PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 5, NO. 10 ▽ DECEMBER, 1924

FOR MANY YEARS THE WHEEL SCRAPER HAS BEEN A STANDARD GRADING IMPLEMENT

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U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

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ACCURATE ACCELEROMETERS DEVELOPED BY THE BUREAU OF PUBLIC ROADS

By Leslie W. Teller, Assistant Testing Engineer, United States Bureau of Public Roads

IN the review of the progress of the impact tests of the Bureau of Public Roads, published in the preceding number of this magazine,[1] the various methods which have been employed in the attempt to measure the force of the impact delivered to a road surface by the wheels of motor trucks were briefly described, and some of the problems and difficulties attending these attempts were indicated. The article recalled the fact that the first measurements were made with calibrated copper cylinders the deformation of

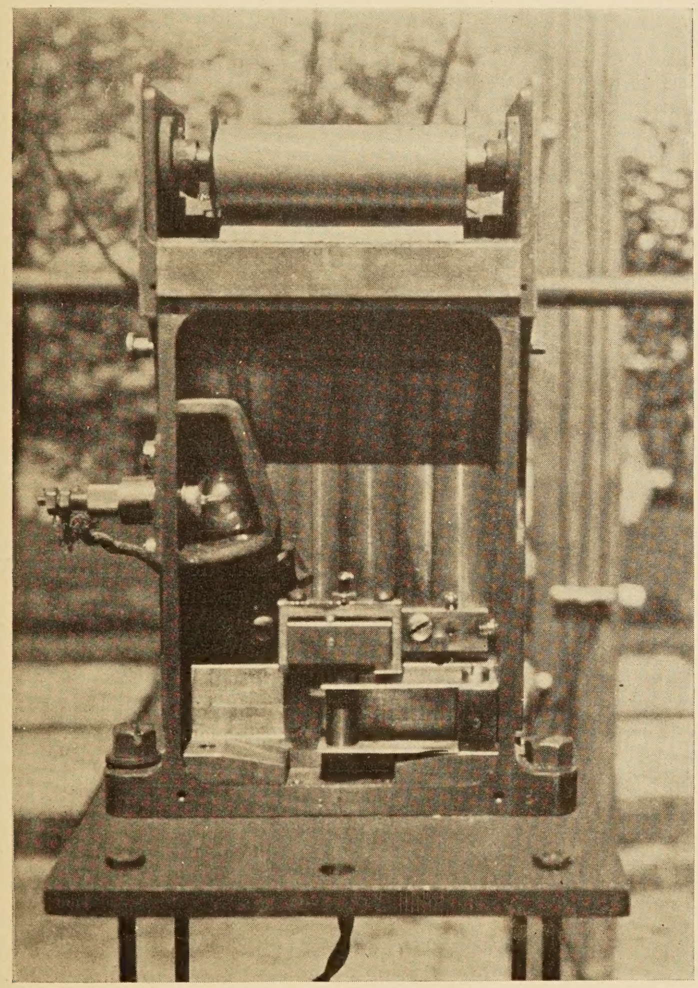


FIG. 1.—Beam accelerometer

which under impact was used as the measure of the force of the blow. The cylinders having been previously calibrated with respect to their deformation under known static loads, the impact forces which produced equal deformations were assumed to be equivalent to the corresponding static loads. The error of this assumption was pointed out and the article described the course of the subsequent experiments which have led to the perfection of a method of determining the

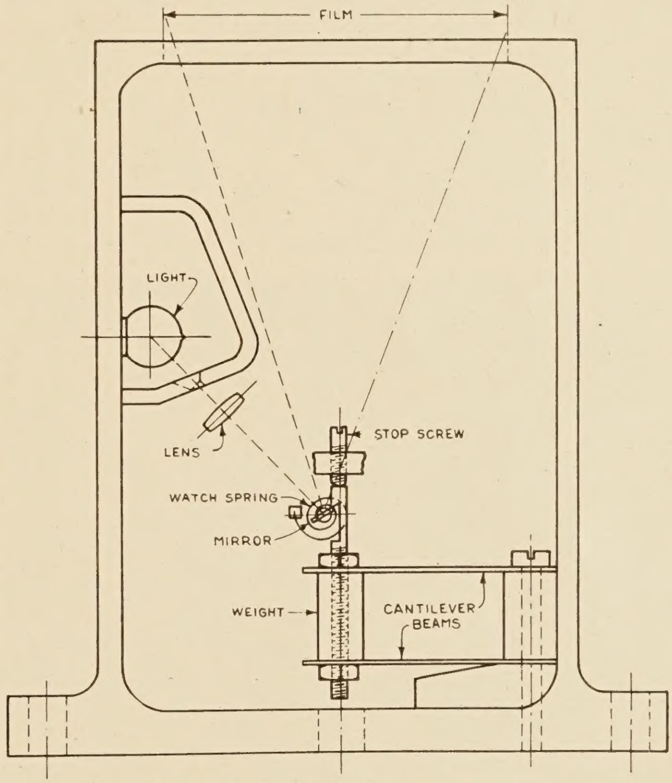


FIG. 2.—Diagram of beam accelerometer

impact forces by the measurement of the deceleration of the vertical motion of the truck wheel when it is arrested by the resistance of the pavement. This method is an application of the well-known principle that the force of impact is equal to the product of mass times acceleration.

As the mass of the various parts of the motor truck is readily determinable the problem has centered about the measurement of the deceleration of the falling wheel, and, as indicated in the article referred to, this problem has now been satisfactorily solved. Two types of accelerometers have been evolved which are believed to be thoroughly scientific in principle. In one type certain practical defects remain which it is thought can be entirely eliminated; the other is believed to be both scientific in principle and wholly adequate as a practical device for the measurement of

[4] See PUBLIC ROADS, Vol. 5, No. 9, November, 1924. The Status of the Impact Tests of the Bureau of Public Roads, p. 11.

the kind of decelerations encountered in the study of the impacts delivered by moving vehicles to a road surface.

The latter instrument is now in use in the experiments which are being conducted with moving trucks

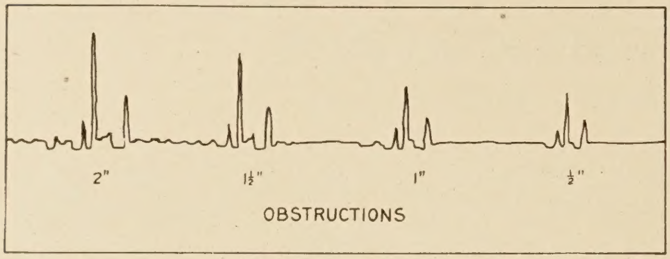


FIG. 3.—A typical beam accelerometer record

operated over actual road surfaces as a result of which it is hoped to determine the magnitude of the impact forces delivered by actual vehicles equipped with various kinds of tires, and the effect of such impacts upon the road surfaces to which they are applied. It is possible that the other type will also be used, and as one or both are certain to play an important part in the subsequent investigations it is desired to record the facts which establish their suitability for the work and the methods used in proving and calibrating them.

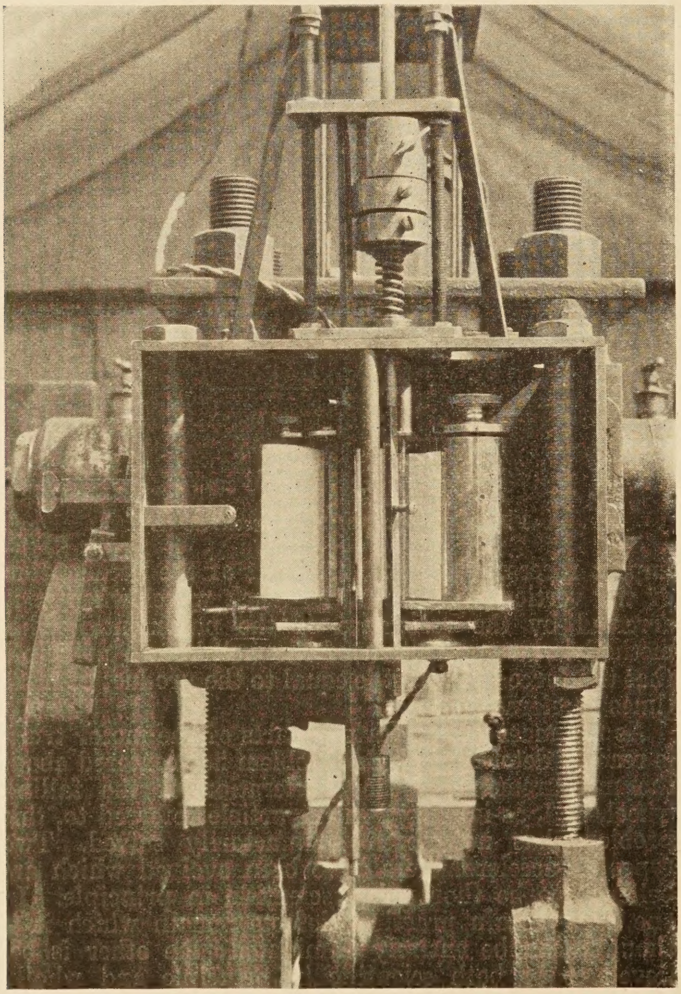


FIG. 4.—Coil spring accelerometer

In addition to the two instuments developed by the bureau and known respectively as the beam type and the coil-spring type, one other accelerometer, known as the sylphon type, was submitted for trial. Although there are a number of other types in existence, varying widely in form and characteristics, all of which have been considered, no other has been found to be suitable for the motor-truck tests.

The beam type of instrument was the first of the two Bureau of Public Roads instruments to be developed. It is shown in Figure 1 and was first described in the Proceedings of the American Society for Test-

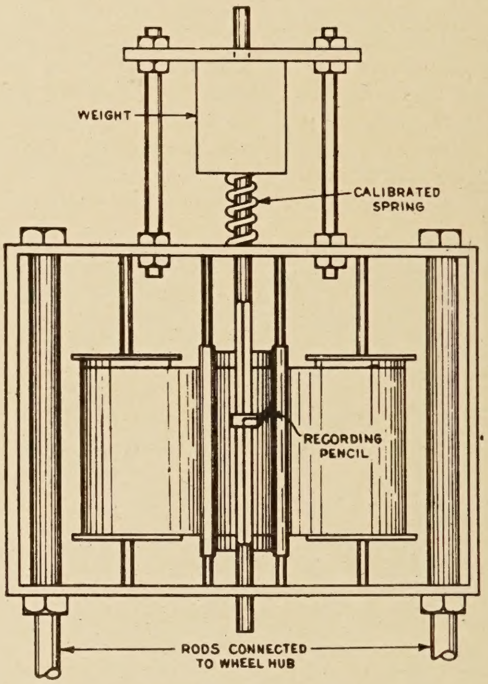


FIG. 5.—Diagram of coil spring accelerometer

ing Materials, 1923, in a paper entitled, "An Accelerometer for Measuring Impact," by E. B. Smith. The second, or coil spring type has been developed more recently and is described in detail in this article for the first time. This instrument makes use of a steel coil spring as the sensitive element instead of the flat steel beam used in the beam type of instrument. The third or "sylphon" type which was submitted to the bureau for trial, employs a sylphon [2] as the sensitive

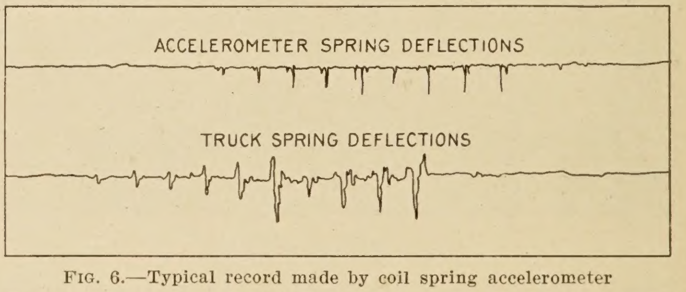


FIG. 6.—Typical record made by coil spring accelerometer

[2] A sylphon is a small accordion-like metal cylinder closed at the ends. As used in the accelerometer the sylphon is filled with a liquid; the impact, which is received on one of the ends, deforms the accordian-like walls, thereby changing the volume of the sylphon and increasing the pressure on the confined liquid. By means of a tubular connection the increased pressure is transmitted to the recording device, which causes movement of the recording point or stylus.

element. It has not yet been developed to the point where it may be regarded as satisfactory for motor truck impact tests.

THE RESULTS OF ACCELEROMETER CALIBRATIONS

These three accelerometers have been subjected to calibration tests in which their indications in response to the same impacts have been compared with the de-

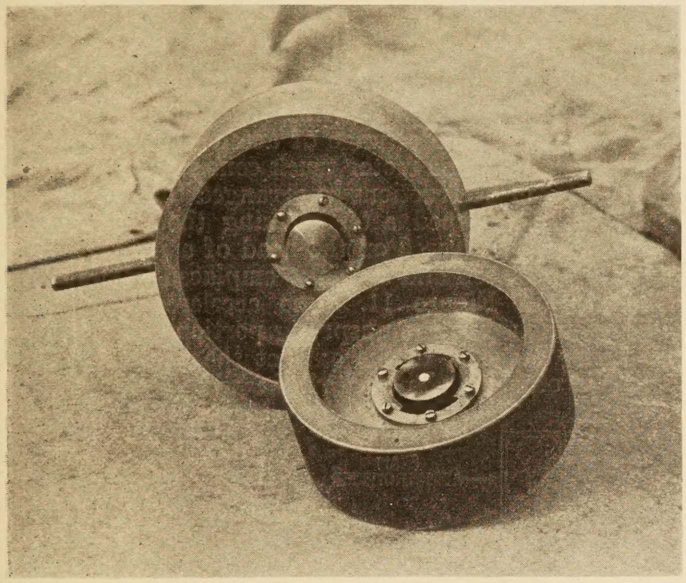


FIG. 7.—Kreuger cell opened to show impression on plane surface

celerations derived from space-time curves of the some impacts, and with each other. The impact computed from the recorded decelerations has also been compared with the force measured directly by means of the Kreuger cell. The aim has been to compare the various types of instruments with respect to their accuracy, consistency, and reliability; to calibrate the instruments which proved satisfactory; to compare impact pressures directly with those computed from the measured decelerations; and finally, to prove that the impact pressure produced by a motor truck in motion can be computed from the measured deceleration, if the masses and spring deflection are known.

The tests show conclusively that the coil spring type of accelerometer is well suited to the measurement of motor truck impact. It consistently indicates the maximum deceleration. The beam type of instrument is thought to be thoroughly scientific in principle, but there are certain defects in its design which make it a less consistent instrument than the coil spring type. The sylphon type has not yet been developed to the point where it may be said to be satisfactory for motor truck impact tests. As an incident of the calibration tests it has also been definitely proved that maximum impact pressures can be computed from space time-curves, made with the apparatus used, with sufficient accuracy for all practical purposes; and that the Kreuger cell indicates the true maximum impact pressure.

THE INSTRUMENTS TESTED

Although the procedure followed in making these tests was comparatively simple, the apparatus used was more or less complicated, and it is thought that familiarity with the latter will help to clarify a description of the former. Therefore, the apparatus will first be described.

Beam accelerometer.—This instrument consists of a flat steel beam, either fixed at the ends or cantilever. A small mass is attached to the beam, and the impressed acceleration, acting on this mass, produces force in direct proportion to the acceleration. This force deflects the beam. The deflection of the beam rotates a small mirror and a ray of light reflected from the mirror onto a strip of photographic film records the magnitude of the acceleration. This instrument is shown in the photograph, Figure 1, and diagramatically in Figure 2. A typical record caused by running over obstructions on the road is shown in Figure 3.

Coil-spring accelerometer.—In this instrument a weight supported on a steel coil spring is impelled downward by a deceleration of vertical velocity, and the consequent deflection of the spring is directly proportional to the magnitude of the deceleration. The recording system, consisting of a paper passing under a stylus which is connected directly to the mass or weight, completes the instrument which is shown in the photograph, Figure 4. A diagram of the instrument is shown in Figure 5 and a record made by running over road obstructions is shown in Figure 6.

Sylphon accelerometer.—A weight on the end of a lever applies pressure to a sylphon when a deceleration is experienced. The pressure is transmitted through a tube to a Bourdon tube recording apparatus.

Kreuger cell.—This simple apparatus, devised by Prof. H. Kreuger, of Stockholm, Sweden, furnishes a means of measuring impact pressures directly. It consists of a spherical steel surface in contact with a plane steel surface which has been coated with a very

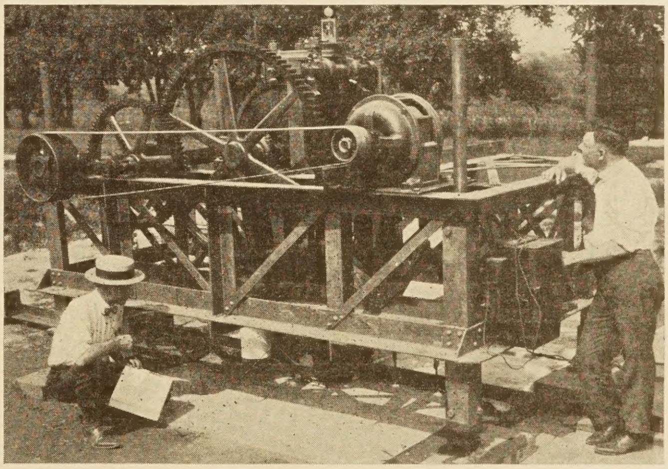


FIG. 8.—The latest type of impact machine

light film of soot from a kerosene lamp. The steel used has a very high elastic limit, and the elastic deformation which occurs under pressure is recorded by the imprint of the maximum area of contact in the smoke on the plane surface. It is only necessary to measure accurately the diameter of the imprint and to refer to the calibration curve to know the maximum pressure which was applied to the cell. Figure 7 shows such a cell opened after a blow, with the imprint visible.

