PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 23, NO. 3 MAY 1942

VISITING ENGINEERS PREPARE TO OBSERVE TRUCK HILL-CLIMBING TESTS

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PUBLIC ROADS ▶▶▶ *A Journal of Highway Research*

issued by the

FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 23, No. 3 May 1942

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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HILL-CLIMBING ABILITY OF MOTOR TRUCKS

BY THE DIVISION OF HIGHWAY TRANSPORT, PUBLIC ROADS ADMINISTRATION

Reported by CARL C. SAAL, Associate Highway Engineer-Economist

The problem of eliminating the traffic congestion that results from slow-moving vehicles on grades has been investigated in an exhaustive study of motor truck performance. The study was divided into three distinct but closely related parts: A study of the performance of new motor trucks in the best of condition; a study of the performance of used motor trucks in various stages of wear and having traveled various mileages; and a study of the hill-climbing ability and the driver behavior of a large number of motor trucks and passenger cars as they operate in every day traffic.

Actual grade tests, the most important part of the new truck study, were made on 30 new truck chassis. The results of these tests showed that for motor trucks even to approach reasonable speeds on grades: Grades must be reduced to 3 percent or less; or engine power must be more than doubled; or gross vehicle weights must be reduced excessively; or some combination of the three must be used that will still be costly to all interests involved and impossible of immediate application.

Deceleration tests were made on each new truck to determine the coefficients of tractive resistance. The most significant finding was that not only the total tractive resistance but also the unit resistance in pounds per 1,000 pounds varied appreciably with weight. The efficiency of the transmission of power was also determined for each new vehicle from the results of the actual grade tests. The evaluation of these two factors makes it possible to compute the performance of a motor truck from its specified characteristics with a fair degree of accuracy.

The results of the actual grade tests were also used to appraise cheaper and shorter methods for determining the grade ability of motor trucks. The acceleration method proved to be the most satisfactory and was adopted for use on the used truck study.

Tests on 17 used trucks of the same make and model as the new trucks tested showed that not over a 10 percent decrease in performance should be expected from wear and mileage. The results also proved definitely that trucks can be maintained so that their performance does not decrease with reasonable use.

The study of motor trucks in actual service under ordinary driving produced results that showed a 30 percent variation between the possible performance and the actual performance of vehicles of the same weight and capacity. Since not over 10 percent of this variation should be due to lack of maintenance, there remains a 20 percent variation that must be charged to improper operation of the vehicle. The shifting of gears at improper speeds was the principal reason for the variation in performance.

ELIMINATION of the traffic congestion that results from slow-moving vehicles on hills is a difficult problem. There are two possible solutions:

1. Facilities can be provided to enable other vehicles to pass the slow-moving vehicles.
2. The speed of the slow-moving vehicles can be increased.

Passing facilities can be provided by the construction of added lanes on hills and the building of highways with longer sight distances, but these solutions are localized in character. A more comprehensive solution and the one that is considered here is that of increasing speeds by reducing grades, increasing power, or reducing gross vehicle weight, or by a combination of these means. The purpose of the research reported herein is to determine if there is a reasonable minimum speed that will eliminate the congestion and, if so, how the three methods (grade reduction, weight reduction, and power increase) should be applied to make this speed a reality.

In order to supply the information that is needed to fulfill this purpose, in the spring of 1938 the Public Roads Administration in cooperation with the Automobile Manufacturers' Association, the Maryland Motor Truck Association, the National Bureau of Standards, and the Quartermaster Corps of the Army, inaugurated an exhaustive study of motor-truck performance. The study was divided into three distinct but closely related parts. A study of the performance of new motor trucks; a study of the performance of used motor trucks in various stages of wear and having traveled various mileages; and a study of the hill-climbing ability and the driver behavior of a large number of motor trucks and passenger cars as they operate in every day traffic. The results reveal some decidedly interesting and significant facts.

The primary purpose of the new truck study was to determine the maximum grade performance that can be expected from various motor trucks. It was desired to obtain accurate information on which to consider the feasibility of imposing performance requirements and the facts needed to determine what methods can best be used to enable motor trucks to maintain reasonable speeds on grades.

It was also proposed to determine, if possible, a means for computing with some degree of accuracy the performance of a motor truck from its specified characteristics. In order to do this it was necessary to evaluate two important factors—the coefficient of tractive resistance and the mechanical efficiency of the transmission of power.

Another purpose of this study was to develop a method that could be used in the used-truck study to determine the performance accurately in less time and with less expense. After experimenting with several methods, one that makes use of values of acceleration was determined to be the most suitable.

The field tests were conducted in the vicinity of Baltimore, Md., with the Holabird Quartermaster Corps Depot as the base of operations. The facilities of the depot were made available for the tests, including personnel, equipment, a gasoline supply, use of the machine shop and dynamometer laboratory, and storage space. The Johns Hopkins University furnished office space for the analysis work, which kept pace with the field work.

LIGHT, MEDIUM AND HEAVY TRUCKS TESTED

The new trucks and tractor trucks involved in the tests were supplied by the manufacturers. The chassis tested were divided into three size groups—light, medium, and heavy. The light group included vehicles rated as 1½ tons; the medium group included vehicles 2 tons to less than 5 tons; and the heavy group included vehicles 5 tons and over. The models selected for each capacity group were those widely used currently and as nearly alike in piston displacement as possible, so that they would represent the vehicles now in common use and also be comparable as to power output. The light, medium, and heavy chassis were generally equipped with engines of approximately 230-, 300-, and 400-cubic inch piston displacement, respectively. The vehicles tested are described in table 1.

The manufacturers furnished expert drivers and mechanics to operate the vehicles and keep them in the best of condition throughout the tests. Every possible care was exercised to insure that the maximum performance was obtained. In addition, each manufacturer was represented during the tests by an engineer who inspected the operations and results to make certain that the maximum performance was being measured. The motors of the new chassis were thoroughly run in before the start of the tests.

A semitrailer equipped with a platform body with 1½-foot side boards and a platform truck body with 2-foot side boards were used for all the tests on the tractor trucks and single-unit trucks, respectively. Although the frontal area of the bodies used was not as great as that of the van type bodies in common use on the highway, any variance in performance that might result from the use of these bodies would not be significant for the speeds involved, especially since the tests were not made if there was a strong head or tail wind.

All of the trucks and tractor trucks were tested with gasoline from pumps operated by the Holabird Quartermaster Corps Depot. The National Bureau of Standards made tests on a sample of gasoline from each tank car that was emptied into the storage tanks from which the gasoline was pumped, in order to determine if the quality of the gasoline remained constant for the duration of the tests. A quart sample was obtained each time a vehicle was serviced with gasoline. A composite sample for a given tank car was then formed by blending the several quart samples at a temperature below 0° centigrade.

TABLE 1.—*Description of trucks and tractor-trucks tested in new truck study*

LIGHT TRUCKS[1]

Make	Model	Year	Engine			Gear ratios						Tire size
			Piston displacement	Maximum torque	Maximum horsepower at r. p. m. given	Rear axle	Transmission					
							1	2	3	4	5	
			Cu. in.	Lb.-ft.								
G. M. C	T16B	1938	230	172	86-3500	[2] 5.14 7.15	7.23	3.48	1.71	1.00	--------	7.50×20
International	D30	1938	232	170	81-3200	6.17	6.40	3.09	1.69	1.00	--------	7.50×20
White	700	1938	250	175	76-2800	5.83	6.40	3.09	1.69	1.00	--------	7.50×20
Dodge	TF37	1939	228	158	80-3200	6.33	6.40	3.09	1.69	1.00	--------	7.00×20
Chevrolet	VD	1939	216	170	78-3200	6.17	7.23	3.48	1.71	1.00	--------	32×6
Diamond T	404	1939	245	170	77-3200	6.33	6.34	3.28	1.65	1.00	--------	32×6
LIGHT TRACTOR TRUCKS[1]												
G. M. C	T16A	1938	230	172	86-3500	[2] 5.14 7.15	7.23	3.48	1.71	1.00	--------	7-50×20
International	D30	1938	232	170	81-3200	6.66	6.40	3.09	1.69	1.00	--------	7.50×20
White	700	1938	250	175	76-2800	6.80	6.15	3.58	1.86	1.00	0.77	7.50×20
Dodge	TF36	1939	228	158	80-3200	6.33	6.40	3.09	1.69	1.00	--------	7.00×20
Chevrolet	VB	1939	216	170	78-3200	6.17	7.23	3.48	1.71	1.00	--------	32×6
Federal	15	1939	228	155	72-3000	6.67	6.40	3.09	1.69	1.00	--------	7.50×20
Ford	98T	1940	239	170	95-3600	6.67	6.40	3.09	1.69	1.00	--------	8.75×18
MEDIUM TRUCKS[1]												
G. M. C	T33H	1938	286	220	99-2800	6.43	7.58	4.38	2.40	1.48	1.00	10.50×20
Mack	EH	1938	310	210	90-3000	8.59	6.10	3.48	2.04	1.00	.768	9.00×20
International	D50	1938	298	218	94-2800	7.16	6.52	3.72	1.92	1.00	.823	9.00×20
White	710	1938	318	245	110-3000	7.14	6.06	3.50	1.80	1.00	.799	9.00×20
MEDIUM TRACTOR TRUCKS[1]												
G. M. C	T33H	1938	286	220	99-2800	6.43	7.58	4.38	2.40	1.48	1.00	10.50×20
Mack	EH	1938	310	210	90-3000	8.59	6.10	3.48	2.04	1.00	.768	9.00×20
International	D50	1938	298	218	94-2800	7.16	6.52	3.72	1.92	1.00	.823	9.00×20
White	710	1938	318	245	110-3000	7.14	6.06	3.50	1.80	1.00	.799	9.00×20
Diamond T	614	1939	320	223	81-2500	[2] 6.43 8.74	7.58	4.38	2.40	1.48	1.00	9.00×20
Federal	29	1939	320	244	95-2800	7.40	7.58	4.38	2.40	1.48	1.00	9.75×20
HEAVY TRACTOR TRUCKS[1]												
G. M. C	T46B	1938	400	304	120-2500	[2] 5.62 7.65	6.63	3.20	1.70	1.00	.74	10.50×20
Mack	BM	1938	415	271	108-2400	8.64	6.90	3.91	1.89	1.00	.794	10.50×20
International	DR70	1938	401	308	114-2600	9.03	6.98	3.57	1.89	1.00	.825	11.25×20
White	750	1938	362	280	116-3000	7.14	7.00	3.97	1.80	1.00	.788	10.50×20
MEDIUM AND HEAVY TRACTOR TRUCKS[3]												
G. M. C	602	1939	213	263	72-2000	[2] 6.43 8.74	6.21	3.52	1.81	1.00	.77	9.75×20
Dodge	TKD	1939	331	226	95-2600	[2] 6.14 8.35	7.58	4.38	2.39	1.48	1.00	9.75×20
Mack	ED	1940	519	383	131-2000	[4] 7.54	6.74 9.30	3.82 5.27	1.92 2.65	1.00 1.38	.78 1.08	10.50×20

[1] Gasoline engines.
[2] 2-speed axles.
[3] Diesel engines.
[4] Auxiliary transmission.

Tests were made to determine the A. S. T. M. octane number, the Reid vapor pressure, the sulfur content, and the distillation range. The results of these tests are contained in table 2. The octane number is 71 for 4 of the samples and 72 for the other 16 samples. The results definitely show that the gasoline used during the period of study was of uniform quality.

Each of the new motor trucks was subjected to an exhaustive series of tests. The grade ability was determined by actual road tests made by placing various loads on the vehicles and observing the sustained speeds maintained on known gradients, and by acceleration tests that measured the drawbar force available at various road speeds over the entire useful speed range of each gear. The tractive resistance, an important variable in any consideration of grade ability, was determined for each vehicle by deceleration tests that measured the force opposing the motion of the vehicle when coasting in neutral on a level grade. Dynamometer tests were made to determine the power output of each engine so that the certified power and torque curves submitted by the manufacturer could be verified.

The actual grade tests, the most important part of the new truck study, involved the testing of the 10 single-unit trucks and the 20 tractor-truck semitrailers on several uniform grades. At the start of the study each truck was tested on grades of 3.2, 4.0, 4.5, 6.0, and 7.0 percent. However, after testing several units sufficient data were obtained to prove that the performance for one grade could be accurately converted to that for another grade. Thereafter the tests were conducted on uniform grades of 4.5 and 6.0 percent.

SUSTAINED SPEEDS DETERMINED FOR VARIOUS LOADS IN EACH GEAR

Known loads were placed on each truck, and the maximum sustained speed that it could maintain on a known grade was determined. The maximum gross vehicle weight that the truck could pull up the grade in a given gear at a constant speed was determined by trial, using the performance indicated by an ability formula as a guide. Starting with the maximum weight that could be hauled in a given gear, the load was decreased by 1,000- or 500-pound decrements and the maximum sustained speed measured for each gross vehicle weight. The weight was decreased until the sustained speed increased to a value that corresponded to an engine speed that approximated the maximum recommended by the manufacturer or, if the motor was governed, to the governed engine speed. Vehicles equipped with governors were tested both with and without the governors in operation. When the tests were completed in one gear, they were continued in the gear with the next lower gear ratio. The tests were continued until the empty weight of the truck or combination was reached.

Several test runs were required to determine the sustained speed for each gross weight because the grades used were not long enough to slow down a vehicle to a crawl speed on the first trial. All of the test runs were made with full throttle. The truck was driven onto the grade at a speed estimated to be that which could be sustained over the entire length of grade. An observer in the cab of the truck recorded the speed indicated by the truck speedometer at the start and the end of the test run, and determined whether a sustained speed was maintained. If the vehicle accelerated or decelerated on the first test run, the grade was entered on the next run at about the speed indicated when the truck left the grade on the previous run. When this procedure finally resulted in a speed that appeared to be the one that the truck could maintain over the entire length of the grade, a check run was made to verify it.

Typical field data for a 6-percent grade are shown in table 3. For third gear, after trying weights of 19,000 and 18,000 pounds, the maximum gross vehicle weight that could be carried at a sustained speed was determined to be 17,500 pounds. From this point the load was decreased by decrements of 1,000 pounds to a gross weight of 11,500 pounds, at which point a road speed was observed that corresponded to the maximum engine speed recommended. For the gross weight of 13,500 pounds, five test runs (46 to 50 inclusive) were required to determine the speed that could be sustained. The grade was entered on the first run at 30 miles per hour, and the truck decelerated to a speed of about 27 miles per hour. On the second run, the truck entered the grade at 25 miles per hour and accelerated to a speed of 27 miles per hour. These two runs indicated that the sustained speed for this particular weight was about 27 miles per hour. The following three runs estab-

TABLE 2.—*Results of tests made on gasoline used in making motor-truck performance studies*

Type of test	Sample No.																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A. S. T. M. octane No.	72	72	71	71	71	72	72	72	72	72	71	72	72	72	72	72	72	72	72	72
Reid vapor pressure *lb/sq. in*	8.6	8.3	8.0	8.0	7.7	7.7	8.2	8.1	8.9	8.9	8.4	7.7	8.2	8.6	9.0	9.9	9.5	9.2	9.1	8.5
Sulfur, *percent*	.09	.09	.09	.09	.09	.09	.07	.06	.06	.07	.09	.10	.10	.10	.12	.11	.10	.10	.10	.10
Distillation:																				
First drop °C	37	37	35	37	37	37	36	35	35	35	38	37	37	35	39	33	33	32	34	34
5 percent distilled °C	53	53	53	54	55	55	53	54	50	50	53	52	53	51	51	49	50	48	49	50
10 percent distilled °C	62	62	61	64	64	64	62	63	59	58	60	59	60	58	58	57	58	56	58	57
15 percent distilled °C	70	70	70	72	72	73	71	71	68	67	67	65	67	66	66	66	67	65	66	65
20 percent distilled °C	78	78	79	80	80	81	80	80	77	76	74	71	74	73	73	75	75	74	74	73
30 percent distilled °C	94	94	94	95	95	96	96	96	94	92	88	84	89	87	87	92	92	91	91	90
40 percent distilled °C	107	108	108	109	108	109	110	110	109	107	102	97	102	101	100	106	106	106	107	106
50 percent distilled °C	120	120	120	121	121	121	123	123	122	122	115	109	115	114	112	118	118	119	120	121
60 percent distilled °C	133	130	133	133	133	133	133	135	134	134	126	121	124	124	124	130	130	130	130	133
70 percent distilled °C	145	147	146	146	147	145	146	146	146	146	139	134	138	138	135	142	137	140	144	146
80 percent distilled °C	159	162	162	163	162	162	160	160	161	159	155	150	155	155	152	158	159	158	159	160
90 percent distilled °C	181	182	182	181	179	182	178	178	178	177	173	170	176	176	173	177	178	179	178	179
95 percent distilled °C	198	200	197	198	195	197	193	192	193	192	192	------	193	193	191	196	196	195	194	194
End Point °C	215	212	214	214	204	214	208	204	202	203	203	203	205	203	202	204	205	203	204	203
Recovery *percent*	96.9	96.9	97.5	97.4	96.9	97.5	97.5	97.5	97.1	97.5	97.4	97.8	97.3	97.5	97.5	96.8	96.7	96.9	97.5	97.7
Residue do	1.1	1.3	1.2	1.1	1.7	1.3	.9	1.1	1.0	1.1	1.0	1.1	1.1	1.1	1.2	.9	1.0	1.0	.9	1.0
Loss do	2.0	1.8	1.3	1.5	1.4	1.2	1.6	1.4	1.9	1.4	1.6	1.1	1.6	1.4	1.3	2.3	2.3	2.1	1.6	1.3
Barometric pressure *mm. of mercury*	752	752	760	754	753	748	747	747	746	746	746	744	760	760	760	749	757	757	757	757

lished the sustained speed at approximately 27 miles per hour. The same procedure was used for each weight.

The radius of the driving wheels when loaded was measured in the field for each test weight as shown in table 3. This measurement must be determined in order to relate the power output at the engine to that available at the driving wheels. It was measured by means of an adjustable arm attached to a meter stick. A small level was mounted on the arm to insure accuracy of measurement.

Table 3.—*Sample of field data recorded for a tractor-truck semi-trailer on a 6-percent grade*

Test No.	Gear used	Gross vehicle weight	Speedometer reading			Radius of driving wheels when loaded			Remarks
			Enter	Leave	Sustained	Right	Left	Average	
		Pounds	*M. p. h.*	*M. p. h.*	*M. p. h.*	*Inches*	*Inches*	*Inches*	
24	2	22,750	14	16+	16+	17.13	17.13	17.13	
25	2	22,750	16+	16+	16+				
26	2	22,750	16+	16+	16+				
27	3	19,000	12	4	--------	17.25	17.15	17.20	Had to shift gears.
28	3	18,000	12	7	--------	17.20	17.20	17.20	Do.
29	3	18,000	9	4	--------				
30	3	17,500	12	10−	10−	17.20	17.24	17.22	
31	3	17,500	9	9+	9+				
32	3	17,500	8	9	9				
33	3	16,500	15	14	--------	17.25	17.31	17.28	
34	3	16,500	12	13+	13+				
35	3	16,500	14	13+	13+				
36	3	16,500	13+	13+	13+				
37	3	15,500	20	20	20	17.41	17.31	17.36	
38	3	15,500	22	20	--------				
39	3	15,500	18	19+	--------				
40	3	15,500	19	20−	20−				
41	3	14,500	25	24	24	17.41	17.35	17.38	
42	3	14,500	22	23+	--------				
43	3	14,500	24	24	24				
44	3	14,500	24	24	24				
45	3	14,500	27−	25−	--------				
46	3	13,500	30	27+	--------	17.52	17.44	17.48	
47	3	13,500	25	27	--------				
48	3	13,500	27+	27	27				
49	3	13,500	27−	27−	27−				
50	3	13,500	27−	27−	27−				
51	3	12,500	28	29+	--------	17.52	17.48	17.50	
52	3	12,500	30	29+	--------				
53	3	12,500	29+	29+	29+				
54	3	12,500	29+	29+	29+				
55	3	12,500	30+	29+	--------				
56	3	11,500	28	31	--------	17.52	17.52	17.52	
57	3	11,500	31	31+	31+				
58	3	11,500	32−	32−	32−				

The speed indicated by the truck speedometer was used only in the field to determine that a sustained speed had been maintained on the grade. The speed was measured more accurately by a time-distance recorder which produced a record of time and distance that was used to determine approximately instantaneous speeds for each test run. The recording unit consisted of a chronograph with three magnetic recording styles. Two brushes, riding on a two-point cam mounted on the axle of a bicycle wheel that was attached to the truck bumper (see cover illustration), were wired in series with one of the styles and caused each half revolution of the wheel to be recorded. A clock with six contacts on the second hand shaft, wired in series with another of the styles, created a time record at 10-second intervals. A telegraph key, wired in series with a third style, was used to mark the beginning and the end of the test course. The recording tape was driven by a spring driven motor with a governor, and the tape speed was kept constant for the duration of each test run. Figure 1 shows the wiring diagram for the time-distance recorder.

