considerable improvement can be made in the stopping ability of these vehicle combinations. The average-weight increases for the four types of truck and full-trailer combinations were as follows: 2-axle truck with 2-axle trailer, 2,800 pounds; 2-axle truck with 3-axle trailer, 11,400 pounds; 3-axle truck with 2-axle trailer, 17,000 pounds; and 3-axle truck with 3-axle trailer, 14,000 pounds. These increases amount to 6½, 28, 36, and 28 percent, respectively. The 3-axle trucks with 2-axle full trailers showed the greatest increase in average gross weights of any of the vehicle types tested and were by far the predominating type of truck and full-trailer combination encountered in the 1955 tests.

[5] See footnote 2, p. 177.

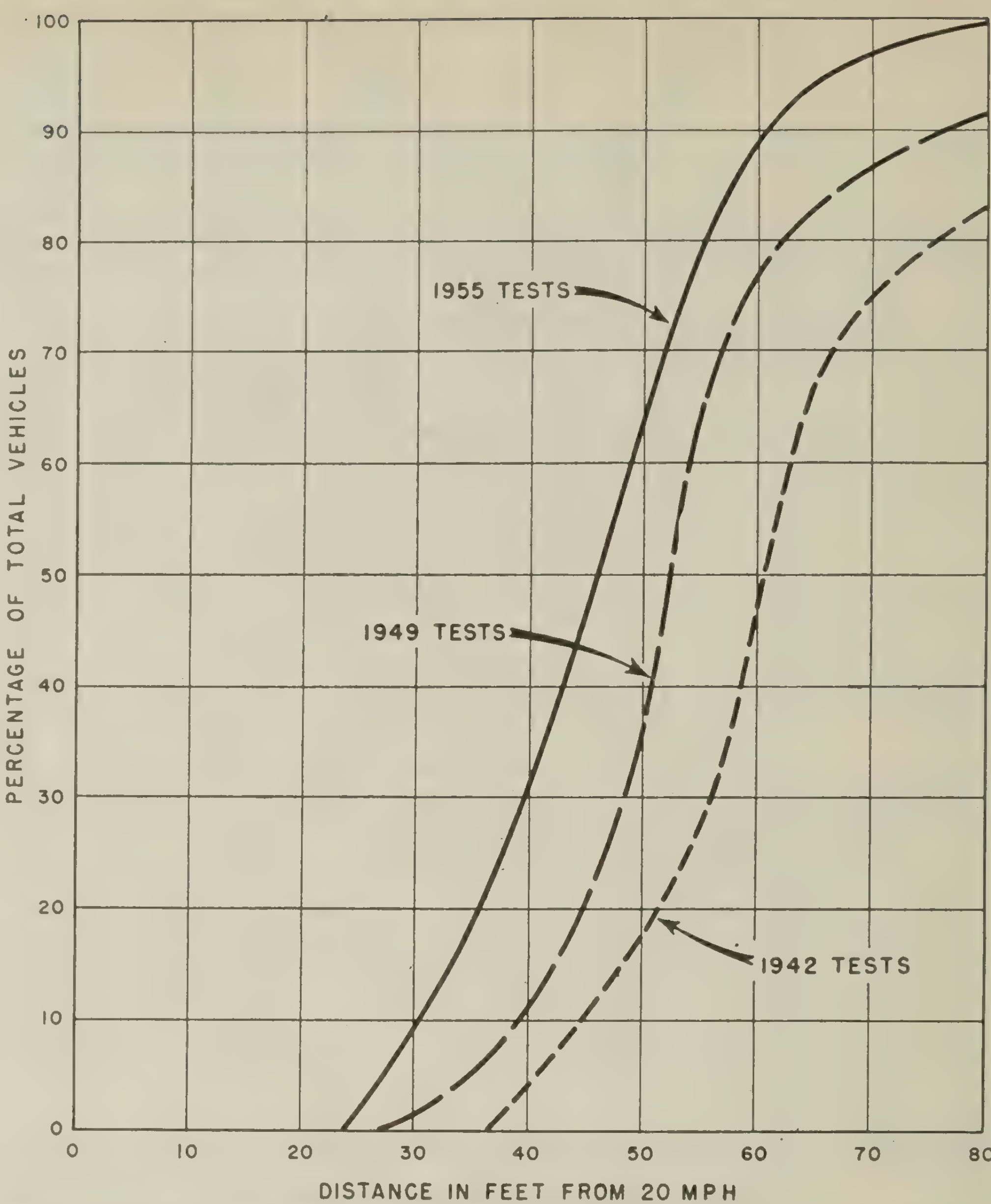

Figure 9.—Cumulative frequency distribution of minimum brake-system application and braking distances of 3-axle truck-tractors with 2-axle semitrailers.

The 3-axle single-unit trucks tested in 1955 were, on the average, 7,300 pounds heavier than those tested in 1949. This increase of approximately 35 percent in average weight was undoubtedly a contributing factor to the small improvement of 2 percent in ability to meet a 50-foot requirement for stopping ability.

Table 6.—Vehicles tested in 1955 capable of meeting the Uniform Vehicle Code requirement for deceleration

Vehicle type	Requirement for deceleration	Vehicles tested in 1955 capable of meeting requirement
	Ft./sec.²	*Percent*
Passenger cars	17	99.7
Very light 2-axle trucks	14	100.0
Other 2-axle trucks	14	93.9
3-axle trucks	14	85.0
2-axle truck-tractors with 1-axle semitrailers	14	82.7
2-axle truck-tractors with 2-axle semitrailers	14	81.7
3-axle truck-tractors with 2-axle semitrailers	14	76.0
Trucks with full trailers (4, 5, and 6 axles)	14	51.2
Truck-tractors with semitrailers and full trailers (5, 6, and 7 axles)	14	69.4

Figure 10 shows by vehicle types the improvement in braking performances which has been made in vehicles of approximately the same weight. However, it should be pointed out that the illustration does not consider vehicle capacities. Vehicles of each type were first classified into weight groups with a range of 5,000 pounds for the 2-axle trucks and 10,000 pounds for the other types. Weight groups representative of each of the seven predominant commercial vehicle types tested were selected. An average brake-system application and braking distance was then computed for each group and year of study. Because of the small sample, no results are given for the two heaviest vehicle types tested in 1942. Figure 10 emphasizes the fact that the improvement in stopping ability of the various types of vehicles between 1942 and 1949 was quite large, whereas between 1949 and 1955 there was little change for most vehicle types.

Table 8 shows that the percentage improvement, based on values indicated in figure 10, although not always identical, was similar to that determined for vehicles grouped according to capacity. The capacity groups having the greatest number of vehicles were selected

Table 7.—Average gross vehicle weights of commercial vehicles tested in 1942, 1949, and 1955

Vehicle type [1]	Number of vehicles tested and average gross weights					
	1942		1949		1955	
	Number	Weight	Number	Weight	Number	Weight
		Pounds		*Pounds*		*Pounds*
2	1,231	13,600	367	12,200	400	11,800
3	172	24,700	46	21,100	73	28,400
2-S1	1,344	28,500	246	30,400	129	32,100
2-S2	186	35,100	98	41,500	153	40,400
3-S2	59	48,800	57	56,900	66	53,700
2-2	30	30,100	9	43,100	16	45,900
2-3	15	31,300	2	40,800	1	52,200
3-2	14	47,800	16	46,900	46	63,900
3-3	144	59,500	27	50,000	7	64,000
2-S1-2	14	39,400	50	58,100	44	59,700
2-S2-2	11	56,300	9	63,400	7	62,200
2-S2-3	6	53,100	1	94,900	2	52,000

[1] For explanation of the code used, see p. 179.

for six of the eight weight groups considered in figure 10. Where there was improvement indicated for vehicles grouped according to weight only, the further grouping according to capacity within that weight group still resulted in an improvement in 1955 when compared with 1949. Likewise, when no improvement was indicated for vehicles grouped according to weight only, no improvement was evident when further classified according to capacity. The foregoing discussion should not be interpreted as indicating that vehicle capacity has no effect on brake performance.

Gross Weight Relations

In order to demonstrate how brake performance varies with vehicle type, capacity, and brake type, it was necessary to establish a relation between weight and brake-system application and braking distance. This was accomplished by classifying vehicles of selected types and capacities into weight groups and computing the average distance for each weight group.

The relation between weight and distance is shown in figures 11 and 12 by types of vehicles, without respect to the manufacturers' ratings of capacity. Insofar as normal highway operation is concerned, brake-system application and braking distance increases with weight for a given type of vehicle; but it is the performance of the vehicles with loads normally carried that must be given primary consideration in regulatory and highway design matters.

The average brake-system application and braking distances indicated in figures 11 and 12 are summarized in table 9 for the gross weight groups having the greatest number of vehicles. These results emphasize the wide variation of stopping ability for the various types of commercial vehicles operating with their most frequently carried loads. It is significant that the range of average brake-system application and braking distances for these vehicle groups extends from 26 feet for the 2-axle trucks with a gross weight of less than 10,000 pounds to 59 feet for the heaviest truck combinations, a variation in stopping ability of 127 percent.

In figure 13 (p. 190) the performance of 2-axle trucks is compared by capacity groups. Results of tests on the heavy capacity 2-axle trucks were not included because the sample was too small. Again, it is seen that the distance required to stop increases with vehicle weight. However, figure 13 shows that the distance required to stop by the light capacity 2-axle trucks in each of the three weight groups, 10,000–14,999 pounds, 15,000–19,999 pounds, and 20,000–24,999 pounds, was greater than that required by the medium capacity vehicles in the corresponding weight groups. Further examination of the chart reveals that the stopping ability for each weight group, except the heaviest of the medium capacity 2-axle trucks, approximates very closely the stopping ability for the next lighter weight group of the light capacity vehicles. Thus, in view of the difference in rating between the two capacity groups indicated in table 3, it appears that the light and the medium capacity 2-axle trucks are rated about on a par with respect to their brake performance.

The average brake performance of light, medium, and heavy capacity 2-axle truck-tractors with 1-axle semitrailers is shown in figure 14 (p. 190). In contrast to the results shown for 2-axle trucks, the average brake-system application and braking distance for a given weight group was greater for the medium capacity vehicles than for the light capacity vehicles. The one exception involved vehicles weighing 40,000 to 49,999 pounds which, in the light capacity group, were loaded considerably beyond the manufacturer's rating.

In comparing the medium and heavy capacity vehicles, any differences in brake performance for a common weight group were generally small. The greatest difference was in the vehicles weighing 10,000 to 19,999 pounds, which were essentially empty vehicles.