Impact machine.—To reproduce motor-truck impact this impact machine was designed and built by the Bureau of Public Roads. In consists of a truck wheel fastened to the center of a truck spring with a suitable mechanism for raising it and dropping it suddenly. Any condition of wheel, tire, spring, unsprung weight, sprung weight, or height of drop can be had, so that

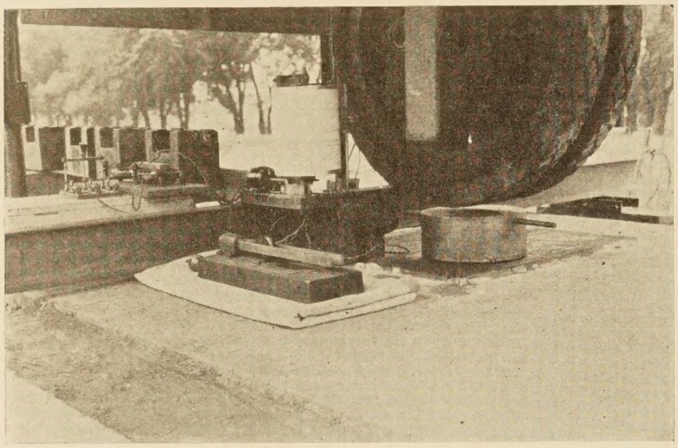


Fig. 9.—Apparatus for making space-time curves attached to impact machine

practically any impact which any motor truck is capable of producing can be reproduced at will. Figure 8 shows a general view of the impact machine.

Space-time curve apparatus.—Figures 9 and 10 show the apparatus used in these tests to record space-time curves of the movement of the truck wheel of the impact machine during impact. The drum carrying silicated paper is revolved at a uniform rate by an electric motor operating through a worm. The speed of the paper is determined from the record on the paper made by a stylus actuated by an electric tuning fork of known period. The stylus which traces the space-time curve is fastened directly to the hub of the wheel, special precaution being taken to eliminate all lost motion from the system. The whole apparatus is supported by a rigid mounting which is independent of the machine and of the base on which the blow is struck.

THE METHODS USED IN THE CALIBRATIONS

Most of the tests were conducted on the impact machine, sufficient work being done on the road with an actual motor truck to prove that the methods developed permitted the accurate measurement of actual motor-truck impact.

The method used on the impact machine was as follows:

Sprung and unsprung weights corresponding to a standard truck were reproduced. The machine was set up over the center of an 8-inch concrete slab. A steel plate was leveled in grout on the surface of the slab and directly under the truck wheel. On this plate was placed the Kreuger cell. The accelerometers under test were mounted on the plunger of the impact machine, the plunger being the rigid frame which is attached to and moves with the truck wheel. The space-time curve apparatus was then attached to the hub of the wheel. A diagrammatic representation of the arrangement of the apparatus is shown in Figure 10. With all the apparatus in readiness a low drop was made. Each accelerometer registered a certain deflection or reading. These were recorded. The diameter of the imprint on the Kreuger cell was read with a microscope, containing a scale divided in tenths of millimeters, and recorded. The point of contact between the truck tire and the Kreuger cell and the position of the wheel at rest under its normal static load were marked on the space-time curve by setting the truck wheel in each of these positions and then revolving the drum of the space-time curve apparatus. The paper was removed from the drum and marked with the date, test number, etc. This completed the field work for one test. A large number of such tests were made covering a wide range of accelerations.

The tests with the motor truck consisted in running the truck over obstructions so arranged that, when the truck wheel dropped after striking the obstruction, the blow was delivered on the head of a jack containing a Kreuger cell and specially emplaced in the road, as shown in Figure 11. The accelerometers were rigidly attached to the unsprung portion of the truck, one being fastened to the axle at the spring connection, the other to the hub of the wheel. There was

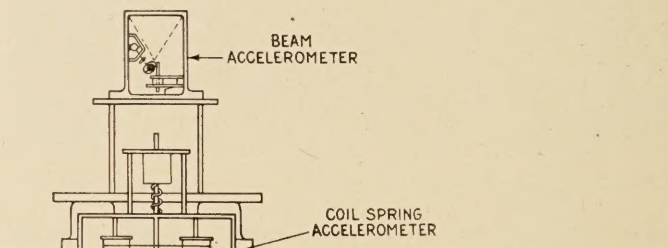


Fig. 10.—Diagram of set-up of accelerometers and space-time apparatus on the impact machine

also a mechanism for recording continuously the deflection of the truck spring. Figure 12 shows the truck equipped with this apparatus, ready for a test run. The data taken consisted of the maximum pressure recorded by the Kreuger cell, the readings of the two accelerometers and the deflection of the truck spring at the instant of impact.

By running the truck at various speeds and over obstructions of varying heights the desired range of accelerations was obtained.

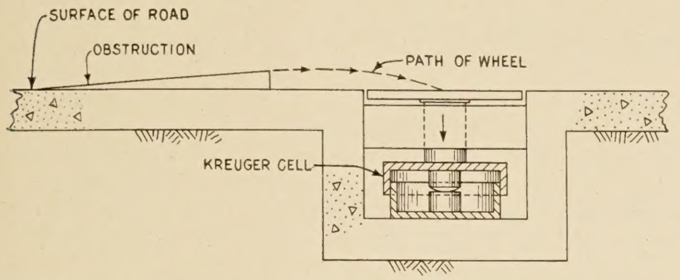


FIG. 11.—Diagram of Kreuger cell emplacement in road

THE ANALYSIS OF THE SPACE-TIME CURVES

If the motion of a body in space, with respect to time is known, its velocity at any point or at any time can be determined. Similarly, if the velocity of the body with respect to time is known, the acceleration at any point or at any time can be determined. From the fundamental laws of motion,

$$dv\ (\text{velocity}) = \frac{ds\ (\text{space})}{dt\ (\text{time})}$$

and

$$\text{acceleration} = \frac{dv}{dt} = \frac{d^2s}{dt^2}$$

The space-time curve is a record of the motion of the mass producing the impact, with respect to time and from it may be obtained a curve showing the changes in velocity during that time, or further, the acceleration values obtaining through those changes.

Those who have worked with space-time curves realize the difficulties and errors which will be encountered in their use. It is necessary that the curve represent with absolute fidelity the motion of the body in space, and it is essential that an accurate determination of time be made. The more closely these requirements are met the more accurate will be the result, and if either is seriously in error the result will be quite unusable. For this reason great care was exercised in making the curves used in this calibration test. Two and usually three curves were made for each height of drop used and any tests that appeared doubtful were repeated. Although there is still some variation, the results are, on the whole, very good and prove conclusively that, with due care, the space-time curve can be used to great advantage.

It was found that greater accuracy could be obtained by enlarging the space-time curves and analyzing the enlarged curve. For this work a precision pantograph was used and the curves were enlarged five times. The pantograph was equipped with a prick point and as soon as the guide point was accurately set over a point on the original curve a point was lightly pricked in a sheet of silicated paper for the enlarged curve. The guide point was moved slightly to a new point on the original curve and the corresponding point pricked on the enlarged curve. The enlarged curve finally appeared as a line of very fine holes in the silicated paper. These holes were then connected with a line using a very fine brass point for a pencil and an irregular curve as a guide. All work was done under a magnifying lens and very good results were obtained.

Having the enlarged space-time curve the next step was to determine the maximum acceleration. One method, which was used principally as a check in these tests, is that of graphical differentiation. A series of tangent lines was drawn to the space-time curve at points around its lower extremity as it is at this time that the maximum pressure occurs. These tangents represent velocity at the point of tangency and from them a velocity-time curve was drawn. These velocity curves all showed that, for a certain length of time immediately preceding the final stopping of the truck wheel, the velocity changes at a uniform rate. In other words the acceleration reaches a maximum value and holds it for an appreciable period of time. This had been indicated in all the previous work which had been done by the Bureau of Public Roads with space-time curves of motor truck impact where rubber-tire cushioning was used.

The fact that the lower portion of the space-time curve is parabolic in form led to the use of another method for determining the maximum acceleration. A series of horizontal lines were drawn through the lower part of the curve. A tangent was drawn to the

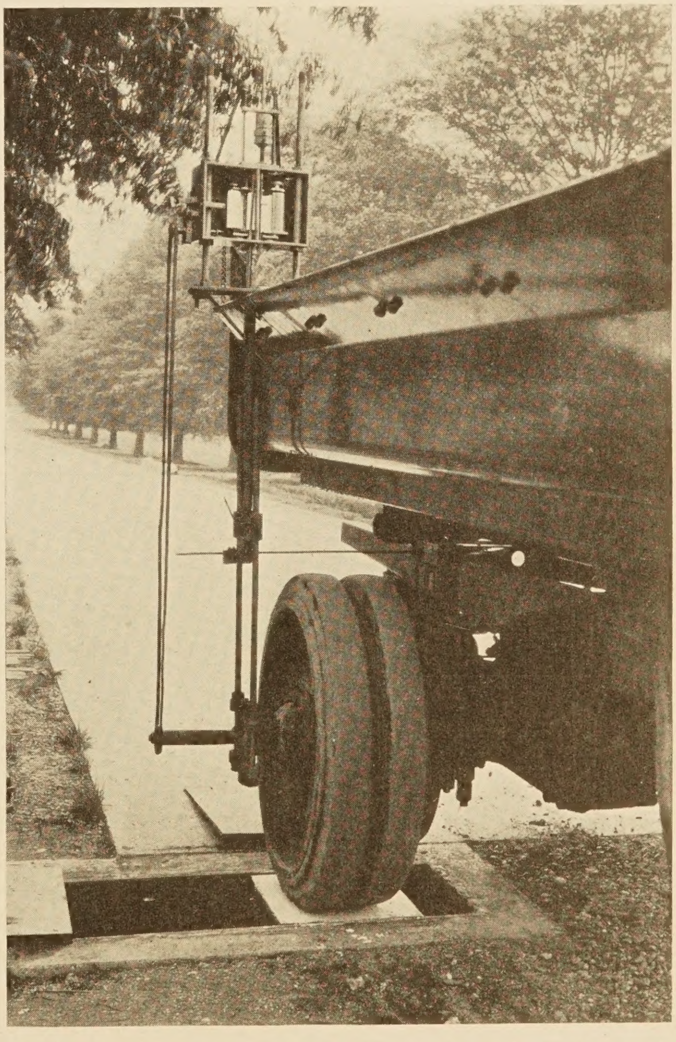
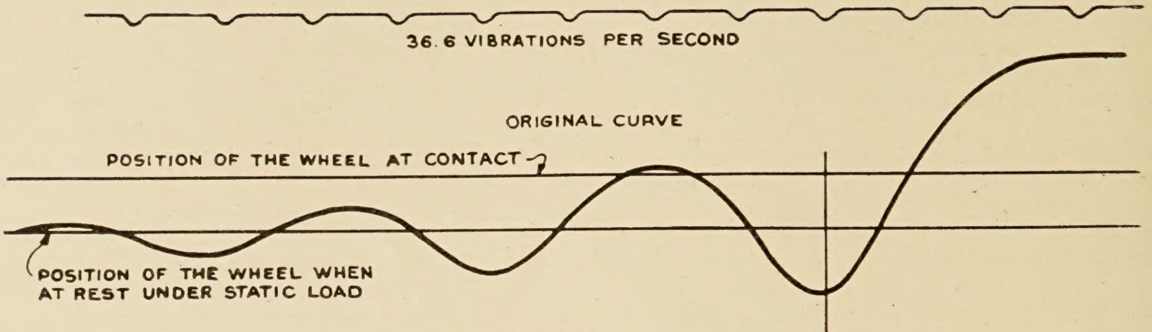


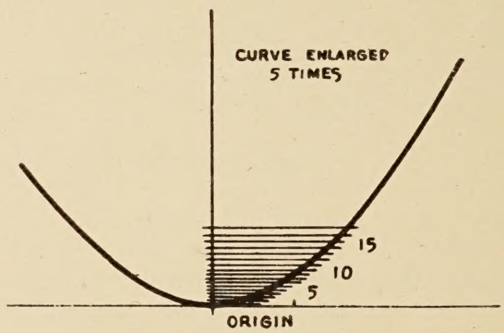
FIG. 12.—Truck equipped with accelerometer and apparatus for recording deflection of truck spring



ANALYTICAL METHOD

COORDINATES

PT.	SPACE IN FEET = S	TIME IN SECONDS = t	t^2
1	.000400	.001713	.00000294
2	.000733	.002220	.00000494
3	.001333	.002856	.00000815
4	.001933	.003428	.00001173
5	.002500	.003860	.00001488
6	.003000	.004251	.00001808
7	.003666	.004690	.00002203
8	.004333	.005078	.00002575
	ΣS = .017898		Σt^2 = .00010850
9	.005065	.005520	.00003043
10	.005800	.005900	.00003480
11	.006666	.006320	.00003990
12	.007500	.006725	.00004520
13	.008500	.007180	.00005150
14	.009600	.007615	.00005790
15	.010670	.008020	.00006425
16	.011670	.008400	.00007050
17	.012900	.008820	.00007760
	ΣS = .078371		Σt^2 = .00047208



GENERAL FORM $S = A + Bt^2$

SUBSTITUTING $.017898 = 8A + .00010850\,B$

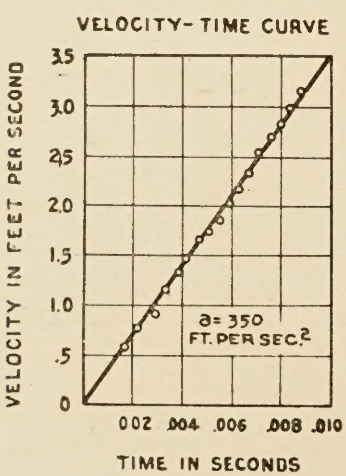
$.078371 = 9A + .00047208\,B$

SOLVING $B = 166.3 \quad A = .0001$

EQUATION OF CURVE, $S = .0001 + 166.3t^2$

$$a = \frac{d^2S}{dt^2} = 332.6$$

GRAPHICAL METHOD



TANGENTS

PT.	y	x	VELOCITY FT.-SEC.	TIME IN SEC = t
1	.0108	.01890	.572	.00171
2	.0128	.01680	.762	.00222
3	.0147	.01590	.925	.00286
4	.0170	.01450	1.170	.00343
5	.0185	.01380	1.340	.00386
6	.0197	.01340	1.470	.00425
7	.0209	.01280	1.633	.00469
8	.0220	.01260	1.745	.00508
9	.0230	.01220	1.885	.00552
10	.0240	.01195	2.010	.00590
11	.0250	.01150	2.172	.00632
12	.0258	.01105	2.343	.00673
13	.0271	.01066	2.540	.00718
14	.0279	.01038	2.690	.00762
15	.0285	.01006	2.830	.00802
16	.0293	.00979	2.993	.00840
17	.0299	.00950	3.150	.00882

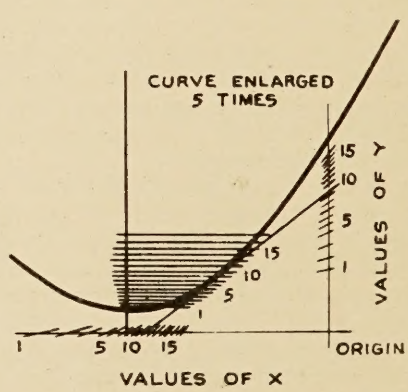


FIG. 13.—Graphical and analytical solutions of space-time curves

tip of the curve and at the point of tangency a perpendicular was erected. Using this point of tangency as an origin the coordinates in terms of space and time were measured for each point where a horizontal line intersected the curve. The number of points taken was usually from 15 to 20. Using these coordinates, expressed in feet and in seconds, the equation of that portion of the curve covered by these points was determined by the method of averages. Having the equation of the curve it is only necessary to differentiate twice to obtain the desired acceleration. A space-time curve and its solution by both methods is shown in Figure 13. Table 1 gives the test data for all the tests on the impact machine for which the space-time curve acceleration values were computed.