Figure 2 shows a section of an actual tape record. The approximate instantaneous speed at any point was calculated by dividing the distance represented by a given number of revolutions by the time required to travel that distance. For example, at the 5-second point marked on the tape record (fig. 2), two complete revolutions of the wheel were used in the computations. Since the circumference of the wheel is 6.5 feet, the distance traveled in two revolutions is 13 feet. The tape speed is 0.85 inch per second, which makes each inch on the tape equivalent to 1.177 seconds. Since the two revolutions occupied 0.70 inch on the tape, it took the vehicle 0.824 second to travel the 13 feet. The speed is then 15.8 feet per second or 10.8 miles per hour.

The circumference of the bicycle wheel used with the recorder was determined by measuring the distance covered in 10 complete revolutions of the wheel and dividing by 10. The measurements were made at the beginning of each series of tests and also several times during the tests to insure that there was no change in the circumference. The distance record obtained with the fifth wheel and recorder was never in error more than 1 foot in 1,000 feet. This accuracy was obtained by underinflating the tire so that the wheel did not bounce off the road surface.

Approximately instantaneous speeds were computed at short time intervals for each test run. From the record of instantaneous speeds it was possible to ascertain definitely whether the truck was accelerating, decelerating, or traveling at a uniform speed. After the runs with sustained speeds had been selected by an inspection of the instantaneous speeds, the uniform speed was computed by dividing the distance traveled by the total time required for the run.

The record of instantaneous speeds for the five runs (Nos. 46 to 50, inclusive, in table 3) that were used to demonstrate the method used in the field to obtain the sustained speed is shown in table 4. Inspection of the instantaneous speeds reveals that a constant speed was maintained on runs 49 and 50. Runs 46, 47, and 48 show that the vehicle was accelerating or decelerating for the greater part of the distance. Actually the sustained speed was 25.7 miles per hour instead of the 27 miles per hour indicated by the truck's speedometer.

Table 4.—*Record of instantaneous speeds for 5 test runs on a 6-percent grade*

Seconds	Run 46	Run 47	Run 48	Run 49	Run 50
	M. p. h.	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*
0	29.0	24.7	26.5	25.9	25.7
2	28.7	24.7	26.5	25.9	25.7
4	28.0	24.7	26.5	25.9	25.7
6	28.0	25.0	26.8	25.9	25.7
8	28.0	25.0	26.5	25.9	25.7
10	27.7	25.0	26.5	25.9	25.7
12	27.7	25.0	26.5	25.7	25.7
14	27.4	25.3	26.5	25.7	25.7
16	27.4	25.3	26.5	25.7	25.7
18	27.1	25.3	26.5	25.7	25.7
20	27.1	25.3	26.2	25.7	25.7
22	27.1	25.7	26.2	25.7	25.7
24	26.8	25.7	26.2	25.7	25.7
26	26.8	25.7	26.2	25.7	25.7
28	26.5	25.3	26.2	25.7	25.7
30	26.5	25.3	25.9	25.7	25.7
32	26.5	25.7	25.9	25.7	25.7
34	26.8	25.7	25.6	25.7	25.7
36	[1] 26.5	25.7	[2] 25.9	25.7	25.7
38	--------	[3] 25.7	--------	[4] 25.7	[5] 25.7

[1] At 36.03 seconds.
[2] At 37.58 seconds.
[3] At 38.9 seconds.
[4] At 38.35 seconds.
[5] At 38.55 seconds.

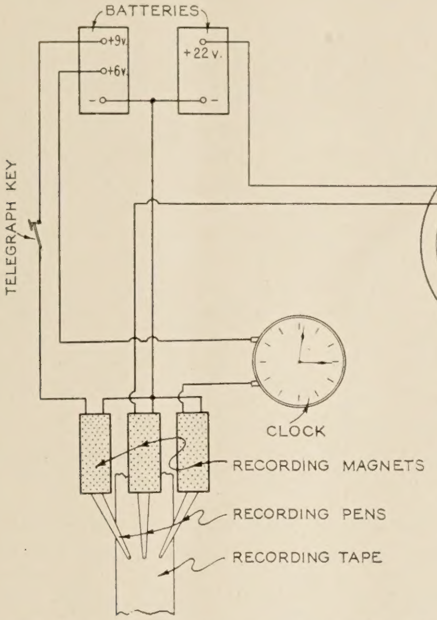

Figure 1.—Wiring Diagram for Time-Distance Recorder.

GRADE PERFORMANCE CORRECTED TO STANDARD ATMOSPHERIC CONDITIONS

In order to place the results of the tests on the 30 single unit trucks and combination units on a comparable basis, the grade performance in every case was corrected to standard atmospheric conditions. The formula used to compute the correction factor is as follows:

$$CF=\frac{29.92}{P_0-H}\sqrt{\frac{T_0}{520}}\qquad\text{(1)}$$

where

CF=correction factor,
P_0=observed barometric pressures in inches of mercury,
H=water vapor pressure in inches of mercury, and
T_0=observed absolute air temperature in degrees Fahrenheit.

The information required to compute this factor was obtained in the field, with the exception of the barometric pressure which was obtained from the Weather Bureau in nearby Baltimore. In addition to the dry and wet bulb temperatures that were used to obtain the water vapor pressure, the wind direction and velocity were also recorded. Tests were not made if the head wind exceeded 10 miles per hour or the tail wind 15 miles per hour. A miniature weather station consisting of a thermometer, a hand asperated psychrometer and an anemometer and wind vane, was operated in the center of each test section. The observations were taken during each test run.

The correction factor was computed for each test run on which a sustained speed was observed and applied to the gross vehicle weight, since for any given speed the power developed by the test vehicle is directly proportional to the weight carried. The corrected performance of a tractor-truck semitrailer operating in third gear on a 6-percent grade is shown in table 5. In this particular case the correction factors are near unity, indicating that the tests were made at approximately standard atmospheric conditions. The last two columns of table 5 contain the corrected gross vehicle weights and the speeds that the vehicle can sustain with those weights.

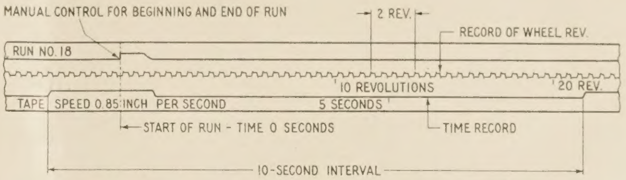

Figure 2.—A Section of Chronograph Tape Record.

The performance of the tractor-truck semitrailer, used as an example above, is shown graphically in figure 3. The performance curves for each transmission gear were obtained by plotting the corrected gross vehicle weight in thousands of pounds as the abscissae, and the speed in miles per hour as the ordinates. The curves show the performance of the vehicle on a 6-percent grade. Similar curves were plotted for each vehicle for grades ranging from 3 to 7 percent, inclusive.

Table 5.—*Actual grade performance corrected to standard temperature and barometric pressure*

[Make—A. Date—10-31-38. Model—X (without governor). Gear—third. Grade—6 percent]

Run No.	Time of day, p. m.	Relative humidity	Temperature			Vapor pressure (H)	Barometric pressure (P_0)	P_0-H	Correction factor	Actual GVW	Corrected GVW	Sustained speed
			Dry bulb	Dry-wet	Dew point							
		Pct.	° *F.*	° *F.*	° *F.*	*In. mercury*	*In. mercury*			*Lb.*	*Lb.*	*M. p. h.*
31	2:25	41	62	12.0	38	0.23	30.07	29.84	1.003	17,500	17,600	9.2
32	2:35	41	61	12.0	36	.21	30.07	29.86	1.001	17,500	17,500	8.7
35	2:55	42	62	12.0	38	.23	30.07	29.84	1.003	16,500	16,500	13.1
36	3:00	42	62	12.0	38	.23	30.07	29.84	1.003	16,500	16,500	13.1
37	3:05	42	61	11.5	38	.23	30.07	29.84	1.002	15,500	15,500	19.6
40	3:10	42	60	11.5	36	.21	30.07	29.86	1.001	15,500	15,500	18.9
43	3:20	42	61	11.5	38	.23	30.07	29.84	1.002	14,500	14,500	23.2
44	3:25	42	61	11.5	38	.23	30.07	29.84	1.002	14,500	14,500	23.2
49	3:35	43	59	11.0	36	.21	30.07	29.86	1.000	13,500	13,500	25.8
50	3:40	43	58	10.5	36	.21	30.07	29.86	.999	13,500	13,500	25.6
52	3:55	43	56	10.5	33	.19	30.07	29.88	.996	12,500	12,500	28.5
53	4:00	43	56	10.5	33	.19	30.07	29.88	.996	12,500	12,500	28.3
54	4:05	43	55	10.0	33	.19	30.07	29.88	.995	12,500	12,400	28.2
55	4:10	43	56	10.5	33	.19	30.07	29.88	.996	12,500	12,500	28.8
57	4:20	43	55	10.0	33	.19	30.07	29.88	.995	11,500	11,400	30.5
58	4:25	43	54	10.0	32	.18	30.07	29.89	.994	11,500	11,400	30.6

Since the trucks were tested on only 4½- and 6-percent grades, it was necessary to convert the ability observed for the 4½-percent grade to that for 3-, 4-, and 5-percent grades, and the ability for the 6-percent grade to that for 5- and 7-percent grades. The ability on a 5-percent grade was derived from the two sources in order to furnish a check on the accuracy of the methods used in the conversion.

The conversion is based on the assumption that a given vehicle will produce a tractive effort on one grade equal to that on another grade when the vehicle is operating in identical gears at like speeds. The tractive effort produced by a vehicle traveling over the grade at a uniform speed is equal to the component of the weight along the grade line plus the tractive resistance. Thus,

$$TE=GVW(f+g)\qquad\text{(2)}$$

where

TE=tractive effort in pounds,
GVW=gross vehicle weight in pounds,
f=coefficient of tractive resistance in pounds per pound, and
g=grade in feet of rise per foot.

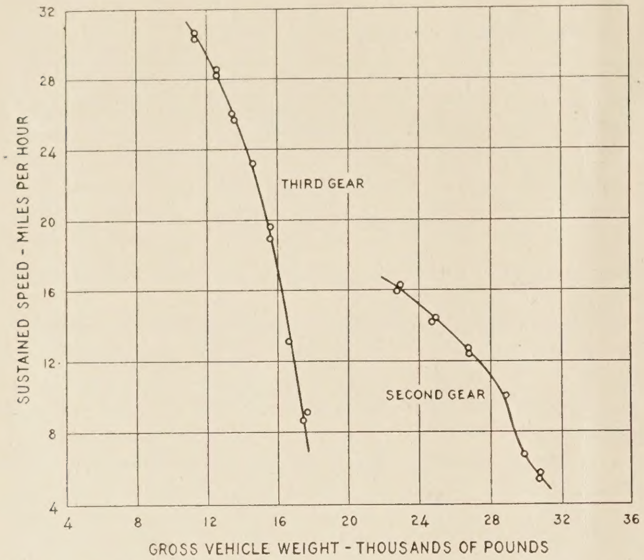

Figure 3.—Performance of Typical Tractor-Truck Semitrailer on a 6-Percent Grade, Without Governor, at Standard Atmospheric Conditions.

When the tractive effort on one grade is equaled to that for another grade, the following results:

$$GVW_1(f_1+g_1)=GVW_2(f_2+g_2)$$

or

$$GVW_2=\frac{GVW_1(f_1+g_1)}{(f_2+g_2)}\text{- - - - - - - - - - - - -}(3)$$

From figure 3, 13,500 pounds were hauled by the tractor-truck semitrailer on a 6-percent grade at 26 miles per hour. Assume that it is desired to determine what weight this truck can haul on a 5-percent grade at the same speed. The coefficient of tractive resistance determined by deceleration tests, described later in this report, is 0.0135 pounds per pound of weight for the speed and weight in question. Therefore, the tractive effort developed on the 6-percent grade at 26 miles per hour is 13,500 (0.06+0.0135) or 992 pounds and it is available at the same speed on any grade. This value represents the term $GVW_1(f_1+g_1)$ in the above equation. Since tractive resistance varies with load, there are two unknowns (GVW_2 and f_2) in the equation, therefore the value for f_2 cannot be directly determined until the approximate weight is known. This means that trial computations must be made to determine GVW_2. The first computation is made assuming f_2 to be 0.0135 pounds per pound, the coefficient for GVW_1. Using the GVW_2 determined on the trial computation another coefficient is obtained and substituted in the formula to obtain a second GVW_2. When a value for GVW_2 is computed that has a coefficient approximately the same as the one used to obtain it, the conversion has been completed.

For example, the first computation for a 5-percent grade would be:

$$GVW_2=\frac{992}{(0.05+0.0135)}=15{,}600\text{ pounds.}$$

The coefficient of tractive resistance for 15,600 pounds and 26 miles per hour is 0.0129 instead of 0.0135 pounds per pound as assumed. A second computation then follows:

$$GVW_2=\frac{992}{(0.05+0.0129)}=15{,}800\text{ pounds.}$$

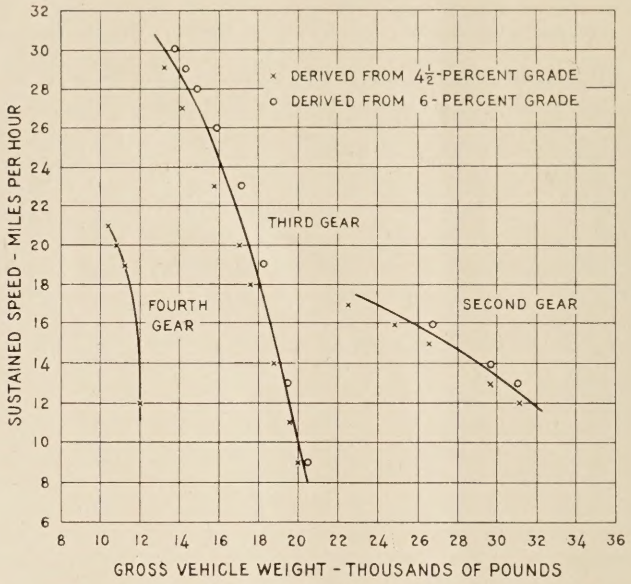

Figure 4.—Performance of Typical Tractor-Truck Semitrailer on a 5-Percent Grade, Without Governor, at Standard Atmospheric Conditions.

As the coefficient of tractive resistance for a load of 15,800 pounds is 0.0129, the same as that for 15,600 pounds, the conversion has been completed. The truck, then is capable of a speed of 26 miles per hour with a weight of 15,800 pounds on a 5-percent grade. Figure 4 shows the grade ability of this truck on a 5-percent grade. The curve is determined from points obtained by converting its performance on 4.5- and 6-percent grades to that for a 5-percent grade. The points derived from the two sources are in close agreement.

PERFORMANCE OF TRUCKS AND TRACTOR-TRUCKS SAME FOR EQUAL WEIGHTS

While the actual grade ability of an individual truck such as that shown in figures 3 and 4 is needed in order to evaluate the mechanical efficiency of the transmission of power and to determine the worth of other methods for measuring performance, both theoretical and experimental, it is the average performance of the vehicles in each capacity group that is more applicable to the existing problems.

The average performance for vehicles in the light, medium, and heavy capacity groups is shown in figures 5, 6, and 7, respectively. The results for the single-unit trucks and the tractor-truck semitrailers are combined, since there is no appreciable difference in performance for identical weights. These charts show the speeds that can be maintained with various gross vehicle weights on grades up to 7 percent.

The results shown in figures 5, 6, and 7 are for motor trucks operated without governors. Since a governor might affect the performance of a vehicle, the vehicles that were equipped with governors were tested both with and without the governors to determine if there was any appreciable difference in the performance of the vehicles when operated under the two conditions. The tests with the governor were limited to one grade only.

For a given vehicle the effect of the governor on the power output was negligible until the engine speed approached to within several hundred revolutions per minute of the governed engine speed. However, there was no consistency between the governors as to the range of engine speed for which there was a decrease in

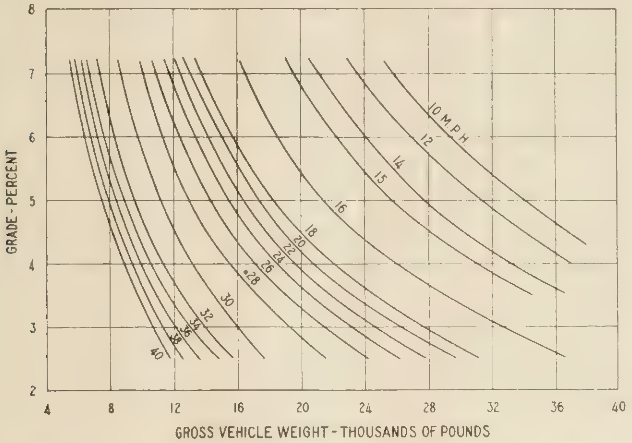

Figure 5.—Grade Ability of Light Trucks and Tractor-Truck Semitrailers, Without Governor.

power output, even for the same make of governor. The average performance of the heavy tractor-trucks operated with governors is shown in figure 8. A comparison between the results shown in figures 7 and 8 indicates that the maximum average performance was obtained without the governor. For example, for common weights of 20,000, 30,000, and 40,000 pounds and a common grade of 4 percent, the sustained speed is 31, 21, and 17 miles per hour, respectively, without the governor, and 29, 19, and 15 miles per hour, respectively, with the governor. The variation measured in speed is not great. However, for a given speed the variation in terms of weight may be as much as 5,000 pounds.

When using the results of the actual grade tests it is important to remember that the performance is an average value determined from the maximum performances obtained for individual vehicles. In order to use the information intelligently it is necessary to know how much the individual performances deviate from the average performance. Table 6 lists the percentages by which the sustained speeds of the individual vehicles deviate from the average sustained speed for several gross vehicle weights. The average deviation varies in most cases between 5 and 10 percent. The dispersion indicated is within the accuracy desired for the uses that will be made of the average performance.

Table 6.—*Deviation of the performance of individual motor trucks from the average performance for each capacity group*

Type of vehicle	Average deviation, in percentage of the speed, for vehicle weights of—				
	12,000 pounds	18,000 pounds	24,000 pounds	30,000 pounds	36,000 pounds
Light trucks and tractor trucks	5.8	7.9	6.6	8.1	-------
Medium trucks and tractor trucks	2.3	8.1	8.0	9.0	4.9
Heavy tractor trucks	-------	7.2	9.2	7.1	14.2

The most significant fact revealed by the performance charts is that the increase in speed that results from a reduction of grade is small. The average gross vehicle weight rating for light tractor-trucks is about 24,000 pounds. With this gross weight the average light tractor-truck is capable of 23, 17, 15, 14, and 12 miles per hour on 3-, 4-, 5-, 6-, and 7-percent grades, respectively. Reduction from a 7- to a 4-percent grade would raise the speed only 5 miles per hour, whereas reduction from a 4- to a 3-percent grade would raise the speed 6 miles per hour. It is evident that grades must be reduced to 3 percent or less if there is to be a marked betterment in performance.