In figure 15 (p. 191) the braking performance of medium and heavy 2-axle truck-tractors with 2-axle semitrailers is compared. It is significant that for a given weight group—except for the 10,000–19,999-pound group, composed of essentially empty vehicles—the

Table 8.—Improvement in stopping ability of commercial vehicles of approximately the same gross weight when grouped without respect to vehicle capacity and when grouped according to manufacturer's vehicle capacity rating

Vehicle type	Weight group	Grouped according to gross weight only				Grouped according to vehicle capacity and gross weight				
		Feet to stop from 20 m.p.h.		Improvement		Capacity group	Feet to stop from 20 m. p. h.		Improvement	
		1949	1955	Feet	Percent		1949	1955	Feet	Percent
	1,000 pounds									
2	10.0–14.9	30	31	−1	−3	Light	30	31	−1	−3
2	15.0–19.9	38	36	2	5	do	42	37	5	12
2-S1	30.0–39.9	46	41	5	11	Medium	48	44	4	8
2-S2	50.0–59.9	53	51	2	4	do	54	51	3	6
3-S2	60.0–69.9	57	47	10	18	Heavy	56	46	10	18
2-S1-2	70.0–79.9	62	62	0	0	do	62	62	0	0

Table 9.—Average brake-system application and braking distance from 20 miles per hour by vehicle type for weight groups having greatest frequency of vehicles

Vehicle type	Vehicle weight group	Number of vehicles	Average brake-system application and braking distance
	1,000 pounds		*Feet*
2-axle trucks	0– 9.9	185	26
	10.0–19.9	162	32
	20.0–29.9	49	41
3-axle trucks	20.0–29.9	23	43
	30.0–39.9	22	48
2-axle truck-tractors with 1-axle semitrailers	20.0–29.9	40	37
	30.0–39.9	32	41
	40.0–49.9	35	51
2-axle truck-tractors with 2-axle semitrailers	40.0–49.9	56	46
	50.0–59.9	35	51
3-axle truck-tractors with 2-axle semitrailers	60.0–69.9	24	47
Trucks with full trailers and truck-tractors with semitrailers and full trailers	70.0–79.9	60	59

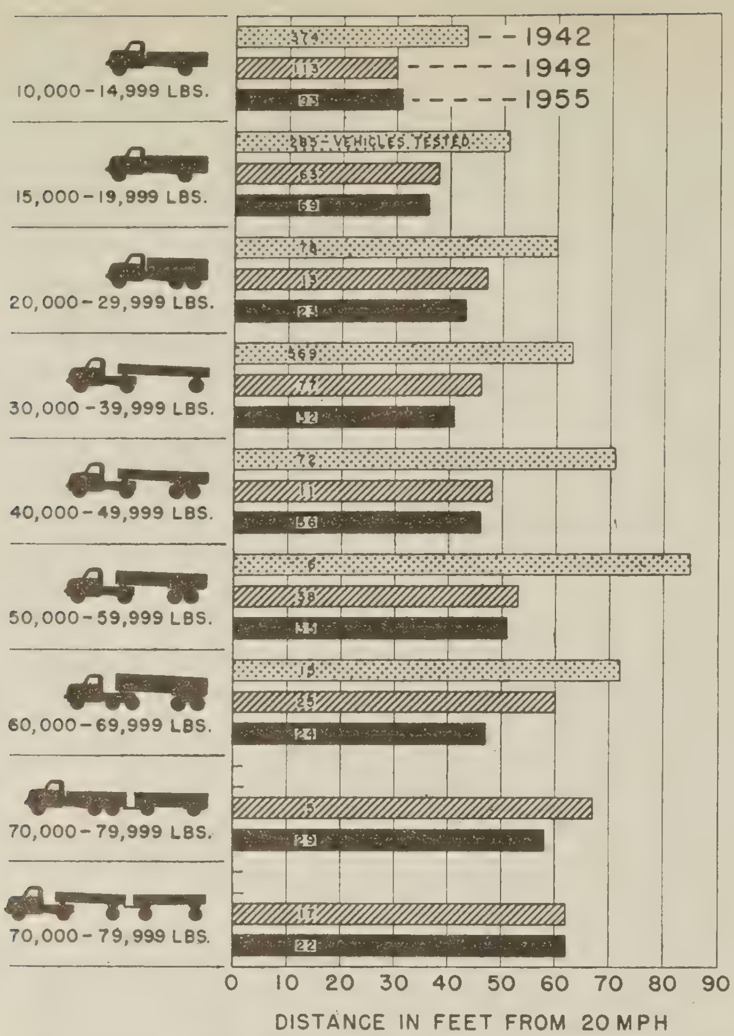

Figure 10.—Comparison of average brake-system application and braking distances observed in 1942, 1949, and 1955 for commercial vehicles loaded to commonly carried gross weights.

average distance required to stop varied with capacity group by not more than 1 foot. Thus, in considering the performance of 2-axle truck-tractors with both 1- and 2-axle semitrailers, it appears that little difference exists in the braking ability of medium and heavy 2-axle truck-tractors carrying approximately the same gross weight.

It has been demonstrated in figures 13–15 how brake-system application and braking distances of the several vehicle types vary with gross weight and with rated capacity. In the case of the 2-axle trucks, it was indicated that loads beyond the rating of the light units could be hauled in a larger capacity vehicle with an improvement in level of brake performance. This was true, also, for light capacity combination vehicles loaded considerably beyond the manufacturer's rating. However, for other 3- and 4-axle truck-tractor-semitrailer combinations vehicle capacity was not a significant factor. In fact, the overall level of performance of medium capacity 2-axle truck-tractors with either 1- or 2-axle semitrailers is not materially affected by loading somewhat beyond the rated capacity of the vehicle.

Figures 16–19 compare the braking performance of different commercial vehicle types in each of three capacity groups. Because the sample of some vehicle types in certain capacity groups was not adequate for distribution into weight groups, not every vehicle type is considered in each capacity group.

Figure 16 (p. 192) compares the stopping ability of the light capacity 2-axle trucks and 2-axle truck-tractors with 1-axle semitrailers. A comparison of identical weight groups for the two vehicle types indicates better braking performance for the combination vehicles. Because the light single-unit trucks and the power units of the light vehicle combinations are basically the same vehicles, the ability of the combination vehicles to stop in the shorter distance, when compared on an equal-weight basis, may be attributed to the added braking provided by the semitrailer.

Since the same basic vehicle is rated for a heavier gross weight when used in combination, it is more logical to compare the performance of the 2-axle trucks in one weight group with that of the 2-axle truck-tractors with 1-axle semitrailers in a heavier group. In table 3, light capacity vehicles are shown as those having a manufacturer's gross vehicle weight rating between 10,001 and 16,000 pounds for single-unit trucks and 27,000 pounds or less for combination vehicles. Therefore, it is appropriate to compare the stopping ability of the 2-axle trucks weighing 10,000–19,999 pounds with that of the 2-axle truck-tractors with 1-axle semitrailers weighing 20,000–29,999 pounds. In making such comparison, figure 16 shows slightly better performance for the single-unit vehicles. On the average, these 2-axle trucks required 33 feet to stop from 20 miles per hour, whereas the 2-axle truck-tractors with 1-axle semitrailers required 35 feet.

Figure 17 (p. 192) compares the stopping ability of medium capacity 2-axle trucks, 2-axle truck-tractors with 1-axle semitrailers, and 2-axle truck-tractors with 2-axle semitrailers. In comparing the medium capacity vehicles, it is appropriate to compare the performance of the single-unit vehicles weighing 20,000–29,999 pounds with that of the combination vehicles weighing 40,000–49,999 pounds, since these weight groups bracket the upper limits of the respective medium capacity ratings given in table 3. In comparing the vehicles on this basis, figure 17 shows the following average brake-system application and braking distances for stops made from 20 miles per hour: 2-axle trucks, 42-feet; 2-axle truck-tractors with 1-axle semitrailers, 52 feet; and 2-axle truck-tractors with 2-axle semitrailers, 46 feet. Again, as in the case of the light capacity vehicles, the 2-axle trucks showed the better performance.

The somewhat poorer performance of combination vehicles may largely be attributed to the inherent characteristics of the braking systems. A certain amount of additional time is required to transmit power to, and to build up force in the trailer brakes. During this time the vehicle combination is traveling faster than at any other time during the stop. Therefore, for a given increment of time, it travels farther and the brake-system application and braking distance is bound to be lengthened somewhat. In the best performing vehicles the application and brake force buildup time is held to a minimum.

In comparing the performance of the two medium capacity truck-tractor-semitrailer types considered in figure 17, it is seen that the average brake-system application and braking distance of each weight group of the combinations with single-axle semitrailers was approximately equal to that of the next heavier weight group of the combinations with tandem-axle semitrailers. For example, truck-tractors with single-axle semitrailers weighing 20,000–29,999 pounds and the combinations with tandem-axle semitrailers weighing 30,000–39,999 pounds, on the average, required 38 feet to stop. Figure 18 (p. 193) indicates the same general relation for the heavy capacity vehicles of these two types. Thus, for vehicles within the same capacity group, it appears that the brake performance of a 2-axle truck-tractor with 2-axle semitrailer of a given gross weight is generally on a par with the performance of a 2-axle truck-tractor with 1-axle semitrailer of about 10,000 pounds less weight.

In figure 19 (p. 193) the stopping ability of heavy capacity 3-axle truck-tractors with 2-axle semitrailers is compared with that of heavy capacity truck and trailer and truck-tractor-semitrailer and full-trailer combinations. The illustration shows that in each weight group the 3-axle truck-tractors with 2-axle semitrailers required less distance to stop than the other vehicle combinations in the corresponding weight group.

The results shown in figure 19 and those shown in figures 10 and 17 indicate that brake-

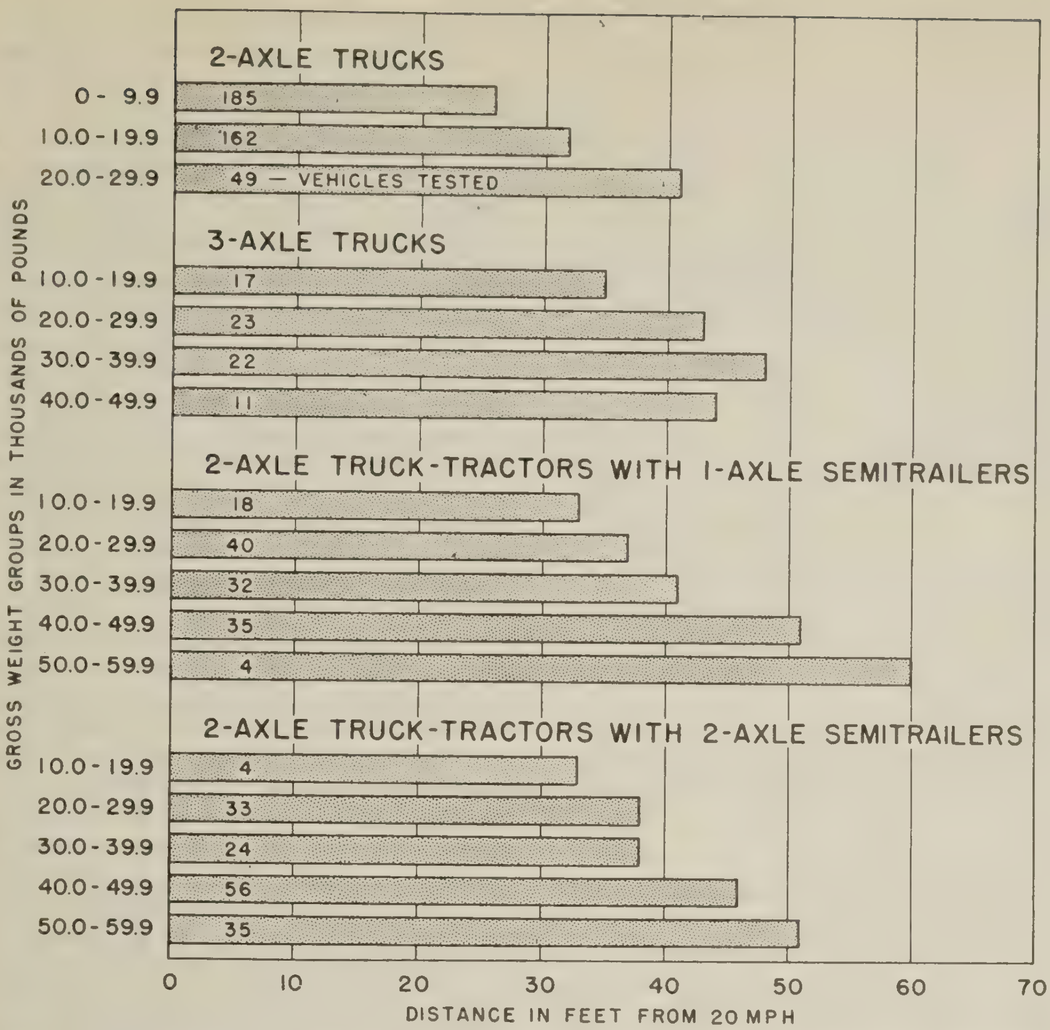

Figure 11.—Variation of average brake-system application and braking distances with gross weights for single-unit trucks and truck-tractor-semitrailer combinations.

system application and braking distance, for vehicles within a given capacity group, increases with the number of units in combination. The additional time required in application and brake force buildup, as mentioned in the previous discussion of figure 17, accounts for the greater distance in stopping combination vehicles. When an additional unit is included in a combination, additional time is required to transmit power to, and to build up full braking force in some of the brakes of the combination. This is due primarily to the longer lines and added connections involved in triggering the power to operate the brakes.