TABLE 1.—*Test data for tests in which space-time curves were computed*

Height of fall		Rubber deflection		Acceleration computed from space-time curve	Accelerometer readings			Kreuger cell	
Total	Free	Static	Impact		Beam No. 6	Coil spring	Sylphon	Diameter	Equivalent static pressure
Inches	*Inches*	*Inches*	*Inches*	*Feet per sec. per sec.*				*mm.*	*Pounds*
0.665	0.010	0.52	0.655	110	--------	0.10	0.07	7.20	8,300
.755	.035	.51	.72	106	0.23	.11	--------	7.76	10,800
.795	.055	.54	.72	112	--------	.12	--------	--------	--------
1.190	.350	.53	.84	183	.48	.18	--------	8.55	14,700
1.620	.64	.53	.98	252	.67	.25	--------	9.12	17,700
1.65	.66	.55	.99	254	--------	.25	--------	--------	--------
1.65	.66	.56	.99	262	--------	.25	--------	--------	--------
1.70	.71	.52	.99	244	.60	.26	.15	9.05	17,800
1.71	.71	.52	1.00	265	.61	.26	.16	9.14	18,400
1.71	.70	.55	1.00	273	.63	.26	.15	9.16	17,800
1.91	.84	.53	1.07	278	.69	.28	--------	9.25	18,300
1.92	.85	.54	1.07	286	.70	.28	.15	9.32	18,800
1.92	.86	.53	1.06	309	.70	.28	.16	9.53	21,000
2.05	.98	.52	1.07	299	.86	.30	--------	9.65	21,000
2.11	1.01	.54	1.11	341	--------	.33	--------	--------	--------
2.13	1.01	.54	1.12	330	.78	.32	--------	9.56	20,400
2.15	1.01	.54	1.14	336	.79	.33	.18	9.85	22,600
2.16	1.02	.54	1.14	337	.78	.33	.18	9.88	22,700
2.16	1.05	.52	1.10	322	--------	.32	.19	9.76	22,700
2.17	1.06	.52	1.11	357	.79	.33	.20	9.80	23,100
2.27	1.12	.53	1.15	364	.94	.34	--------	9.94	23,700
2.33	1.16	.55	1.17	383	.90	.36	.17	10.05	24,200
2.33	1.16	.55	1.17	377	.88	.36	.16	10.06	24,250
2.34	1.17	.55	1.17	373	.88	.36	.16	10.00	23,900
2.34	1.17	.55	1.17	375	--------	.35	.18	10.02	24,900
2.34	1.17	.55	1.17	375	.86	.36	.18	10.10	25,500
2.34	1.17	.55	1.17	378	.86	.35	.18	10.12	25,700
2.47	1.28	.53	1.19	410	1.00	.39	--------	10.13	24,900
2.50	1.30	.54	1.20	401	.96	.38	--------	10.13	24,900
2.55	1.36	.53	1.19	409	--------	.40	.18	10.10	24,500
2.55	1.34	.54	1.21	422	.93	.40	.19	10.08	24,400
2.55	1.34	.54	1.21	403	.92	.40	.17	10.12	24,800
2.59	1.37	.53	1.22	395	.96	.39	.21	10.12	25,700
2.59	1.38	.53	1.21	424	.96	.39	.17	10.42	28,300
2.69	1.47	.52	1.22	463	--------	.43	--------	10.23	25,700
2.69	1.46	.53	1.23	465	--------	.43	--------	10.18	25,200
2.76	1.50	.54	1.25	469	--------	.45	.18	10.44	27,500
2.75	1.49	.55	1.25	444	1.11	.45	.19	10.35	26,700
2.93	1.66	.52	1.27	473	1.10	.45	.20	10.58	28,600
2.98	1.70	.53	1.28	472	1.22	.48	.21	10.63	29,300
2.99	1.70	.52	1.29	482	1.27	.49	.20	10.73	30,300

METHOD OF COMPUTING MAXIMUM IMPACT PRESSURE FROM MEASURED ACCELERATION

The fundamental formula, force = mass $\times$ acceleration, must be somewhat modified to suit the case of a motor-truck impact. The total maximum pressure exerted on the pavement by the truck wheel during impact will consist of three parts and the formula may be written—

$$F = ma + mg + Mg$$

where F = maximum pressure during impact.

m = the unsprung weight of the truck (one rear wheel) divided by 32.2.

M = the sprung weight of the truck acting on one rear wheel divided by 32.2.

a = the acceleration indicated by the accelerometer.

g = the acceleration due to gravity (taken as 32.2 feet per second per second).

When the truck wheel is not in contact with the ground, the spring pressure forces a wider separation of the sprung and unsprung parts, thereby reducing the spring pressure. When, at the instant of impact, the wheel strikes the ground, the spring is again deflected and the deflection increases as the downward motion of the sprung and unsprung parts continues for a time after initial contact of the wheel. It is some time after the total pressure has passed its maximum value before the spring is deflected by an amount equal to its normal deflection under the static weight of the sprung load; i. e., before the full weight of the sprung portion (Mg) comes into effect. The result is that a further modification of the above equation must be made since the third term of the above equation is always less than Mg. However, the deflection of the truck spring at the moment when the impact is a maximum is a measure of the pressure existing at the instant, so that instead of Mg the third term more properly becomes P, the residual pressure exerted by the spring at the instant the unsprung mass has reached its maximum deceleration. The formula then becomes

$$F = m(a + g) + P$$

and this form is used in computing impact from measured accelerations during these tests.

As an example suppose the accelerometer on a certain drop of the impact machine records a deflection of 0.40 inch, m=53.8 and Mg=3,900 pounds.

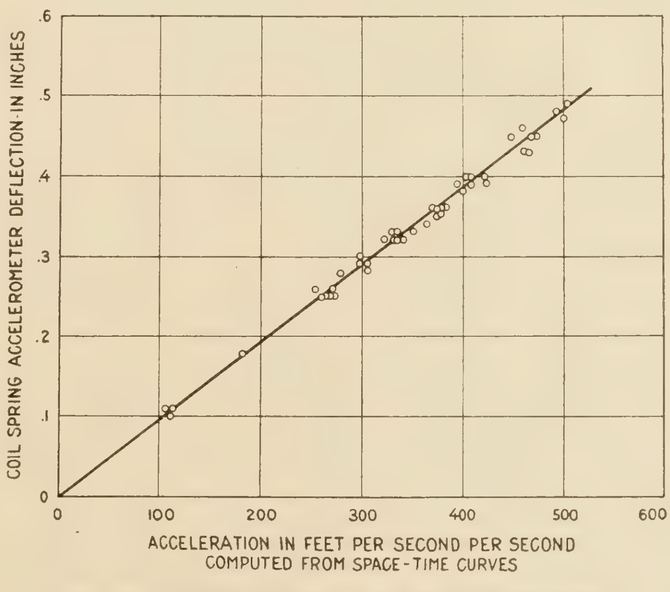


FIG. 14.—Calibration curve of coil spring accelerometer

From the calibration curve (fig. 14) the corresponding acceleration is found to be 416 feet per second per second.

At the moment of maximum impact the spring deflection is less than the static value by 0.74 inches, and as an inch of spring deflection corresponds to a pressure of 1,800 pounds,

P becomes $3{,}900 - .74(1{,}800) = 2{,}560$ pounds
and $F = 53.8\ (416 + 32.2) + 2{,}560 = 26{,}673$ pounds

The average maximum pressure recorded by the Kreuger cell for an accelerometer reading of 0.40 inch is 25,400 pounds (fig. 15).

THE CHARACTERISTICS OF THE VARIOUS ACCELEROMETERS

Beam accelerometer.—It is thought that this instrument is thoroughly scientific in principle and can be made to serve many useful purposes in the measurement of impact. It is not perfect, and certain changes have suggested themselves during these tests.

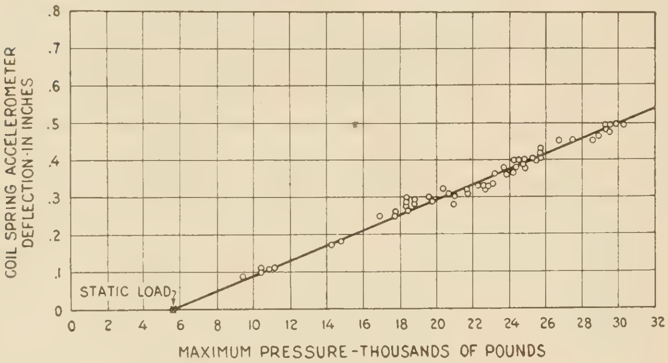


FIG. 15.—Relation of coil spring accelerometer readings and Kreuger cell measurements

One of the first instruments used was fitted with a pair of thin beams fixed at both ends. The deflections or readings for the same conditions of drop seemed to vary from day to day. As the beams were of steel and the mounting was of brass, it was suspected that perhaps temperature was the cause of the variation. A test was run, using static loads to deflect the beam. By varying the temperature of the surrounding air it was found that for a given load considerable variation in deflection resulted. Brass expands roughly 50 per cent more than steel under a given change in temperature so that as the temperature was raised the steel beam became stressed in tension. In this condition the deflection for a given load would be smaller. This was the case during the temperature test. Stiffer beams would not show this effect to such a great extent. A similar temperature test was run on an instrument fitted with cantilever beams and it was found impossible to change the deflection of the light ray for a given load by changing the temperature of the surrounding air as much as 35° F. Thus it was felt that a simple solution of this difficulty had been found. If the other type of beam is preferred, then the beam and mounting should be made of the same material.

It was also found that those instruments which were fitted with a leaf spring to keep the mirror in contact with the hook were inclined to be insensitive to low accelerations because of the resistance of this spring. One of the accelerometers is fitted with a spiral hair spring and this gives a much better curve, i. e., it is a more sensitive instrument than the others.

Considerable trouble was experienced with the electric light bulbs. One trouble was that the bulbs tended to work loose under constant vibration. This was remedied by locking them in the socket with a set screw. The ideal bulb for this instrument would be one with a short straight filament, but so far none has been found.

All of the indications of the test are that the instrument as corrected to eliminate the effect of temperature is consistent and reliable. The accuracy with which the records can be read depends on the sharpness of the record, and this is affected by slight vibration of the lamp filament. An especially designed light bulb would improve this considerably. It is believed that the instrument is very sensitive when properly adjusted and records faithfully the impressed accelerations.

As in the study of motor truck impact, the negative accelerations are the only ones of interest, a stop was provided which keeps the beam from deflection upward beyond its normal position. With such a stop it is not necessary to damp the beam as it can not oscillate in its natural period.

There is a disadvantage in the use of photographic film in that the data are not available until the film is developed, and this work requires another man and special equipment, such as a dark room, etc. This may be of deciding importance in work where speed is the paramount consideration.

The photographic attachment functioned satisfactorily throughout the tests. It was found advisable to use a cloth hood over it, as at times external light got in and injured the record.

Sylphon accelerometer.—This instrument was submitted at the time these calibration tests were about to begin and was tested in its original form without attempt at improvement or development. It is believed that it could be developed into an instrument satisfactory for the measurement of accelerations up to a certain magnitude. In its present state it is quite erratic, and the probable error in the readings is large, too large to give anything like the accuracy desired in these tests. It was found that the vibration of the connecting tube produced comparatively large movements of the recording pen. There was also indication that the deflection was affected by temperature, although no tests were run to prove this.

COIL-SPRING TYPE BEST FOR IMPACT STUDIES

Coil spring accelerometer.—For several reasons this type of instrument has shown itself to be better suited to the measurement of motor truck impact than either of the others. In the first place, the data are immediately available, which is a decided advantage. In the second place, by adding another stylus connected to the truck body, the spring deflection is continuously recorded on the same paper so that the records are simplified. Furthermore, from the very nature of the instrument it can not record accelerations which occur during movements of small magnitude. The movement of the accelerated mass during which a given acceleration is attained must always be greater than the movement or deflection of the sensitive element of the accelerometer in response to this acceleration. For instance, an acceleration caused by the impact of two metal surfaces may reach a magnitude of, say, 100 feet per second per second in a total movement of two or three thousandths of an inch. The record of the coil spring accelerometer can not be greater than this total movement so no record will be made. In motor-truck impact when rubber tires are used the acceleration will always take place during a considerable movement of the unsprung mass, due to rubber deformation. It has been found that the coil-spring type of instrument will record only those accelerations which are occurring in this unsprung mass and will not show an appreciable record from those other accelerations which may occur from mechanical vibration of metal on metal. Some difficulty was experienced with the beam-type accelerometer from this cause. Due to the very small movement of the beam it is sensitive to accelerations which occur during very small movements, such as those due to mechanical vibration, and it was found, both in the tests on the impact machine and on the trucks where a connecting link was used between the instrument and the truck wheel, that such vibration caused a variety of accelerations to be recorded. On the trucks this difficulty was overcome by mounting the beam-type accelerometer directly on the axle over the spring connection. On the impact machine a special stand was built which interposed four slender columns between the base of the instrument and the crosshead of the machine on which it was mounted. These columns served to cushion the instrument against lateral vibrations and largely eliminated the effect of vibration. The magnitude of the movement during which an acceleration occurs is a very important consideration which should not be lost sight of wherever accelerometers of any type are used.

Kreuger cell.—The chief difficulty experienced in the use of the Kreuger cell is in the accurate measurement of the diameter of the imprint left on the plane surface after the blow. Due to the thickness of the film of carbon, there are two rings marking the circumference of the record, the inner one being the actual area of contact and being composed of compressed carbon, the outer one appearing as a " halo " around the area of contact due to the carbon being pushed away from the area of contact. If the film of carbon is very thin the " halo " band will be very narrow and vice versa. The method of measurement used in these tests was as follows: A microscope containing a scale graduated in tenths of millimeters was placed over the record and the diameter of the area of contact estimated to the nearest 0.05 millimeter. Two diameters were taken at right angles to each other and averaged. This was done by two observers. If the readings all checked within about 0.1 millimeter the average of the four readings was taken as the diameter. Otherwise all readings were checked. If the edge of the circle of contact always appeared as a sharp line, there would be no trouble in making this determination, but very often the edge of this area is quite indefinite. It was found in calibrating that errors of between 5 and 10 per cent would sometimes be made in pressure values, although both observers had checked fairly well on the diameter of the area of contact. Sometimes, however, the records are very clear and close determinations can be made. It has been found that a very light smoke film and warm, dry steel surfaces improve the quality of the record. This instrument furnishes a most valuable addition to the instruments for the measurement of impact.

THE ROAD TESTS

The ultimate aim of this calibration was to determine whether or not it is possible to compute impact pressures from measured accelerations on a motor truck in motion if the sprung and unsprung weights are known and the spring deflection is measured. It has been conclusively demonstrated that such impact pressures can be computed with a satisfactory degree of accuracy.

Table 2 shows the data of 39 road tests where the computed pressure is compared with the pressure indicated by the Kreuger cell. These comparisons were made for loaded and unloaded trucks, four heights of drop and four speeds. With speeds greater than 10 miles per hour it is very difficult to cause the truck to land squarely on the Kreuger cell. But it is thought that the data show that the accuracy of the method is independent of the speed of the truck.

The accelerations range from 0 to 400 feet per second and the spring pressure P varies from -200 pounds to $+2{,}000$ pounds. In all cases there is a possible variation of perhaps 10 per cent in the pressures measured by the Kreuger cell. Considering these things it is thought that the two measurements check very well.

TABLE 2.—*Comparison of computed and measured impact pressure during motor truck impact*

Example:

$$m=37.3$$

Accelerometer reading 0.236=245 feet per second per second.
Spring deflection 0.658″ corresponding value of $P=755$ pounds.
$F=m(a+g)+P=37.3(245+32.3)+755=11{,}094$ pounds.
F measured by Krugergesell=10,500 pounds.

Test No.	Sprung weight	Unsprung weight	Spring deflection	P	Acceleration	Pressure by computation	Pressure by Kreuger cell	Speed of truck
	Pounds	*Pounds*	*Inches*	*Pounds*	*Feet per sec. per sec.*	*Pounds*	*Pounds*	*Miles per hour*
1	2, 075	1, 200	0. 03	2, 015	0	3, 215	3, 500	2
2	2, 075	1, 200	. 02	2, 035	0	3, 235	3, 600	2
3	2, 075	1, 200	. 09	1, 900	41	4, 630	3, 800	4
4	2, 075	1, 200	. 20	1, 675	98	6, 535	6, 550	4
5	2, 075	1, 200	. 37	1, 330	118	6, 930	6, 500	4
6	2, 075	1, 200	. 41	1, 270	162	8, 510	8, 400	4
7	2, 075	1, 200	. 70	675	256	11, 425	11, 450	4
8	2, 075	1, 200	. 66	755	262	11, 715	11, 900	4
9	2, 075	1, 200	. 70	675	254	11, 350	10, 500	4
10	2, 075	1, 200	. 66	755	245	11, 105	10, 500	4
11	2, 075	1, 200	1. 22	−40	259	10, 810	11, 400	4
12	2, 075	1, 200	1. 04	320	255	11, 050	11, 700	4
13	2, 075	1, 200	. 49	1, 090	143	7, 625	6, 950	7
14	2, 075	1, 200	. 44	1, 200	121	6, 910	6, 900	7
15	2, 075	1, 200	1. 03	350	243	10, 625	11, 300	7
16	2, 075	1, 200	1. 05	320	250	10, 850	11, 700	7
17	2, 075	1, 200	1. 28	−160	323	13, 090	13, 800	7
18	2, 075	1, 200	. 25	1, 600	156	8, 620	6, 700	10
19	2, 075	1, 200	. 27	1, 500	127	7, 430	6, 200	10
20	2, 075	1, 200	. 56	965	197	9, 515	9, 100	10
21	2, 075	1, 200	. 54	1, 000	170	8, 550	8, 900	10
22	2, 075	1, 200	. 68	1, 040	175	8, 765	9, 500	10
23	2, 075	1, 200	1. 10	200	225	9, 800	9, 400	10
24	2, 075	1, 200	1. 11	180	225	9, 780	11, 200	10
25	2, 075	1, 200	1. 22	−40	230	9, 740	10, 300	10
26	2, 075	1, 200	1. 25	−100	258	10, 720	10, 700	10
27	2, 075	1, 200	1. 33	−200	265	10, 900	10, 400	10
28	2, 075	1, 200	1. 28	−150	286	11, 730	11, 400	10
29	2, 075	1, 200	1. 32	−200	255	10, 510	10, 700	10
30	3, 800	1, 200	1. 74	320	385	15, 870	15, 900	10
31	3, 800	1, 200	1. 89	0	345	14, 050	15, 600	10
32	3, 800	1, 200	2. 10	−400	310	12, 380	14, 600	10
33	3, 800	1, 200	2. 01	−220	322	12, 980	13, 700	10
34	3, 800	1, 200	1. 59	620	384	16, 170	15, 900	10
35	3, 800	1, 200	1. 80	200	365	14, 975	15, 600	10
36	3, 800	1, 200	1. 44	920	416	17, 620	15, 400	10
37	3, 800	1, 200	1. 62	560	364	15, 300	14, 800	10
38	3, 800	1, 200	1. 50	800	385	16, 300	15, 200	10

HIGHWAY TRAFFIC IN CALIFORNIA

SOME APPLICATIONS OF THE TRAFFIC COUNTS MADE BY THE BUREAU OF PUBLIC ROADS

By L. I. HEWES, Deputy Chief Engineer, United States Bureau of Public Roads

THE position of California with respect to highway transportation is unique. The very large motor-vehicle registration, the outdoor climate, and the well-developed highway system of the State combine to make traffic exceptional. The measure of this traffic has been taken and will continue to be taken, and these things combine to make the experience of this State of general interest and value to highway engineers and highway economists. An indefinite number of statistical relations from the state-wide traffic counts might be set up, but it is the object of this paper to present only the major features of the traffic development and their economic significance.