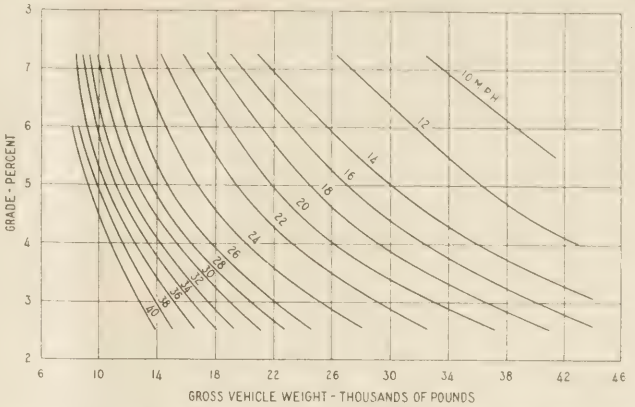

Figure 6.—Grade Ability of Medium Trucks and Tractor-Truck Semitrailers, Without Governor.

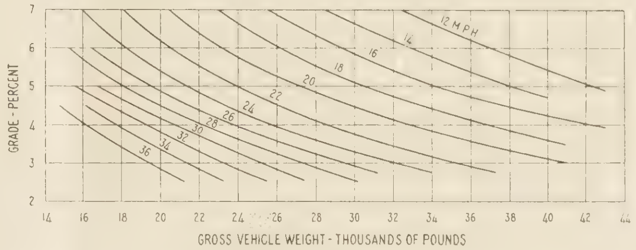

Figure 7.—Grade Ability of Heavy Tractor-Truck Semitrailers, Without Governor.

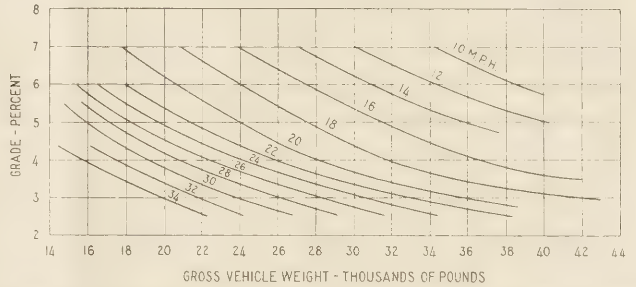

Figure 8.—Grade Ability of Heavy Tractor-Truck Semitrailer, With Governor.

Another very significant fact is that there must be a large reduction in gross weight to increase the speed of a vehicle appreciably. To raise the speed of the same light tractor-truck from 14 to 17 miles per hour on a 6-percent grade (the increase that would be obtained by reducing the grade from 6 to 4 percent) the gross weight must be reduced about 7,000 pounds. Since all of this reduction would come from the payload which originally would be about 12,000 pounds, there is a net reduction in load of almost 60 percent.

An increase in the power of the motor has also been mentioned as a means of bettering the speed. In order to increase the speed of the vehicle with a 24,000-pound gross weight from 14 to 17 miles per hour (an increase that would require a payload reduction of 60 percent or a 2-percent grade reduction) a motor almost as powerful as that used in a heavy truck would be required. This means about a 45-percent power increase to obtain an increase of 3 miles per hour in road speed on a 6-percent grade. The power would have to be at least doubled to provide what could be considered a reasonable speed.

It appears that it will be impracticable to apply any one method to obtain a reasonable speed. However, there is the possibility that a combination of the three methods can be used. For example, if a 25-percent reduction in payload is made, the weight of the light truck originally weighing 24,000 pounds will be reduced to 21,000 pounds. With this reduced weight and a power increase of 25 percent (an increase that would result if a motor as powerful as that in the medium truck were used), the speed on a 6-percent grade would be 18 miles per hour. A grade reduction from a 6- to a 4-percent grade would further increase the speed to 23 miles per hour. The combination of the three methods would thus increase the speed from 14 to 23 miles per hour. It is evident that the use of a combination of the three methods would result in a large cost to the interests concerned, and even then the speeds would not even approximate desirable road speeds.

DECELERATION TESTS MADE TO DETERMINE TRACTIVE RESISTANCE

The determination of tractive resistance is of secondary importance but it is a very necessary part of the study. Deceleration tests were made on each vehicle to determine the total tractive resistance, which is composed principally of the friction between tires and road surface, the inherent friction of the vehicle, and the resistance offered by the air. The first two forces named are commonly grouped as rolling resistance. The conversion of performance from one grade to another, the use of acceleration values to determine grade ability, the determination of efficiency factors, and the computation of a theoretical performance, all depend on this factor.

The deceleration of a vehicle when coasting on the level in neutral gear is proportional to the forces (rolling resistance and air resistance) that oppose the motion of the vehicle. The following equation expresses the relation:

$$TR = ma \qquad (4)$$

where

TR = total tractive resistance in pounds,
m = mass of vehicle, and
a = linear deceleration of vehicle in feet per second per second.

However, the above equation does not take into consideration a certain energy that is stored in the rotating parts when decelerating or accelerating. The energy of the rotating parts must be added to the energy of linear motion which is expressed by the above equation. The force equivalent to this energy is:

$$F = \frac{I}{r}\,\alpha \qquad (5)$$

where

F = force equivalent to energy of linear motion,
I = moment of inertia of rotating parts,
r = effective radius of rotating parts in inches, and
α = angular acceleration in radians per second per second.

When a vehicle is coasting in neutral, the only rotating parts decelerating are the wheels, brake drums, propeller shaft, and rear axle assembly. The moments of inertia of the propeller shaft and rear axle are so small in comparison to that for the wheels that it is practical to omit them from the consideration of the stored energy. For the wheels and brake drums the angular acceleration is equal to $\frac{a}{r}$ where a is equal to the linear deceleration and r is equal to the effective radius of the wheels. Substituting $\frac{a}{r}$ for α and combining the equations for the energy of the rotating parts and of linear motion the formula for determining tractive resistance is found to be:

$$TR = ma + \frac{I}{r^2}a \qquad (6)$$

or

$$= (m + k_0)\,a$$

where

TR = total tractive resistance in pounds,
m = mass of vehicle,
a = linear deceleration of vehicle in feet per second per second, and
k_0 = mass equivalent constant for neutral gear.

The mass equivalent constant can be determined experimentally if the deceleration is measured for a vehicle coasting on two different grades, one of which can be, and in this study was, level. As the total resistance on the grade is equal to the total resistance on the level for the same road speed and for the same load, the mass equivalent constant can be determined by solving the following equation for k_0:

$$W \sin A - a_g(m + k_0) = a_l(m + k_0) \qquad (7)$$

where

W = weight of vehicle in pounds,
A = angle in degrees that grade line makes with horizontal,
a_g = linear acceleration on grade in feet per second per second,
a_l = linear acceleration on level in feet per second per second,
m = mass of vehicle = $\frac{W}{32.2}$, and
k_0 = mass equivalent constant for neutral gear.

It can also be computed theoretically if the moments of inertia of the wheel assemblies are known. In most cases they were obtained from the manufacturer and used to compute a constant that could be used to check the experimental value. The theoretical k_0 is obtained by adding the moments of inertia for the wheels and brake drums and dividing the total by the effective radius squared. Table 7 contains the average mass equivalent constants, both theoretical and experimental, by capacity groups and vehicle types for all the vehicles tested.

TABLE 7.—*Average mass equivalent constants for neutral gear by capacity groups and vehicle types*

Capacity group and vehicle type	Tire size		Mass equivalent constants	
	Truck or tractor	Semitrailer	Experimental value	Theoretical value
Light trucks	7.50×20		23	15
Light tractor-truck semitrailers	7.50×20	34×7	28	27
Medium trucks	9.00×20		29	25
Medium tractor-truck semitrailers	9.00×20	9.75×20	52	40
Heavy tractor-truck semitrailers	10.50×20	9.75×20	56	51

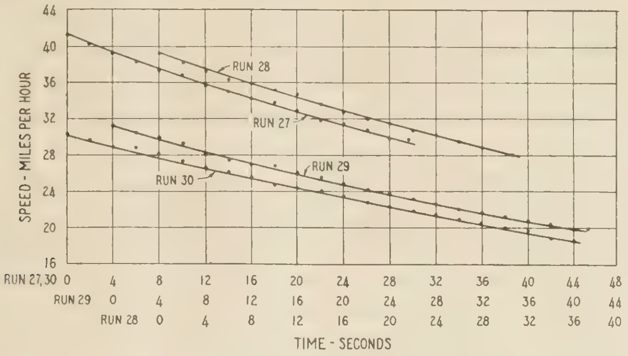

Figure 9.—Time-Speed Curves for Tractor-Truck Semitrailer Coasting on 0-Percent Grade With Gross Vehicle Weight of 12,000 Pounds.

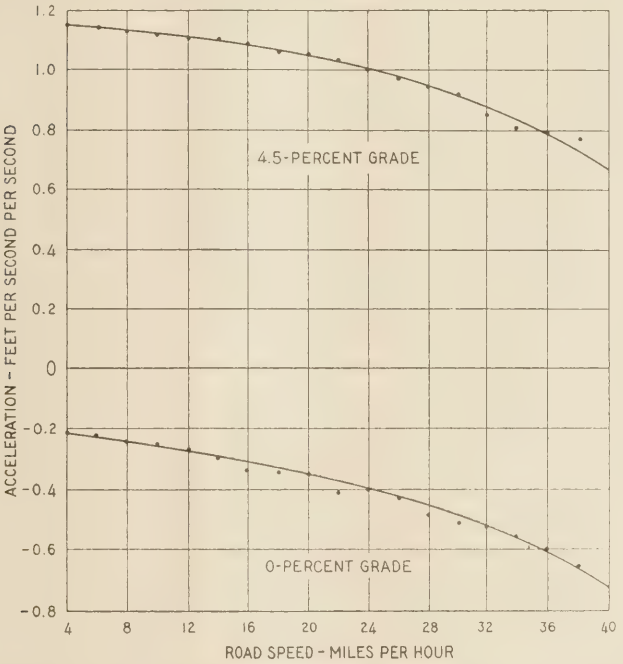

Figure 10.—Acceleration-Speed Curves for a Tractor-Truck Semitrailer Coasting on a 0-Percent and a 4.5-Percent Grade With a Gross Vehicle Weight of 12,000 Pounds.

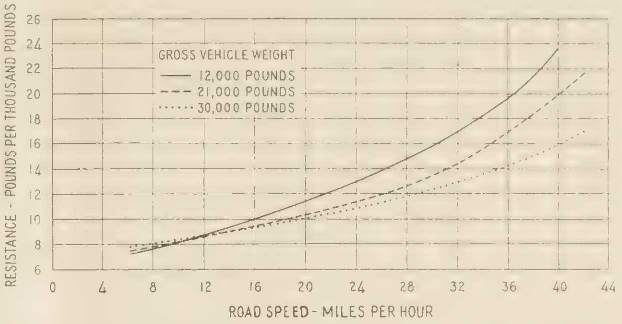

Figure 11.—Variation of Tractive Resistance With Speed and Weight for a Tractor-Truck Semitrailer.

The deceleration tests were made on two sections of concrete pavement. One was level and the other a 4½ percent grade. Values of deceleration were obtained for speeds ranging from 4 miles per hour to about 40 miles per hour. The effect of wind and any irregularities of grade on the tractive resistance was compensated for in some measure by test runs in both directions on the level section.

UNIT TRACTIVE RESISTANCE FOUND TO VARY WITH WEIGHT

At the start of the tests the tractive resistance was determined for but one gross weight. However, it was soon discovered that not only the total tractive resistance but also the unit resistance in pounds per thousand pounds varied appreciably with weight. Thereafter each vehicle was tested with three different loads. The difference in total tractive resistance for any two gross weights was proved to vary directly with the increase in weight, so it was possible to determine the tractive resistance for any combination of weight and speed.

A time-distance record of each deceleration run was obtained with the time-distance recorder described under the actual grade tests. The time-distance record was divided into 2-second intervals, and approximately instantaneous speeds were computed at each time interval. Time-speed curves were plotted with the time in seconds as the abscissa and the speed in miles per hour as the ordinate. Since the slope of the time-speed curve at any point is the deceleration in miles per hour per second, it is possible to determine the values of deceleration at any given speed. Figure 9 shows time-speed curves for one of the tractor-truck semitrailers.

The slope was measured at 2-mile-per-hour intervals by drawing tangents to the curve by means of a mirror that was specially developed for the purpose. The mirror is so silvered that it both reflects and transmits light. The mirror is held perpendicular to the plane of the curve and the bottom edge is placed over the point at which a determination is to be made. By causing the image of the part of the curve in front of the mirror to coincide with the part of the curve visible through the mirror, the vertical face of the mirror becomes a plane perpendicular to the tangent. Table 8 contains the values of deceleration obtained for one of the tractor-truck semitrailers having a gross weight of 12,000 pounds. The values of deceleration in table 8 are plotted against speed in figure 10. The decelerations used to compute the tractive resistance were transcribed from the smooth curve shown on this figure.

Table 8.—*Values of deceleration for a tractor-truck semitrailer coasting on a 0-percent grade with a gross vehicle weight of 12,000 pounds*

Speed, m. p. h.	Deceleration in miles per hour per second for —									
	Run No. 27, north	Run No. 28, south	Run No. 29, north	Run No. 30, south	Run No. 31, north	Run No. 32, south	Run No. 33, north	Run No. 34, south	Average	
									M. p. h./sec.	*Ft./sec./sec.*
2	------	------	------	------	------	------	0.145	0.141	0.143	0.210
4	------	------	------	------	------	------	.154	.141	.148	.217
6	------	------	------	------	------	------	.162	.141	.152	.223
8	------	------	------	------	------	------	.173	.151	.162	.238
10	------	------	------	------	0.172	0.163	.184	.158	.169	.248
12	------	------	------	------	.182	.177	.197	.181	.184	.270
14	------	------	------	------	.194	.181	.215	.210	.200	.293
16	------	------	------	------	.213	.197	.241	.244	.224	.329
18	------	------	------	------	.237	.218	------	------	.228	.334
20	------	------	0.234	0.241	.270	.246	------	------	.248	.364
22	------	------	.257	.253	.306	.291	------	------	.277	.406
24	------	------	.271	.271	------	------	------	------	.271	.397
26	------	------	.299	.294	------	------	------	------	.296	.434
28	------	------	.332	.322	------	------	------	------	.327	.480
30	0.359	0.320	.378	.348	------	------	------	------	.351	.515
32	.374	.341	------	------	------	------	------	------	.358	.525
34	.393	.371	------	------	------	------	------	------	.382	.560
36	.414	.404	------	------	------	------	------	------	.409	.600
38	.444	.456	------	------	------	------	------	------	.450	.660

The total tractive resistance that was computed from the deceleration shown in figure 10 for the 0-percent grade is contained in table 9. The total resistance is divided by the thousands of pounds of gross weight (12) to determine the coefficient of tractive resistance in pounds per 1,000 pounds. The vehicle for which these results were derived was also tested with weights of 21,000 and 30,000 pounds. The coefficients of tractive resistance for each of the three weights are shown in figure 11 to indicate how the tractive resistance varies with gross weight as well as with speed.

TABLE 9.—*Tractive resistance*[1] *for a tractor-truck semitrailer with a gross vehicle weight of 12,000 pounds*

Speed, m. p. h.	Deceleration	Total tractive resistance	Unit tractive resistance	Speed, m. p. h.	Deceleration	Total tractive resistance	Unit tractive resistance
	Ft./sec./sec.	*Pounds*	*Lb./1,000 lb.*		*Ft./sec./sec.*	*Pounds*	*Lb./1,000 lb.*
4	0.212	82.5	6.9	24	0.401	156.1	13.0
6	.223	86.7	7.2	26	.430	167.4	13.9
8	.239	93.0	7.7	28	.459	178.2	14.8
10	.253	98.4	8.2	30	.490	190.8	15.9
12	.271	105.4	8.8	32	.523	203.3	16.9
14	.290	112.8	9.4	34	.561	218.2	18.2
16	.310	120.6	10.0	36	.604	234.8	19.6
18	.330	128.4	10.7	38	.660	256.8	21.4
20	.352	137.0	11.4	40	.728	283.0	23.6
22	.378	147.0	12.2				

[1] Tractive resistance, $TR=-a(m+k_0)$
$m=373$
$k_0=16$
$TR=-389a$

From the total resistance in pounds determined for the three weights, tables are prepared that enable the tractive resistance to be obtained for any weight and speed within the limits of the tests. Since the difference in total resistance for any two gross weights was proved to vary directly with the increase in weight, it was possible to prorate the difference to other weights. Table 10 shows the total tractive resistance for various loads and speeds and table 11 lists the coefficients that were determined from the values of total tractive resistance given in table 10. Similar results were developed for each of the vehicles tested.

It was necessary to know the tractive resistance for each of the vehicles tested in order that certain analysis could be accurately made. However, in order to obtain values of unit tractive resistance that are more applicable for general use, the average tractive resistance has been obtained from the results of the individual vehicles for the single unit trucks and the tractor-truck semitrailers in each size group (light, medium, and heavy).

TABLE 11.—*Unit tractive resistance for a tractor-truck semitrailer at various speeds and weights*

Speed, m. p. h.	Unit tractive resistance, in pounds per 1,000 pounds, for weights of—										
	12,000 pounds	14,000 pounds	16,000 pounds	18,000 pounds	20,000 pounds	21,000 pounds	23,000 pounds	25,000 pounds	27,000 pounds	29,000 pounds	30,000 pounds
6	7.2	7.2	7.3	7.3	7.3	7.3	7.4	7.5	7.6	7.7	7.8
8	7.7	7.8	7.8	7.8	7.8	7.8	7.9	7.9	8.0	8.0	8.1
10	8.2	8.2	8.2	8.2	8.2	8.2	8.3	8.3	8.3	8.4	8.4
12	8.8	8.8	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
14	9.4	9.3	9.2	9.2	9.2	9.2	9.1	9.1	9.1	9.0	9.0
16	10.0	9.9	9.7	9.6	9.6	9.5	9.5	9.5	9.4	9.4	9.4
18	10.7	10.4	10.2	10.1	9.9	9.9	9.8	9.8	9.8	9.8	9.8
20	11.4	11.1	10.8	10.6	10.5	10.4	10.3	10.3	10.2	10.1	10.1
22	12.2	11.8	11.4	11.1	10.9	10.8	10.7	10.7	10.6	10.6	10.5
24	13.0	12.5	12.1	11.8	11.5	11.4	11.3	11.2	11.2	11.1	11.1
26	13.9	13.3	12.8	12.4	12.1	12.0	11.8	11.7	11.6	11.5	11.5
28	14.8	14.1	13.6	13.2	12.9	12.7	12.5	12.3	12.1	12.0	11.9
30	15.9	15.1	14.5	14.1	13.7	13.5	13.2	12.9	12.7	12.5	12.4
32	16.9	16.1	15.5	15.0	14.6	14.5	14.0	13.7	13.4	13.1	13.0
34	18.2	17.3	16.7	16.2	15.8	15.6	15.0	14.6	14.2	13.8	13.6
36	19.6	18.7	18.0	17.5	17.1	16.9	16.1	15.5	14.9	14.5	14.3
38	21.4	20.4	19.7	19.1	18.6	18.4	17.5	16.7	16.0	15.4	15.2
40	23.6	22.4	21.5	20.8	20.3	20.0	18.9	17.9	17.1	16.4	16.1
42	------	------	------	------	------	21.6	20.3	19.2	18.2	17.3	17.0

The average unit tractive resistance in pounds per thousand pounds for the light and medium single unit trucks and for the light, medium, and heavy tractor-truck semitrailers is shown in tables 12 to 16 inclusive. These tables contain the coefficient of tractive resistance for various conditions of weight and speed. For the light tractor-truck semitrailers, table 14, the unit tractive resistance is shown for speeds ranging from 4 to 38 miles per hour and for gross weights ranging from 12,000 to 30,000 pounds. At the lower speeds the variation of unit tractive resistance with weight is negligible. At 4 miles per hour the coefficient is 7.2 at 12,000 pounds and 7.8 at 30,000 pounds. However, at the higher speeds there is a large variation. At 38 miles per hour the coefficient is 23.7 for 12,000 pounds and only 15.3 for 30,000 pounds, a decrease of 35 percent. The results have been confined to the range of loads and speeds used on the tests, but the values can be expanded to determine the approximate resistance for speeds and weights not included in these results.