Brake Performance Summarized

In order to define the practical levels of brake performance for vehicles currently using the highways, the average, 15-, and 85-percentile values of brake-system application and braking distance observed for vehicles as commonly loaded are summarized in table 10 by vehicle type, capacity, and weight range. Most of the previous analyses have been concerned only with the average performance level for a given group of vehicles. In this table, the 15- and 85-percentile values are included to indicate the spread of data about the average.

The 15-percentile values represent the performance of the top 15 percent of the vehicles in a group; and the 85-percentile values, the performance attained by 85 percent of the vehicles (and not attained by the poorest 15 percent). The 85-percentile value may be useful for highway design purposes, whereas the 15-percentile value gives some idea of what can be expected in the future.

A significant point to be made from this summary is the need for a concentrated effort to bring the brake performance of truck-tractors with semitrailers and full trailers, trucks with full trailers, and the heaviest groups of truck-tractors with semitrailers into line with the performance of the other groups of truck-tractors with semitrailers. The results should also prove beneficial in testing the practicability of minimum regulatory requirements and in developing highway design factors. The 15-percentile values show definitely that considerable improvement is possible for each type of vehicle.

Axle Weight Relations

In the previous analyses, brake-system application and braking distances have been related either directly or indirectly to gross vehicle weight. The following discussion considers the relation existing between axle load and brake-system application and braking distance for 2-axle trucks and 2-axle truck-tractors with 1-axle semitrailers. It was not possible to consider other vehicle types since the number of vehicles of a given type was either too few, or the typical axle-load distribution for a given type of vehicle was too varied.

In order to establish the relation, vehicles were first classified by axle-weight groups with a range of 4,000 pounds. Only the principal load carrying axles were considered; the weight of the front axle was disregarded. If both axles of a truck-tractor-semitrailer combination did not fall in the same weight group, that particular vehicle was not considered. Following the classification, an average brake-system application and braking

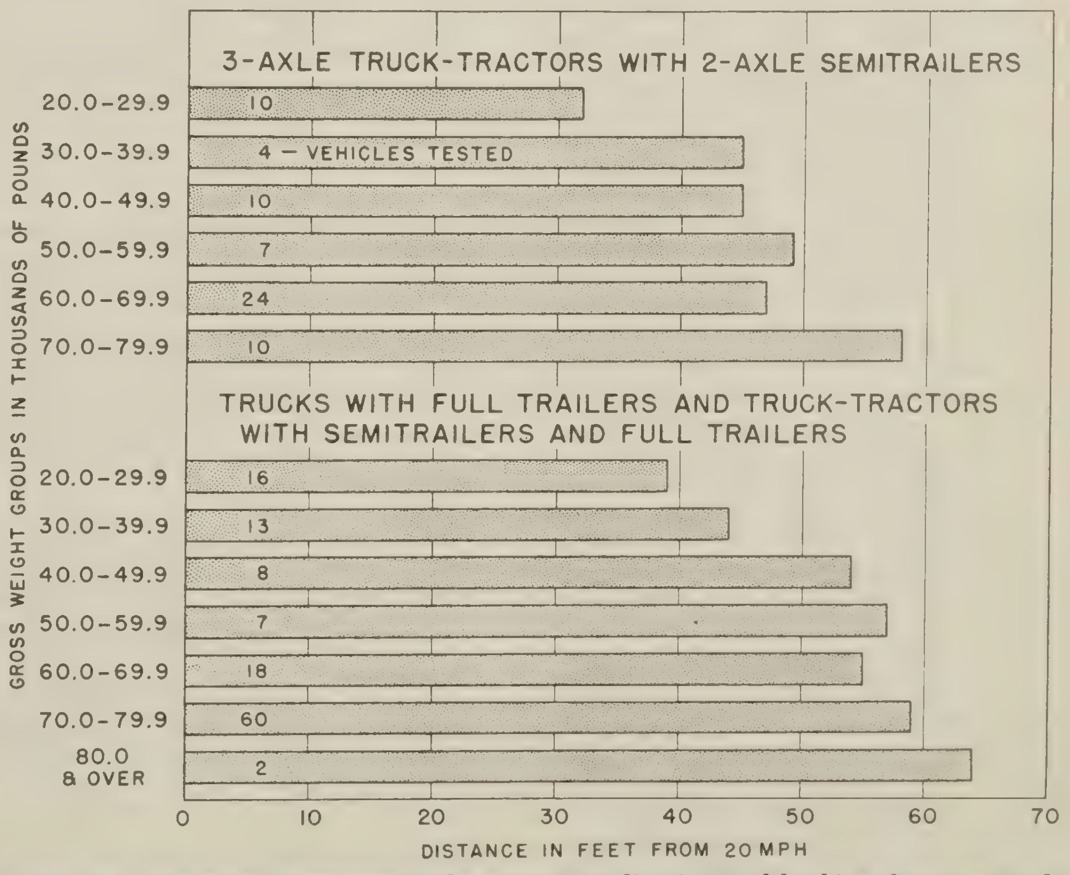

Figure 12.—Variation of average brake-system application and braking distances with gross weights for the larger truck combinations.

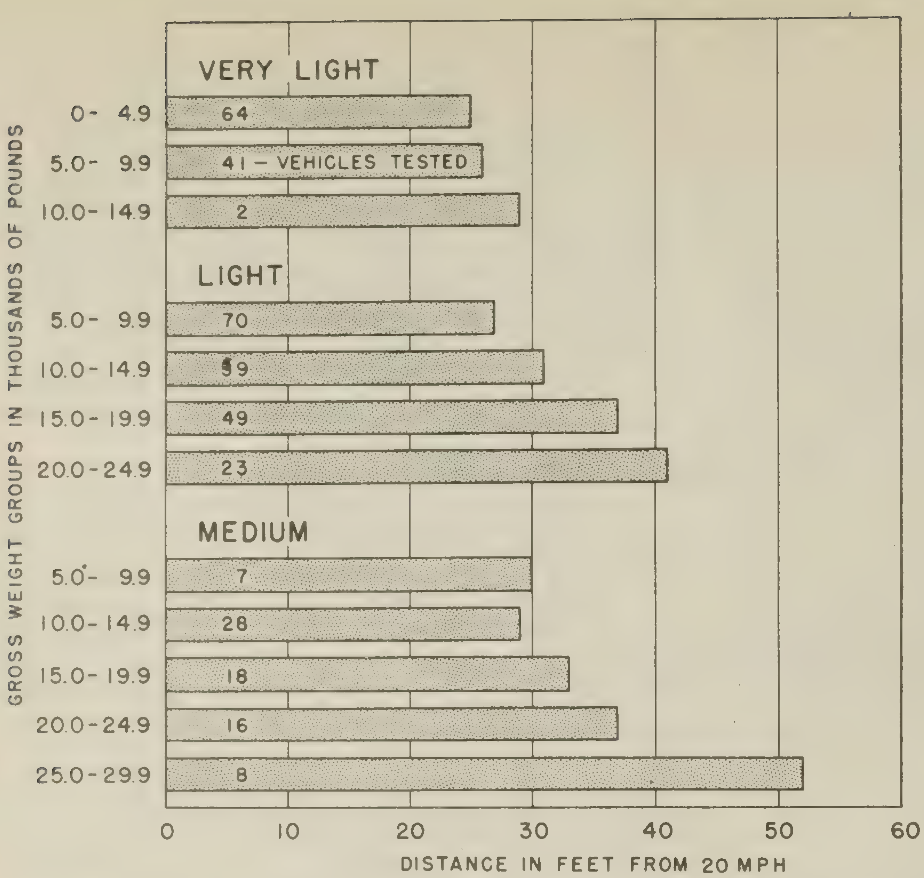

Figure 13.—Variation of average brake-system application and braking distances with gross weights by capacity groups for 2-axle trucks.

distance was computed for each axle-weight group.

The results are shown in figure 20 (p. 194) for vehicles tested in 1955 and 1949. So far as the general traffic is concerned, average brake-system application and braking distance for both years definitely increased with an increase in axle load. This would be expected, to some degree, since many vehicles were undoubtedly tested with either partial loads or loads in excess of the brake design. Except for the vehicles in the 14,000–17,999-pound axle-weight group, there was little change in the relation between brake performance and axle load from 1949 to 1955. The improvement in braking performance for vehicles in the 14,000–17,999-pound group amounted to 7 feet for the 2-axle trucks, and 4 feet for the 2-axle truck-tractors with 1-axle semitrailers.

In viewing the results presented in figure 20, it should not be construed that heavy axle loads cannot be adequately braked. The report, published in 1954, pointed out that a few of the vehicles tested in that study showed that axle loads commonly carried could be braked to the degree of wheel locking on dry concrete pavement with a relatively high coefficient of friction. One of several examples cited was a 2-axle truck-tractor with 1-axle semitrailer carrying 22,900 pounds on the tractor drive-axle and 22,800 pounds on the trailer axle. After adjusting the brakes just prior to testing, this vehicle stopped in 32 feet from 20 miles per hour. Other heavily loaded vehicles tested in that study showed equally good brake performance.

A few of the vehicles tested in 1955 add further proof that axle loads now commonly carried can be adequately braked. It should be remembered that all of the vehicles tested in the present study were selected at random from the general traffic, and in no instance was special maintenance performed for the tests. There were four examples of heavily loaded 2-axle truck-tractors with 1-axle semitrailers. The weights of the drive axle and trailer axle, along with the brake-system application and braking distance for each of the four respective vehicles, were as follows: 21,000 and 22,800 pounds, 36 feet; 19,500 and 23,800 pounds, 36 feet; 22,500 and 22,100 pounds, 38 feet; and 20,400 and 20,400 pounds, 38 feet. Results of the controlled tests reported in 1954 indicate that these vehicles could have done even better if the brakes had been adjusted prior to the tests.

Regardless of what can be done, the fact remains that commercial vehicles from the general traffic—at least the two types considered in figure 20, and very likely all types—were not provided with braking ability in proportion to the loads carried on an axle. In view of the performance possible with current designs of braking systems, and in view of the performance of a few of the vehicles selected at random from the general traffic, the range of about 25 feet between the lightest and heaviest axle-load groups seems excessive. Some of the increase of brake-system application and braking distance with axle load might be attributed to longer application and buildup time, since the frequency of use of power-brake systems increases with axle load. However, the magnitude of the difference between what can be done and what is generally being done suggests that insufficient attention is given to providing adequate braking force for the axle loads carried.