Before 1920 there had never been a State highway traffic count in California. That year, in connection with a study of the State highway system made by the Bureau of Public Roads, a preliminary traffic count was made on the basis of one equivalent 16-hour day at 103 stations on 2,150 miles of the main State highways. The count was intended to sample the summer traffic, June 1–November 1, only. It was made between August 7 and October 14, and showed that the average total traffic between 6 a. m. and 10 p. m. was 1,382 vehicles. Of this traffic 12.58 per cent was motor trucks and 2.7 per cent horse-drawn vehicles.

Beginning about 1915, traffic counts had been made by Kern and Los Angeles Counties on selected highways, and they showed a progressive increase in average truck traffic in Kern County from 25 in 1915 to 140 in 1920, and in Los Angeles County from 95 trucks in 1915 to 330 in 1920.

The State census of 1920 was intended principally to determine the usefulness of the State highways and to measure the relation between traffic and the existing condition of 2,150 miles of constructed roads. For each of the roads on which the traffic was observed traffic diagrams or traffic profiles were prepared, these consisting of a plot with State highway routes shown horizontally and daily motor trucks and vehicles vertically, both to suitable scales. The area below the traffic curve on a given route thus indicated the total daily traffic in vehicle-miles. From these daily traffic diagrams for the several routes the total daily use of the State highways was developed. Thus the daily summer traffic in 1920 was estimated as approximately two and one-half million vehicle-miles for the main surfaced highways. From the daily traffic profiles of all routes measured a total estimated movement of traffic of 375,000,000 vehicle-miles was computed for the summer interval alone (June 1 to November 1).

In making this count it was necessary to observe the 8-hour law and instead of one continuous 16-hour day from 6 a. m. to 10 p. m. it was frequently found convenient to build up an equivalent day by two or more shifts. Thus the equivalent-day count represents the assembly and average of 8-hour fractions of from 2 to 12 calendar days at the various stations. Sufficient 24-hour counts were made to check the relation with the 16-hour traffic, and it was found to be 88 per cent of the total for the 24 hours.

A questionnaire was sent to 21,000 truck owners, to which there were 1,930 available replies, which attempted to answer the questions of average distance operated daily, average weight, advantageous speed, and miles per gallon of gas. The questionnaire involved considerable labor and expense, and while it was not satisfactory it had certain value as a check. It showed that the trucks of larger capacity (from 3½ to 7 tons) operated a greater average daily distance and at a reduced speed; that agricultural products constituted the main commodity hauled, with back hauls of groceries, provisions, and general merchandise, but preeminently of building materials and machinery. The questionnaire indicated that the average net load of 1920 was 2.1 tons, and that the inbound tonnage had a ratio to the outbound of 1.38.

In 1920 attention was also given to the passenger bus lines, which had already reached an advanced stage of development. Bus lines are regulated by the State railroad commission under the act of May 1, 1917, as amended May 13, 1919.[1] The commission regulates rates and conditions and requires reports on operations. Under their jurisdiction and protection against unfair and unnecessary competition, and enforcement of schedules, etc., passenger bus business has developed. In 1920 there were 103 independent bus lines, excluding those with insufficient data. The operation of these bus lines involved 3,075 miles of State highways, with an average daily movement of 65,220 vehicle-miles, of which 46,046 were on State highways only. The longest trip then possible by purchase of through transportation tickets over connecting lines was from El Centro, via San Diego, Los Angeles, and San Francisco to Portland, Oreg., a distance of 1,448 miles. Passenger-carrying bus capacities of the larger companies ranged from 8 to 22.

TRAFFIC COUNT OF 1922

At the request of the California highway commission the Bureau of Public Roads cooperated in a second State-wide traffic census in 1922.[2] For purposes of comparison it was essential that traffic be counted at the same 103 stations occupied in 1920. In addition to these, 138 other stations were established which completed the original counts and extended the scope of the count from 2,150 miles to 3,200 miles, thus including graveled portions and some graded mileage in the State system. The traffic was classified as passenger cars and trucks, and this classification was again subdivided into light and heavy. Trucks were recorded as loaded and empty separately. There was also a provision for horse-drawn vehicles, busses, and trailers.

The summer traffic count for 1922 was commenced on August 27, and was completed September 20. This was followed by a winter count, which was begun January 25, 1923, and ended March 3. The average summer traffic in 1922 was found to be 2,037 total vehicles per day, an increase of 47.4 per cent over the corresponding figure of 1920. The winter day average for 1922–23 was 1,578, and the yearly average 1,800.

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[1] This law exempted bus lines operating prior to May 1, 1917.
[2] This census was actually completed in 1923.

In addition to the State highway counts, others were made by 24 cooperating counties at 190 stations which, in general, included records of from 6 to 24 days per station, usually for 16 hours. The total number of stations at which traffic was counted in 1922–23 was, therefore, 431. The counts of 135 of the county stations synchronized sufficiently with the State counts to permit the inclusion of the resulting data in the State-wide satistics. The daily summer average of all vehicles on county roads was 722, except in Los Angeles County where it ran up to 5,338. Since the trucks were heavy. About 55 per cent of the total trucks were found to be loaded, in counting, and about 68 per cent in the weighing, but in the weighing empties were neglected when traffic was very dense. Nearly 60 per cent of the loaded trucks were overloaded with reference to the rated capacity of truck. But, of the trucks weighed, 11.7 per cent were overloaded with respect to the 1921 law (700 pounds per lineal inch width of tires), and of these overloads with respect to the law 52.8 per cent could have been avoided by redistribution of the load.

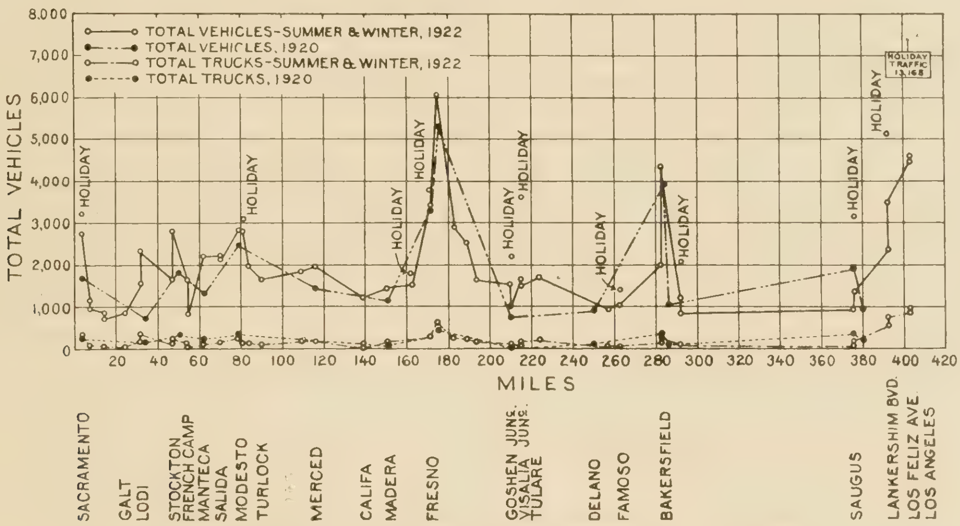

Fig. 1.—Traffic profile of highway from Sacramento to Los Angeles

county stations represent about 2,100 miles of county highways adjoining the State highways, such county highways may be said to carry about 26 per cent of the total traffic recorded.

Samples of the traffic profiles prepared from the 1922 census are shown in Figures 1 and 2. The total annual movement of motor vehicles on all State roads observed (about 3,200 miles), computed from these profiles was 1,370,000,000 vehicle-miles. The daily average traffic on the same 2,150 miles observed in 1920 was approximately 2,750,000 vehicle-miles in 1922, an increase of about 13 per cent over 1920.[3] The 1922 count also represents an equivalent 16-hour day from 6 a. m. to 10 p. m. This 16-hour day, as in 1920, was built up by combinations and averages of about 3,000 eight-hour fractions. For the most part, however, the 16-hour days in 1922–23 were continuous and both the summer and winter average daily counts are representative of an average of approximately four days each.

During the 1922–23 traffic count, trucks were weighed at 80 stations where truck traffic was sufficiently heavy to justify the expense. Approximately 13,000 trucks and 1,100 trailers were weighed. It was found by counting that winter trucking was to summer trucking about as 55 to 100 numerically, and that truck traffic was approximately 10 per cent of all traffic. Trucks classed by counting as heavy (over 2½ tons capacity) were about 38.3 per cent of the total. The weighing statistics indicated, however, that 45.1 per cent of

The average net load in 1922 was 3.3 tons.[4] Trucks of capacity of ½ to 1½ tons constituted 24.5 per cent, and trucks of capacity 2 to 2½ tons, 31.8 per cent; trucks of capacity 3 to 4 tons, 27.2 per cent; and trucks of capacity 5 to 7½ tons, 16.5 per cent, of all the trucks weighed. The 16.5 per cent of large trucks, however, carried 25 per cent of the net loads weighed. It was found that approximately half the truck traffic from a given point fell within a range of approximately 21 miles, but the average haul was 31 miles.

PASSENGER BUS LINES INCREASING

In 1922 there were 710 franchised motor freight and passenger bus lines of all sorts under the control of the railroad commission. Some of the passenger bus lines carried express also and some carried freight. There were 61 class A automotive transportation corporations, having an annual operating revenue exceeding $20,000, of which 17 had revenues exceeding $100,000.[5] Many of the smaller lines have United States mail contracts and carry passengers. The figures for 1922 show that the ratio of operating expenses of the class A lines to operating revenues was 93.3 per cent. Total net operating revenue was in excess of half a million dollars. The average length of bus lines is apparently 41 miles. There appears to be a tendency toward consolidation, the most successful lines acquiring the smaller lines. Bus traffic on some of the highways has become a considerable fraction of the total traffic. Between San Francisco and San Mateo there

[3] The apparent discrepancy between this percentage of increase and the 47.4 per cent of increase in average traffic is due to the much greater accuracy of the 1922 traffic profiles.

[4] Compare with net load of 2.1 tons reported in 1920 by questionnaire.

[5] Most of the lines having an operating income in excess of $100,000 were in operation prior to May 1, 1917.

are 200 busses daily, and about 115 between San Mateo and San Jose. Between Los Angeles and Whittier there are over 200 busses daily and about 130 per day north of Santa Ana. The average rate per passenger-mile is apparently about 5.4 cents. Of 246 bus lines classified as to length of operation, 80, representing the largest class, operated from 25 to 50 miles, and the total length of these lines is approximately 10,500 miles.

Freight trucking lines, in filing applications for certificates of convenience and necessity with the railroad commission, must show proposed rates, schedules, and freight classifications. They usually make their own classifications, but a gradual standardization is being evolved by the larger operators. The present rates vary from 20 cents per ton-mile for short hauls down to 8.3 cents per ton-mile for hauls of about 100 miles.

COMPARISON OF THE 1920 AND 1922 TRAFFIC COUNTS

In connection with the census of 1920 the Bureau of Public Roads attempted to ascertain characteristic or invariant elements connected with California highway transportation. Among these were the seasonal changes in traffic, the weekly periodic variation for which was found a first approximation, the daily variation from hour to hour, the balance of going and coming traffic, and the percentage of traffic between 6 a. m. and 10 p. m. Studies of speed of various classes of vehicles were also made with some useful results. All the 1920 results and deductions have since been refined and checked by the census of 1922.[6]

The seasonal variation which was shown to exist in 1920, but only approximated, was satisfactorily established in 1922 to indicate a ratio of total winter to total summer traffic, approximately as 77 is to 100, with an exception for trucks. Truck travel fell off much more during the winter and the study showed the importance of the harvest season in California. The characteristic weekly variation of traffic in California shows that only 58 per cent of the weekly traffic occurs in the first five days. The balance occurs on Saturday and Sunday. The daily variation of traffic is found to be characterized by a forenoon peak about 10 o'clock, and a greater afternoon peak at 5 o'clock. There is some deviation from the characteristic curve during the winter, when the afternoon peak seems to increase and the forenoon peak to decrease. The daily total traffic variation differs somewhat from that of the truck traffic alone, the two peaks of which tend to be more nearly equalized, and a greater percentage of truck traffic occurs prior to 6 a. m. The going and coming traffic so nearly equalizes (as it should) that in 1922 no separate records of direction were made, and this simplified the counting. It was found in 1922 that about 92 per cent of total traffic occurs between 6 a. m. and 10 p. m., against 88 found in 1920. The higher percentage checks with the counts in several Tennessee counties in 1922. As in 1920, stop-watch speed tests on measured sections of the highway were made in 1923, and compared with the 1920 results without revealing marked differences. The 1922 tests were more accurate and showed a higher average speed. Heavy passenger cars operate with a greater speed, and heavy trucks at the lowest speed, but commercial passenger busses operate at the highest speed of all, approximating 33 miles per hour on an average. Table 1 shows the average week-day traffic at the comparable 103 stations for the two years, 1920 and 1922.

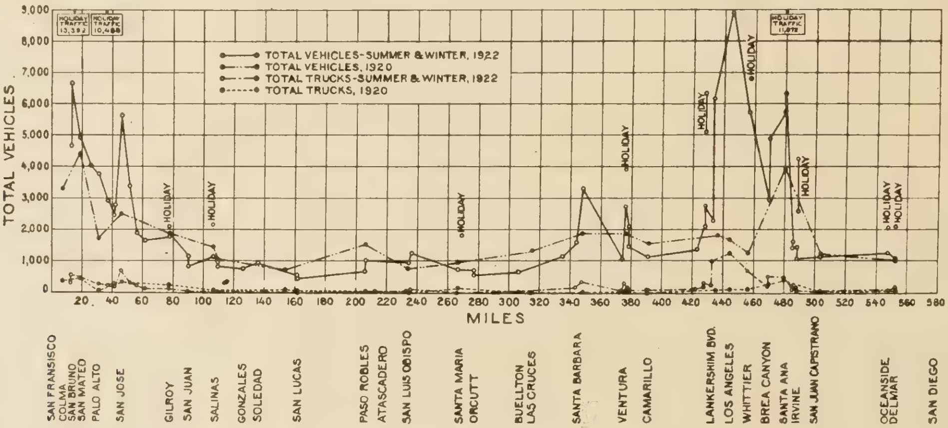

FIG. 2.—Traffic profile of highway from San Francisco to San Diego

TABLE 1.—*Average week-day traffic at 103 stations, 1920 and 1922*

	Number of vehicles					Percentage of total vehicles				
	Summer 1920	Summer 1922	Winter 1922	Average day 1922	Counties	Summer 1920	Summer 1922	Winter 1922	Average day 1922	Counties
						Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Total vehicles	1,382	2,037	1,578	1,800	722	100.0	100.0	100.0	100.0	100.0
Total trucks only	173	231	127	180	83	12.5	11.3	8.0	10.0	11.5
Passenger cars	1,146	1,724	1,388	1,547	604	83.0	84.7	88.0	85.9	83.7
Light trucks, loaded	173	73	38	55	27	12.5	3.6	2.4	3.0	3.7
Light trucks, empty		69	41	56	28		3.4	2.6	3.1	3.9
Heavy trucks, loaded		58	30	44	18		2.8	1.9	2.5	2.5
Heavy trucks, empty		31	18	25	10		1.5	1.1	1.4	1.4
Horse-drawn vehicles	32	24	17	21	17	2.3	1.2	1.1	1.2	2.3
Busses	31	35	31	33	6	2.2	1.7	2.0	1.8	.8
Truck trailers	-----	23	15	19	12	------	1.1	0.9	1.1	1.7

On the 2,150 identical miles covered both in 1920 and 1922 traffic was found to be 98.8 per cent motor driven,

[6] For details of the 1920 count see "Study of California Highway System" by U. S. Bureau of Public Roads, and for 1922 count see "A report of Traffic on State Highways and County Roads in California," 1922, both published by the California Highway Commission.

as against 97.7 per cent in 1920. The increase in total daily traffic was 47.4 per cent, or from a summer average of 1,382 vehicles in 1920 to 2,037 in 1922. In the same interval the automobile registration had increased 48 per cent. On the county roads also 97.7 per cent of all traffic in 1922 was found to be motor driven.