The average unit tractive resistance for the light trucks is compared with that for the light tractor-truck semitrailers in figure 12 for a common weight of 16,000

TABLE 10.—*Total tractive resistance for a tractor-truck semitrailer at various speeds and weights*

Speed m. p. h.	Total tractive resistance for weights of—											Increase, 12,000 to 21,000 pounds		Increase, 21,000 to 30,000 pounds	
	12,000 pounds	14,000 pounds	16,000 pounds	18,000 pounds	20,000 pounds	21,000 pounds	23,000 pounds	25,000 pounds	27,000 pounds	29,000 pounds	30,000 pounds	Total	Per 2,000 pounds	Total	Per 2,000 pounds
6	86.7	101.4	116.1	130.8	145.5	153.0	170.8	188.6	206.4	224.2	233.1	66.3	14.7	80.1	17.8
8	93.0	108.7	124.4	140.1	155.8	163.8	181.2	198.6	216.0	233.4	242.0	70.8	15.7	78.2	17.4
10	98.4	115.0	131.6	148.2	164.8	173.0	190.3	207.6	224.6	242.2	251.3	74.6	16.6	78.3	17.4
12	105.4	122.5	139.6	156.7	173.8	182.3	199.5	216.7	233.9	251.1	259.9	76.9	17.1	77.6	17.2
14	112.8	130.4	148.0	165.6	183.2	192.2	209.6	227.0	244.4	261.8	270.4	79.4	17.6	78.2	17.4
16	120.6	138.2	155.8	173.4	191.0	199.7	218.0	236.3	254.6	272.9	282.2	79.1	17.6	82.5	18.3
18	128.4	145.9	163.4	180.9	198.4	207.0	226.1	245.2	264.3	283.4	292.9	78.6	17.5	85.9	19.1
20	137.0	155.0	173.0	191.0	209.0	217.9	237.0	256.1	275.2	294.3	304.0	80.9	18.0	86.1	19.1
22	147.0	164.8	182.6	200.4	218.2	227.0	246.9	266.8	286.7	306.6	316.5	80.0	17.8	89.5	19.9
24	156.1	174.7	193.3	211.9	230.5	239.9	260.4	280.9	301.4	321.9	332.0	83.8	18.6	92.1	20.5
26	167.4	186.0	204.6	223.2	241.8	251.0	271.5	292.0	312.5	333.0	343.4	83.6	18.6	92.4	20.5
28	178.2	197.9	217.6	237.3	257.0	267.1	287.2	307.3	327.4	347.5	357.5	88.9	19.7	90.4	20.1
30	190.8	211.5	232.2	252.9	273.6	284.0	303.5	323.0	342.5	362.0	372.0	93.2	20.7	88.0	19.5
32	203.3	225.7	248.1	270.5	292.9	304.0	323.1	342.2	361.3	380.4	390.0	100.7	22.4	86.0	19.1
34	218.2	242.4	266.6	290.8	315.0	327.0	345.4	363.8	382.2	400.6	409.9	108.8	24.2	82.9	18.4
36	234.8	261.4	288.0	314.6	341.2	354.9	371.1	387.3	403.5	419.7	428.0	120.1	26.7	73.1	16.2
38	256.8	285.8	314.8	343.8	372.8	387.1	402.2	417.3	432.4	447.5	455.0	130.3	29.0	67.9	15.1
40	283.0	313.6	344.2	374.9	405.4	421.0	434.6	448.2	461.8	475.4	482.0	138.0	30.6	61.0	13.6
42	------	------	------	------	------	455.0	467.0	479.0	491.0	503.0	509.0	------	------	54.0	12.0

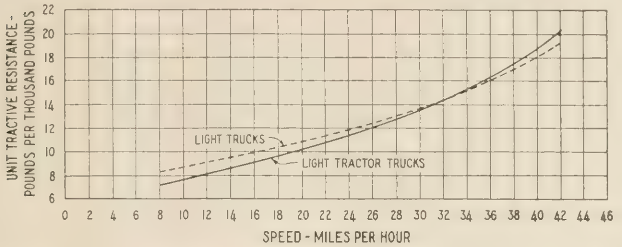

FIGURE 12.—VARIATION OF UNIT TRACTIVE RESISTANCE WITH SPEED FOR LIGHT TRUCKS AND LIGHT TRACTOR-TRUCK SEMITRAILERS WITH A 16,000-POUND GROSS WEIGHT.

pounds. The variation in unit resistance shown by this comparison is slight, as would be expected, since the frontal area is about the same for the two types of vehicles. The addition of a third axle has little effect on the unit tractive resistance.

The average unit tractive resistance for the light, medium, and heavy tractor-truck semitrailers is shown in figure 13 for a common weight of 16,000 pounds, to-

TABLE 12.—*Average unit tractive resistance for light trucks (6 makes)*

Speed, m. p. h.	Unit tractive resistance, in pounds per 1,000 pounds, for weights of—								
	8,000 pounds	9,000 pounds	10,000 pounds	11,000 pounds	12,000 pounds	13,000 pounds	14,000 pounds	15,000 pounds	16,000 pounds
4	8.3	8.3	8.4	8.4	8.4	8.5	8.5	8.5	8.6
6	8.8	8.8	8.8	8.8	8.8	8.8	8.9	8.9	8.9
8	9.3	9.3	9.3	9.3	9.3	9.2	9.2	9.2	9.2
10	10.0	9.9	9.8	9.8	9.7	9.7	9.7	9.6	9.6
12	10.7	10.6	10.5	10.4	10.3	10.2	10.1	10.0	10.0
14	11.6	11.4	11.2	11.0	10.8	10.7	10.6	10.5	10.4
16	12.5	12.2	11.9	11.7	11.5	11.3	11.1	11.0	10.9
18	13.6	13.1	12.7	12.4	12.2	11.9	11.7	11.5	11.4
20	14.7	14.1	13.6	13.2	12.9	12.6	12.3	12.1	11.9
22	15.9	15.2	14.6	14.1	13.7	13.3	13.0	12.7	12.5
24	17.2	16.3	15.6	15.0	14.5	14.1	13.7	13.4	13.1
26	18.5	17.5	16.7	16.0	15.4	14.9	14.5	14.1	13.8
28	19.9	18.8	17.8	17.1	16.4	15.9	15.4	14.9	14.6
30	21.4	20.1	19.0	18.2	17.4	16.8	16.3	15.8	15.4
32	22.9	21.4	20.3	19.3	18.5	17.8	17.2	16.7	16.2
34	24.5	22.9	21.6	20.5	19.7	18.9	18.2	17.6	17.1
36	26.1	24.4	23.0	21.9	20.9	20.1	19.3	18.6	18.1
38	27.9	26.1	24.6	23.3	22.3	21.4	20.5	19.8	19.2
40	29.9	27.9	26.3	25.0	23.9	22.8	21.9	21.1	20.4

TABLE 13.—*Average unit tractive resistance for medium trucks (3 makes)*

Speed, m. p. h.	Unit tractive resistance, in pounds per 1,000 pounds, for weights of—													
	11,000 pounds	12,000 pounds	13,000 pounds	14,000 pounds	15,000 pounds	16,000 pounds	17,000 pounds	18,000 pounds	19,000 pounds	20,000 pounds	21,000 pounds	22,000 pounds	23,000 pounds	24,000 pounds
4	8.7	8.7	8.6	8.6	8.6	8.5	8.5	8.7	8.9	9.1	9.3	9.4	9.5	9.6
6	9.4	9.3	9.2	9.1	9.1	9.0	9.0	9.1	9.3	9.4	9.5	9.7	9.7	9.8
8	10.0	9.9	9.8	9.7	9.6	9.6	9.5	9.6	9.7	9.8	9.9	9.9	10.0	10.0
10	10.9	10.7	10.5	10.3	10.2	10.1	10.0	10.1	10.1	10.1	10.2	10.2	10.2	10.3
12	11.6	11.4	11.2	11.0	10.8	10.7	10.6	10.6	10.5	10.6	10.6	10.6	10.6	10.6
14	12.6	12.4	11.9	11.7	11.5	11.3	11.1	11.1	11.2	11.1	11.1	11.1	11.0	11.0
16	13.5	13.1	12.8	12.5	12.2	12.0	11.8	11.7	11.7	11.6	11.6	11.6	11.5	11.5
18	14.6	14.1	13.7	13.3	12.9	12.7	12.4	12.4	12.3	12.2	12.2	12.1	12.1	12.0
20	15.7	15.1	14.6	14.1	13.8	13.4	13.1	13.0	13.0	12.9	12.8	12.8	12.7	12.6
22	16.9	16.2	15.6	15.1	14.6	14.2	13.9	13.8	13.7	13.6	13.5	13.4	13.4	13.3
24	18.1	17.3	16.6	16.0	15.5	15.1	14.7	14.5	14.4	14.3	14.2	14.1	14.1	14.0
26	19.4	18.5	17.7	17.0	16.5	15.9	15.5	15.4	15.2	15.1	15.0	14.9	14.8	14.7
28	20.8	19.8	18.9	18.2	17.5	16.9	16.5	16.3	16.1	16.0	15.9	15.8	15.6	15.5
30	22.5	21.4	20.4	19.5	18.8	18.1	17.5	17.3	17.2	17.0	16.9	16.7	16.6	16.5
32	24.1	22.9	21.8	20.9	20.1	19.4	18.7	18.5	18.3	18.1	17.9	17.7	17.6	17.4
34	26.1	24.7	23.5	22.5	21.7	20.9	20.2	19.9	19.6	19.3	19.1	18.8	18.6	18.5
36	28.5	26.9	25.6	24.5	23.5	22.6	21.9	21.5	21.1	20.8	20.5	20.2	20.0	19.7
38	31.6	29.9	28.4	27.2	26.1	25.1	24.3	23.7	23.2	22.7	22.3	21.9	21.6	21.3

TABLE 14.—*Average unit tractive resistance for light tractor trucks (7 makes)*

Speed, m. p. h.	Unit tractive resistance, in pounds per 1,000 pounds, for weights of—									
	12,000 pounds	14,000 pounds	16,000 pounds	18,000 pounds	20,000 pounds	22,000 pounds	24,000 pounds	26,000 pounds	28,000 pounds	30,000 pounds
4	7.2	7.3	7.3	7.4	7.5	7.6	7.6	7.7	7.8	7.8
6	7.6	7.7	7.7	7.7	7.7	7.8	7.9	7.9	8.0	8.0
8	8.2	8.2	8.1	8.1	8.1	8.2	8.2	8.3	8.3	8.3
10	8.8	8.7	8.6	8.6	8.5	8.6	8.6	8.6	8.6	8.7
12	9.4	9.3	9.1	9.0	9.0	9.0	9.0	9.0	9.0	9.0
14	10.1	9.8	9.7	9.5	9.4	9.4	9.3	9.3	9.3	9.3
16	10.8	10.5	10.2	10.0	9.9	9.8	9.7	9.7	9.7	9.6
18	11.5	11.1	10.8	10.5	10.3	10.2	10.1	10.1	10.0	10.0
20	12.3	11.8	11.4	11.1	10.9	10.7	10.6	10.5	10.4	10.4
22	13.2	12.6	12.1	11.7	11.4	11.2	11.1	11.0	10.9	10.8
24	14.2	13.4	12.8	12.4	12.0	11.8	11.6	11.5	11.3	11.2
26	15.2	14.3	13.6	13.1	12.7	12.4	12.2	12.0	11.8	11.7
28	16.3	15.2	14.5	13.9	13.4	13.0	12.8	12.5	12.3	12.2
30	17.4	16.3	15.4	14.7	14.2	13.7	13.4	13.1	12.9	12.7
32	18.7	17.4	16.4	15.6	15.0	14.5	14.1	13.8	13.5	13.2
34	20.1	18.7	17.6	16.7	16.0	15.4	14.9	14.5	14.2	13.8
36	21.8	20.1	18.9	17.9	17.1	16.4	15.8	15.3	14.9	14.5
38	23.7	21.8	20.4	19.3	18.5	17.6	16.9	16.3	15.8	15.3

TABLE 15.—*Average unit tractive resistance for medium tractor trucks (6 makes)*

Speed, m. p. h.	Unit tractive resistance, in pounds per 1000 pounds, for weights of—												
	14,000 pounds	16,000 pounds	18,000 pounds	20,000 pounds	22,000 pounds	24,000 pounds	26,000 pounds	28,000 pounds	30,000 pounds	32,000 pounds	34,000 pounds	36,000 pounds	38,000 pounds
6	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.2	7.3	7.4	7.4	7.5	7.5
8	7.7	7.7	7.6	7.6	7.5	7.5	7.5	7.5	7.6	7.7	7.7	7.8	7.8
10	8.4	8.2	8.1	8.0	7.9	7.9	7.8	7.9	7.9	7.9	8.0	8.0	8.0
12	9.1	8.8	8.6	8.5	8.4	8.3	8.2	8.2	8.2	8.3	8.3	8.3	8.3
14	9.8	9.4	9.2	9.0	8.8	8.7	8.6	8.6	8.6	8.6	8.6	8.6	8.6
16	10.5	10.1	9.8	9.5	9.3	9.1	9.0	9.0	9.0	8.9	8.9	8.9	8.9
18	11.2	10.8	10.4	10.1	9.8	9.6	9.5	9.4	9.4	9.3	9.3	9.3	9.2
20	12.0	11.4	11.0	10.7	10.4	10.1	9.9	9.8	9.8	9.7	9.6	9.6	9.6
22	12.9	12.2	11.7	11.3	10.9	10.6	10.4	10.3	10.2	10.1	10.0	10.0	9.9
24	13.8	13.0	12.4	11.9	11.5	11.2	10.9	10.7	10.6	10.5	10.4	10.4	10.3
26	14.8	13.9	13.2	12.6	12.1	11.8	11.4	11.3	11.1	11.0	10.9	10.8	10.7
28	15.8	14.8	14.0	13.4	12.8	12.4	12.0	11.8	11.7	11.5	11.4	11.2	11.1
30	17.0	15.8	14.9	14.2	13.6	13.1	12.7	12.4	12.2	12.0	11.9	11.7	11.6
32	18.3	17.0	16.0	15.2	14.5	13.9	13.4	13.1	12.9	12.7	12.4	12.3	12.1
34	19.9	18.3	17.2	16.2	15.5	14.8	14.3	13.9	13.6	13.3	13.1	12.9	12.7
36	21.4	19.8	18.5	17.4	16.5	15.8	15.2	14.8	14.4	14.1	13.8	13.6	13.3
38	23.4	21.5	20.0	18.8	17.9	17.1	16.4	15.9	15.4	15.0	14.7	14.4	14.1
40	25.9	23.7	22.0	20.6	19.5	18.6	17.8	17.2	16.6	16.1	15.7	15.3	14.9

TABLE 16.—*Average unit tractive resistance for heavy tractor trucks (4 makes)*

Speed, m. p. h.	Unit tractive resistance, in pounds per 1,000 pounds, for weights of—												
	16,000 pounds	18,000 pounds	20,000 pounds	22,000 pounds	24,000 pounds	26,000 pounds	28,000 pounds	30,000 pounds	32,000 pounds	34,000 pounds	36,000 pounds	38,000 pounds	40,000 pounds
6	7.9	7.8	7.7	7.6	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
8	8.5	8.3	8.2	8.1	8.0	8.0	8.0	7.9	7.9	7.9	7.8	7.8	7.8
10	9.2	9.0	8.8	8.6	8.5	8.4	8.4	8.3	8.3	8.2	8.2	8.1	8.1
12	10.0	9.7	9.5	9.3	9.1	9.0	8.9	8.8	8.7	8.7	8.6	8.5	8.5
14	10.8	10.4	10.1	9.9	9.7	9.5	9.4	9.3	9.2	9.1	9.0	8.9	8.9
16	11.6	11.1	10.8	10.5	10.3	10.1	9.9	9.8	9.6	9.5	9.4	9.3	9.2
18	12.4	11.9	11.5	11.2	10.9	10.7	10.5	10.3	10.1	10.0	9.8	9.7	9.6
20	13.3	12.7	12.3	11.9	11.6	11.3	11.1	10.8	10.6	10.5	10.3	10.2	10.1
22	14.2	13.6	13.1	12.6	12.3	11.9	11.6	11.4	11.2	11.0	10.8	10.6	10.5
24	15.2	14.5	13.9	13.4	13.0	12.6	12.3	12.0	11.7	11.5	11.3	11.1	10.9
26	16.2	15.4	14.7	14.2	13.7	13.3	12.9	12.6	12.3	12.0	11.8	11.6	11.4
28	17.2	16.3	15.6	15.0	14.5	14.0	13.6	13.2	12.9	12.6	12.3	12.1	11.9
30	18.3	17.3	16.5	15.8	15.3	14.7	14.3	13.9	13.5	13.2	12.9	12.7	12.5
32	19.4	18.3	17.4	16.7	16.1	15.5	15.0	14.6	14.2	13.9	13.6	13.3	13.0
34	20.5	19.4	18.4	17.7	17.0	16.4	15.8	15.4	15.0	14.6	14.3	14.0	13.7
36	21.8	20.5	19.5	18.7	18.0	17.4	16.8	16.3	15.8	15.5	15.1	14.8	14.5
38	23.1	21.8	20.7	19.9	19.1	18.4	17.8	17.3	16.8	16.4	16.0	15.7	15.4
40	24.6	23.2	22.1	21.1	20.4	19.6	19.0	18.4	17.9	17.5	17.1	16.7	16.4

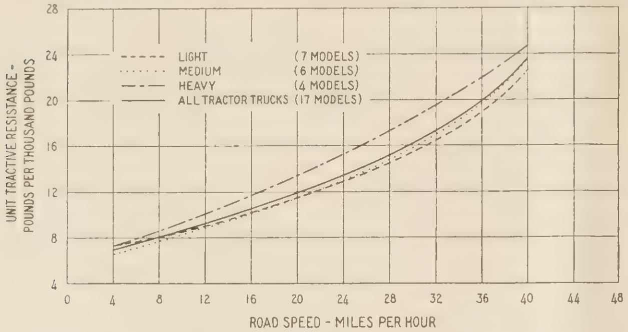

Figure 13.—Variation of Unit Tractive Resistance With Speed for All Tractor-Truck Semitrailers With a 16,000-Pound Gross Weight.

gether with the average unit resistance for all the vehicles of this type. The average tractive resistances indicated by the four curves are in close agreement with the exception of those shown for the heavy tractor trucks. Only four heavy tractor trucks were tested and one of these had a very high tractive resistance. The average resistance of the other three heavy vehicles is in line with that shown for the light and medium capacity groups.

AVERAGE VALUES OF UNIT TRACTIVE RESISTANCE ACCEPTABLE FOR ALL PRACTICAL PURPOSES

The comparisons made in figures 12 and 13 prove that there is little variation in the average unit tractive resistance for the types and sizes of vehicles considered in this study. For this reason it is acceptable for all practical purposes to use average values of tractive resistance for all the single units and other average values for all the combination units. These average values of the unit tractive resistance are given in tables 17 and 18. For the single unit trucks (table 17) the resistance is shown for weights ranging from 8,000 to 24,000 pounds and for speeds ranging from 4 to 38 miles per hour. For the tractor-truck semitrailers (table 18) it is shown for weights ranging from 12,000 to 42,000 pounds and for speeds ranging from 6 to 40 miles per hour. There is little variation in the unit tractive resistance for a given speed and weight between the average values obtained for the two types of vehicles as is shown in figure 14.