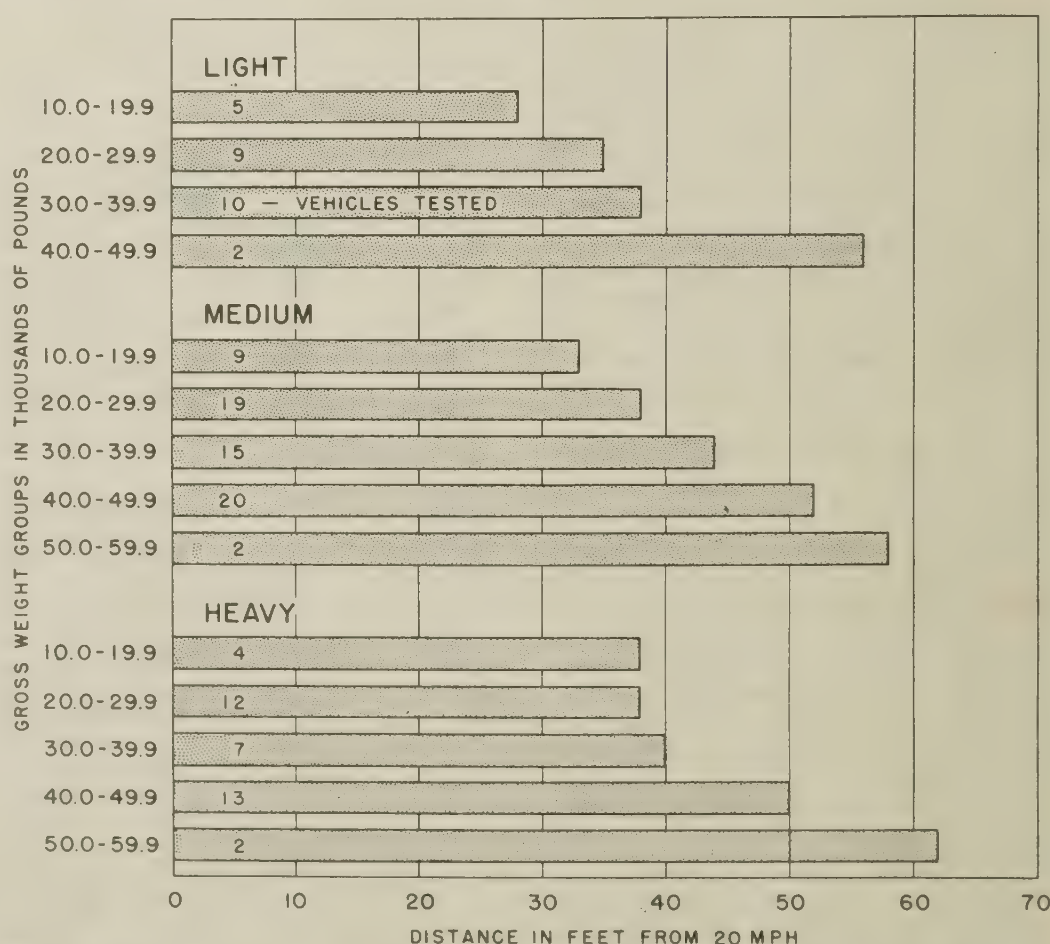

Figure 14.—Variation of average brake-system application and braking distances with gross weights by capacity groups for 2-axle truck-tractors with 1-axle semitrailers.

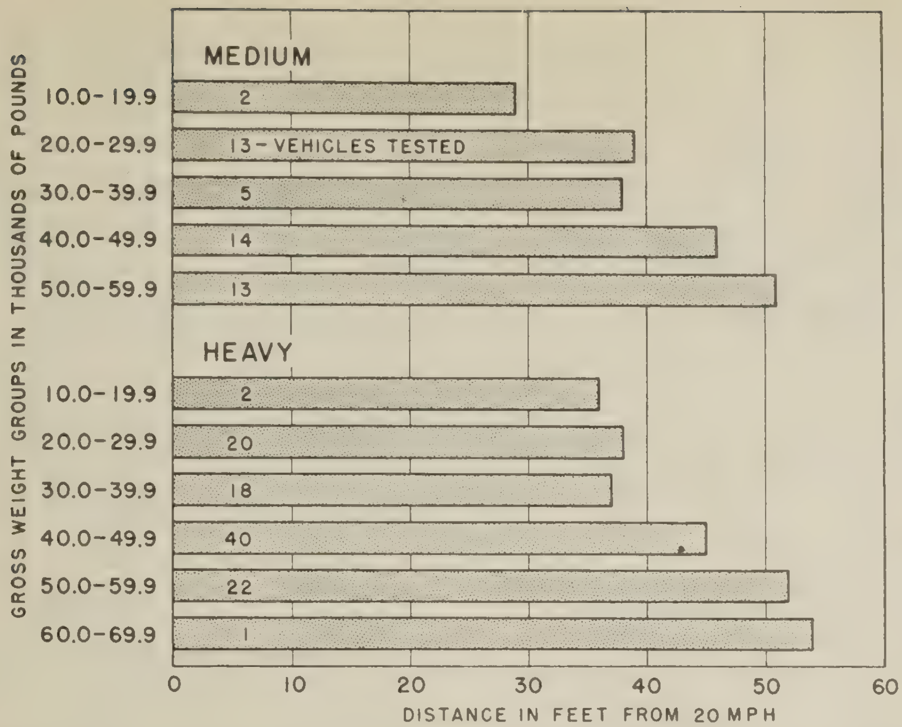

Figure 15.—Variation of average brake-system application and braking distances with gross weights by capacity groups for 2-axle truck-tractors with 2-axle semitrailers.

The existing condition, as revealed in figure 20, may be attributed to loading beyond the axle loads used in designing the brake components, inadequate maintenance of equipment, and obsolete design of the overall braking system. The operators have the responsibility of loading the axles in keeping with the braking force available, of properly maintaining the braking system, and of modernizing old equipment still being used on the highways. There is also a joint responsibility of both operators and manufacturers in the selection of and the provision for adequate braking equipment.

Brake-Type Relations

From the classification of vehicles made in table 2, it is apparent that comparisons of brake performance by brake type were possible for only the passenger cars, light 2-axle trucks, and medium 2-axle truck-tractors with 1-axle semitrailers. It was not possible to compare the stopping ability by brake type for other groups of vehicles because of the limited sample and the nature of its distribution by vehicle type, capacity group, and brake type.

For passenger cars, the stopping ability of vehicles equipped with conventional hydraulic brakes was compared with the stopping ability of vehicles equipped with vacuum-booster hydraulic brakes (commonly called power brakes). Average brake-system application and braking distance was computed for each of the two groups of passenger cars. Since the cars equipped with power brakes were predominantly 1953–56 models, only those models were included in the computations. The results showed that the average brake-system application and braking distance for passenger cars with hydraulic brakes was 20.5 feet, and with power (vacuum-booster hydraulic) brakes, 21.5 feet.

The relation established between brake type and brake-system application and braking distance for commercial vehicles of the same type, capacity, and approximate weight is shown in tables 11 and 12. The average performance of light 2-axle trucks with hydraulic and with vacuum-booster hydraulic brakes is compared in table 11 for three weight groups. The results indicate slightly better performance for the vehicles with vacuum-booster hydraulic brakes in the 10,000–14,999-pound group, and identical performance for the two brake types in the other two weight groups.

Results of the 1949 tests indicated that a power booster on the brakes of light trucks in the 10,000–14,999-pound group was desirable, and that light vehicles weighing 15,000 pounds and over should be equipped with a booster. The present study tends to indicate that a booster is not beneficial (except for reducing driver fatigue) on the brakes of present light 2-axle trucks if they are not loaded beyond the manufacturer's gross weight rating.

Table 12 shows the average brake performance for each of three gross weight groups of medium capacity 2-axle truck-tractors with 1-axle semitrailers equipped with two different types of brakes. Average brake-system application and braking distances from 20 miles per hour are shown for vehicle combinations with vacuum-booster hydraulic brakes on the truck-tractor and vacuum-mechanical brakes on the semitrailer, and for combinations with air-mechanical brakes on both units. The table indicates that vehicles with air-mechanical brakes were capable of stopping in 2 to 5 feet shorter distance than those equipped with vacuum-power systems.

Table 10.—Summary of brake-system application and braking distances from 20 miles per hour for commercial vehicles with gross weights commonly carried on the highway

Vehicle type	Capacity group	Weight group	Number of vehicles	Brake-system application and braking distance: Average	15-percentile level	85-percentile level
		1,000 pounds		*Feet*	*Feet*	*Feet*
2	Very light	0 – 4.9	61	25	20	30
	do	5.0– 9.9	33	26	22	30
	Light	10.0–14.9	60	31	24	37
	do	15.0–19.9	49	37	28	48
	do	20.0–24.9	23	41	29	48
	Medium	15.0–19.9	18	33	30	36
	do	20.0–24.9	16	37	31	43
	do	25.0–29.9	8	52	37	63
	Heavy	20.0–29.9	2	38	------	------
	do	30.0–34.9	3	44	------	------
3	Light	20.0–29.9	6	42	------	------
	Medium	20.0–29.9	6	45	------	------
	do	30.0–39.9	11	48	37	58
	Heavy	20.0–29.9	11	42	29	49
	do	30.0–39.9	10	47	34	53
	do	40.0–49.9	6	43	------	------
2-S1	Light	20.0–29.9	9	35	27	37
	do	30.0–39.9	10	38	29	45
	Medium	30.0–39.9	15	44	36	50
	do	40.0–49.9	20	52	38	62
	Heavy	30.0–39.9	7	40	33	45
	do	40.0–49.9	13	50	42	53
	do	50.0–59.9	2	62	------	------
2-S2	Medium	40.0–49.9	14	46	36	54
	do	50.0–59.9	13	51	39	58
	Heavy	40.0–49.9	40	45	39	51
	do	50.0–59.9	22	52	41	59
3–S2	Heavy	60.0–69.9	20	46	37	54
	do	70.0–74.9	10	58	50	63
2–2	Heavy	60.0–64.9	5	56	------	------
3–2	do	70.0–79.9	29	58	45	67
3–3	do	70.0–79.9	5	65	------	------
2–S1–2	do	70.0–79.9	20	62	48	74
2–S2–2	do	75.0–84.9	4	59	------	

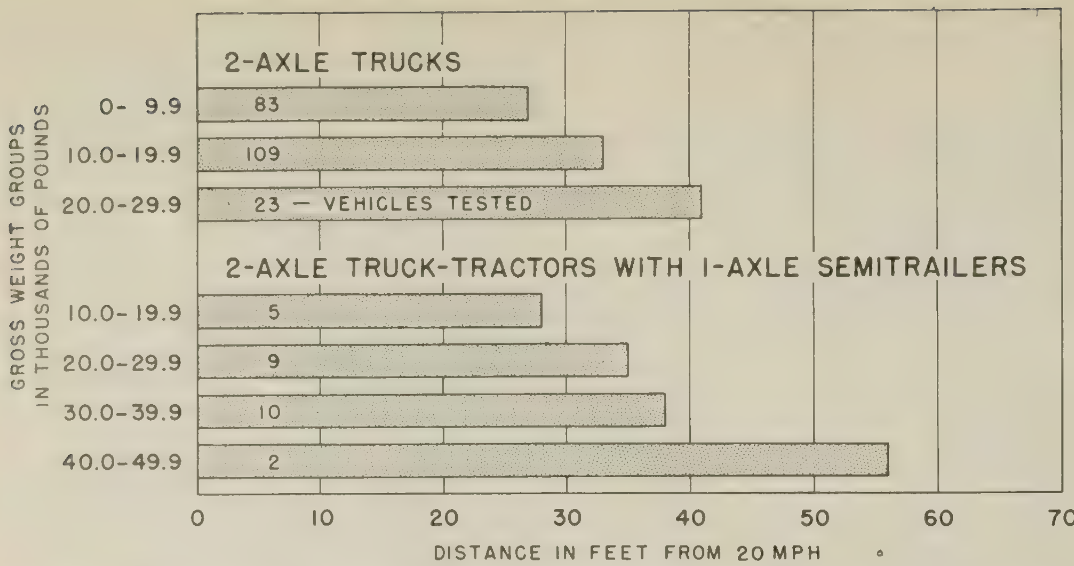

Figure 16.—Variation of average brake-system application and braking distances with gross weights for light capacity single-unit trucks and truck combinations.