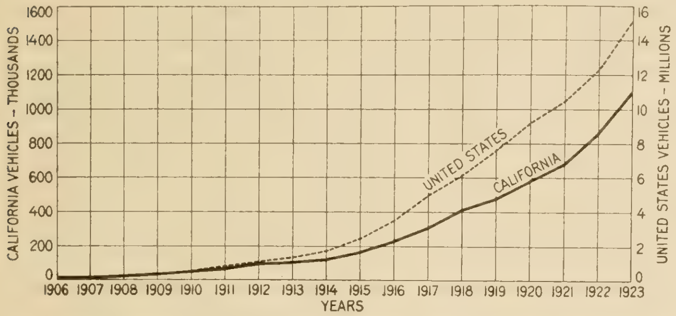

FIG. 3.—Increase in motor vehicle registration in California compared with increase in United States from 1906 to 1923

In 1922 special attention was given to motor-truck data. The results of weighing 13,000 trucks and inquiry at 80 stations show that the ratio of winter to summer trucks is as 55 to 100.[7]

THE CALIFORNIA AND CONNECTICUT TRAFFIC SURVEYS COMPARED

By comparison with the results of the Connecticut traffic census, taken in 1921 and 1922 by the Bureau of Public Roads, it is found that the California truck traffic in general shows characteristics similar to the traffic in Connecticut. In both States manufactured products predominate as the commodity hauled. It is found in both States that the percentage of empty trucks decreases with increases in the length of haul. It is found in California that light trucks (1½ to 2½ tons) were 56.3 per cent of all trucks and carried 40.1 per cent of the total net tonnage, while in Connecticut similar light trucks, which were 66.6 per cent of all trucks, carried 45.3 per cent of all commodities. There are, however, some interesting differences. In California there is a greater tendency for the loads to overrun the rated capacity of the truck. In California the 1922 census indicated that about half the trucks haul less than 21 miles and that the average haul is approximately 31 miles, whereas in Connecticut the average truck haul was only 15.7 miles for Connecticut trucks alone. No particular relation between width of truck body and overloading of the truck was observed in California, although a fairly definite relation was found to exist in Connecticut.

Truck registration data in California in the past have not been satisfactory because commercial vehicles or trucks with pneumatic tires have been registered up to 1924 as automobiles, and only vehicles with solid tires have been classed as trucks. This classification probably accounts for a decrease from 41,689 trucks registered in 1920 to 35,092 in 1921. Registrations for 1922 and 1923, however, show increases to 39,413 and 43,527, respectively. In the 1920 traffic census all trucks were counted as such irrespective of their tire equipment, and the daily average on the highways was found to be 173 at the 103 stations comparable with the 1922 count. In 1922 the truck traffic was found to be 231, exclusive of the pneumatic-tired vehicles, which, in harmony with the registration procedure, were classed as heavy automobiles. It is thought that the small increase shown in truck registration from year to year is probably due to the adoption of pneumatic tires to an increasing extent for all lighter trucks, particularly commercial vehicles of the delivery type, and also to a relatively large increase in this class of commercial vehicles operating in cities. The motor vehicle law as amended in 1923 now provides for registration of commercial vehicles irrespective of their tire equipment as trucks, and up to April, 1924, there had already been registered approximately 106,000 pneumatic-tired trucks and 35,000 solid-tired trucks. This total of 141,000[8] trucks immediately reflects the change in classification over the preceding year.

The progress of California motor-vehicle registration since 1907 is shown in Table 2. The increases in registration shown in the table are compared with the increases in the United States as a whole in Figure 3, and with those of the five leading States in Figure 4. Based on the 1920 census, with conservative allowance for population increase, the number of persons per motor vehicle in California in 1923 was approximately

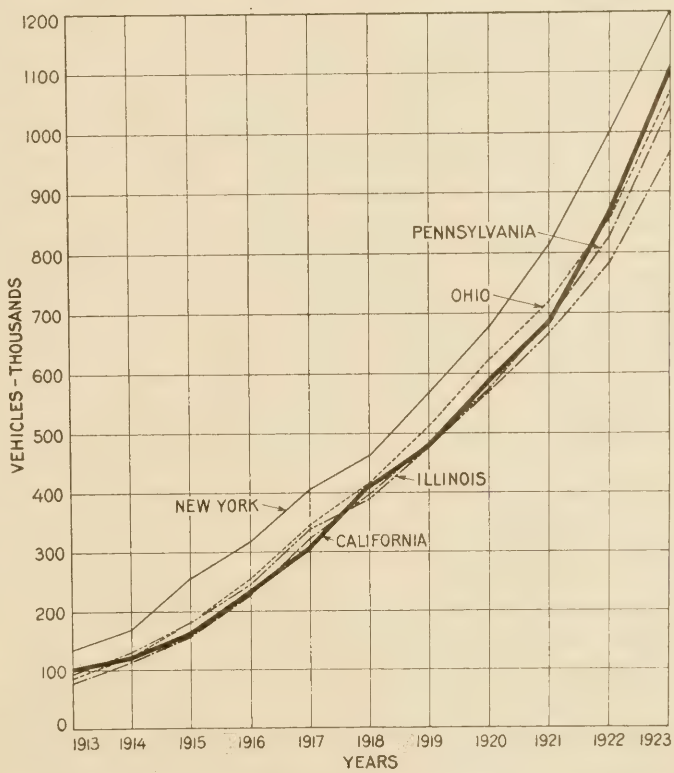

FIG. 4.—Motor vehicle registration in California and five leading States compared

3.5, and the average number of persons per motor vehicle for the entire United States was approximately 7.3. The ratio of motor vehicles to people in California is not exceeded in any other State.

[7] See "A Report of Traffic on State Highways and County Roads in California," published by the California Highway Commission.

[8] Up to July 1, 1924, the registration of trucks was 166,459.

TABLE 2.—*Motor vehicle registration and revenues in California, by years*

Year	Total vehicles			Trucks only			Registration receipts		
	Number[1]	Increase		Number[3]	Increase		Amount	Increase	
		Number	Per cent		Number	Per cent		Amount[4]	Per cent
1907[2]	10,020								
1907	14,051	4,031	40						
1908	19,561	5,510	39						
1909	28,633	9,072	46						
1910	44,122	15,489	54						
1911	60,779	16,657	38						
1912	91,194	30,415	50						
1913	118,716	27,522	30						
1914	123,504	4,788	4	6,156			$1,333,785		
1915	163,797	40,293	33	8,189	2,033	33	2,027,432	$693,647	52
1916	232,440	68,643	42				2,192,699	165,267	8
1917	306,916	73,476	32				2,846,030	653,331	30
1918	407,761	100,845	33	13,953			3,524,036	678,006	24
1919	477,450	69,689	17				4,468,721	944,685	27
1920	583,623	106,173	22	41,689			5,714,717	1,245,996	28
1921	680,614	96,991	17	35,092	−6,597		6,834,089	1,119,372	19
1922	861,807	181,193	26	39,413	4,321	12	8,384,606	1,550,517	23
1923	1,100,283	238,476	28	43,527	4,114	10	10,608,544	2,223,938	27

[1] Years 1907 to 1913, inclusive, from Report of a Study of the California Highway System, by the U. S. Bureau of Public Roads, p. 121. Years 1914 to 1923, inclusive, from PUBLIC ROADS, Vol. 5, No. 2, April, 1924.

[2] Prior to Apr. 8, 1907.

[3] Years 1914, 1915, and 1918, from Report of a Study of the California Highway System, by the U. S. Bureau of Public Roads, p. 121. Years 1920 to 1923, inclusive, from Division of Motor Vehicles, California.

[4] From PUBLIC ROADS, Vol. 5, No. 2, April, 1924.

STATISTICS INDICATE LIFE OF VEHICLES

Since 1921 the actual number of new motor vehicles sold in the State has been made a matter of record. These statistics accumulated for a sufficient period and coupled with the registration statistics will furnish the most reliable index of the average life of the motor vehicles. Figure 5 illustrates the method. The total supply curve for the years 1921 to 1923, inclusive, represents the actual number of new vehicles sold in the State. For the years prior to 1921 the points have been obtained by computation in the following manner: From the total annual production of the United States there have been allocated to California a number of new vehicles, fixed by the ratio of California's registration to the total registration of the country for the corresponding year. The total discharge curve is obtained by subtracting from the total supply the California registrations for each corresponding year. Both curves are cumulative. They represent the total number of vehicles supplied and discharged from service at a given date. By construction, the vertical distance between them represents the registration for each year; and the horizontal distance intercepted represents, for any given year, the average life of the vehicles produced during the year. The approximate curves of Figure 5 indicate that the vehicles sold in 1915 have had an average life of about 8.5 years. There is no certainty that this figure represents their actual life, but a continuation of the actual record of sales will soon yield figures of real dependability. Such figures, indicative of the life and rate of depreciation of vehicles, are essential to the determination of vehicle operating costs which in turn are required as a means of estimating the economic worth of highway improvement and the share of the cost of such improvement which properly may be laid upon the motor vehicle.

VEHICLE OPERATING COSTS AND TAX RATES IN RELATION TO THE COSTS OF HIGHWAY IMPROVEMENT

There is a growing conviction that highway traffic must be sufficiently taxed to pay the cost of maintenance and upkeep and at least a part of the cost of highway construction.

Taxation for such a purpose is essentially rate making for highway transportation and should follow closely the principles of rate making applying to other public utilities. A method by which the tax return can be adjusted to highway costs and the validity of the latter determined is illustrated by the following analysis.

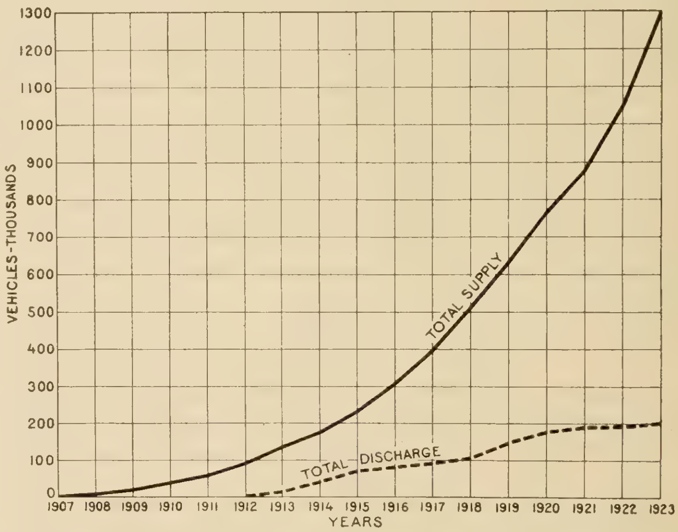

FIG. 5.—Supply and discharge curves for motor vehicles

The two highways selected for analysis are routes Nos. 2 and 4, running south from San Francisco and Sacramento, respectively, to San Diego and Los Angeles, with practically continuous hard surfacing, mostly of concrete and concrete with an asphaltic concrete top. The combined length of the two roads is approximately 857 miles, excluding mileage in towns and cities. The daily average traffic profiles, as derived from the 1920 and 1922 traffic counts, are shown for these two routes, respectively, in Figures 1 and 2. The costs of the original construction of these routes are known, as are also the costs of reconstruction and improvement and the approximate annual maintenance cost. The cost information available shows the annual cost per mile for the two routes to be approximately as follows:[9]

	Annual cost per mile
Bond requirements, 6 per cent on $19,270 construction cost per mile (exclusive of Federal aid)	$1,156
Maintenance and reconstruction	1,327
Improvement	1,101
Total annual cost per mile	3,584

[9] Construction costs, taken from the State records, include general items amounting to 14 per cent of the distributed items. Up to June 30, 1923, the cost had amounted to $17,616,088, from which is subtracted $1,101,566 of Federal-aid funds. The balance of $16,514,522 derived from bond revenues is equivalent to $19,270 per mile. Bond requirements of 6 per cent include approximately 1½ per cent for amortization requirements.

Of this total annual charge of $3,584 per mile, the bond requirements are already met by general State taxes. There remains a balance of $2,428 to be found from current revenue if this figure prevails for the next succeeding year. What portion of this balance which must be met with current revenues will be covered by the taxes on motor vehicles?

California taxes motor vehicles in two ways: (1) By a tax of 2 cents per gallon on gasoline; and (2) by a flat license fee of $3 for automobiles and a surcharge for trucks. The portion of the total taxes collected in this way which can properly be allotted to routes 2 and 4 can be determined in the following manner: From the 1922 traffic count it has been found that the total annual vehicular movement on all roads and streets is approximately 8,500,000,000 vehicle-miles. The daily movement on the two roads is 1,607,400 vehicle-miles. Allowing 8 per cent for night traffic as shown by the 1922 traffic count and remembering that the traffic for the first five days of the week is only about 58 per cent of the weekly total, the total annual traffic will be found to be approximately 784,000,000 vehicle-miles.

Comparing this measure of the traffic on the two roads with the total traffic of 8,500,000,000 vehicle-miles the ratio of 9.22 per cent is obtained, and this ratio may be applied to the total collection of license fees and truck surcharges to obtain the amount which may properly be allocated to the two roads in question. Assuming then an average motor-vehicle performance of 15 miles per gallon of gasoline, an average surcharge on the 43,000 motor trucks in the State of $25, and allowing 6 per cent for collection of license fees and assuming that there is no additional charge for collection of gasoline taxes, the following revenues which may be allocated to the two roads result:

Total gasoline tax on 784,000,000 vehicle-miles, at $0.001333		$1, 045, 072
9.22 per cent of $3 license fees on 1,100,000 vehicles	$304, 260	
9.22 per cent of $25 surcharge fees on 43,000 solid-tired trucks	99, 115	
	403, 375	
Less 6 per cent for collection expenses	24, 202	
		379, 173
Total revenues, routes 2 and 4		1, 424, 245
Average per mile		1, 662

This analysis of operating revenues and expenses is made from existing current data, but some adjustments are required. Since truck registrations and total vehicle registrations for 1924 are not known, the 1924 rates are applied to 1922–23 traffic figures. The total operating income per vehicle-mile on the 8.5 billion vehicle-miles annually, indicated for 1922–23, is $0.001847. This figure includes prorated gasoline tax, $0.001333; license fee, $0.000388; and prorated truck surcharge, $0.000126. The indicated gross revenue is thus about $15,700,000. This figure will doubtless be exceeded in 1924. Consequently the apparent operating deficit of $766 per mile from the first analysis is subject to decrease, unless the costs of maintenance and reconstruction and improvement correspondingly increase with the traffic.

Another analysis may now be made. Since the State highway commission by law receives one-half the net motor revenues for maintenance and improvement of State highways, the current State highway income from this source is about $7,500,000. This income divided by 1.5 billion vehicle-miles of indicated State highway operation yields $0.005 of operating revenue per vehicle-mile. To the 784,000,000 vehicle-miles produced on routes 2 and 4 there accrues then $3,920,000, or $4,574 per mile, or a surplus of $2,146 over the current requirements on this route. If the bond requirements were included in the charges the surplus would reduce to $990 per mile. Routes 2 and 4 are the heaviest traveled long routes in the State highway system and the operating revenue is higher in proportion to expense than the average for the entire system. A study of the entire system by the first method of analysis would reveal a larger proportionate deficit, and similarly by the second method probably a smaller surplus, than the figures given above for routes 2 and 4.

The foregoing analysis necessarily contains some tentative assumptions, particularly with respect to the vehicle-miles per gallon of gasoline and the percentage of total annual operation of vehicles on the combined State highways and county roads. The analysis is given, however, to indicate a method by which highway operating costs and highway revenue may be compared. Manifestly the difference between vehicle taxation and benefits to the vehicle by improved highways is still too wide to warrant over-refinement of the basic assumptions. Apparently the benefit of the highway to the vehicle is at least five times the cost of upkeep of the highway to the vehicle only, and this is probably the important element of modern highway construction.

There is perhaps no stronger reason for the continuation of State-wide traffic counts than the necessity for accurate measure of annual traffic as a basis for determining the correct taxation of motor vehicles. The division of motor-vehicle revenues between State and local purposes requires further investigation. The principle of paying for country roads by city revenue, which was begun with the advent of State aid in Massachusetts and New Jersey in the early nineties, is being carried out in California and other States in a new form under the present motor-vehicle taxation by reason of the evident large movement of traffic in cities from which revenue accrues to the State and county highways. If State highways are to be extended for the general benefit of the people, this principle of taxing the city traffic for country roads must continue.

HIGHWAY RESEARCH BOARD TO HAVE NEW CONTACTS

Appointment at an early date of representatives of various engineering schools to serve on the Highway Research Board was announced by Director Charles M. Upham at the recent annual meeting of the board at Washington, D. C. The appointment of the college representatives follows the policy of the new management of the board recently announced, which is to keep in close touch with the various agencies conducting highway research or employing its findings through the medium of "contact men." Similar appointments of representatives of the State highway departments were announced a short time ago.

THE ECONOMICAL USE OF WHEEL SCRAPERS

By J. L. HARRISON, Highway Engineer, United States Bureau of Public Roads

FOR many years the wheel scraper has been a standard implement for moving earth in grading operations. In the days of the slip scraper, the wheeler was used for the haul distances which were too long for economical slip work and too short for economical wagon work. More recently the fresno has supplanted the slip to a great extent, because it uses relatively more horsepower and relatively less man power. This has made it an economical implement for the short haul and has extended its effective range of haul as compared with that of the slip, thus raising, somewhat, the economical minimum haul distance for the wheeler as commonly employed.