Table 17.—*Average unit tractive resistance for all single-unit trucks*

Speed, m. p. h.	Unit tractive resistance, in pounds per 1,000 pounds, for weights of—								
	8,000 pounds	10,000 pounds	12,000 pounds	14,000 pounds	16,000 pounds	18,000 pounds	20,000 pounds	22,000 pounds	24,000 pounds
4	8.4	8.5	8.5	8.6	8.6	8.6	8.6	8.6	8.6
6	9.0	9.0	9.0	9.0	8.9	8.9	8.9	8.9	8.9
8	9.8	9.6	9.5	9.4	9.3	9.3	9.2	9.2	9.2
10	10.6	10.3	10.0	9.9	9.8	9.7	9.6	9.5	9.5
12	11.5	11.0	10.6	10.4	10.2	10.1	10.0	9.9	9.8
14	12.4	11.7	11.3	11.0	10.7	10.5	10.4	10.2	10.1
16	13.5	12.6	12.0	11.6	11.2	11.0	10.8	10.6	10.5
18	14.8	13.6	12.8	12.2	11.8	11.5	11.2	11.0	10.8
20	16.0	14.6	13.6	12.9	12.4	12.0	11.7	11.4	11.2
22	17.4	15.7	14.5	13.7	13.1	12.6	12.2	11.9	11.6
24	18.8	16.8	15.4	14.5	13.8	13.2	12.8	12.4	12.1
26	20.3	18.0	16.5	15.3	14.5	13.9	13.4	12.9	12.6
28	21.9	19.3	17.5	16.3	15.4	14.6	14.0	13.6	13.2
30	23.6	20.6	18.7	17.3	16.3	15.5	14.8	14.3	13.9
32	25.3	22.1	19.9	18.4	17.3	16.4	15.7	15.1	14.6
34	27.2	23.7	21.3	19.6	18.4	17.4	16.6	16.0	15.4
36	29.5	25.5	22.9	21.0	19.6	18.5	17.6	16.9	16.3
38	32.0	27.7	24.8	22.7	21.2	20.0	19.0	18.2	17.5

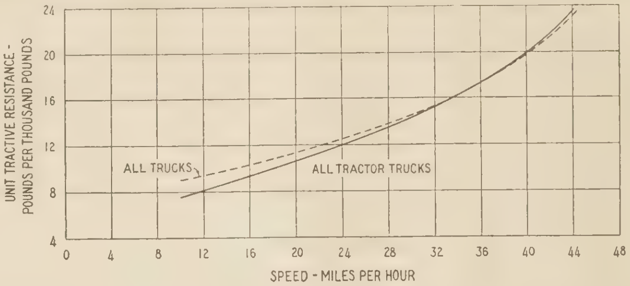

Figure 14.—Variation of Unit Tractive Resistance With Speed for All Trucks and Tractor-Truck Semitrailers With a 16,000-Pound Gross Weight.

The average deviations of the unit tractive resistance for the single-unit trucks and for the tractor-truck semitrailers from the average values shown in tables 18 and 19 are 10.0 and 11.3 percent, respectively. Assuming that the average deviation is about 10 percent, which appears to be a reasonable value, the error that might be introduced in the computation of grade ability with the average values for a given vehicle would not be great. For example, for a gross weight of 40,000 pounds and a speed of 20 miles per hour, the coefficient of tractive resistance is 9.8 pounds per 1,000 pounds. The average expectant error would be 1 pound per 1,000 pounds, which is equivalent to a 0.1 percent grade. If a 4-percent grade was being considered, the resultant error would be only 2 percent.

An important point to remember when using the tractive resistances reported here is that the tests were made on trucks equipped with a body 8 feet wide with 24-inch sideboards, and on tractor-trucks with a semitrailer 8 feet wide with 18-inch sideboards. If a van type body had been used instead of the platform body, the tractive resistance would undoubtedly have been greater than that shown, particularly for the higher speeds. Also, since all tests were made on concrete surfaces, the application of the results must be limited accordingly.

The development of a method for computing the performance of a vehicle from its specified characteristics required a determination of efficiency as well as tractive resistance. The common practice has been to assume an efficiency factor in order to allow for losses in the transfer of power from the clutch to the driving wheels. However, no efficiency factor has yet received general acceptance. The results of the actual grade tests, together with the certified power, have been used to provide efficiency factors for all the vehicles tested. The efficiency factors were obtained by applying the results of the actual grade tests to a basic performance formula derived by equating the force produced at the driving wheels to the sum of the grade resistance and the tractive resistance.

The basic performance formula used to compute the grade ability of a vehicle is as follows:

$$GVW=\frac{T\times GR\times E}{r(f+g)} \text{-------------} (8)$$

where

GVW=gross vehicle weight in pounds,
T=torque at a given engine speed in pound-inches,
GR=total gear reduction,
E=efficiency,

TABLE 18.—*Average unit tractive resistance for all tractor trucks*

Speed, m. p. h.	Unit tractive resistance, in pounds per 1,000 pounds, for weights of—															
	12,000 pounds	14,000 pounds	16,000 pounds	18,000 pounds	20,000 pounds	22,000 pounds	24,000 pounds	26,000 pounds	28,000 pounds	30,000 pounds	32,000 pounds	34,000 pounds	36,000 pounds	38,000 pounds	40,000 pounds	42,000 pounds
6	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.7	7.7	7.7	7.7	7.7
8	8.1	8.1	8.1	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.9
10	8.8	8.7	8.6	8.5	8.5	8.4	8.4	8.4	8.3	8.3	8.3	8.3	8.2	8.2	8.2	8.2
12	9.6	9.4	9.2	9.1	9.0	8.9	8.8	8.8	8.7	8.7	8.6	8.6	8.5	8.5	8.5	8.5
14	10.4	10.1	9.8	9.6	9.5	9.4	9.3	9.2	9.1	9.0	9.0	8.9	8.9	8.8	8.8	8.8
16	11.2	10.8	10.5	10.2	10.0	9.8	9.7	9.6	9.5	9.4	9.3	9.3	9.2	9.2	9.1	9.1
18	12.1	11.6	11.2	10.8	10.6	10.4	10.2	10.1	9.9	9.8	9.7	9.6	9.6	9.5	9.4	9.4
20	13.0	12.4	11.9	11.5	11.2	10.9	10.7	10.5	10.4	10.3	10.1	10.0	9.9	9.9	9.8	9.7
22	14.0	13.2	12.6	12.2	11.8	11.5	11.3	11.0	10.9	10.7	10.6	10.4	10.3	10.2	10.2	10.1
24	15.4	14.1	13.4	12.9	12.5	12.1	11.8	11.6	11.4	11.2	11.0	10.9	10.7	10.6	10.5	10.4
26	16.2	15.1	14.3	13.7	13.2	12.8	12.4	12.1	11.9	11.7	11.5	11.3	11.2	11.1	10.9	10.8
28	17.4	16.2	15.2	14.5	13.9	13.5	13.1	12.8	12.5	12.2	12.0	11.8	11.6	11.5	11.4	11.2
30	18.7	17.3	16.2	15.4	14.8	14.2	13.8	13.4	13.1	12.8	12.5	12.3	12.1	12.0	11.8	11.7
32	20.1	18.5	17.3	16.4	15.6	15.0	14.5	14.1	13.8	13.4	13.2	12.9	12.7	12.5	12.3	12.2
34	21.7	19.9	18.5	17.5	16.6	16.0	15.4	14.8	14.5	14.1	13.8	13.5	13.3	13.1	12.9	12.7
36	23.4	21.4	19.9	18.7	17.8	17.0	16.3	15.8	15.3	14.9	14.6	14.3	14.0	13.7	13.5	13.3
38	25.5	23.2	21.5	20.1	19.0	18.2	17.4	16.8	16.3	15.8	15.4	15.1	14.8	14.5	14.2	14.0
40	27.9	25.2	23.3	21.8	20.6	19.6	18.7	18.0	17.4	16.9	16.4	16.0	15.7	15.3	15.1	14.8

TABLE 19.—*The determination of over-all efficiency for a typical tractor-truck semitrailer*

[Make—A. Model—X. Transmission gear—2d. Total gear reduction—20.58. Grade—4½ percent]

Corrected *GVW*	Sustained speed	Rolling radius	Engine speed	Manufacturer's engine torque		Coefficient of tractive resistance	$f+g$	Over-all efficiency	
				Maximum	Net			Maximum	Net
Pounds	*M. p. h.*	*Inches*	*R. p. m.*	*Lb.-ft.*	*Lb.-ft.*	*Lb./lb.*	*Lb./lb.*	*Percent*	*Percent*
33,800	12.0	16.83	2,465	154	144	0.0087	0.0537	80.4	86.1
33,800	12.0	16.83	2,465	154	144	.0087	.0537	80.4	86.1
33,100	12.5	16.77	2,580	151	141	.0088	.0538	80.2	85.8
33,100	12.6	16.77	2,600	151	140	.0088	.0538	80.2	86.4
31,600	13.4	16.96	2,730	148	136	.0089	.0539	79.3	86.2
31,600	13.4	16.96	2,730	148	136	.0089	.0539	79.3	86.2
29,600	14.9	17.03	3,025	139	125	.0092	.0542	79.7	88.7
29,600	14.7	17.03	2,980	140	127	.0091	.0541	79.2	87.3
27,500	16.0	17.17	3,220	130	116	.0094	.0544	80.0	89.7
27,500	15.7	17.17	3,160	133	119	.0094	.0544	78.2	87.3
27,600	15.6	17.17	3,140	134	120	.0093	.0543	77.9	86.9
24,400	16.8	17.22	3,340	124	109	.0096	.0546	74.9	85.3

r = effective radius of driving wheels in inches,
f = coefficient of tractive resistance in pounds per pound of weight, and
g = grade in feet of rise per foot.

The efficiency is then determined by solving equation 8 for E as follows:

$$E=\frac{GVW(f+g)r}{T\times GR} \quad (9)$$

where the numerator represents the torque actually produced at the driving wheels and the denominator the torque that would have been produced at the same point if there were no losses during the transmission of power.

EFFICIENCY COMPUTED FOR A SAMPLE TRUCK

The actual grade tests measured the speed that a vehicle could maintain on a given grade with a given gross vehicle weight. The coefficient of tractive resistance was determined by the deceleration tests that have been described. The effective radius of the driving wheels was measured in the field for each gross vehicle weight. The torque and the total gear reduction were obtained from specifications supplied by the manufacturer. All information necessary for determination of the efficiency was therefore available.

For example, a certain tractor-truck semitrailer maintained a uniform speed of 25.2 miles per hour in fourth gear on a 4.5-percent grade with a weight of 12,500 pounds. The radius of the driving wheels for this weight and the coefficient of tractive resistance for the weight and speed involved were determined to be 16.9 inches and 0.015 pounds per pound of weight, respectively. The total gear reduction when the vehicle was operated in fourth gear was 7.15.

Charts that show the certified power and torque at various engine speeds were used to obtain the torque produced by the engine. In order to obtain the torque it was first necessary to find the engine speed equivalent to the road speed of 25.2 miles per hour. The engine speed was computed in the following manner:

$$RPM=\frac{168\times GR\times S}{r} \quad (10)$$

$$=\frac{168\times 7.15\times 25.2}{16.9}=1{,}780,$$

where

RPM = engine speed in revolutions per minute,
S = road speed in miles per hour,
GR = total gear reduction,
r = effective radius of driving wheels in inches, and
168 = factor to convert units to revolutions per minute.

The torque produced at 1,780 revolutions per minute was 165 and 156 pound-feet, the manufacturer's certified maximum and net torque respectively. The efficiency factors for the maximum and net torque were then determined to be 90.5 percent and 94.4 percent by substituting the values given above in the equation for efficiency:

1. For maximum torque,

$$E=\frac{12500\ (0.015+0.045)\ 16.9}{165\times 12\times 7.15}=90.5.$$

2. For net torque,

$$E=\frac{12500\ (0.015+0.045)\ 16.9}{156\times 12\times 7.15}=94.4.$$

The maximum torque is produced by an engine that is stripped of all accessories except those that are necessary for its functioning. The net torque is that produced by an engine that has all the accessories operating, such as fan, generator, exhaust pipe, muffler, and

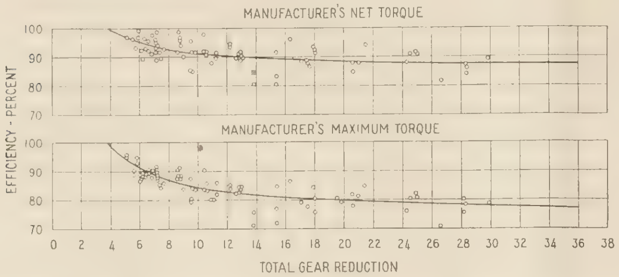

Figure 15.—Variation of Efficiency With Gear Reduction for All Trucks and Tractor-Truck Semitrailers.

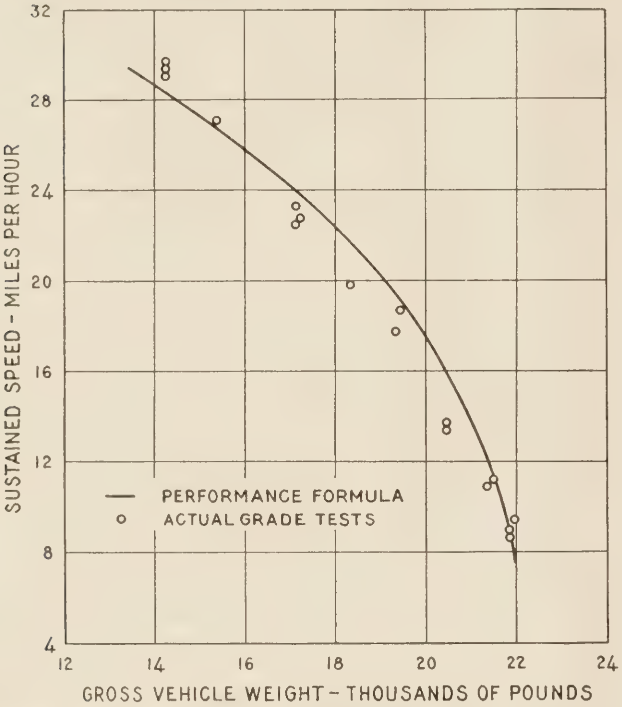

Figure 16.—Comparison of Hill-Climbing Ability as Determined by Actual Grade Tests and Performance Formula for a Tractor-Truck Semitrailer in Third Gear on a 4.5-Percent Grade.

trail pipe, that are standard or regular equipment on the engine. The engines of the chassis tested in the field were removed and tested on a cradle dynamometer to determine the net torque and horsepower available at various engine speeds at full throttle. The results of these tests were compared with the net torque and power values certified by the manufacturer and were found to be in close agreement with them in all except a few cases. In instances where there was a marked variation that could not be reasonably explained, the efficiency factors were not computed.

The determination of the maximum and net efficiency factor for one gear ratio of a vehicle is given in table 19. An average efficiency factor was obtained in this manner for each gear ratio for each of the vehicles tested. The variation of the efficiency factors with the total gear reduction for all the vehicles tested, regardless of capacity and type, is shown in figure 15 for the maximum and net torque. The values of 85 and 90 percent that are commonly used appear to be fair average values, but for particular speed conditions much more accurate values are now available. The curves drawn through the scattered points are hyperbolas, the equations of which were determined by the method of least squares. The hyperbola was found to fit the points and the conditions better than either a straight line or a parabola. The equations for the curves are:

1. For maximum torque,

$$E=74.36+\frac{99.69}{GR}.$$

2. For net torque,

$$E=85.64+\frac{56.15}{GR}.$$

The variation that occurs about the average efficiency is defined by a standard deviation of 3.5 for the maximum torque and 3.1 for the net torque. In other words, about 68 percent of the values lie within 3.5 percent of the efficiency shown by the curves.

Figure 16 compares the performance of a tractor-truck semitrailer computed by using the basic performance formula with that actually measured on a 4.5-percent grade. The net torque certified by the manufacturer and the values of efficiency and tractive resistance shown on figure 15 and table 18 were used to determine the theoretical performance. The actual performance is indicated by the plotted points. The theoretical performance is shown by the solid line. The average variation between the two sets of results is about 2.5 percent. This degree of accuracy cannot be expected in all cases, but the variation will seldom exceed 5 percent.

GRADE ABILITY OF USED TRUCKS DETERMINED BY ACCELERATION METHOD

A cheaper and shorter method for determining grade ability was desired for use in the used-truck study. Of the various methods investigated,[1] the acceleration method proved to be the most satisfactory. Its accuracy was checked by using it to determine the grade ability for each new truck for the grades on which the actual grade tests were made and by comparing the results determined by the two methods.

The drawbar pull or force produced at the driving wheels of an accelerating vehicle at a given road speed is a function of the acceleration at the given road speed and the mass of the vehicle. The following equation expresses the relationship:

$$P=a(m+k_x) \qquad (11)$$

where

P=drawbar pull in pounds,

a=linear acceleration of vehicle in feet per second per second,

m=mass of vehicle, and

k_x=mass equivalent constant for a given transmission gear.

The mass equivalent constant, which is used to compensate for the energy stored up by the rotating parts when a vehicle is accelerating or decelerating, was discussed and defined in the discussion of tractive resistance. In the case of a vehicle accelerating in a given gear the mass equivalent constant can be determined experimentally by equating the power output on the

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[1] Comparison of Methods for Determining the Hill Climbing Ability of Trucks, by C. C. Saal, PUBLIC ROADS, February 1939, p. 233.

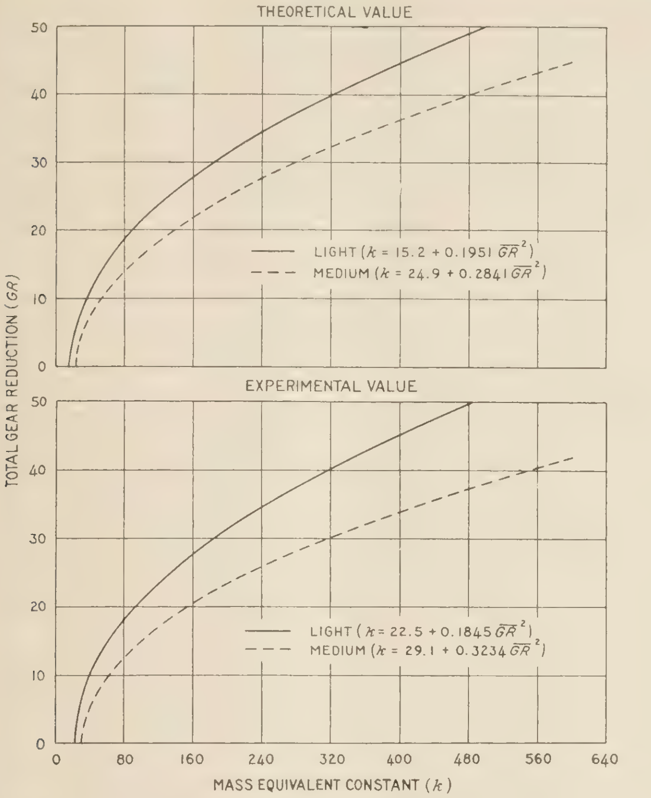

Figure 17.—Mass Equivalent Constants for Light and Medium Single-Unit Trucks.

level at a given speed and weight to the power output on a known grade at the same speed and weight. The following equation results:

$$W \sin A + a_g(m+k_x) = a_l(m+k_x)$$

or

$$k_x = \frac{W \sin A}{a_l - a_g} - m \quad \text{--------------} (12)$$

where

W=weight of vehicle in pounds,
A=angle in degrees that grade line makes with horizontal,
a_g=linear acceleration on grade in feet per second per second,
m=mass of vehicle=$\frac{W}{32.2}$,
a_l=linear acceleration on level in feet per second per second, and
k_x=mass equivalent constant for a given transmission gear.