The 1949 tests showed a similar relation in performance of the two brake types for vehicles selected from the general traffic. However, controlled tests conducted during the earlier study showed that the 2-axle truck-tractors with 1-axle semitrailers equipped with vacuum-booster hydraulic brakes on the tractor and vacuum-mechanical brakes on the trailer could perform as well as similar vehicles equipped with air-mechanical brakes. This was true for vehicles weighing up to 40,000 pounds, provided proper components of the braking systems were selected and used, and provided the braking systems were properly maintained.

Brake Performance Compared by Regions

The previous analyses have been concerned with average brake-system application and braking distances for all vehicles tested in the three States. Each State actually represents a region since the normal sample of out-of-State vehicles was included. Table 13 shows, by States, the average brake performance and the average gross weight of each of the most common vehicle types tested in 1955. It is interesting to note that 10 of the 11 vehicle types considered showed better average stopping ability in Michigan than in either Maryland or California. For some vehicle types the better showing may be partly attributed to differences in average gross weights. However, the average weight was heavier in Michigan for 4 of the 10 types which showed the best performance in that State. The average weight of the one type of vehicle with the poorest performance in Michigan, the 2-axle truck-tractor with 2-axle semitrailer and 2-axle trailer, was 20,600 pounds heavier than the same type tested in California.

In general, the average level of performance was better in Maryland than California. Of the 7 vehicle types tested in both States, 5 had a better average braking performance in Maryland than in California. The average weight was heavier in Maryland for 3 of the 5 vehicle types. Passenger cars showed about 10 percent better braking performance in California, and the very light 2-axle trucks required the same distance to stop in both States. However, the average weight of each of these two vehicle types was slightly heavier in Maryland.

Since the improvement in stopping ability of the 3-axle truck-tractors with 2-axle semitrailers has previously been emphasized, it is of particular interest to investigate the performance of this vehicle type in the individual States. Because only two vehicles of this type were tested in Maryland, comparisons are confined to vehicles tested in Michigan and in California.

Figure 21 shows four cumulative frequency distribution curves for brake-system application and braking distances of 3-axle truck-tractors with 2-axle semitrailers. Two curves represent the vehicles tested in Michigan and California in 1955, and the other two represent the total samples of this vehicle type tested in

Table 11.—Relation between brake type and brake-system application and braking distance for light 2-axle trucks

Gross vehicle weight group (pounds)	Number of vehicles		Average brake-system application and braking distance from 20 m. p. h.	
	Hydraulic brakes	VBH brakes [1]	Hydraulic brakes	VBH brakes [1]
			Feet	*Feet*
5,000–9,999	10	59	26	26
10,000–14,999	9	70	33	31
15,000–19,999	3	44	38	38
20,000–24,999		22		39

[1] VBH = vacuum-booster hydraulic.

Table 12.—Relation between brake type and brake-system application and braking distance for medium capacity 2-axle truck-tractors with 1-axle semitrailers

Gross combination weight group (pounds)	Number of vehicles		Average brake-system application and braking distance from 20 m. p. h.	
	VBH-VM brakes [1]	AM-AM brakes [1]	VBH-VM brakes [1]	AM-AM brakes [1]
			Feet	*Feet*
20,000–29,999	7	8	40	35
30,000–39,999	8	6	46	42
40,000–49,999	4	11	51	49

[1] VBH = vacuum-booster hydraulic, VM = vacuum-mechanical, and AM = air-mechanical.

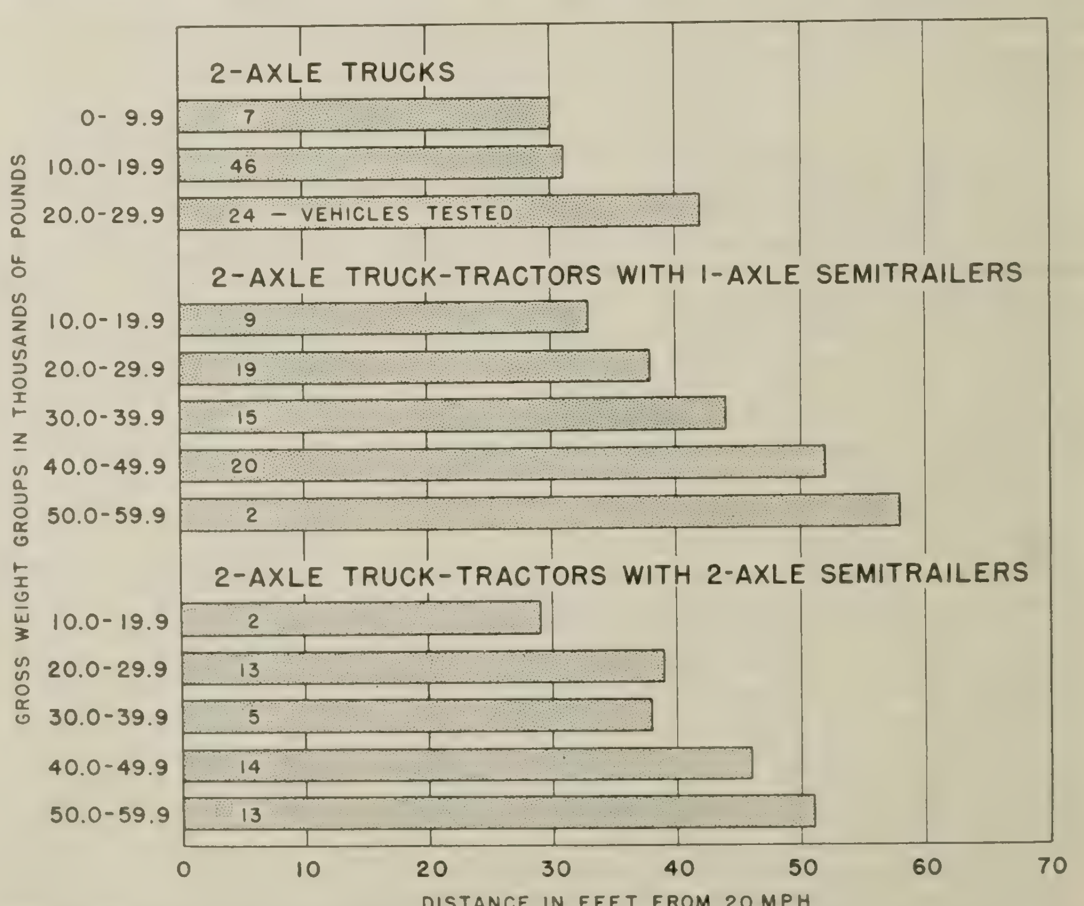

Figure 17.—Variation of average brake-system application and braking distances with gross weights for medium capacity single-unit trucks and truck combinations.

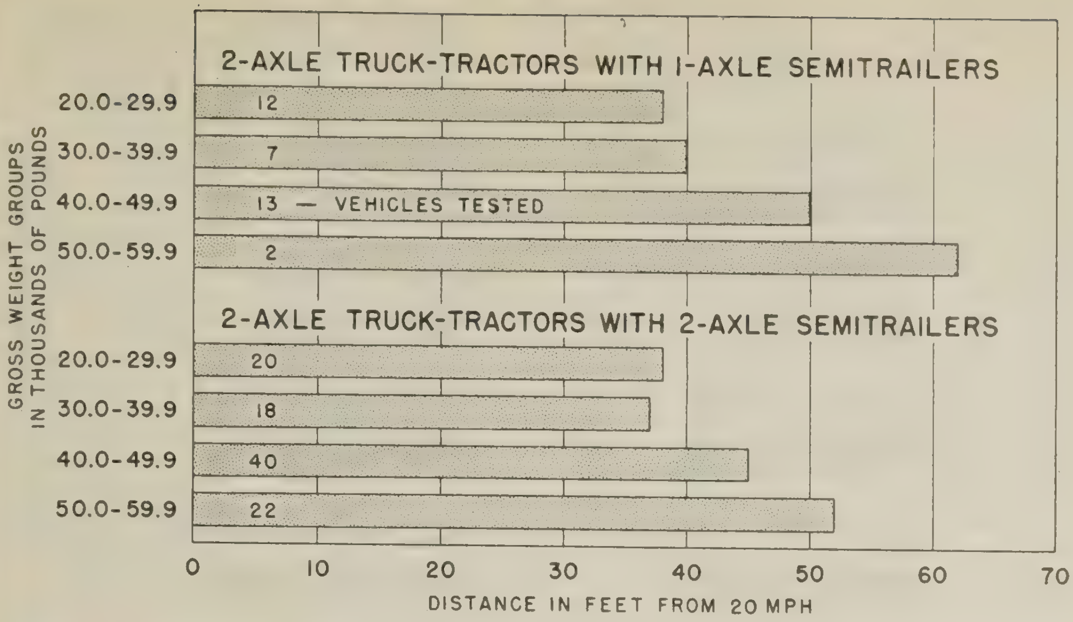

Figure 18.—Variation of average brake-system application and braking distances with gross weights for heavy capacity truck combinations.