Meanwhile, the elevator grader and the steam shovel, by shortening the time required in loading wagons, have lowered the minimum haul distance at which wagons and trucks are effective dirt movers, and thus have shortened the maximum haul required of wheelers. As a result the haul distances for which the wheeler may be considered standard equipment have been somewhat modified.

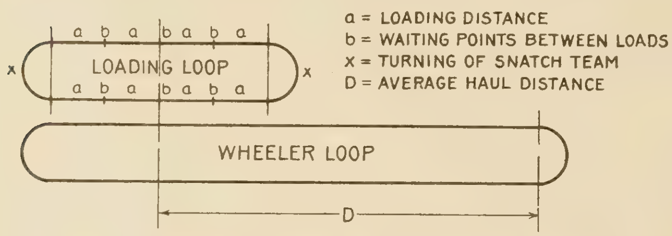

FIG. 1.—Diagram of wheeler and snatch team operation

Although there yet remains a field in which it is the most economical implement, its exclusive use under any but exceptional circumstances is precluded by the very fact that its most effective use is in hauls of moderate length. It is, rather, a tool to be used in connection with some other implement, and on highway work this is generally the fresno, although occasionally a slip-wheeler combination is encountered. From the practical standpoint, therefore, the operation of wheelers can not be dealt with as a problem by itself. Even the number of wheelers that are to be used on a job may be secondary to the question of how many fresnoes or how many slips it is best to use. In any event, as both fresnoes (or slips) and wheelers are likely to be used on any job where either is used, one of the problems that confronts the contractor at once is the determination of the proper point at which to shift from one to the other. On the basis of general theory this shift should be made at a little over 300 feet. This is probably accurate enough for ordinary estimating purposes. Moreover, it is quite as accurate as current contracting practice for contractors make the shift at from something under 300 feet to something over 400 feet without regard to theoretical considerations and often allow the maximum fresno haul to overlap the minimum wheeler haul, preferring to do this rather than bother with too frequent exchanges of equipment. This is natural enough when one considers that the change from fresnoes or slips to wheelers calls for the use of different methods in handling the job and means that extra men must be secured if the whole outfit of teams is to be employed. But while the proper exchange point as between fresnoes and wheelers is generally assumed to be under 350 feet, for outfits of ordinary size if all of the outfit is utilized a generalization of this kind overlooks two facts of considerable importance.

(1) An error of 50 feet in the selection of the exchange point will often affect the unit cost at which excavation is handled by 10 per cent or more.

(2) The size of the outfit together with the pay scale prevailing may affect the exchange point by more than 100 feet.

Therefore, on projects involving a large amount of haul between 275 feet and 450 feet the cost of material moved over these distances may easily be affected as much as 30 per cent and sometimes more by error in the selection of the exchange point. Such a difference may be sufficient to turn a possible profit into an actual loss.

SIGNIFICANT DIFFERENCES BETWEEN WHEELER AND FRESNO OUTFITS

Before attempting to show how such losses can be avoided it will be well to direct attention to certain well-known differences between normal fresno and wheeler outfits which have an important bearing on their relative production. The standard 4-foot fresno is ordinarily drawn and loaded by 3 mules, and the driver is able to load and dump without help. In a fresno outfit the only force required in addition to the drivers and teams for the fresnoes themselves is that which is needed for plowing. Each wheeler, on the other hand, requires 2 mules and a driver for the haul, but for loading and dumping additional force is required which usually consists of a snatch team, a loader, and a dumper. The force required for plowing is the same in either case. For example, a typical 24-mule outfit organized for fresno operation would employ 18 mules and 6 drivers for 6 fresnoes, 4 mules and 1 driver for the plow, leaving 2 extra mules. Organized as a wheeler outfit 16 mules would be hitched to wheelers with 8 drivers, 2 mules and 1 driver would be required for the snatch team, 4 mules and 1 driver for the plow, and there would be the same reserve of 2 mules, but 2 extra men would be required to load and dump. In other words, the wheeler outfit requires 5 more men than the fresno force for the same number of mules, and diverts 2 mules from hauling to loading.

WHEELER PRODUCTION LIMITED BY SNATCH-TEAM CAPACITY

These differences in organization between wheeler and fresno outfits have an important bearing on the relative production of the two kinds of equipment at various hauls and the cost of the production. Inherent in them are the factors which determine the haul distance at which it is profitable to substitute a wheeler outfit for a fresno outfit and vice versa. The fact that the wheeler outfit needs a snatch team which is not required in the fresno organization has a very important effect upon the relative output of the two organizations. In the case of the fresno, therefore, output depends directly on the haul distance. When the haul distance is short the output is relatively large and vice versa, and there is a uniform decrease in output as the haul distance increases.[1] The output of the wheeler organization, on the other hand, is limited in the shorter hauls, not by the length of the haul, but by the capacity of the snatch team to load the wheelers as quickly as they return for loading. With increase of haul distance, however, a point is reached beyond which the output is governed, as in the case of fresnoes, by the time required for the wheeler haul.

The relation of the snatch team to the rest of the job is shown graphically in Figure 1. Actually the wheeler loop is superimposed on the loading or snatch-team loop. It is separated in the figure merely for convenience and clarity.

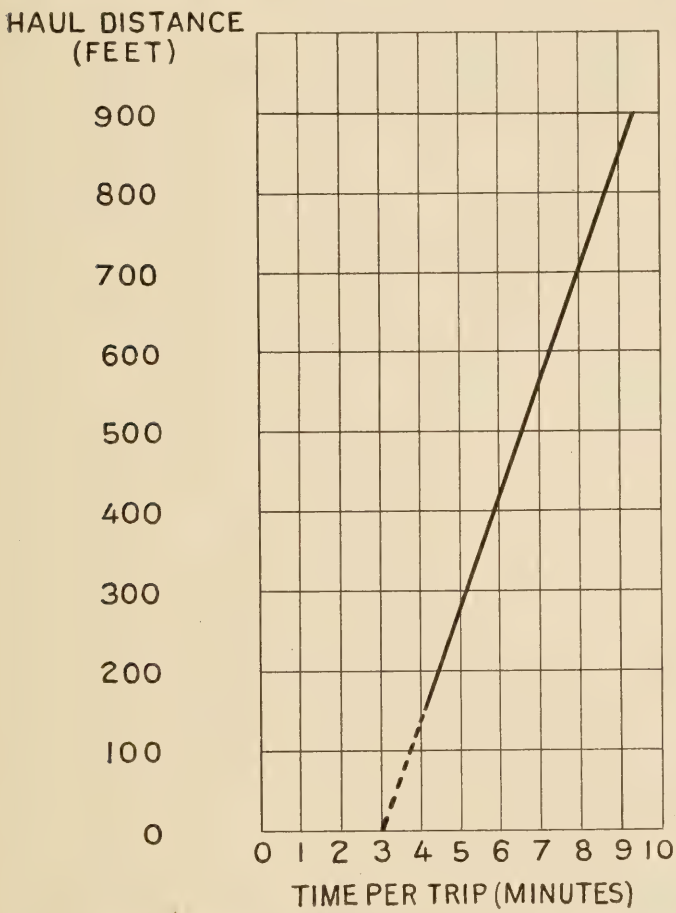

Fig. 2.—Relation between length of haul by No. 2 wheel scraper and time per trip

The loading loop consists of a series of loading operations, each extending over a distance *a* (fig. 1), followed by waiting periods at points *b*, during which the loaded wheeler is driven out and the next wheeler is driven in and coupled up. In practice the distance required in taking on a load *a* varies considerably, but averages from 12 to 15 feet. The time required to load is about 0.35 minute. The exchange of wheelers takes about 0.4 minute. The turns at the end of the loading loop (*x* in fig. 1) require about 0.7 minute, which in practice takes the place of a waiting period *b*, the slight difference in time required being so small as to be of no significance. Practically, then, the loading operation absorbs 0.75 minute. Knowing this, the number of wheelers that can be loaded with one snatch team without delay can be calculated from the time-distance graph (fig. 2) which gives the average time required in moving a load over ordinary working distances.[2] An illustration of its use for this purpose follows:

Suppose the average haul distance *D* (fig. 1) is found to be 400 feet. By reference to the time-distance graph (fig. 2) it will be seen that the average time per round-trip for a 400-foot wheeler haul is 5.9 minutes. As the average time required to load one wheeler is 0.75 minute, it follows that 8 wheelers (5.9÷0.75) operated with average efficiency will deliver a wheeler supply to the snatch team which will slightly exceed the capacity of the snatch team as commonly managed. By substituting the appropriate figures for loading time and trip time the same method can be used to determine the economical number of wheelers for any haul distance and for any job. On a well-managed job the average loading time of 0.75 minute will be reduced; a poorly handled outfit will require a longer time. For ready reference the following table, based on average efficiency in operating both the snatch team and the wheelers, is included:

Table 1.—*Number of wheelers which can be loaded by one snatch team at various haul distances with average management*

Length of haul (feet)	Number of wheelers for each snatch team
165 to 270	6
270 to 375	7
375 to 480	8
480 to 585	9
585 to 690	10
690 to 795	11
795 to 900	12
900 to 1,005	13
1,005 to 1,110	14

TIME OF LOADING NOT AFFECTED BY KIND OF MATERIAL

Within the range of materials observed in the bureau's studies which have been confined to the Mississippi Valley, the kind of material, whether sand, light gravel, loam, or clay, appears to have comparatively little influence on the time used in loading. Plowing any of these materials is a matter of power. Heavy materials will require an extra team on the plow and an extra horse on the snatch team. When these are provided the time required for loading the wheelers can be kept reasonably constant, regardless of the material handled.

So long as the snatch team is unable to load all of the wheelers which can be made available the wheeler output is practically constant and is fixed by the rate at which the snatch team can work. The output remains constant until the haul distance becomes so long that the full supply of wheelers is thrown in, after which any further increase in haul distance is accompanied by a drop in production. Over what range of haul distance the output will remain constant will depend on how many wheelers are available. The bearing of this fact on the output of a wheeler organization

[1] See Public Roads, Vol. 5, No. 8, October, 1924. The Cost of Grading with Fresnoes, p. 10.

[2] For the derivation of the time-distance graph and its significance see Public Roads, Vol. 5, No. 7, September, 1924. The Effect of Haul on the Cost of Earthwork, p. 14.

and its effect on the relative cost of wheeler and fresno operation are shown in graph B, Figure 3, from which it is clear that when this condition prevails the exchange point may be such as to involve the use of a fresno haul somewhat longer than is commonly supposed to be appropriate.

The contractor can sometimes obtain an advantage by working surplus stock on fresnoes. The result of this, if the fresnoes are worked in parallel with wheelers, is to increase output (see graph C, fig. 3) with relatively little increase in cost of operation, so that when this is done it may become appropriate to exchange fresnoes for wheelers at a somewhat reduced haul distance. Each case, however, should receive independent study, and any effort to treat it in any other way would lead to erroneous impressions.

Part of a typical series of stop-watch readings on snatch team operation in sandy loam soil is presented

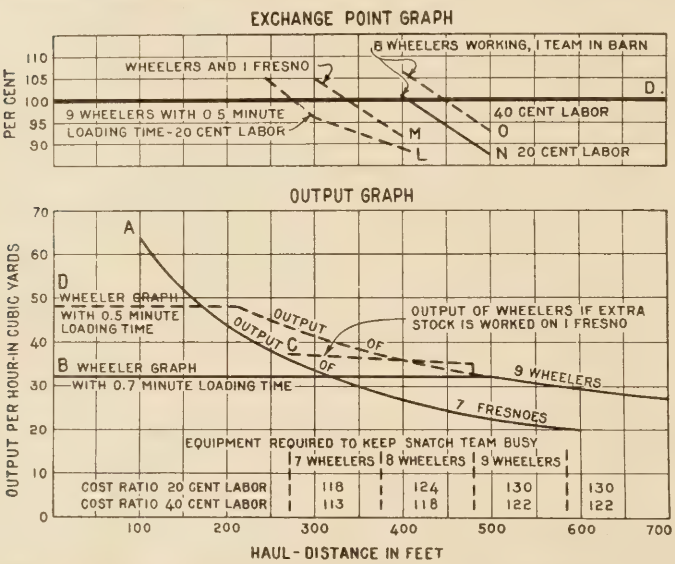

Fig. 3.—Output and exchange point graphs for a small-sized outfit. An outfit of this size is used to illustrate the fact that some outfits are not well suited to handle work involving hauls of from 300 to 600 feet

in Table 2. The fact that the loading time varies from 12 to 33 seconds and the waiting interval between loads from 14 to 37 seconds suggests that with a little more attention to detail the output of the snatch team could be increased from a load every 46 seconds (0.75 min.) to a load every 30 or 36 seconds (0.5 to 0.6 min.). The result of this would be to make it possible to utilize all of the stock on the wheelers at haul distances much lower than is now generally practical. The effect of such a reduction in loading and waiting time on the output at the shorter hauls is shown by dashed lines in Figures 3 and 4. In the case illustrated in Figure 4 this would be of no advantage, but in the case illustrated in Figure 3 the advantage would be considerable. The cost of fresno yardage at 275 feet, the exchange point if the wheeler loading and waiting time can be reduced to 0.5 minute (see exchange point graph, fig. 3[3]), as compared with the cost of yardage moved by fresnoes 405 feet, the normal exchange point (with 20-cent labor), is about in the ratio of 100 to 135. At 405 feet wheeler operation with 0.5 minute loading time costs about 88.5 per cent of the cost of fresno operation at the same haul distance. The saving effected by the use of wheelers with this reduced loading time would therefore amount to about 11.5 per cent at 405 feet and would average about 6 per cent on earth moved between 275 and 405 feet.

[3] The exchange point graph is derived from the output graph by dividing the output of the fresno force for any haul distance by the output of the wheeler force at the same haul distance and multiplying the result by the operating cost ratio, thereby obtaining the relative efficiency of wheeler movement from the standpoint of cost per cubic yard with respect to the unit cost of fresno operation considered as 100 per cent. The manner of plotting the exchange point graph is described in detail on page 19.

Table 2.—*Stop-watch readings on snatch-team operation in sandy-loam soil*

Loading time	Waiting interval between loads	Waiting interval due to lack of wheelers		Loading time	Waiting interval between loads	Waiting interval due to lack of wheelers	
Seconds	*Seconds*	*Min.*	*Sec.*	*Seconds*	*Seconds*	*Min.*	*Sec.*
12	19	-	--	15	--	2	7
23	19	-	--	19	--	0	51
16	22	-	--	18	--	2	55
15	--	3	50	22	25	-	--
19	24	-	--	20	30	-	--
28	26	-	--	20	--	1	48
33	18	-	--	20	28	-	--
25	21	-	--	17	--	2	3
24	--	2	1	25	30	-	--
22	35	-	--	18	30	-	--
15	--	1	2	19	--	2	0
15	--	1	43	35	--	1	25
25	--	2	54	29	34	-	--
16	20	-	--	33	17	-	--
17	27	-	--	20	37	-	--
17	23	-	--	27	--	2	55
13	--	1	8	32	--	1	8
16	--	2	30	23	--	1	38
24	22	-	--	25	--	0	52
25	20	-	--	25	--	2	6
18	--	0	55	30	--	0	47
17	21	-	--	33	--	1	0
18	--	1	23	18	--	0	54
17	14	-	--	25	--	0	45
15	18	-	--	25	--	1	15
19	--	1	7	26	--	0	59
14	18	-	--	24	34	-	--
20	--	1	20	31	20	-	--
14	19	-	--	16	--	0	45
19	24	-	--	24	25	-	--
19	--	0	43	19	--	1	45
25	22	-	--	30	34	-	--
--	19	-	--	19	20	-	--
21	33	-	--	33	--	-	--
20	21	-	--				

Average loading time ________ seconds __ 22
Average waiting interval between loads ________ do ____ 24
Average distance traveled in loading ________ feet __ 13

Operating in this fashion would require constant attention, but it is only by giving attention to details of this sort that satisfactory profits can be secured. The snatch team is the key of a wheeler job whenever there is a surplus of wheelers because its production sets an absolute limit on output no matter how many wheelers may be made available. It is so futile to attempt to boost production by adding more wheelers after the capacity of the snatch team has been reached that it seems trite to lay emphasis on it, but the tendency to make this effort has been so apparent on many of the jobs which have been observed that an impression has been formed that contractors often overlook small repetitive delays, forgetting that in the course of a day these may cost quite as much as it would cost to have a team or two with their drivers standing idle at the side of the road. Generally there is miscellaneous work which extra teams can do, and much would be saved if teams which can not be effectively used in moving earth were employed on work of this sort.