The mass equivalent constant can be determined theoretically by adding the constant determined for the vehicle in neutral gear to that for the crankshaft, flywheel, and clutch. It is determined by the following equation:

$$k_x = k_0 + \frac{I\overline{GR}^2}{r^2} \quad \text{--------------} (13)$$

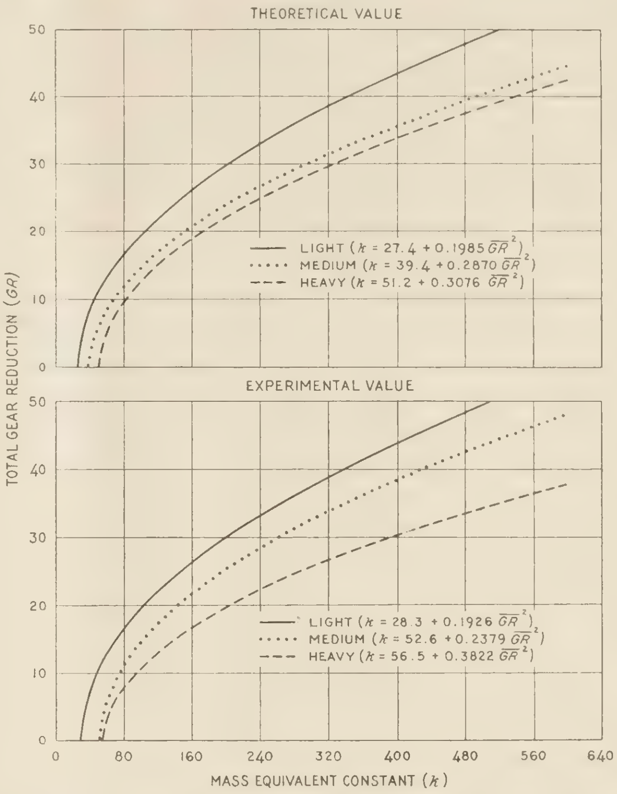

Figure 18.—Mass Equivalent Constants for Light, Medium, and Heavy Tractor-Truck Semitrailers.

where

k_x=mass equivalent constant for a given transmission gear,
k_0=mass equivalent constant for neutral gear,
I=moment of inertia of rotating parts,
GR=total gear reduction, and
r=effective radius of rotating parts in inches.

The average experimental and theoretical mass equivalent constants (k) by capacity groups and vehicle type are shown in figures 17 and 18.

The total force or tractive effort produced at the tire surface of the driving wheels at a given speed is equal to the drawbar pull plus the tractive resistance of the test vehicle. This force can be utilized to pull a certain gross vehicle weight up a given grade at the road speed for which the force is measured. In order to compute grade ability the force must be equated to the component of the gross vehicle weight parallel to the gradient and the tractive resistance of the vehicle on the grade. The following equation expresses this relation:

$$P + GVW_1f_1 = GVW_2g + GVW_2f_2$$

or

$$GVW_2 = \frac{TE}{(g+f_2)} \quad \text{--------------} (14)$$

where

GVW_2=gross vehicle weight in pounds that can be carried on a given grade,
TE=tractive effort=$P+GVW_1f_1$,
P=$a\ (m+k_x)$=the drawbar pull in pounds,
GVW_1=gross weight of test vehicle in pounds,
f_1=coefficient of tractive resistance in pounds

per pound for the speed and weight for which the drawbar pull was measured,
f_2=coefficient of tractive resistance in pounds per pound for the weight that can be carried on the grade, and
g=grade in feet of rise per foot.

There are two unknowns in the above equation, the gross vehicle weight that can be hauled up a given grade at a sustained speed and the coefficient of tractive resistance for that weight. In other words, before the coefficient (f_2) can be determined accurately, the gross vehicle weight (GVW_2) must be known. Since this is impossible, a trial computation is made assuming (f_2) to be equal to (f_1). Using the trial weight, a new coefficient is obtained with which a second computation of weight is made. The weight computed on the second trial seldom varies enough from the first one to cause a variation in the coefficient that would necessitate another trial computation.

Each test vehicle was accelerated at full throttle in each transmission gear, starting at the slowest speed at which the engine would operate smoothly and ending at the maximum permissible engine speed. The tests were made on a level section of highway and also on a 4.5-percent grade. The tests on the grade were necessary in order to determine the constant for the energy stored by the rotating parts. A time-distance record was obtained for each test run from which the values of acceleration were determined in the same manner as described for the determination of the values of deceleration.

SAMPLE CALCULATION OF GRADE ABILITY USING ACCELERATION VALUES

An illustration of the computation of the grade ability from values of acceleration is given in table 20. The values of acceleration were obtained for a tractor-truck semitrailer operating in third gear with a weight of 12,000 pounds. The effective mass is composed of the mass of the loaded tractor-truck semitrailer (373) and the mass equivalent constant (64). At 20 miles per hour the acceleration is 2.210 feet per second per second. The drawbar pull is therefore 2.210 (373+64) =966 pounds. For this particular vehicle the coefficient of tractive resistance for a weight of 12,000 pounds and a speed of 20 miles per hour is 11.4 pounds per thousand pounds. The total tractive resistance is thus (11.4×12)=137 pounds. Since the tractive effort of 1,103 pounds (966+137) is directly proportional to the power output, the correction to standard atmospheric conditions is made at this point. The factor in this case is 1.001 indicating that the tests were made at almost standard conditions. A corrected tractive effort of 1,104 pounds was used to compute the grade performance for this vehicle on 4.5- and 6-percent grades, the grades on which the actual grade tests were conducted.

From table 20 it is seen that the tractor-truck semitrailer had sufficient power to sustain a speed of 20 miles per hour on a 6-percent grade with a gross weight of 15,600 pounds. The first trial computation of the gross vehicle weight utilized the coefficient of 11.4 pounds per thousand pounds. A gross weight of 15,500 pounds resulted from the first trial. Since the coefficient for 15,500 pounds and 20 miles per hour is 10.9 instead of 11.4 pounds per thousand pounds, as assumed, a second trial was necessary. The second trial with the new coefficient resulted in a weight of 15,600 pounds, for which the coefficient is still 10.9. A third trial was therefore not necessary.

Figure 19 shows a comparison between the grade abilities determined for a tractor-truck semitrailer on a 6-percent grade. The plotted points indicate the results determined by the actual tests. The solid line shows the results determined by the acceleration tests. The variation between the two sets of results is of small magnitude. This is a fair sample of the accuracy that can be expected.

Figure 20 shows a cumulative frequency distribution of the percentage of variation between the results obtained by the two methods for all the vehicles. In almost 80 percent of the cases the variation was less than 5 percent. The acceleration method was considered accurate enough to be used in the controlled tests of used trucks and tractor-trucks.

The purpose of the tests on used trucks was to determine the effect of wear and mileage on the performance of motor trucks. Acceleration tests were made on used trucks, of the same make and model as the new trucks tested, to obtain a factor that would represent the decrease in performance resulting from wear and mileage. The Maryland Motor Truck Association cooperated to the fullest extent in this phase of the study. Their members furnished, without compensation, 17 vehicles that had mileages ranging from 10,000 to 90,000 miles. The grade abilities of these vehicles were compared with those of the new trucks to determine the effect of use on their performance.

TABLE 20.—*Grade ability by acceleration method for a tractor truck semitrailer operating in third gear*
[Correction factor=1.001. GVW=12,000 lb. M=373. K_3=64. $M+K_3$=437]

Speed (m. p. h.)	Acceleration, a	Drawbar pull $437a$	Tractive resistance f_1	Actual tractive effort	Corrected tractive effort	4.5=percent grade			6-percent grade		
						GVW	Tractive resistance f_2	GVW using f_2	GVW	Tractive resistance f_3	GVW using f_3
	Ft./sec./sec.	*Pounds*	*Lb./1,000 lb.*	*Pounds*	*Pounds*	*Pounds*	*Lb./1,000 lb.*	*Pounds*	*Pounds*	*Lb./1,000 lb.*	*Pounds*
8	2. 540	1, 110	7. 7	1, 202	1, 203	22, 900	7. 9	22, 800	17, 800	7. 8	17, 800
10	2. 512	1, 098	8. 2	1, 196	1, 197	22, 500	8. 3	22, 500	17, 600	8. 2	17, 600
12	2. 472	1, 080	8. 6	1, 183	1, 184	22, 100	8. 7	22, 100	17, 300	8. 7	17, 200
14	2. 421	1, 058	9. 3	1, 170	1, 171	21, 600	9. 2	21, 600	16, 900	9. 2	16, 900
16	2. 361	1, 032	10. 0	1, 152	1, 153	21, 000	9. 5	21, 200	16, 500	9. 7	16, 600
18	2. 290	1, 001	10. 7	1, 129	1, 130	20, 300	9. 9	20, 600	16, 000	10. 2	16, 100
20	2. 210	966	11. 4	1, 103	1, 104	19, 600	10. 5	19, 900	15, 500	10. 9	15, 600
22	2. 120	926	12. 2	1, 072	1, 073	18, 800	11. 0	19, 200	14, 900	11. 6	15, 000
24	2. 025	885	13. 0	1, 041	1, 042	18, 000	11. 8	18, 300	14, 300	12. 4	14, 400
26	1. 920	839	13. 9	1, 016	1, 017	17, 300	12. 5	17, 700	13, 800	13. 4	13, 900
28	1. 810	791	14. 8	969	970	16, 200	13. 6	16, 600	13, 000	14. 5	13, 000
30	1. 690	739	15. 8	929	930	15, 300	14. 7	15, 600	12, 300	15. 6	12, 300
32	1. 568	685	16. 9	888	889	14, 400	16. 0	14, 600	11, 600	17.2	11, 500

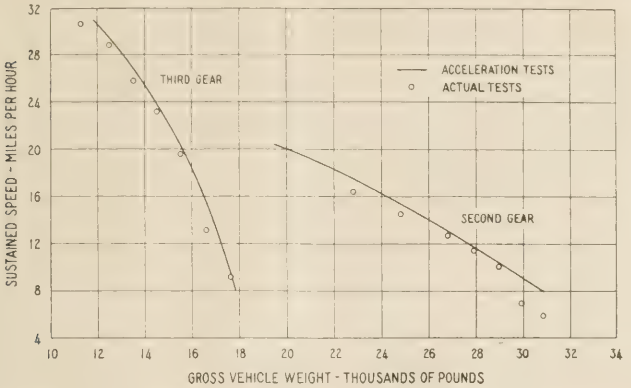

Figure 19.—Comparison of Grade Abilities Determined by Actual Grade Tests and by Acceleration Tests for a Typical Tractor-Truck Semitrailer on a 6-Percent Grade.

The acceleration method which was developed in conjunction with the actual grade tests on new trucks and which has already been described was used to measure the performance of the used vehicles. Because it was not always possible to obtain vehicles of the same model that had the same gear ratios and tire sizes, it was necessary to compare the performance of the new and used vehicles measured in terms of tractive effort at a given engine speed rather than in terms of gross vehicle weight and speed on a given grade.

The tractive effort of a new vehicle operating on a given grade and in a given gear was computed for various road speeds by equation 2:

$$TE = GVW(f+g) \quad \text{-------------} \quad (2)$$

where

TE = tractive effort in pounds,
GVW = gross vehicle weight in pounds,
f = coefficient of tractive resistance in pounds per pound of weight, and
g = grade in feet of rise per foot.

The engine speed equivalent to the road speed for which the tractive effort was measured was determined by use of equation 10.

$$RPM = \frac{168 \times GR \times S}{r} \quad \text{------------} \quad (10)$$

where

RPM = engine speed in revolutions per minute,
S = road speed in miles per hour,
GR = total gear reduction,
r = effective radius of driving wheels in inches, and
168 = factor to convert units to revolutions per minute.

TRACTIVE EFFORT–ENGINE SPEED CURVES PLOTTED FOR USED VEHICLES

The tractive effort of a used vehicle was measured by acceleration and deceleration tests made on a level section of road. The drawbar pull and the tractive resistance determined from the values of acceleration and deceleration were combined to obtain the tractive effort available at various engine speeds. A tractive effort–engine speed curve was then plotted for each transmission gear. The following equation was used to compute the tractive effort for the used trucks:

$$TE = a(m+k_x) + GVW(f) \quad \text{----------} \quad (15)$$

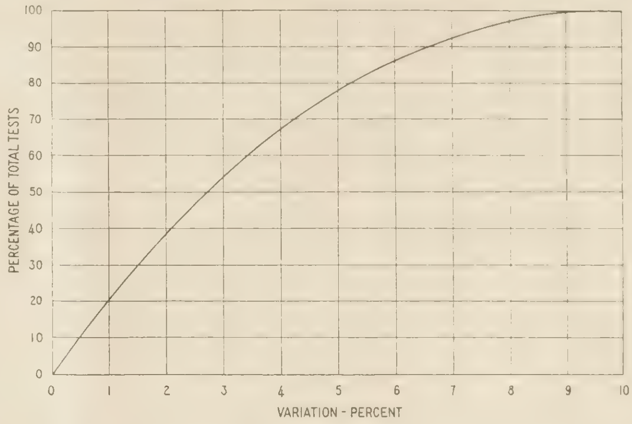

Figure 20.—Cumulative Frequency Distribution of the Percentage of Variation Between the Grade Ability Determined by the Actual Grade Tests and by the Acceleration Tests.

where

TE = tractive effort in pounds,
a = linear acceleration of vehicle in feet per second per second,
m = mass of vehicle $= \frac{GVW}{32.2}$
k_x = mass equivalent constant for a given gear,
$a(m+k_x)$ = drawbar pull in pounds,
GVW = gross vehicle weight in pounds,
f = coefficient of tractive resistance in pounds per pound of weight, and
$GVW(f)$ = tractive resistance in pounds.

In the case where the used models had the same tire size and gear ratios as the new model, the comparison of performances for a given gear is a direct one between the tractive efforts at a given engine speed or road speed, computed by using equations 2 and 15 shown above. But when the final gear reductions are not the same, it is necessary to convert the tractive effort of the used model for one gear reduction to that for the gear reduction of the new model.

The relation that was used to convert the tractive effort of a used model to one that could be compared with that of the new model was derived as follows, starting with the basic performance formula (equation 8):

$$GVW = \frac{T \times GR \times E}{r(f+g)} \quad \text{------------} \quad (8)$$

since

$$GVW(f+g) = TE \quad \text{--------------} \quad (2)$$

$$TE = \frac{T \times GR \times E}{r} \quad \text{--------------} \quad (16)$$

therefore for one set of conditions

$$TE_1 = \frac{T \times GR_1 \times E_1}{r_1} \quad \text{------------} \quad (17)$$

and for another set of conditions

$$TE_2 = \frac{T \times GR_2 \times E_2}{r_2} \quad \text{------------} \quad (18)$$

Dividing equation 17 by equation 18 and assuming that for similar engines the torque, T in the equations, will be the same at a given engine speed and that the

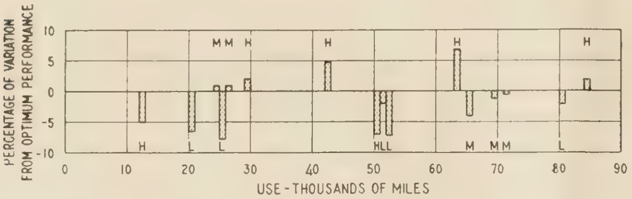

FIGURE 21.—THE EFFECT OF USE ON THE HILL-CLIMBING ABILITY OF MOTOR TRUCKS.

over-all efficiency will be equal, which is the case when the variation in gear reduction is not great, the following relationship results:

$$TE_1 = TE_2\left(\frac{GR_1 \times r_2}{GR_2 \times r_1}\right) \qquad (19)$$

where

TE_1 = converted tractive effort of used model.
TE_2 = tractive effort determined for used model.
GR_1 = total gear reduction of new model.
GR_2 = total gear reduction of used model.
r_1 = loaded radius of driving wheels on new model in inches, and
r_2 = loaded radius of driving wheels on used model in inches.

For example, one new model produced a tractive effort of 1,522 pounds at 2,200 revolutions per minute with a final gear reduction of 12.85 and a loaded radius of 19.11 inches. The used model with the same engine produced a tractive effort of 1,442 pounds at 2,200 revolutions per minute with a final gear reduction of 12.89 and a loaded radius of 19.85 inches. Using equation 19:

$$TE_1 = 1{,}442\left(\frac{12.85 \times 19.85}{12.89 \times 19.11}\right) = 1{,}493 \text{ pounds.}$$

The variation between the performance of the new and used model is therefore $\frac{1{,}522 - 1{,}493}{1{,}522} = 0.019$, or a reduction in performance due to use of 1.9 percent, since the tractive efforts of both chassis are for the same set of conditions of engine speed, gear reduction, and loaded tire radius.

The percentage of variation between the tractive effort produced by the new and used models was computed at several engine speeds over the useful speed range of at least one gear. The procedure followed and the results of the tests on a new truck and two used trucks of the same make and model are shown in table 21.

The performance of the new truck was obtained from the results of the actual grade tests on a 5-percent grade. The tractive effort was computed by multiplying the gross vehicle weight by the factor ($f+g$) which is the sum of the coefficient of tractive resistance and the tangent of the angle of grade.

The tractive effort determined for the used truck by the acceleration method is plotted against engine speed. From these curves the tractive effort shown in the table was obtained for the engine speed at which the tractive effort for the new truck was determined. This tractive effort, designated as TE_2 in the table, was converted to the gear reduction and loaded tire radius of the new truck in the manner just described. The percentage of variation between the performance of the new and used vehicle was then computed using the performance of the new truck as a base.

TABLE 21.—*Comparison of the tractive effort for new and used trucks of the same make and model*

Speed, m. p. h.	Performance of new truck on a 5-percent grade					Performance of used truck with 12,000 miles				Performance of used truck with 51,000 miles			
	GVW	Speed	*f*	*f+g*	*TE*	*TE*$_2$	*TE*$_1$	Variation		*TE*$_2$	*TE*$_1$	Variation	
	1,000 Lb.	*R. p. m.*	*Lb./ 1,000 lb.*		*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Percent*	*Lb.*	*Lb.*	*Lb.*	*Percent*
10	30.6	1,060	9.9	0.0599	1,835	1,770	1,755	80	−4.4	2,090	1,745	90	−4.9
12	30.1	1,275	10.4	.0604	1,820	1,750	1,735	85	−4.7	2,050	1,710	110	−6.0
14	29.4	1,485	10.9	.0609	1,790	1,720	1,705	85	−4.7	2,010	1,680	110	−6.1
16	28.4	1,690	11.6	.0616	1,750	1,680	1,660	90	−5.1	1,950	1,630	120	−6.8
18	27.2	1,900	12.3	.0623	1,695	1,620	1,600	95	−5.6	1,880	1,570	125	−7.4
20	25.6	2,110	13.3	.0633	1,620	1,550	1,530	90	−5.6	1,790	1,495	125	−7.7
22	23.8	2,320	14.3	.0643	1,530	1,470	1,450	80	−5.2	1,680	1,405	125	−8.2
24	22.0	2,520	15.5	.0655	1,440	1,380	1,355	85	−5.9	1,570	1,310	130	−9.0
26	20.0	2,730	17.0	.0670	1,340	1,280	1,255	85	−6.3	1,440	1,200	140	−10.4
28	17.5	2,940	18.8	.0688	1,205	1,180	1,160	45	−3.7	1,310	1,095	110	−9.1
Average variation									−5.1				−7.6

TRUCK PERFORMANCE NEED NOT DECREASE WITH USE

The percentage of variation between the performance of new and used trucks is shown graphically in figure 21 for all the tests. The abscissa is the mileage the vehicle had been driven and the ordinate is the percentage of variation from the base performance. The variation from the base line is never more than 8 percent. However, it is not always in the negative direction. In about one-third of the cases the performance of the used truck was better than that of the new truck. The bars are marked L, M, and H, to indicate that the test vehicle was in the light, medium, or heavy group. It is interesting to note that the heavier models of used vehicles had performances better than those of new vehicles. Since a majority of the vehicles were obtained from operators who service their motors regularly, the performance of the used vehicles may have been of a higher standard than that found generally on the highway. The results definitely prove that trucks can be maintained so that the performance does not decrease with reasonable use.

The amount of maintenance on the used trucks should be known when considering the effect of use on the performance. Some of the motors of vehicles tested had been overhauled prior to the tests. The medium truck with 69,000 miles was given a major overhaul at 54,700 miles, and the medium truck with 65,000 miles was overhauled at 23,000 miles because sand had gotten into the motor. Both of these vehicles were used to haul material from a sand pit and their performance as shown on figure 21 is slightly less than the base performance. The light vehicle with 80,000 miles was overhauled at about 40,000 miles. Its performance is also about the same as that of a new vehicle. In one instance a light vehicle was tested immediately before and again immediately after overhauling. The performance after the overhaul was slightly less than that before the overhaul as is indicated by the values of variation plotted at 51,000 and 52,000 miles. None of the other vehicles were overhauled prior to the tests.