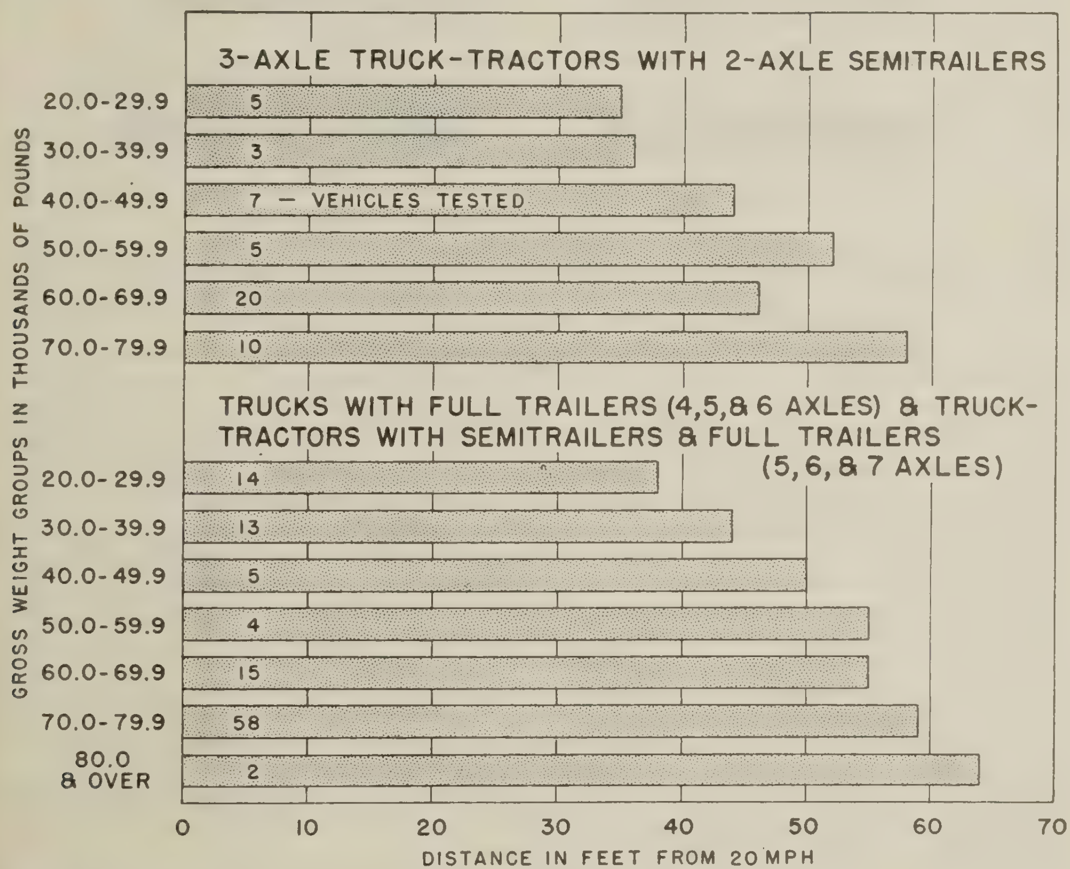

Figure 19.—Variation of average brake-system application and braking distances with gross weights for the larger heavy capacity truck combinations.

1955 and 1949. The 1949 curve can be considered as essentially representing the performance of vehicles tested in California, as only 2 of the 57 vehicles it represents were tested elsewhere. The wide variation in performance of similar vehicles tested in the two States is of particular interest. The graph indicates that only small improvements in the performance of these vehicles were made in California between 1949 and 1955. The greater part of the improvement for the total sample was due to the performance of vehicles tested in Michigan.

Table 14.—Comparison of brake-system application and braking distance by weight groups for 3-axle truck-tractors with 2-axle semitrailers tested in California and Michigan

Gross combination weight group (pounds)	Number of vehicles		Average brake-system application and braking distance from 20 m. p. h.	
	California	Michigan	California	Michigan
			Feet	*Feet*
20,000–29,999	1	9	43	31
30,000–39,999	4	...	45	...
40,000–49,999	6	3	49	37
50,000–59,999	6	1	54	55
60,000–69,999	9	15	52	44
70,000–74,999	9	1	59	51
All groups	35	29	52	40

It is pointed out later that differences in terrain may contribute to differences in performance of vehicles tested in different States. However, for the 3-axle truck-tractors with 2-axle semitrailers some of the difference should be attributed to another factor. Table 1 shows that in 1949 only two vehicle combinations of this type were tested in Michigan. Since 1949, this vehicle type has been gaining in popularity in the Midwest. The data recorded in 1955 show that on the average the age of the power units of these vehicles tested in California was 5 years, and in Michigan, 2½ years. Thus, it is probable that the 3-axle truck-tractors with 2-axle semitrailers tested in Michigan were generally equipped with more modern braking equipment.

Since table 13 showed that the average weight of these vehicle combinations was 8,100 pounds less in Michigan, it might be construed that the difference in weight was a major contributing factor to the difference in performance. Table 14 compares by weight groups the average brake-system application and braking distances for 3-axle truck-tractors with 2-axle semitrailers of approximately the same weight tested in each of the two States. It is significant that in general the vehicles of this type tested in Michigan were able to stop in 8 to 12 feet shorter distance than those of approximately equal weight tested in California. The results shown in table 14

Table 13.—Average minimum brake-system application and braking distance and average gross weight by States for various vehicle types

Vehicle type	Brake-system application and braking distance			Gross weight		
	Maryland	Michigan	California	Maryland	Michigan	California
	Feet	*Feet*	*Feet*	*Pounds*	*Pounds*	*Pounds*
Passenger cars	23	19	21	4,050	4,000	3,850
Single-unit trucks:						
2-axle (very light)	26	23	26	5,250	5,600	4,950
2-axle (other than very light)	35	30	36	15,700	12,800	14,500
3-axle	43	37	48	26,600	30,600	27,500
Truck-tractors with semitrailers:						
2–S1	42	41	45	33,900	31,300	28,000
2–S2	44	43	46	40,800	40,200	38,900
3–S2	42	40	52	50,900	49,300	57,400
Trucks with full trailers:						
2–2	--------	48	55	--------	48,100	43,200
3–2	--------	48	57	--------	47,800	70,200
Truck-tractors with semitrailers and full trailers:						
2–S1–2	--------	54	56	--------	65,100	58,300
2–S2–2	--------	57	46	--------	70,600	50,000

substantiate the relative performances indicated in figure 21.

The relative performance by States of the vehicles considered in table 13 undoubtedly reflects the type of terrain they normally traverse. Most of the vehicles tested in Michigan usually travel over level to rolling terrain; whereas in Maryland, hilly and mountainous country is encountered; and in California, mountainous terrain with long sustained grades is not uncommon. Where long or steep grades are found, wear of the brakes is generally more severe than in flat country, and more frequent brake adjustments are needed. The differences in brake performance by regions emphasize the need for more frequent brake maintenance for vehicles which travel over hilly or mountainous terrain.

Incidental Observations

A considerable amount of data which may be termed incidental to the main purposes of the study was obtained in connection with the brake tests. Much of these data are interesting and useful for reference purposes, and in some cases have a bearing on the results just reported.

Pedal reserve

Pedal reserve is the distance in inches between the floorboard and the back of the brake pedal at the end of an emergency stop. Except for vehicles equipped with certain power-brake systems which upon full application the pedal rests on the floorboard, zero pedal reserve is an indication of need for brake maintenance. A comparison of the percentages of vehicles having zero pedal reserve in the 1942, 1949, and 1955 studies is shown in table 15. The decrease in percentages of vehicles with zero pedal reserve in 1949, and again in 1955, probably reflects improvements in both maintenance and design of the braking systems. The magnitude of the reductions is in keeping with improvements in stopping ability which were previously discussed.

Swerving

The term "swerving" describes an uncontrollable lateral movement of the vehicle when the brakes are applied. In severe cases the vehicle may enter the opposing traffic lane or leave the road. If this condition exists in stops made from 20 miles per hour, experience has shown that it is usually accentuated in stops from higher speeds. This is one very important reason why tests on the highway should not be conducted at a speed greater than 20 miles per hour. Some vehicles of each type swerved to some extent. The passenger cars and the very light 2-axle trucks were the worst offenders. A comparison of percentages of vehicles that swerved in the 1942, 1949, and 1955 studies is given in table 15. The condition of swerving appears to have improved somewhat since 1949, but there is need for much more improvement, particularly in passenger cars and single-unit trucks.

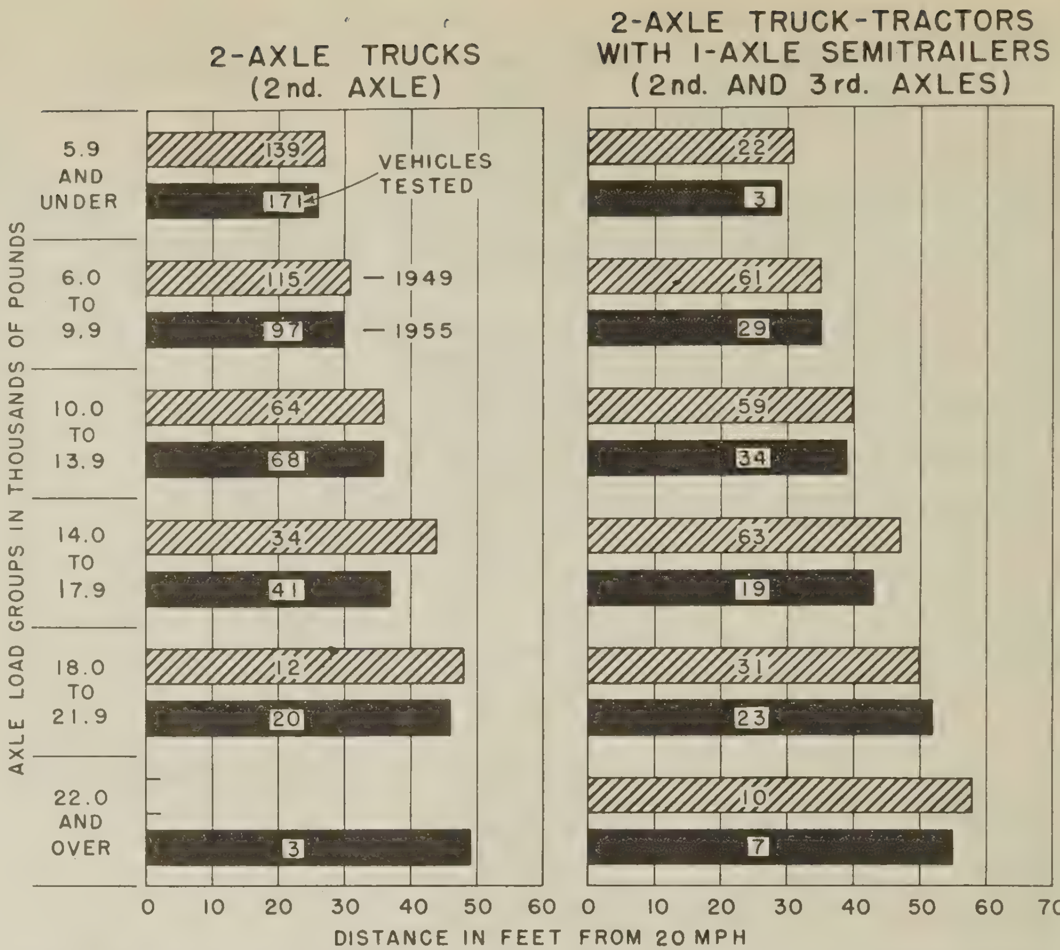

Figure 20.—Relation between axle loads and average brake-system application and braking distances for single-unit trucks and truck combinations.

Wheel slides

The sliding of wheels on a vehicle making a stop indicates that more than adequate braking force is being applied, at least for some part of the stop, with respect to the wheel loads and the frictional characteristics of the particular pavement and tire. The ideal condition, which is difficult to attain because of varying conditions of pavement surface, tires, and brake lining, is to apply just enough braking force to bring the wheel to the point of impending skidding. The fact that a wheel does not slide does not necessarily mean that more braking force is needed. However, the number of vehicles of a sample that slid wheels, when considered in connection with the general levels of brake performance, does give a clue as to whether more braking force could be used.

The percentage of vehicles of various types that slid one or more wheels on any axle is

Table 15.—A comparison of the percentages of vehicles with zero pedal reserve after an emergency stop, and the percentages of vehicles swerving following brake application in the 1942, 1949, and 1955 studies

Vehicle type	Percentage of vehicles with zero pedal reserve			Percentage of vehicles swerving		
	1942	1949	1955	1942	1949	1955
Passenger cars	41	7	3	20	34	28
Very light 2-axle trucks	(1)	(1)	2	(1)	(1)	29
All 2- and 3-axle trucks	56	10	4	16	18	14
2-axle truck-tractors with 1-axle semitrailers	75	7	2	12	12	5
Combination vehicles with 4 or more axles	(2)	(2)	(2)	6	8	4

[1] Percentages not determined. [2] Not applicable.