OPERATING COST RATIO AN IMPORTANT FACTOR IN COMPARING FRESNO AND WHEELER OPERATION

In the foregoing, wheeler and fresno outfits have been compared on the basis of their respective outputs, and it has been shown that at hauls ranging from 300 to 500 feet the wheeler output becomes greater than that of the fresno force. This larger output is apt to be accepted as evidence of superior performance without giving adequate attention to the difference in the cost at which the wheeler yardage is secured. To avoid reaching erroneous conclusions every contractor should have clearly in mind, as an important item in determining when to change equipment, an accurate statement of the relative cost of operating as a fresno outfit and as a wheeler outfit. An estimate, developed to show the nature of the operating cost ratio follows:

Comparative estimates of the cost of working the same outfit on fresnoes and on wheelers

	With teamsters at 20 cents an hour		With teamsters at 40 cents an hour	
	6 fresnoes	8 wheelers	6 fresnoes	8 wheelers
Outfit:				
4 mules on plow, 18 mules on fresnoes, 2 mules extra; 24 mules, total	[1] $15.00	[1] $15.00	[1] $15.00	[1] $15.00
Add one-fifth for Sundays and lost time	3.00	3.00	3.00	3.00
1 foreman	4.00	4.00	6.00	6.00
1 plowholder	2.50	2.50	4.50	4.50
1 four-line driver	2.50	2.50	4.50	4.50
6 fresno drivers	12.00		24.00	
8 wheeler drivers		16.00		32.00
1 snatch-team driver		2.00		4.00
1 loader		2.50		4.50
1 dump man		2.00		4.00
1 extra laborer	2.00	2.00	4.00	4.00
Total cost	41.00	51.50	61.00	81.50
Operating cost ratio	100 to 126		100 to 133	
Less 1 driver if 1 wheeler is not used		2.00		4.00
Total cost	41.00	49.50	61.00	77.50
Operating cost ratio	100 to 121		100 to 127	
Less 2 drivers if 2 wheelers are not used		4.00		8.00
Total cost	41.00	47.50	61.00	73.50
Operating cost ratio	100 to 116		100 to 120	

[1] Cost used includes barn help, veterinary services, etc., as well as feed.

The cost estimate shows that to make wheeler operation in this case advisable as compared with fresno operation, all wheelers being in use, something more than 126 cubic yards must be moved by the wheeler organization for each 100 yards produced by fresno operation when the common labor wage is 20 cents per hour, and that something more than 133 cubic yards must be produced by the wheelers for every 100 yards which can be produced by the fresnoes when the common labor wage is 40 cents per hour. On the other hand, if less than the full number of wheelers are used the operating ratio drops (assuming, of course, that labor not used is not paid for). As it has been previously shown that on hauls under 375 feet the full equipment of an outfit capable of placing 8 wheelers and a snatch team on the job can not be utilized, the advantage of keeping extra teams at the barn as compared with sending them on to the job (unless they are put on fresnoes or set at miscellaneous necessary work) is apparent from the manner in which the operating ratio falls as teams are laid off, in this case dropping from 126 to 116 (with 20-cent labor), or about 8 per cent. Of course, if all of the wheelers could be loaded, the reduction in operating cost would be attended by an even greater reduction in the production and would result in a net loss. Thus (see fig. 3), if while the haul is in the neighborhood of 300 feet, wheelers being in use, two of the nine teams used in this illustration are kept in the barn, there is no loss in output because the snatch team can only load seven wheelers. Under such circumstances the reduction in the operating ratio, which is due to the employment of two less drivers, is a positive saving. But if two teams are laid up when the haul is 700 feet, though the operating cost ratio would be reduced as before (from 122 to 113—if the wage of labor is 20 cents), because the output would fall off 22 per cent, the increase in cost per cubic yard, as compared with production with a full force at work, would be about 18 per cent.

In this connection it might be noted that contractors operating wheelers have been found by observation to be rather careless about keeping available stock and equipment at work. There are, of course, many angles to this question, but in allowing stock to stand idle the ordinary contractor appears to be under the impression that his loss is only the feed consumed. As a matter of fact the increase in the cost per yard of output which is due to the fact that the cost of superintendence, plow team, snatch team, loader, dump man, etc., must be distributed over a smaller yardage is often a more important consideration than the feed involved.

There are certain refinements covering profit, depreciation, etc., which might be considered in drawing such an estimate as the one shown above. The contractor who desires to go into this matter in greater detail will include such items, but for governing field operations it is thought that the more simple form of estimate is preferable.

OPERATING COST RATIO AFFECTED BY WAGES AND SIZE OF OUTFIT

The above estimate is presented for purposes of illustration. It serves, however, to show that, depending on the wage scale prevailing, the ratio of the output of fresnoes to the output of wheelers for equal cost per yard on equal haul distances will vary considerably. If estimates such as the above are prepared for outfits of different size, it will be found that the size also affects the ratio. This is because of the relation of the cost of the snatch team or teams, the superintendence, the plow team, etc., to the output produced. Contractors should make up their own estimates, using prices actually paid, and develop their own operating cost ratios. No two jobs are exactly alike. The illustrations which have been given show the salient characteristics of operating cost ratios, but they are intended only as a guide to contractors in preparing ratios which take into consideration the special features of their own systems of management and practices in arrangement of organization and, more particularly, the special conditions governing the pay scale prevailing.

The next step in determining the point at which fresnoes should be exchanged for wheelers involves a knowledge of output. For average conditions output can be predicted from the time-distance graph. It is developed in detail in Figure 5 for one wheeler and one fresno. Operation which yields more than the quantities here shown is above average for highway construction, and operation which yields less than the quantities here shown is below average.

Having the above-mentioned points in mind, it is possible to determine the haul distance at which the wheelers should be placed in service, the number of wheelers and the number of fresnoes which are to be operated being known. To do this proceed as follows:

(*a*) Plot output graph (see curve A, fig. 4) for the number of fresnoes which are to be used. If the contractor has collected the data on the efficiency of his outfit, he should use this, particularly if his outfit is

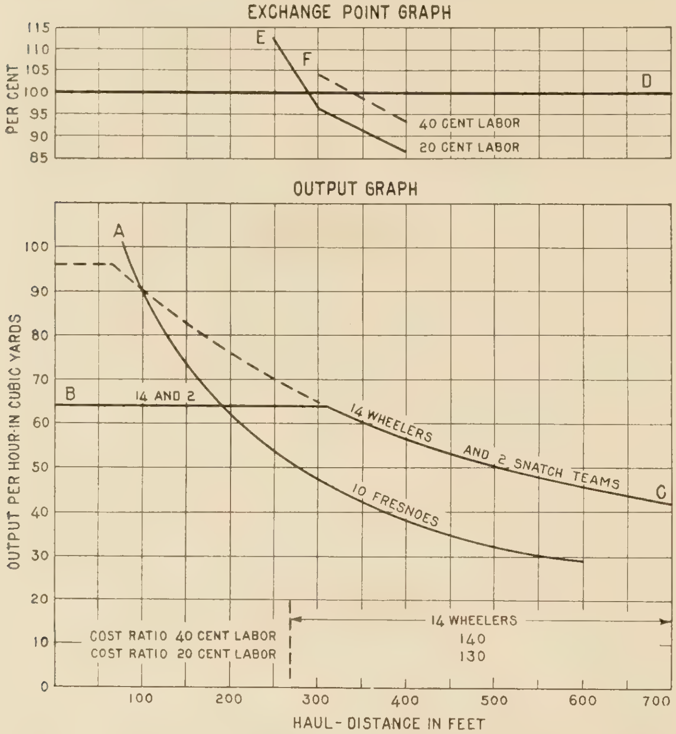

Fig. 4.—Output and exchange point graphs for medium-sized outfit. An outfit of this size is well suited to work involving hauls of from 300 to 600 feet. A large part of the yardage on most grading projects falls within these haul limits

above or below average in efficiency. If he has collected no data on his own outfit, the fresno graph given in Figure 5, which is for one fresno, should be used, the readings for every 50 feet being multiplied by the number of fresnoes which are to be used, and a new graph plotted from the products so secured.

(*b*) Draw a horizontal line (see B, fig. 4) at 32 cubic yards if one snatch team is used (at 64 cubic yards if two snatch teams are to be used).

(*c*) Beginning at the right at about 1,000 feet, plot the output graph for the number of wheelers that are to be used (see curve C, fig. 4) obtaining values from Figure 5 and proceeding as above) to an intersection with the horizontal line above referred to. The full wheeler output graph is that part of the horizontal line lying to the left of the intersection and the plotted graph lying to the right of the intersection.

(*d*) Proceeding with the development of the point at which an exchange between fresnoes and wheelers should be made, draw a horizontal line (see D, fig. 4) to represent the cost of fresno output at any haul distance, considered as 100 per cent.

	Fresnoes	Wheelers
Then, beginning at the right at 400 feet read output in cubic yard for fresnoes and wheelers—in this case	38	56.8
Divide wheeler yardage by operating ratio—in this case 1.30 (20-cent labor)	----	43.7

Divide fresno yardage by adjusted wheeler yardage as secured above: 38÷43.7=87 per cent.

Proceed in similar fashion at 300 feet and 200 feet, obtaining 97 and 127 per cent, respectively. These points when plotted and connected give graph E, Figure 4, which indicates that fresnoes should be exchanged for wheelers when the haul reaches 290 feet.

Calculated in a similar manner the dashed line F (fig. 4) gives the point of intersection, i. e., the point at which a transfer from fresnoes to wheelers should be made, when the wage of labor is 40 cents an hour—in this case 340 feet.

THE EFFECT OF MINOR DELAYS ON OUTPUT

Another matter to which the contractor should give careful attention is the operation of the wheelers. Figure 6 shows the relation of trip time to haul distance for a typical wheeler job as plotted from extended field observations. It will be observed that on this job, the results secured were slightly better than the average indicated by Figure 2, the constant or x intercept being 2.9 minutes per load instead of 3 minutes. Of this, only 1.25 minutes can be accounted for in such operations as turning at the cut (18 seconds), turning at the fill (16 seconds), manipulating pan (16 seconds), loading (21 seconds), and dumping (4 seconds). These are operations which must be performed with every load, and the fact that they sum only 1.25 minutes as against an average time consumption of 3 minutes per load, in addition to the time used in hauling and in returning from the dump draws attention to the importance of miscellaneous losses as a factor in cutting down output. This loss of 1.75 minutes per load is about 30 per cent of the time required for a 400-foot haul and about 20 per cent of the time required for an 800-foot haul. Such losses arise from all sorts of minor delays which, in their general nature, are similar to the losses encountered on fresno jobs.[4] These losses are prevent-

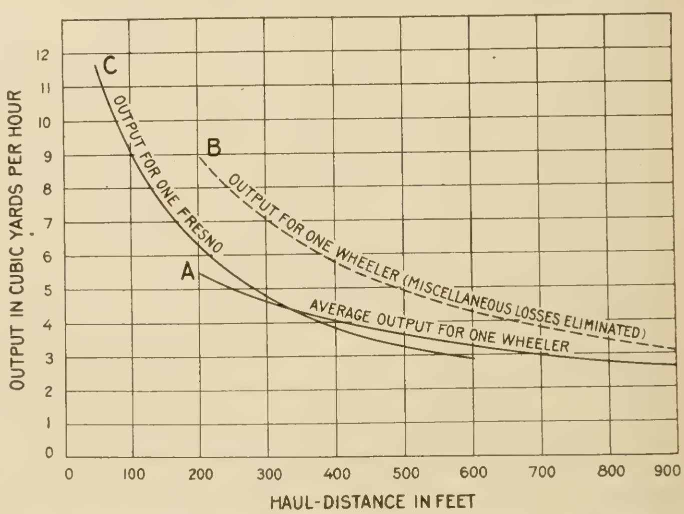

Fig. 5.—Average output curves for one wheeler and one fresno

able in a large measure, but only by persistent effort on the part of the foreman. A wheeler job is like any other construction operation in that it will not run itself. It must be carefully and continually directed. The tendency of grading foremen to allow their jobs

[4] See Public Roads, Vol. 5, No. 8, October, 1924. The Cost of Grading with Fresnoes, p. 10.

to run themselves can be emphasized in no better way than by calling attention to the fact that these miscellaneous delays average more than 4 minutes for each cubic yard moved. The solid line A in Figure 5 shows what has been found by observation to be the average hourly output per wheeler. The dashed line B shows what it would be if these miscellaneous losses were totally eliminated. The value of real management on wheeler work should be apparent from these graphs.

Particularly in the case of large contractors who must work through field superintendents, the problem has always been to find some effective means of checking up on the efficiency of the grading work with-

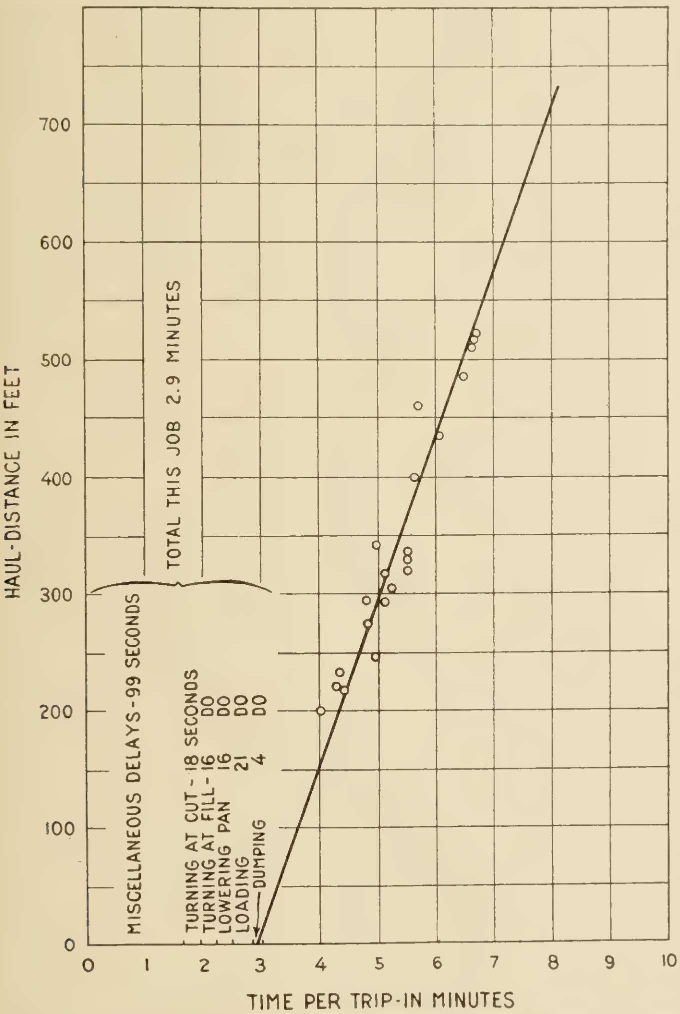

Fig. 6.—Relation of trip time to haul distance, showing various losses

out being constantly on the job. This is done on other forms of construction work by first determining the force which will be employed and then determining how long it will take such a force to do the work. In the highway grading field it has not been possible to employ a similar method because no adequate data have been available from which to calculate the relation of haul distance to the time required to perform specific grading operations. This deficiency the time-distance graph supplies, and from it it is possible by simple methods to calculate the time required to perform any grading operation involving the use of wheelers, and thus schedule the job quite as accurately as any other contract operation can be scheduled. Once this is done, a contractor can handle distant work with confidence by simply keeping it up to the time schedule. Cost and profit having been determined in advance, his problem is reduced to one of finding a superintendent who can, with the force specified, keep within the time limit imposed on him. Moreover, as the contractor may have confidence that the time limit is reasonable, he can place his finger on the exact cause of failure to meet the time schedule whenever the job lags.

TIME SCHEDULES SHOULD BE BASED ON PREVAILING CONDITIONS

Before entering into the details of the method of preparing a schedule, a number of matters should be briefly touched upon:

(1) The time-distance graph referred to above is an average-performance graph. The pitch of the time-distance line varies only slightly from job to job, indicating that mules walk at a fairly steady pace. On one or two horse jobs it has been found that there is some tendency for the animals to walk slower than this line indicates as standard. This suggests that horse jobs may require a little more attention than mule jobs, if the rate of travel is to be kept up to standard. On the whole, however, there appears to be less danger that losses will occur here than in the constant which, as shown, is known to contain about 1.75 minutes of miscellaneous avoidable loss per load moved. It, therefore, seems pertinent to note that while it would be improper to suggest the use of a constant of less than three minutes in estimating wheeler work until a contractor has developed foremen who can conduct the work with losses that are less than those now included in the constant, the wide-awake contractor will make an effort to eliminate such losses. Once he is sure that he has developed foremen who can work with lower losses he will adjust his formula for estimating accordingly. To do this all that is necessary is to reduce the constant, given in the estimating procedure below as 3, to whatever his experience shows he can attain.

(2) In estimating the cost of moving such materials as heavy clay, gumbo, etc., the correct procedure is to allow for the cost of extra power where it will be needed—on the plow and on the snatch team. Once the power is available at these two points, the rate of output of the wheelers can be kept practically as high as in lighter materials. As a matter of fact, the output often falls off when heavy materials are encountered, but this appears, generally, to be due to a failure to apply sufficient power at these two critical points.

(3) In preparing the time schedule which follows it has been assumed that Sundays and rainy days will absorb one-fifth of the time. Such an assumption is necessarily made for purposes of illustration only. The careful contractor will consult the Weather Bureau records for the locality where the work is to be done and, depending on the months during which he expects to operate, will determine the amount of wet weather for which he should allow. Obviously, it would be improper to make the same allowance for bad weather on an east Texas project to be done during the first quarter of the year and a central Dakota project to be executed in the third quarter.

(4) Another matter which deserves a word of comment is that the method here presented presumes the existence of data on which a contractor can determine for any given project what is wheeler work and what is fresno work. This is essential, as in almost every case where one of these implements is used the other must also be used. In some sections the wheelers are used with slip scrapers, but the latter are so inefficient (under Mississippi Valley conditions), as compared with the fresnoes, that they have practically disappeared. To draw up a proper cost estimate it is, therefore, essential that the contractor know not only the quantities to be moved, with their haul distances, but that he know the quantities, their location, and their haul distances for all cuts and borrow pits which involve a wheeler haul.