In two cases the used models had the same gear reduction and tire size as the new model. In these cases a direct comparison could be made between the grade performances in terms of gross vehicle weight and speed. Figures 22 and 23 show the comparison of grade ability

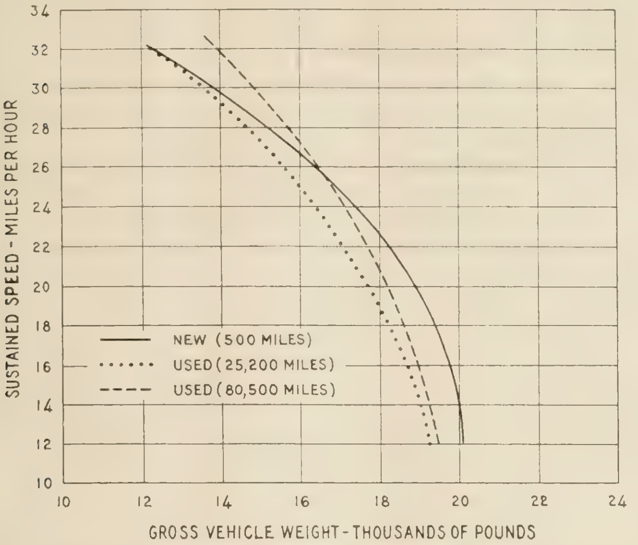

Figure 22.—Comparison of the Hill-Climbing Ability in Third Gear of New and Used Light Tractor-Truck Semitrailers of the Same Make and Model on a 5-Percent Grade.

for groups of light and medium tractor trucks. These comparisons serve to verify the conclusions drawn from the results shown in figure 21.

In figure 22 the performance curve of the used vehicle with 80,500 miles crosses that for the new vehicle and is better than the performance of the vehicle with 25,200 miles. The effect of use is practically nil in this case.

In figure 23 the performance curves of the used vehicles cross the one for the new vehicle. The average variation between the curves for the two used vehicles and the one for the new vehicle is approximately zero when negative variation is weighed against positive variation.

The purpose of the tests on vehicles in service was to measure the behavior of other vehicles in the traffic stream with respect to the slow-moving vehicles and the hill-climbing ability of motor trucks when operated under ordinary driving. These tests have been conducted on various gradients under different traffic densities in Massachusetts, Illinois, California and Oregon, in connection with their respective highway planning surveys. Included in this report are the results found in Massachusetts and California. The analysis of data in the vehicle behavior portion of the study, which has as its principal objective the determination of what may be considered a reasonable minimum speed from the point of view of congestion, has not been concluded.

The actual performance of all vehicles on the selected grades was measured with the equipment used on passing studies.[2] The trucks and combination units were identified when they passed a control station on the grade. After they had climbed the grade they were stopped at a loadometer station where they were weighed and complete data were obtained, as to make, year, model, capacity, vehicle type, tire size, etc. In this way it was possible to match the speed record of the vehicle with the vehicle characteristics without permitting the operator to know that his actions were being observed on the grade.

In analyzing the charts each vehicle was treated in the order in which it arrived at the grade. The average speed of each truck was measured for each 50-foot section. From this record of speed it was possible to obtain the sustained or crawl speed and also the length of grade required to reduce the approach speed to various speeds.

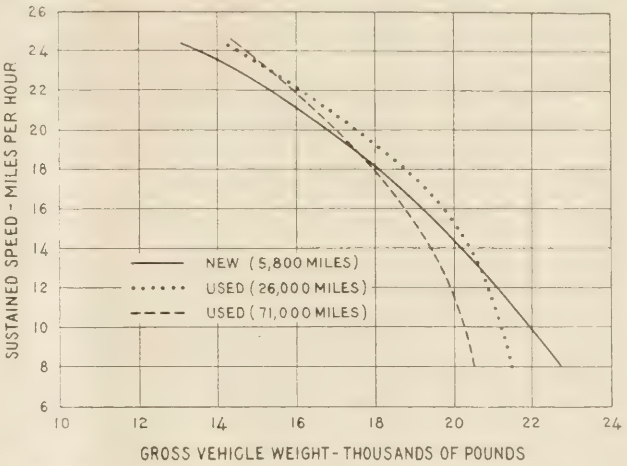

Figure 23.—Comparison of the Hill-Climbing Ability in Third Gear of New and Used Medium Tractor-Truck Semitrailers of the Same Make and Model on a 6-Percent Grade.

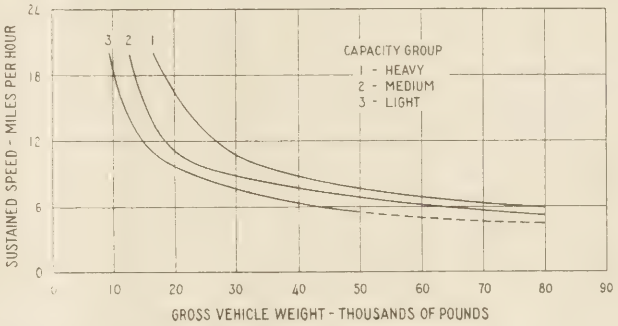

Figure 24.—Grade Ability of Light, Medium, and Heavy Trucks and Tractor-Truck Semitrailers in Actual Service on a 6-Percent Grade.

The trucks and combination units observed were classified into the three capacity groups corresponding to those used in the new truck study. The vehicles in each capacity group were distributed into weight groups and the average sustained speed obtained for each weight group. Figure 24 shows the average performance of 517 vehicles observed in Massachusetts and California on 6-percent grades. Above 30,000 pounds there is little difference in the speed for a given weight between the performance of vehicles in the three capacity groups. This finding is particularly important when it is considered that an increase in power is one of the means that has been considered for raising the speed.

From the performance curves for the new trucks, a requirement of 20 miles per hour on a 4-percent grade, one that has been proposed in some quarters, is indicated to be equivalent to one of 14 miles per hour on a 6-percent grade. From figure 24, this speed could be maintained with gross vehicle weights of 12,500, 16,000 and 22,500 pounds for the light, medium, and heavy vehicles, respectively. These weights are approximately the empty weights of the combination units. The effect of such a requirement based on actual operation on the tractor-truck semitrailers is apparent. It would permit no carried load whatsoever.

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[2] Procedure Employed in Analyzing Passing Practices of Motor Vehicles, by F. H. Holmes, PUBLIC ROADS, vol. 19, No. 11, January 1939.

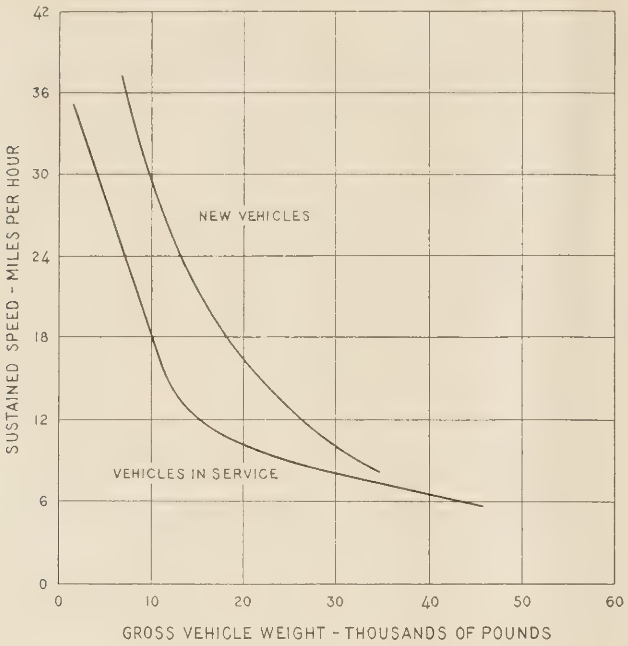


Figure 25.—Comparison Between the Grade Ability Determined by Controlled Tests on New Vehicles and by Tests on Vehicles in Actual Service for Light Trucks and Tractor-Truck Semitrailers on a 6-Percent Grade.

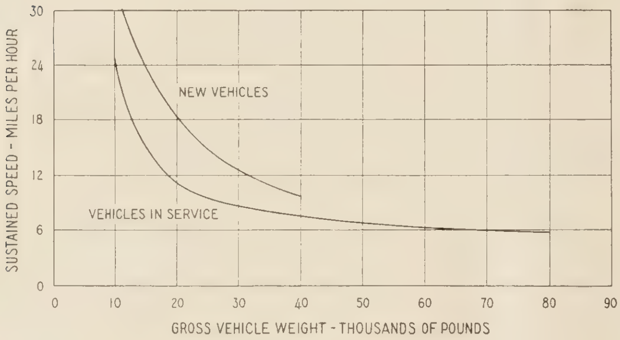


Figure 26.—Comparison Between the Grade Ability Determined by Controlled Tests on New Vehicles and by Tests on Vehicles in Actual Service for Medium Trucks and Tractor-Truck Semitrailers on a 6-Percent Grade.

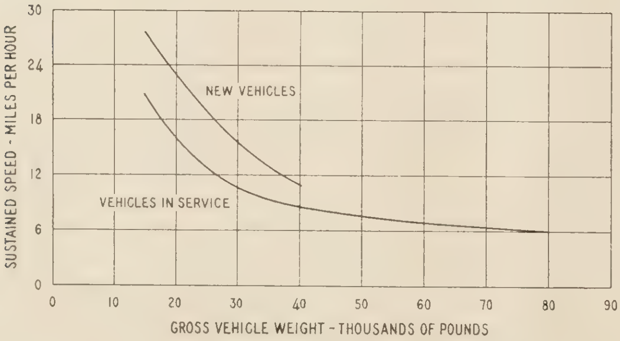


Figure 27.—Comparison Between the Grade Ability Determined by Controlled Tests on New Vehicles and by Tests on Vehicles in Actual Service for Heavy Trucks and Tractor-Truck Semitrailers on a 6-Percent Grade.

INFERIOR PERFORMANCE CAUSED BY IMPROPER DRIVING

A direct comparison between the performance of new trucks and that of the vehicles in service on a 6-percent grade is shown in figures 25, 26, and 27, for the light, medium, and heavy trucks and combination units. The difference in performance is caused either by improper maintenance or improper driving or both. In each figure the two curves tend to close at the lower speeds, which indicates that much of the difference is due to the improper selection of gears, a fact that is further supported by the results of the used-truck study. The average variations are 31, 30, and 27 percent for the light, medium, and heavy groups, respectively. An average variation of 30 percent can therefore be expected for all the vehicles studied. This decrease in performance must be given careful consideration in any development of a reasonable performance requirement.

The effect of the length of grade on the speed of motor trucks is given by figure 28 for a 6-percent grade studied in Massachusetts. The curve for each gross weight group was obtained by averaging the speeds of all the vehicles in a group at a given distance along the grade. These curves can be used by the designer to determine how long a grade can be and yet not reduce the speed below a given value. For instance, a 6-percent grade could be 800 feet long and yet not slow the average vehicle to less than 20 miles per hour. The results apply to a grade with a level approach. Similar results are being developed for other gradients having different rates of grade and approach characteristics.

The correlation of the results of the actual grade tests with the information obtained at weight stations to determine the effect of various requirements on the present operation of motor trucks is one of the important developments of this study. The number of vehicles affected and the tons of payload that would be lost to the operators using U. S. Routes 1 and 40 between Richmond, Virginia, and Havre de Grace, Maryland have been determined for certain assumed requirements. The weight of the vehicles, their capacity (light, medium, or heavy) and their type were recorded at weight stations. The maximum performance that can be expected from these vehicles is shown in table 22 for various conditions of speed and grade as determined by the actual grade tests on new vehicles. The number of vehicles that cannot meet a specified requirement, such as 20 miles per hour on a 4-percent grade, was determined by

Table 22.—*Grade ability of light, medium, and heavy trucks and tractor-truck semitrailers on various grades*

Grade, percent	Capacity	Gross vehicle weights for speeds of—		
		15 miles per hour	20 miles per hour	25 miles per hour
		Pounds	*Pounds*	*Pounds*
3	Light	39,000	26,000	22,000
	Medium	42,000	33,000	23,000
	Heavy	54,000	41,000	31,000
4	Light	31,000	21,000	18,000
	Medium	34,000	26,000	19,000
	Heavy	44,000	33,000	25,000
5	Light	26,000	17,000	15,000
	Medium	29,000	22,000	16,000
	Heavy	36,000	27,000	20,000
6	Light	22,000	15,000	13,000
	Medium	24,000	19,000	14,000
	Heavy	31,000	23,000	17,000

counting the vehicles that had weights that were more than the weight given in table 22 for a given set of conditions.

The percentage of the single-unit trucks and tractor-truck semitrailers that must decrease their payload to meet a requirement of 20 miles per hour on a 4-percent grade is shown by the bar graphs in figure 29. The variation in performance between the two types of vehicles is very pronounced. Approximately 65 percent of the combination units would be affected as compared to about 5 percent of the single units. Similar relationships have been determined for other conditions of speed and grade. Table 23 lists the percentage of light, medium, and heavy vehicles using U. S. Route 1 between Washington, D. C. and Baltimore, Md., that cannot meet various requirements of speed and grade. For a requirement of 20 miles per hour on a 3-percent grade, 27.2 percent of the combination units would be affected as compared to 0.8 percent of the single units. For 20 miles per hour on a 5-percent grade, 80.9 percent of the combination units would be affected as compared to 10.6 percent of the single units. It is evident that the operators of the tractor-truck semitrailers would suffer the most.

The figure and the table just reviewed indicate the number of vehicles that are affected, but they do not show in what measure they are affected. The amount of payload that would have to be removed from the vehicles to permit them to meet a given requirement is more important. Table 24 lists the total payload hauled by all the vehicles operating between Washington, D. C., and Baltimore, Md., for an average 24-hour period. It also lists the payload in excess of that which could be carried if a speed of 20 miles per hour were required on 3-, 4-, 5-, or 6-percent grades.

TABLE 23.—*Percentage of light, medium, and heavy vehicles between Washington, D. C., and Baltimore, Md., that cannot meet various requirements of speed and grade.*

Requirement		Percentage of single-unit trucks that cannot meet requirement				Percentage of tractor-truck semitrailers that cannot meet requirement			
Speed, m. p. h.	Grade	Light	Medium	Heavy	Average	Light	Medium	Heavy	Average
	Percent								
15	3	0	0	0	0	0	2.8	0	1.5
	4	0	.7	0	.2	6.6	22.0	0	14.0
	5	.6	1.9	8.4	1.3	34.2	51.3	25.6	42.2
	6	2.1	7.6	13.3	4.2	60.9	72.4	59.0	66.8
20	3	.6	1.7	0	.8	34.2	28.4	0	27.2
	4	2.8	3.6	13.3	3.5	68.3	64.3	45.0	63.5
	5	8.5	14.0	21.7	10.6	83.1	79.1	82.1	80.9
	6	17.8	26.9	39.8	21.2	88.5	88.9	94.9	89.4
25	3	2.1	10.9	13.3	5.0	60.9	76.0	59.0	68.7
	4	6.4	26.9	31.3	13.0	80.2	88.9	91.0	86.0
	5	17.8	48.6	66.3	28.5	88.5	96.1	98.7	93.7
	6	32.1	60.9	84.3	42.5	93.4	97.8	100.0	96.5

For this requirement on a 4-percent grade the total payload must be reduced 14.4 percent with 13.5 percent of this coming off the tractor-truck semitrailers. For a 3-percent grade, the payload must be reduced 3.4 percent. For the 5- and 6-percent grades, 28.0 and 39.8 percent of the payload must be removed. In either case at least 85 percent of the excess load is found on the combination units. The translation of the excess load into terms of ton-miles and lost income can easily be made. The effect of these requirements on the transportation industry, even if they were sufficient to eliminate the congestion on grades, would be drastic. In

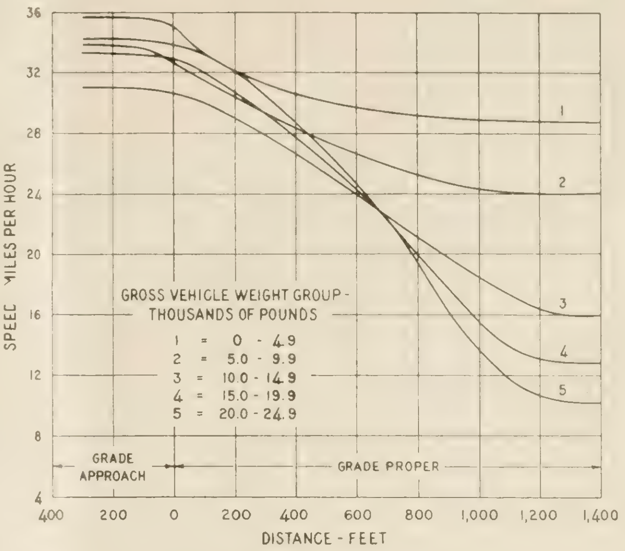


FIGURE 28.—EFFECT OF THE LENGTH OF A 6-PERCENT GRADE ON THE SPEED OF MOTOR TRUCKS.

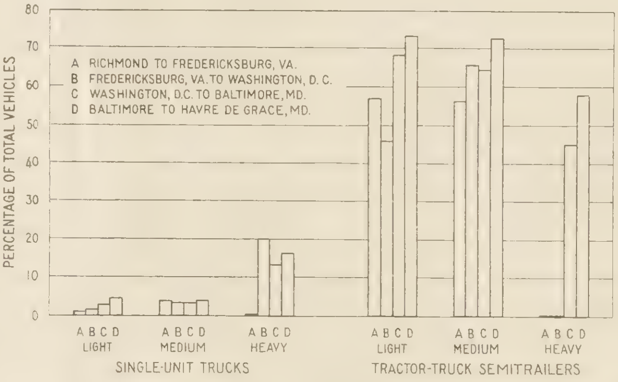


FIGURE 29.—PERCENTAGE OF TOTAL VEHICLES THAT CANNOT MEET REQUIREMENT OF 20 MILES PER HOUR ON A 4-PERCENT GRADE.

TABLE 24.—*Average excess load for trucks and tractor-truck semitrailer combinations on 3-, 4-, 5-, and 6-percent grades at 20 miles per hour; 24-hour daily average traffic on U. S. Route 1 between Washington, D. C., and Baltimore, Md.*

Type and capacity of vehicle	24-hour volume	Total pay load	Excess load for various grades							
			3 percent		4 percent		5 percent		6 percent	
		Tons	*Tons*	*Percent*[1]	*Tons*	*Percent*[1]	*Tons*	*Percent*[1]	*Tons*	*Percent*[1]
Light trucks	1,084	2,380	2	0.02	31	0.3	122	1.4	233	2.6
Medium trucks	422	1,220	7	.08	34	.4	94	1.1	202	2.3
Heavy trucks	83	438	----	-----	15	.2	51	.5	100	1.1
Total trucks	1,589	4,038	9	.10	80	.9	267	3.0	535	6.
Light tractor-truck semitrailers	243	1,530	114	1.3	400	4.5	770	8.6	965	10.9
Medium tractor-truck semitrailers	359	2,715	178	2.0	750	8.4	1,255	14.2	1,700	19.2
Heavy tractor-truck semitrailers	78	565	----	-----	52	.6	197	2.2	334	3.7
Total tractor semitrailers	680	4,810	292	3.3	1,202	13.5	2,222	25.0	2,999	33.8
Total	2,269	8,848	301	3.4	1,282	14.4	2,489	28.0	3,534	39.8

[1] Percentage of total payload hauled by all vehicles.

studying this table it is important to note that, while the combination units represent only 30 percent of the total number of vehicles, they haul 55 percent of the total payload.

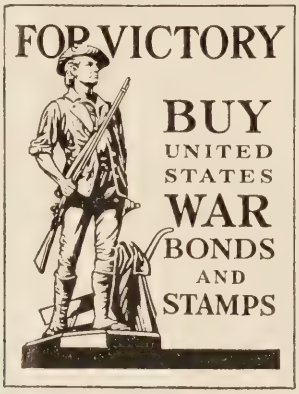
CONCLUSIONS

The most important conclusions are derived from the results of the actual grade tests and the applications just described. They showed that for motor trucks even to approach reasonable speeds on grades:

1. Grades must be reduced to 3 percent or less, or
2. Engine power must be more than doubled, or
3. Gross vehicle weights must be reduced excessively, or
4. Some combination of the three must be used that will still be costly to all interests involved and practically impossible of immediate application. Before a final conclusion can be reached, the reasonable minimum speed must be determined and the relative economics of the three basic methods and of their combinations must be determined. The results do show plainly that it will not be possible to find a comprehensive solution. It appears that the immediate solution is the localized one—the provision of wider surfaces at the points of most serious congestion. This does not mean, however, that emphasis should be removed from the other methods as a means of gradually improving the performance of motor trucks.