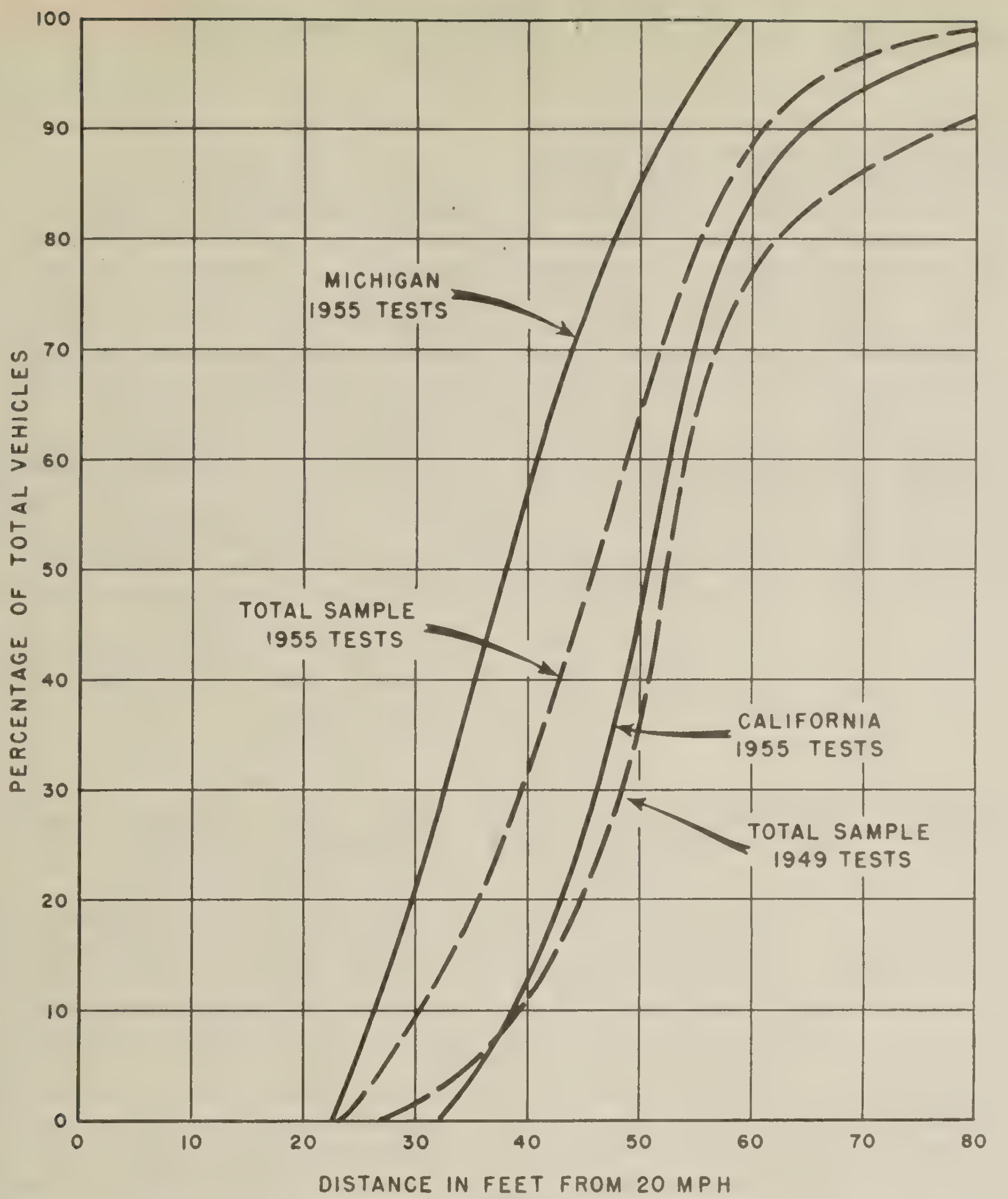

Figure 21.—Cumulative frequency distribution of minimum brake-system application and braking distances for 3-axle truck-tractors with 2-axle semitrailers tested in Michigan and California in 1955.

Table 16.—Percentage of vehicles sliding one or more wheels

Vehicle type	Percentage of vehicles sliding wheels on—							
	Front axle	Second axle	Third axle	Fourth axle	Fifth axle	Sixth axle	Seventh axle	One or more axles
Passenger cars	54	74	----	----	----	----	----	85
Very light 2-axle trucks	18	74	----	----	----	----	----	76
Other 2-axle trucks	6	48	----	----	----	----	----	51
3-axle trucks	0	45	48	----	----	----	----	51
2-axle truck-tractors with 1-axle semitrailers	0	26	31	----	----	----	----	40
2-axle truck-tractors with 2-axle semitrailers	1	17	37	45	----	----	----	53
3-axle truck-tractors with 2-axle semitrailers	0	17	18	27	38	----	----	50
Trucks with full trailers (4, 5, and 6 axles)	0	9	7	10	19	3	----	29
Truck-tractors with semitrailers and full trailers (5, 6, and 7 axles)	0	11	33	22	48	4	4	61

shown in table 16. A relatively small percentage of the commercial vehicles, especially the combination vehicles, slid wheels as compared with passenger cars. Percentages of empty trucks and combinations sliding wheels were as follows: 40 percent of the very light 2-axle trucks, 37 percent of the other single-unit vehicles, 31 percent of the truck-tractors with semitrailers, and 31 percent of the other vehicle combinations. Many of the remaining vehicles with sliding wheels were only partly loaded.

Thirty-five percent of the passenger cars, 8 percent of the very light 2-axle trucks, and 2 percent of the other 2-axle trucks slid all wheels. In no instance did this happen to 3-axle trucks or vehicle combinations.

From the foregoing discussion of the vehicles with sliding wheels, and from the levels of performance described earlier in this article, it is reasonable to assume that loaded combination vehicles now operating in the general traffic could use additional braking force. The deficiency in braking effort, if that is the case, could be attributed either to loads greater than those for which the brakes were designed or to inadequate brake-system maintenance.

Miscellaneous vehicle combinations

Included in the 1955 study, as shown in table 1, were three passenger-car driveaway-towaway combinations and five housetrailer factory-towaway combinations. Although the performance of such a small sample cannot be considered representative, it does provide some indication of the stopping ability of these combinations. The three passenger-car towaway combinations required 39, 46, and 67 feet to stop. In the case of the combination which stopped in 39 feet, the brakes on the towed car, as well as those on the towing car, were applied in stopping. Both of these cars were new. The other two towaway combinations were secondhand cars, and the brakes were operative on only the towing vehicle.

The power units of the five housetrailer factory-towaway combinations were very light trucks with manufacturers' gross weight ratings varying from 5,800 to 9,500 pounds for use as single-unit vehicles. These combinations were equipped with hydraulic brakes on the power units and electric brakes on the trailers. The average gross weight of the five combinations was 12,800 pounds, and their average brake-system application and braking distance was 36 feet. Additional housetrailer combinations were stopped, but the drivers requested that they be excused from the test because of the possibility of damaging refrigerators or other equipment inside of the trailers.

Construction Specifications for Federal Highway Projects

The Bureau of Public Roads has recently published a 363-page book entitled *Standard specifications for construction of roads and bridges on Federal highway projects.* As indicated by the title, the book is intended primarily for use in the construction of Federal road and bridge projects under the direct supervision of the Bureau. Such projects include work for which Public Roads receives direct appropriations, as for major highways through National forests, and work performed by Public Roads for other Federal agencies.

The book, which for simplified reference may be cited as FP–57, supersedes a previous publication, *Specifications for construction of roads and bridges in National forests and National parks* (FP–41), issued in 1941.

The new book contains up-to-date specifications for those items of work and materials and construction methods that are generally applicable to direct Federal highway contracts. They are considered to be good specifications, which will result in highway work of high quality. These specifications are not required or intended to be used in Federal-aid highway work performed by the States with funds administered by the Bureau of Public Roads since, as prescribed in the basic Federal-aid highway legislation, each State prepares its own specifications for Federal-aid highway construction, subject to approval by Public Roads. However, these specifications will undoubtedly be of interest to specifications writers in particular and to most engineers in highway design and construction, as well as to engineering students.

During the preparation of the new specifications, the material was reviewed by both field and office engineers of the Bureau of Public Roads and by committees and individual representatives of national organizations of highway contractors and of producers and suppliers of materials and equipment. The benefits of their comments and suggestions are reflected in the book.

Standard specifications for construction of roads and bridges on Federal highway projects (FP–57) is available for purchase from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at $2.00 a copy.

First Progress Report of the Highway Cost Allocation Study

The Secretary of Commerce transmitted to the Congress on Feburary 28, 1957, a progress report on the highway cost allocation study. The report, due on or before March 1, 1957, was prepared by the Bureau of Public Roads in compliance with subsection (d) of section 210 of the Highway Revenue Act of 1956. Another progress report is due one year later, and the final report is to be made available to the Congress as soon as possible but not later than March 1, 1959.

The 131-page report, entitled *First progress report of the highway cost allocation study*, has been published as House Document No. 106, and is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 35 cents a copy.

The objective of the study is "to provide the Congress with information on the basis of which it may determine what taxes should be imposed and in what amounts, in order to assure, insofar as practicable, an equitable distribution of the tax burden for the support of the Federal-aid highway program."

The study, which is being made in cooperation with the State highway departments and with other Federal agencies, inquires into both highway costs occasioned and the benefits derived by the use of Federal-aid highways of vehicles of different dimensions, weights, and other specifications. Inquiry will also be made into benefits, direct or indirect, that may be derived by any class of persons from public expenditures on the Federal-aid highways, other than through direct use of such highways.

The present report is in three parts: Part I is a presentation of the background of the equity problem in highway taxation; part II discusses the methods of research and analysis which will be employed in the search for equitable allocations of cost responsibility; and part III outlines the planning and organization of the study and summarizes the accomplishments to date.

Errata

The article *Applications of electrical resistivity measurements to subsurface investigations* included in the April 1957 issue of Public Roads, vol. 29, No. 7, requires a correction on page 168. The references *left* and *right* in the legend for figure 15 should be interchanged to agree with the placement of the illustrations.

U. S. GOVERNMENT PRINTING OFFICE: 1957

A list of the more important articles in PUBLIC ROADS may be obtained upon request addressed to Bureau of Public Roads, Washington 25, D. C.

PUBLICATIONS of the Bureau of Public Roads

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ANNUAL REPORTS

Work of the Public Roads Administration:
1941, 15 cents. 1948, 20 cents.
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Public Roads Administration Annual Reports:
1943; 1944; 1945; 1946; 1947.
(*Free from Bureau of Public Roads*)

Annual Reports of the Bureau of Public Roads:
1950, 25 cents. 1953 (out of print). 1956, 25 cents.
1951, 35 cents. 1954 (out of print).
1952, 25 cents. 1955, 25 cents.

PUBLICATIONS

Bibliography of Highway Planning Reports (1950). 30 cents.
Braking Performance of Motor Vehicles (1954). 55 cents.
Construction of Private Driveways, No. 272MP (1937). 15 cents.
Criteria for Prestressed Concrete Bridges (1954). 15 cents.
Design Capacity Charts for Signalized Street and Highway Intersections (reprint from PUBLIC ROADS, Feb. 1951). 25 cents.
Electrical Equipment on Movable Bridges, No. 265T (1931). 40 cents.
Factual Discussion of Motortruck Operation, Regulation, and Taxation (1951). 30 cents.
Federal Legislation and Regulations Relating to Highway Construction (1948). Out of print.
Financing of Highways by Counties and Local Rural Governments: 1931–41, 45 cents; 1942–51, 75 cents.
First Progress Report of the Highway Cost Allocation Study, House Document No. 106 (1957). 35 cents.
General Location of the National System of Interstate Highways, Including All Additional Routes at Urban Areas Designated in September 1955. 55 cents.
Highway Bond Calculations (1936). 10 cents.
Highway Bridge Location, No. 1486D (1927). 15 cents.
Highway Capacity Manual (1950). $1.00.
Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.
Highway Practice in the United States of America (1949). 75 cents.
Highway Statistics (annual):
1945 (out of print). 1949, 55 cents. 1953, $1.00.
1946, 50 cents. 1950 (out of print). 1954, 75 cents.
1947, 45 cents. 1951, 60 cents. 1955, $1.00.
1948, 65 cents. 1952, 75 cents.
Highway Statistics, Summary to 1945. 40 cents.
Highways in the United States, *nontechnical* (1954). 20 cents.
Highways of History (1939). 25 cents.
Identification of Rock Types (reprint from PUBLIC ROADS, June 1950). 15 cents.
Interregional Highways, House Document No. 379 (1944). 75 cents.
Legal Aspects of Controlling Highway Access (1945). 15 cents.
Local Rural Road Problem (1950). 20 cents.
Manual on Uniform Traffic Control Devices for Streets and Highways (1948) (*including 1954 revisions supplement*). $1.25.
Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate*, 15 cents.

PUBLICATIONS (Continued)

Mathematical Theory of Vibration in Suspension Bridges (1950). $1.25.
Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.
Opportunities in the Bureau of Public Roads for Young Engineers (1955). 25 cents.
Parking Guide for Cities (1956). 55 cents.
Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft (1943). $2.00.
Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents.
Public Control of Highway Access and Roadside Development (1947). 35 cents.
Public Land Acquisition for Highway Purposes (1943). 10 cents.
Public Utility Relocation Incident to Highway Improvement, House Document No. 127 (1955). 25 cents.
Results of Physical Tests of Road-Building Aggregate (1953). $1.00.
Roadside Improvement, No. 191MP (1934). 10 cents.
Selected Bibliography on Highway Finance (1951). 60 cents.
Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways, 1956: a reference guide outline. 55 cents.
Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-57 (1957). $2.00.
Standard Plans for Highway Bridge Superstructures (1956). $1.75.
Taxation of Motor Vehicles in 1932. 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces (1943). 10 cents.
Transition Curves for Highways (1940). $1.75.

MAPS

State Transportation Map series (available for 39 States). Uniform sheets 26 by 36 inches, scale 1 inch equals 4 miles. Shows in colors Federal-aid and State highways with surface types, principal connecting roads, railroads, airports, waterways, National and State forests, parks, and other reservations. Prices and number of sheets for each State vary—see Superintendent of Documents price list 53.
United States System of Numbered Highways. 28 by 42 inches, scale 1 inch equals 78 miles. 20 cents.

Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.

Bibliography on Automobile Parking in the United States (1946).
Bibliography on Highway Lighting (1937).
Bibliography on Highway Safety (1938).
Bibliography on Land Acquisition for Public Roads (1947).
Bibliography on Roadside Control (1949).
Express Highways in the United States: a Bibliography (1945).
Indexes to PUBLIC ROADS, volumes 17–19 and 23.
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STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF APRIL 30, 1957

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			CONTRACTS ADVERTISED, CONSTRUCTION NOT STARTED			PROJECTS UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$22,762	$35,685	$26,987	327.7	$11,224	$7,164	94.8	$74,229	$45,335	897.4	$121,138	$79,486	1,319.9
Arizona	6,230	25,652	22,390	197.2	6,943	5,764	63.0	19,535	15,886	98.5	52,130	44,040	358.7
Arkansas	37,021	19,355	11,124	474.4	11,344	5,759	105.1	35,469	21,510	425.4	66,168	38,393	1,004.9
California	9,623	57,515	33,422	235.7	50,044	39,015	45.1	391,893	181,954	318.8	499,452	254,391	599.6
Colorado	28,342	18,547	13,212	127.1	6,686	4,911	46.7	34,878	23,929	221.8	60,111	42,052	395.6
Connecticut	34,803	7,458	3,739	6.8	16,952	10,883	7.9	16,888	10,590	29.0	41,298	25,212	43.7
Delaware	17,907	3,090	1,557	26.8	1,909	1,205	12.8	14,702	8,141	63.9	19,701	10,903	103.5
Florida	24,595	26,591	20,532	217.7	18,272	13,171	40.8	46,683	26,680	316.0	91,546	60,383	574.5
Georgia	45,747	56,758	36,206	698.8	7,808	4,150	48.4	87,750	48,490	875.3	152,316	88,846	1,622.5
Idaho	30,786	7,447	5,737	89.0	1,913	1,404	18.7	15,674	10,254	199.8	25,034	17,395	307.5
Illinois	25,517	103,717	73,303	761.0	40,325	27,833	112.4	154,109	108,117	680.3	298,151	209,253	1,553.7
Indiana	86,366	27,694	15,381	111.8	13,160	7,007	95.8	41,024	25,651	142.8	81,878	48,039	350.4
Iowa	4,003	61,410	45,757	757.1	21,672	12,361	399.8	51,448	34,447	940.6	134,530	92,565	2,097.5
Kansas	11,179	53,019	42,711	990.2	8,242	4,503	183.7	40,911	23,955	1,135.1	102,172	71,169	2,309.0
Kentucky	57,037	8,371	5,909	62.3	1,250	814	5.5	43,044	26,959	330.5	52,665	33,682	398.3
Louisiana	39,436	34,779	17,896	192.1	15,149	8,220	60.3	42,494	22,808	274.8	92,422	48,924	527.2
Maine	24,955	11,621	6,209	91.7	1,150	680	8.4	19,128	9,972	119.2	31,899	16,861	219.3
Maryland	6,773	23,020	11,672	131.8	13,575	10,614	10.2	60,068	39,995	160.3	96,663	62,281	302.3
Massachusetts	37,580	35,282	21,522	32.5	43,246	25,733	29.8	55,896	30,966	48.1	134,424	78,221	110.4
Michigan	17,027	83,064	62,818	648.0	44,966	27,020	98.9	94,753	63,397	338.5	222,783	153,235	1,085.4
Minnesota	27,476	27,992	20,134	941.2	13,126	8,121	237.8	66,628	45,641	729.2	107,746	73,896	1,908.2
Mississippi	11,356	41,915	29,866	708.8	20,702	17,158	128.6	33,306	19,083	670.9	95,923	66,107	1,508.3
Missouri	29,343	43,532	27,533	1,269.3	11,262	9,026	25.4	111,299	69,708	1,092.9	166,093	106,267	2,387.6
Montana	38,567	9,338	5,746	185.6	7,934	4,823	117.4	46,344	33,132	437.4	63,616	43,701	740.4
Nebraska	38,636	27,994	16,677	444.8	5,577	3,145	108.6	33,853	19,279	984.0	67,424	39,101	1,537.4
Nevada	29,385	6,655	5,958	70.1	2,331	1,919	15.9	15,019	12,809	196.4	24,005	20,686	282.4
New Hampshire	11,261	12,126	8,608	31.5	1,063	530	6.4	17,073	10,227	71.7	30,262	19,365	109.6
New Jersey	72,862	18,622	10,431	75.9	8,821	4,686	14.5	42,864	24,638	33.5	70,307	39,755	123.9
New Mexico	10,891	9,928	7,919	72.6	7,683	6,240	46.0	32,511	25,773	246.1	50,122	39,932	364.7
New York	87,828	52,616	31,306	157.2	90,778	59,349	83.1	354,488	203,567	425.5	497,882	294,222	665.8
North Carolina	60,549	26,390	16,407	320.4	13,226	10,171	83.3	67,584	34,391	835.6	107,200	60,969	1,239.3
North Dakota	13,386	24,237	17,347	1,407.1	13,303	9,145	312.0	22,555	13,399	957.4	60,095	39,891	2,676.5
Ohio	38,016	92,742	65,374	191.9	14,654	10,569	12.6	165,287	108,768	228.5	272,683	184,711	433.0
Oklahoma	27,470	46,285	32,457	571.1	10,057	5,584	88.3	44,520	26,086	398.7	100,862	64,127	1,058.1
Oregon	23,627	7,404	5,976	66.5	2,844	2,460	16.0	41,611	29,666	240.4	51,859	38,102	322.9
Pennsylvania	36,605	117,886	81,657	205.3	83,704	55,975	78.5	163,870	97,930	333.9	365,460	235,562	617.7
Rhode Island	6,223	2,032	1,128	2.6	10,079	8,670	10.3	26,187	16,707	19.8	38,298	26,505	32.7
South Carolina	36,418	22,753	14,727	477.2	2,051	1,483	10.7	36,399	20,566	703.6	61,203	36,776	1,191.5
South Dakota	11,597	32,607	24,539	607.7	5,236	2,929	141.8	26,477	17,429	769.0	64,320	44,897	1,518.5
Tennessee	45,715	30,790	19,144	474.4	12,242	6,250	33.1	81,250	45,654	582.6	124,282	71,048	1,090.1
Texas	93,180	30,323	24,023	271.2	60,370	42,656	239.0	160,820	99,025	1,720.1	251,513	165,704	2,230.3
Utah	16,380	17,114	14,265	156.9	1,654	1,335	2.1	14,938	11,913	179.7	33,706	27,513	338.7
Vermont	11,442	3,753	2,676	32.1	3,740	2,477	5.9	16,844	11,298	63.4	24,337	16,451	101.4
Virginia	41,533	41,428	28,898	177.5	7,915	5,318	21.9	44,993	24,272	371.3	94,336	58,488	570.7
Washington	36,130	15,280	9,883	277.8	8,210	6,545	51.4	43,089	26,650	270.5	66,579	43,078	599.7
West Virginia	23,336	38,873	27,200	64.5	4,741	2,393	25.9	30,078	16,234	82.2	73,692	45,827	172.6
Wisconsin	53,967	21,216	11,682	401.5	6,362	3,273	28.3	65,914	38,833	410.5	93,492	53,788	840.3
Wyoming	1,046	15,709	13,147	81.3	15,180	12,647	112.0	27,251	20,066	331.0	58,140	45,860	524.3
Hawaii	5,969	3,246	1,623	11.0	3,157	1,575	4.5	4,935	2,373	9.0	11,338	5,571	24.5
District of Columbia	15,394	13,242	10,504	8.4	3,172	1,904	2.0	11,210	8,487	.1	27,624	20,895	10.5
Puerto Rico	10,789	5,638	2,303	15.8				18,949	9,044	61.1	24,587	11,347	76.9
Alaska	1,226	14,589	13,130	413.8	80	72	9.0	653	606		15,322	13,808	422.8
TOTAL	1,535,292	1,574,330	1,080,352	16,372.7	787,084	526,639	3,560.4	3,209,375	1,922,290	21,072.1	5,570,789	3,529,281	41,005.2

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