On the average, there is a 30-percent variation between the possible performance and the actual performance of vehicles in service. Since not over 10 percent of this variation should be due to lack of maintenance, there remains a 20-percent variation that must be charged to improper operation of the vehicle. In some cases the speed could have been doubled if the gears had been shifted at the proper engine speed. A considerable improvement in performance could be realized merely by instructing the drivers as to the proper speeds at which to shift gears.

The performance of a motor vehicle may be computed by using the unit tractive resistances and efficiencies developed by this study, with a degree of accuracy not heretofore possible. Further research is necessary to determine the tractive resistance for higher speeds, for motor trucks with other types of bodies, and for various types of road surface.



STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF APRIL 30, 1942

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$6,456,126	$3,256,172	228.2	$4,278,809	$2,323,129	115.2	$198,900	$99,450	0.2	$2,493,120
Arizona	1,683,959	1,241,721	68.1	1,283,758	1,048,608	47.3	238,615	188,508	1.7	1,821,467
Arkansas	3,640,340	1,662,291	57.4	1,173,174	585,470	60.1	192,792	118,191	1.7	1,706,344
California	8,996,533	4,864,759	150.1	4,900,628	3,268,188	55.5	873,300	596,634	20.7	4,187,244
Colorado	2,377,987	1,327,638	155.2	3,579,256	2,302,210	155.1	1,165,565	652,450	41.2	2,095,717
Connecticut	1,419,554	696,181	17.1	1,988,467	957,191	23.1	208,175	104,067	4.7	1,228,870
Delaware	595,356	333,581	17.1	441,010	216,559	9.0	268,040	134,020	8.4	1,462,962
Florida	1,342,189	698,897	66.7	3,130,037	1,821,323	49.2	512,242	319,028	4.6	2,915,875
Georgia	3,007,820	1,488,938	111.7	7,491,049	3,796,161	286.3	3,219,349	1,699,825	122.1	6,732,293
Idaho	1,916,219	1,264,905	95.4	1,176,165	831,418	61.4	58,224	36,000	.1	1,988,253
Illinois	4,119,357	2,001,308	89.5	7,144,698	4,170,552	121.7	1,361,200	680,600	6.2	6,514,422
Indiana	4,624,009	2,129,006	75.1	7,377,291	3,609,880	107.1				2,895,234
Iowa	3,909,378	1,887,029	170.5	4,479,059	1,800,695	136.5	407,151	86,450	6.8	2,496,741
Kansas	4,723,956	2,399,067	263.2	6,187,277	3,230,881	258.3	893,346	416,787	43.0	4,799,194
Kentucky	4,071,654	2,006,401	146.9	6,142,754	2,928,407	118.8	2,546,540	1,341,834	27.3	1,616,384
Louisiana	1,505,665	789,834	33.4	1,382,924	914,401	28.5	3,008,481	1,564,690	60.4	3,963,622
Maine	944,081	470,251	26.8	2,064,492	1,055,796	27.7	78,610	39,305	.1	1,130,475
Maryland	2,765,267	1,381,529	29.6	3,496,909	1,483,654	15.0	310,000	202,500	3.2	1,384,707
Massachusetts	2,351,882	1,178,572	17.3	2,239,503	1,159,262	14.9	1,273,400	658,873	9.1	3,817,721
Michigan	8,514,375	4,188,577	174.2	2,967,748	1,935,599	51.6	1,325,800	828,550	11.5	3,011,267
Minnesota	4,681,764	2,286,967	384.8	9,551,361	4,732,108	391.6	113,720	56,860	10.0	3,522,288
Mississippi	5,332,567	2,602,918	283.3	3,750,524	1,882,462	218.1	21,400	13,700		2,276,878
Missouri	5,218,752	2,659,656	165.0	10,654,415	6,097,445	192.4	1,930,351	665,452	25.4	3,957,120
Montana	2,170,862	1,258,436	117.1	4,203,667	2,521,973	202.5	210,734	119,823	26.6	4,403,366
Nebraska	3,062,166	1,513,744	297.7	5,092,749	2,561,329	456.7	174,888	109,530	14.2	4,414,959
Nevada	2,217,826	1,893,244	110.6	883,384	770,620	26.0	817,668	737,447	24.6	812,356
New Hampshire	343,779	211,723	6.0	1,800,559	1,022,873	20.2				818,906
New Jersey	2,998,818	1,460,264	26.6	2,988,902	1,494,371	16.2				3,051,981
New Mexico	1,874,157	1,221,453	125.0	905,551	647,891	51.1				2,753,730
New York	9,538,881	4,786,928	126.7	8,683,891	5,561,808	86.7	429,000	193,500	6.4	5,148,137
North Carolina	4,638,838	2,495,290	187.3	2,282,864	1,213,544	99.0	561,756	283,902	8.8	3,667,794
North Dakota	3,225,343	1,875,878	287.6	2,588,295	1,469,013	203.9	2,396,350	1,257,134	205.5	4,018,917
Ohio	9,983,010	5,462,688	97.9	14,619,362	7,609,744	83.8	1,970,140	870,818	19.5	2,923,526
Oklahoma	2,643,551	1,383,859	122.3	2,692,322	1,500,534	64.9	1,360,930	734,857	38.3	6,154,092
Oregon	2,783,897	1,644,626	73.0	3,200,754	1,659,318	71.4	1,061,993	802,010	37.6	1,110,688
Pennsylvania	10,764,735	5,315,777	106.2	9,735,865	5,037,114	72.1	1,300,656	831,617	9.7	4,413,736
Rhode Island	1,194,495	678,165	10.0	1,046,898	669,630	5.0	242,264	121,132	1.8	717,226
South Carolina	2,401,104	1,210,729	101.0	3,982,258	2,526,202	92.0	524,690	281,300	11.0	1,437,385
South Dakota	2,380,869	1,398,927	287.9	4,709,133	3,116,405	533.3	545,110	325,580	59.4	2,883,332
Tennessee	4,543,199	2,540,192	109.9	4,562,862	2,627,570	99.7	200,928	118,090	3.5	3,505,818
Texas	12,767,078	6,254,887	617.9	11,080,522	5,295,251	353.1	1,100,810	361,565	29.5	9,405,618
Utah	1,252,200	941,940	53.9	1,838,587	1,393,120	46.7				1,254,463
Vermont	803,276	449,292	28.8	1,193,326	715,241	20.7	36,906	18,453	.3	393,034
Virginia	4,144,660	1,921,249	74.9	3,402,388	1,843,051	57.2	35,490	17,745	.4	2,734,942
Washington	1,808,560	987,042	26.5	2,514,659	1,362,843	30.5	43,686	23,400	1.0	2,164,196
West Virginia	2,908,443	1,442,392	53.1	2,621,338	1,387,129	29.0	972,390	544,930	5.7	1,603,136
Wisconsin	2,202,064	1,146,706	92.7	5,618,496	3,567,693	163.9	655,983	482,100	11.8	3,767,879
Wyoming	1,439,453	1,027,059	148.4	1,773,023	1,317,527	123.5				1,272,971
District of Columbia	1,056,968	542,738	3.5	198,302	127,960	.9	945,456	564,688	1.5	144,168
Hawaii	141,835	75,057	2.8	1,098,684	813,357	10.9	499,587	480,115	5.2	1,424,204
Puerto Rico	499,945	238,835	3.9	2,295,515	1,173,260	18.0	258,665	138,464	3.5	606,323
TOTALS	179,988,802	94,195,318	6,125.8	204,495,464	113,157,770	5,583.3	36,551,281	19,921,974	934.2	145,025,081

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF APRIL 30, 1942

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$1,392,972	$695,108	62.5	$685,882	$362,410	31.1	$40,801	$19,550	0.1	$581,490
Arizona	255,110	184,247	14.1	138,065	101,042	6.8				513,118
Arkansas	629,977	237,235	33.1	483,854	241,861	26.5	70,062	34,701	2.4	301,121
California	1,041,542	641,734	18.3	743,259	567,493	7.6				1,031,859
Colorado	209,672	112,570	20.9	131,800	73,914	3.2	152,386	35,323	5.0	502,702
Connecticut	298,035	136,331	6.1	266,247	115,937	4.8				199,604
Delaware	164,535	79,371	.4	141,464	70,732	11.9	102,873	37,618	3.9	246,037
Florida	1,042,471	519,285	11.6	292,018	153,304	6.1				398,953
Georgia	545,666	257,833	43.4	1,205,213	694,956	74.9	400,257	200,129	43.7	1,126,812
Idaho	293,347	172,516	26.2	225,220	157,021	7.7	38,149	23,587	2.8	285,992
Illinois	1,087,608	515,800	59.4	1,168,384	584,192	54.5	96,500	48,250	10.6	896,158
Indiana	586,368	285,054	39.8	1,279,755	606,721	51.0	88,800	44,400	3.2	922,073
Iowa	640,297	295,716	165.0	560,916	253,045	73.4	141,325	64,325	35.1	589,961
Kansas	846,435	427,455	111.7	1,806,645	905,910	92.4	238,353	119,176	29.7	1,035,351
Kentucky	1,157,864	321,329	83.2	1,249,010	417,668	37.2	74,213	24,400	5.6	324,331
Louisiana	539,462	265,678	20.6	7,700	3,850		289,362	138,761	21.5	666,650
Maine	78,522	39,261	3.6	235,218	117,609	10.6	16,850	2,714	.4	160,925
Maryland	579,966	289,808	20.7	226,410	113,205	1.8				345,564
Massachusetts	179,789	93,569	4.1	688,233	377,683	10.1				547,304
Michigan	1,290,556	636,337	79.4	710,798	355,399	21.7	307,870	153,935	11.2	644,804
Minnesota	1,597,866	790,632	217.1	1,029,197	520,337	91.8	279,496	139,348	26.8	588,655
Mississippi	829,715	414,858	46.5	1,494,546	709,614	59.0				386,494
Missouri	435,434	214,924	52.9	932,442	448,633	94.0	186,244	63,193	32.4	1,045,552
Montana	375,564	211,817	58.5	292,724	170,722	31.0	13,569	7,715	4.5	901,005
Nebraska	361,584	178,543	49.4	493,954	249,591	66.6				699,809
Nevada	331,931	266,129	28.6	92,429	60,188	4.6				234,872
New Hampshire	156,054	95,143	4.7	239,437	118,819	3.6				133,643
New Jersey	487,496	239,245	9.6	464,115	256,160	13.9				575,787
New Mexico	566,935	357,245	47.7	196,149	126,792	15.2	66,176	42,419	4.4	250,178
New York	956,940	468,240	28.8	1,160,340	620,808	14.9	245,600	122,800	.9	1,085,178
North Carolina	330,711	170,040	34.9	522,407	278,748	36.3	69,820	20,000	5.0	695,703
North Dakota	29,802	15,664	2.4	7,382	7,382		808,050	793,860	42.7	755,172
Ohio	1,782,884	888,281	57.6	901,610	498,775	14.5	76,000	38,000	2.0	1,375,489
Oklahoma	400,166	210,874	27.6	27,872	14,715	4.0	1,260,706	665,688	75.9	894,506
Oregon	459,181	244,030	41.8	487,568	284,564	28.5	30,482	18,000	1.3	322,918
Pennsylvania	2,015,130	996,906	37.6	513,989	256,587	10.4	73,588	36,794	1.8	771,950
Rhode Island	227,579	118,127	2.6	15,494	11,497					130,911
South Carolina	787,356	307,866	54.6	221,700	79,945	.5				397,720
South Dakota	37,125	22,152	15.2	4,156	4,156		1,143,430	1,047,600	114.5	762,018
Tennessee	468,207	232,400	14.1	1,357,954	688,977	46.0	158,042	79,021	4.6	750,269
Texas	1,534,043	749,810	158.3	527,559	257,547	41.7				2,249,798
Utah	204,014	136,160	20.2	136,491	88,790	3.5				337,043
Vermont	40,708	18,109	1.2	222,515	117,328	8.9				53,580
Virginia	403,187	189,037	16.2	348,516	156,180	4.6	23,400	11,700	3.8	679,170
Washington	391,635	228,446	23.8	349,818	147,362	7.8				409,402
West Virginia	412,849	207,432	19.8	301,364	150,069	6.4				510,286
Wisconsin	946,341	475,307	42.7	1,411,616	644,981	46.0	88,199	38,880	1.1	582,353
Wyoming	365,617	160,649	18.8	508,423	218,112	34.3				218,048
District of Columbia	79,178	39,035	.9							163,600
Hawaii	1,158	1,096		1,279	1,279					334,875
Puerto Rico	170,027	77,541	7.5	73,642	38,810	3.1				217,968
TOTALS	30,046,611	14,931,975	1,965.7	26,582,779	13,501,420	1,224.4	6,580,603	4,071,887	496.9	29,834,761

U. S. GOVERNMENT PRINTING OFFICE: 1942

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Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

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Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.
Report of the Chief of the Bureau of Public Roads, 1932. 5 cents.
Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.
Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.
Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.
Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.
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Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.
Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.
Work of the Public Roads Administration, 1940.
Work of the Public Roads Administration, 1941.

HOUSE DOCUMENT NO. 462

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Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.
Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.
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DEPARTMENT BULLETINS

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No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.
No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.
House Document No. 272 . . . Toll Roads and Free Roads.
Indexes to PUBLIC ROADS, volumes 6–8 and 10–21, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

REPORTS IN COOPERATION WITH UNIVERSITY OF ILLINOIS

No. 303. . . Solutions for Certain Rectangular Slabs Continuous Over Flexible Support.
No. 304. . . A Distribution Procedure for the Analysis of Slabs Continuous Over Flexible Beams.
No. 313. . . Tests of Plaster-Model Slabs Subjected to Concentrated Loads.
No. 314. . . Tests of Reinforced Concrete Slabs Subjected to Concentrated Loads.
No. 315. . . Moments in Simple Span Bridge Slabs With Stiffened Edges.

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.
Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.
Act III.—Uniform Motor Vehicle Civil Liability Act.
Act IV.—Uniform Motor Vehicle Safety Responsibility Act.
Act V.—Uniform Act Regulating Traffic on Highways.
Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF APRIL 30, 1942

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	
Alabama	$151,770	$151,234	2	4	2	$390,025	$386,803	5	2	2	$181,625	$181,235	4		5	$997,199
Arizona	184,378	184,361	1	1		138,529	129,838		1	2	4,095	4,095			1	230,684
Arkansas	474,307	471,932	5		9	169,826	168,116	1		2	7,394	7,394			2	687,407
California	838,839	649,267	2	1	6	870,516	868,399	8			7,529	7,529			2	2,319,499
Colorado	5,685	5,646				670,460	670,460	7		3	14,914	14,914			7	745,747
Connecticut	166,222	165,415	2			61,712	60,676		1		231,374	222,740		1		540,683
Delaware	89,725	89,725	1		1	191,599	189,867	1	1		508,406	321,785	2			179,564
Florida	120,961	120,961			20	843,067	840,887	8		6	82,492	82,432			14	871,382
Georgia	668,629	668,629	7	2	6	1,002,916	1,002,916	6	6	13	790,188	790,188	2	4	10	1,505,777
Idaho	27,850	23,603			3	322,273	313,602	4	1		4,190	4,190			2	427,671
Illinois	851,050	598,683	2		95	1,648,238	1,565,041	8	1	2	385,449	385,249	1	1	31	2,546,395
Indiana	611,831	611,831	6		28	474,802	469,093	2	1	17	76,703	76,703			23	1,165,932
Iowa	375,728	365,422	3	1	33	1,432,878	1,180,856	10	2	11	212,237	204,790	1		44	621,957
Kansas	89,963	80,557	2		7	745,377	745,377	9		4	141,011	141,011	3		6	1,304,511
Kentucky	1,109,873	1,107,509	9		1	441,711	441,711	4	1							411,382
Louisiana	6,965	6,965				586,220	586,220	8			481,835	480,667	4		4	924,798
Maine	10,383	10,383			3	363,086	363,086	2			1,861	1,861			1	285,059
Maryland	500,850	469,057	2	2	12	874,458	730,660	4		4	30,175	30,175			6	399,876
Massachusetts	346,270	335,829	1		1	791,642	790,770	5	2		763,830	763,830	2	1		1,250,554
Michigan	1,333,563	1,322,460	3	4	26	240,766	240,766	1			752,429	722,268	2		9	906,424
Minnesota	643,147	642,783	5	4	2	977,175	977,175	5	4	6	4,985	4,985			1	1,236,480
Mississippi	253,874	253,874	2	1	10	843,110	843,110	10			25,808	25,808			2	646,344
Missouri	120,702	120,702		2		2,192,393	1,736,973	8	2		203,565	203,565		2		1,480,365
Montana	141,549	141,549	2		2	99,778	99,778	1								733,051
Nebraska	297,242	296,146	4		21	1,023,081	1,023,081	19		1	13,020	13,020			3	475,292
Nevada	120,817	116,466	2		1	63,435	63,435	2		2	22,635	22,635			7	196,853
New Hampshire	265,368	265,069	4	1	3	96,565	96,240	2	1	2						313,961
New Jersey	852,812	850,349	4	1	2	622,904	497,354	3	1		354,985	295,560	1	2		941,341
New Mexico						71,000	71,000	1			259,103	252,068	3		1	519,348
New York	2,422,733	2,364,650	2	13		1,982,146	1,941,007	3	8		502,645	464,285		1		3,729,719
North Carolina	619,637	616,759	2	6	31	176,292	176,292	1	1	1	51,795	51,795			13	1,407,381
North Dakota	289,022	287,819	5			470,895	470,895	5								872,117
Ohio	1,557,247	1,542,030	8	1	12	2,752,053	2,428,331	10		1	392,870	188,740	1		2	1,715,420
Oklahoma	250,854	245,570	2		34	880,359	878,439	6		3	372,820	334,783	3		4	1,458,144
Oregon	419,535	355,255	4		3	281,502	228,715	2			13,433	13,433			4	403,396
Pennsylvania	1,907,614	1,876,905	14	1		3,016,940	3,002,411	14			359,074	359,074	2			2,526,669
Rhode Island	205,241	205,241		1		3,655	3,655									273,921
South Carolina	351,099	334,334	6		23	259,152	241,711	3	3	1	214,585	99,452		2	7	992,889
South Dakota	511,858	511,747	13		9	515,821	499,871	9			41,200	41,200	2			829,275
Tennessee	301,580	289,686	3	3		1,325,647	1,325,647	7	1		102,106	102,106		1	2	1,005,387
Texas	1,329,036	1,309,617	16			1,359,773	1,356,641	13		4	4,350	4,350			1	2,368,884
Utah	68,276	67,534	2		22	59,888	59,888	1		6	60,140	60,140			23	359,457
Vermont	17,469	16,742			4	322,869	293,090	2								114,613
Virginia	562,165	562,165	4	4	3	347,127	327,167	3	1	1	4,015	4,015			1	965,269
Washington	392,291	392,044	3	2	3	1,041,232	344,558	5			5,192	5,192			2	435,542
West Virginia	253,143	247,512	3		6	654,510	654,510	6	1	2	349,830	349,830	1		1	430,253
Wisconsin	468,542	451,283	2		39	571,419	570,431	3	2	7	12,687	12,687			2	1,674,169
Wyoming	481,187	466,531	6		1	1,974	1,974				8,416	8,416			6	430,012
District of Columbia	3,655	3,655				298,213	273,744		1							103,351
Hawaii	189,832	189,811	2			211,977	211,462	2								282,756
Puerto Rico	103,629	102,980	1			780,619	772,706	11								363,914
TOTALS	23,365,998	22,566,277	169	55	484	35,563,605	33,216,435	250	45	103	8,056,996	7,360,195	34	15	249	47,608,074