Generally the responsible engineers will gladly furnish such data to an interested contractor, but there are now a number of States where the information can be had only by special request.

HOW TO SCHEDULE A WHEELER JOB

Assuming that the basic data are available, the following method may be used in calculating the time required in executing a wheeler project:

(1) Multiply the wheeler yardage of each cut or borrow pit by the sum of 3 plus 7/10 of the distance in stations over which it must be moved. As the latter factor represents the time in minutes required to move a wheeler load, which is 4/10 of a cubic foot, the product is 4/10 of the time in minutes required to move the given yardage.

(2) Divide the product for each cut, as obtained above, by 240 to obtain the number of 10-hour work days required to move the yardage with one wheeler. (Use 216 for a 9-hour day and 192 for an 8-hour day. These factors are 4/10 of the number of minutes in the working day.)

(3) Divide the number of work days for one wheeler, as obtained above for each cut, by the number of wheelers that can be used with one snatch team, as shown in Table I, to obtain the number of work days per outfit in each cut (or borrow pit). If the number of wheelers that will be available is less than the number which can be used with one snatch team—a condition likely to occur where small outfits are engaged on long hauls—divide by the number of wheelers which will be available. If the outfit is so large that two snatch teams must be used on the shorter hauls, divide by twice the number of wheelers called for in Table I or by the total number of wheelers which can be supplied, using whichever of these gives the smaller number.

(4) The sum of the "day's work for the outfit" obtained for the various cuts (and borrow pits) is the number of day's work required for the job. This presumes that one outfit will be placed on the job. If two or more outfits are to be used, the sum developed should be appropriately divided by the number of outfits that will be worked.

A brief illustration follows. In working up this time schedule it has been developed for two outfits; the first (outfit A), 6 fresnoes or 8 wheelers, and the second (outfit B), 10 fresnoes or 14 wheelers.

Quantities and haul distances

	Fresno operation		Wheeler operation	
	Quantity	Average haul	Quantity	Average haul
	Cu. yds.	*Stations*	*Cu. yds.*	*Stations*
Mile 1 (cuts)	1,100	2.25	820	6.82
	820	1.80	373	3.80
	778	1.50		
	550	1.90	352	4.90
	722	2.20	1,320	8.62
	430	2.30	280	5.97
Total	4,400		3,145	
Mile 2 (cuts)	875	2.25	1,020	7.35
	490	1.75		
	550	2.25	792	6.06
	635	2.15	530	5.77
	580	2.10	513	5.29
	420	2.00	360	3.51
	625	2.20	745	5.88
	845	2.30	865	8.62
Total	5,020		4,825	

Detailed time schedule

	Day's work for 1 fresno	Day's work for outfit A	Day's work for outfit B	Progress schedule	
				Outfit A	Outfit B
Mile 1 (Fresno work):[1]					
4,400×1.2 =5,280				Start May 1	Start May 1.
1,100×2.25=2,475					
820×1.8 =1,476					
778×1.5 =1,167					
550×1.9 =1,045					
722×2.2 =1,588					
430×2.3 = 989					
200) 14,020	70.1	11.7	7.0		
Mile 1 (Wheeler work):					
$\frac{820}{240}(3+0.7\times6.82)$	26.6	3.33	1.90		
$\frac{373}{240}(3+0.7\times3.80)$	8.8	1.10	0.63		
$\frac{352}{240}(3+0.7\times4.90)$	9.4	1.18	0.67	Allow ½ day for bad weather.	
$\frac{1320}{240}(3+0.7\times8.62)$	49.7	6.21	3.55		
$\frac{280}{240}(3+0.7\times5.97)$	8.4	1.05	.60	Finish May 29	Finish May 17 (noon).
		12.87	7.35		
Mile 2 ([1] Fresno work):					
5,020×1.2=6,024					
875×2.25=1,969					
490×1.75= 858					
550×2.25=1,238					
635×2.15=1,365					
580×2.10=1,218					
420×2.00= 840					
625×2.20=1,375					
845×2.30=1,944					
200) 16,831	84.2	14.0	8.4		
Mile 2 (Wheeler work):					
$\frac{1020}{240}(3+0.7\times7.35)$	34.6	4.32	2.47		
$\frac{792}{240}(3+0.7\times6.06)$	23.9	2.99	1.71		
$\frac{530}{240}(3+0.7\times5.77)$	15.5	1.94	1.11	Allow 1 day for bad weather.	Allow ½ day for bad weather.
$\frac{513}{240}(3+0.7\times5.29)$	14.3	1.79	1.02		
$\frac{360}{240}(3+0.7\times3.51)$	8.2	1.17	.59		
$\frac{745}{240}(3+0.7\times5.88)$	22.1	2.76	1.58		
$\frac{865}{240}(3+0.7\times8.62)$	32.6	4.07	2.33	Finish July 10	Finish June 11 (noon).
		19.04	10.81		

[1] For method of scheduling fresno work see PUBLIC ROADS, Vol. 5, No. 8, October, 1924. The Cost of Grading with Fresnoes, p. 10.

The above time schedule shows that outfit A (working 6 fresnoes or 8 wheelers) in handling this work will have to operate 25.7 days as a fresno outfit, and 31.91 days as a wheeler outfit. Similarly outfit B (working 10 fresnoes or 14 wheelers) will have to operate 15.4 days as a fresno outfit and 18.16 days as a wheeler outfit. To reduce these data to a cost estimate it is only necessary to multiply the number of fresno days by the cost of a day's work calculated as shown above in estimating the operating ratio, and to add to this the cost of the wheeler work obtained in the same way. To this must be added such items as the cost of getting to and away from the job, depreciation, wintering stock, as well as cost of complying with specifications as to maintaining completed grade, etc. Finally the profit should be added. The sum of these items divided by the number of cubic yards to be handled will give the appropriate price to bid on the job.[5] An estimate developed in this way includes overhaul in the bid price.

[5] For a more detailed discussion of the method of estimating, see PUBLIC ROADS, Vol. 5, No. 8, October, 1924. The Cost of Grading with Fresnoes, p. 10.

NORTH CAROLINA INVESTIGATING PRESSURE ON PIPE CULVERTS

The vertical pressure transmitted to pipe culverts through earth fills is the subject of an experimental investigation which has been under way for some time by the North Carolina State Highway Department in cooperation with the University of North Carolina.

The experiments are being conducted with full-sized pipes, which are covered with fills of various materials to depths ranging up to 20 feet. The earth fill rests on the upper semicircumference of the pipe. Two concrete slabs in the plane of the horizontal diameter support the soil at the sides of the pipe and allow the space beneath the pipe to remain open for the weighing apparatus, which consists of four Riehle testing machines.

The investigation is being carried on at Chapel Hill, N. C., under the direction of Dean G. M. Braune.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

NOVEMBER 30, 1924

STATES	FISCAL YEARS 1917-1924			FISCAL YEAR 1925									BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1924			PROJECTS COMPLETED SINCE JUNE 30, 1924			* PROJECTS UNDER CONSTRUCTION			PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 4,598,721.63	$ 2,186,247.54	464.1	$ 766,721.98	$ 380,509.23	85.3	$ 15,333,651.52	$ 7,436,225.92	838.0	$ 79,416.15	$ 39,708.07	0.6	$ 1,210,272.24	Alabama
Arizona	8,338,365.41	4,287,683.88	527.8	713,173.87	406,825.70	37.5	1,758,155.58	1,065,094.20	150.4	504,350.11	308,208.92	55.2	1,427,888.30	Arizona
Arkansas	11,094,751.31	4,424,345.63	944.4	1,637,568.79	688,383.74	68.1	6,453,537.33	2,651,817.83	339.6	642,304.57	289,362.76	53.7	1,008,490.04	Arkansas
California	12,999,075.03	5,647,148.17	533.7	3,373,385.31	1,799,005.25	135.5	12,121,739.55	6,306,673.24	394.2	505,746.86	298,390.64	8.2	3,042,088.70	California
Colorado	8,108,070.31	4,029,898.97	502.6	880,626.15	444,393.39	47.6	5,316,483.73	2,891,641.04	199.9	35,740.10	20,057.34	2.9	2,173,890.26	Colorado
Connecticut	3,062,872.02	1,269,558.60	73.6	199,024.56	98,423.00	4.9	3,262,054.48	1,045,804.04	54.1				967,409.36	Connecticut
Delaware	3,056,832.22	1,007,714.83	72.5	462,969.09	197,825.82	13.8	1,318,788.24	504,231.10	33.1				29,758.25	Delaware
Florida	961,134.07	461,470.92	48.8	1,415,010.74	681,331.64	25.4	8,274,647.58	4,060,548.44	236.4	398,642.71	171,123.94	10.2	912,412.06	Florida
Georgia	17,167,373.32	7,955,805.20	1214.2	1,245,033.93	597,200.65	113.1	11,053,717.87	5,271,180.34	782.7	754,833.02	346,867.14	38.6	278,843.67	Georgia
Idaho	8,181,697.92	4,092,395.52	506.8	243,867.57	139,962.62	18.7	2,531,548.92	1,519,975.55	170.5	430,193.23	283,175.76	31.3	642,202.55	Idaho
Illinois	26,964,706.06	12,279,546.33	804.7	1,355,788.15	670,702.08	40.5	15,741,331.50	7,820,073.10	538.7	53,063.82	26,531.91	2.0	2,639,638.58	Illinois
Indiana	7,577,444.16	3,655,540.97	225.7	1,572,755.01	773,197.42	56.6	15,763,091.38	7,675,466.21	502.3				2,208,187.40	Indiana
Iowa	23,195,778.19	9,237,031.86	1682.9	837,879.52	354,112.26	74.1	8,319,885.79	3,840,599.47	585.4	1,364,138.90	613,800.00	59.7	1,290,593.41	Iowa
Kansas	17,084,136.48	6,043,176.80	502.7	4,996,700.82	1,901,478.91	146.0	14,944,690.02	6,008,613.63	630.5	2,895,451.26	1,338,396.49	158.1	7,623.17	Kansas
Kentucky	10,822,980.31	4,613,947.28	429.4	1,755,750.19	717,266.65	63.7	8,336,630.31	3,828,889.32	321.4	474,276.14	204,477.96	17.1	1,007,157.79	Kentucky
Louisiana	8,488,463.18	3,636,143.36	661.2	1,358,277.16	662,014.97	127.0	4,808,164.95	2,389,108.72	284.1	191,242.29	95,621.14	1.1	482,553.81	Louisiana
Maine	6,911,058.78	3,299,935.38	230.7	295,533.42	147,087.77	12.3	1,704,509.38	823,525.56	62.4	113,667.57	56,833.78	6.3	762,589.51	Maine
Maryland	6,760,044.42	3,213,321.78	243.2	358,411.02	179,205.49	16.4	2,801,989.31	1,199,249.89	85.3	171,075.41	52,750.00	4.2	4,422.84	Maryland
Massachusetts	10,191,202.02	4,105,727.22	232.8	88,434.91	28,760.00	1.4	6,555,098.99	2,103,931.92	107.3	466,585.01	137,365.00	7.1	1,543,995.86	Massachusetts
Michigan	13,434,135.07	6,060,612.23	494.5	300,204.10	144,889.87	15.1	16,355,771.29	7,750,146.06	551.3				1,924,123.84	Michigan
Minnesota	24,037,561.24	9,885,843.07	2292.0	2,615,732.90	1,105,086.98	175.3	9,515,469.39	4,218,900.00	849.0	1,051,402.19	81,300.00	117.2	27,288.95	Minnesota
Mississippi	7,888,193.89	3,828,941.39	655.0	765,843.84	381,194.15	50.7	8,531,159.03	4,251,388.50	518.4	670,401.44	338,200.70	53.9	734,548.26	Mississippi
Missouri	11,352,027.70	5,245,899.18	803.5	1,317,280.96	650,328.61	100.6	21,821,865.23	9,892,913.18	852.4	2,838,049.81	898,120.55	109.5	1,252,926.48	Missouri
Montana	8,867,279.16	4,384,335.12	791.4	699,306.93	462,086.35	77.2	2,421,045.82	1,804,547.70	213.3	1,047,664.72	595,727.63	118.4	3,719,720.20	Montana
Nebraska	7,876,337.16	3,714,691.59	1440.4	375,488.75	175,160.67	26.9	7,884,545.40	3,859,752.19	831.7	916,341.27	458,170.60	109.1	3,243,170.95	Nebraska
Nevada	3,460,245.52	1,853,624.98	225.6	1,102,421.45	928,932.16	92.2	4,477,532.42	3,774,003.69	383.1	107,368.80	93,647.06	16.0	240,113.11	Nevada
New Hampshire	3,076,750.19	1,487,867.58	171.3	126,997.20	61,883.10	5.1	1,645,336.04	774,553.81	53.8	29,611.26	13,680.00	0.9	96,979.51	New Hampshire
New Jersey	7,623,795.12	2,661,531.49	148.7	580,788.45	210,700.00	10.5	10,201,407.15	2,901,941.24	79.2				815,074.27	New Jersey
New Mexico	5,306,286.45	2,758,849.68	714.3	814,405.30	476,119.86	77.2	6,719,429.09	4,452,053.64	673.6	250,983.39	154,354.77	16.7	747,954.05	New Mexico
New York	18,862,742.49	8,257,844.44	572.7	1,037,210.72	427,221.06	33.4	30,206,722.96	11,457,356.72	674.7	5,778,138.00	1,579,790.00	102.8	4,985,935.78	New York
North Carolina	12,567,732.97	5,676,757.66	884.7	2,948,359.40	979,101.39	77.1	9,412,925.25	3,747,669.05	264.8	1,275,120.60	588,594.60	40.3	1,302,128.30	North Carolina
North Dakota	9,088,973.11	4,418,505.42	1587.9	1,037,063.57	501,626.34	212.2	3,247,983.03	1,629,601.15	460.5	343,514.58	171,757.24	25.9	1,642,165.85	North Dakota
Ohio	33,122,751.43	11,879,917.99	962.5	2,530,801.09	1,015,479.44	65.8	13,210,187.64	4,893,752.12	373.4	1,237,508.10	468,652.35	39.2	1,882,362.10	Ohio
Oklahoma	12,986,865.26	5,888,852.03	497.3	1,474,245.36	713,674.21	72.6	8,680,178.53	4,149,670.95	360.2	2,371,131.26	965,663.18	139.7	818,942.63	Oklahoma
Oregon	12,082,873.17	5,819,093.79	655.6	1,209,085.39	707,463.39	95.4	2,705,614.72	1,587,737.37	140.9	239,530.50	110,954.29	9.3	280,910.16	Oregon
Pennsylvania	36,825,248.98	14,114,694.79	729.7	1,193,968.79	536,982.44	27.7	23,214,354.17	6,291,402.50	385.6	2,843,557.39	887,575.00	58.8	2,770,961.27	Pennsylvania
Rhode Island	1,774,397.25	779,227.96	46.0	486,927.24	210,838.14	11.2	1,569,460.07	470,790.83	23.4				472,184.07	Rhode Island
South Carolina	9,016,476.73	4,124,045.22	924.4	1,424,195.60	648,194.80	209.0	5,589,680.42	2,295,989.37	387.6	593,331.01	116,728.18	65.9	502,588.43	South Carolina
South Dakota	8,674,597.86	4,244,636.27	989.8	1,751,410.13	938,913.15	262.9	7,089,603.57	3,470,256.37	955.9	183,622.64	8,599.56	34.6	56,274.65	South Dakota
Tennessee	6,805,683.35	3,313,936.07	259.6	3,695,741.78	1,822,625.45	127.2	12,838,518.25	5,805,258.99	436.9	913,841.02	456,920.49	56.9	625,896.00	Tennessee
Texas	42,341,998.56	16,190,624.91	3122.8	4,466,439.28	1,746,748.39	291.3	24,603,135.06	9,993,410.74	1512.7	4,775,652.39	2,024,008.84	302.6	1,769,420.12	Texas
Utah	3,304,423.75	1,895,805.92	219.0	719,066.79	390,456.24	91.2	4,502,514.72	8,983,163.11	266.7	493,275.89	349,367.29	32.9	497,680.44	Utah
Vermont	1,922,114.16	942,769.12	74.4	145,101.06	72,550.52	6.2	2,108,819.21	998,976.84	51.6	53,364.64	26,682.31	1.4	493,000.21	Vermont
Virginia	10,035,301.48	4,801,782.43	552.5	924,582.46	421,537.81	29.2	9,998,047.20	4,653,970.57	352.6	747,489.36	353,972.26	28.3	361,689.93	Virginia
Washington	11,384,615.67	5,290,895.45	457.0	444,972.29	198,980.09	29.4	3,953,074.35	1,823,200.00	147.8	76,148.13	38,000.00	5.2	535,602.46	Washington
West Virginia	5,489,747.95	2,365,041.53	255.6	1,232,116.91	562,933.47	42.8	4,619,497.76	2,069,387.81	156.0	77,099.55	27,448.00	0.3	729,321.19	West Virginia
Wisconsin	18,753,903.15	7,441,033.57	1325.3	1,018,641.46	481,571.65	49.9	4,326,468.60	2,083,976.04	178.1	135,408.28	67,703.00	7.2	3,604,166.74	Wisconsin
Wyoming	6,127,625.61	3,078,098.70	687.6	992,457.57	581,593.73	119.1	4,412,501.34	2,784,694.56	293.6				242,964.01	Wyoming
HAWAII													365,625.00	HAWAII
TOTALS	$ 549,655,391.27	$ 237,852,399.82	32452.9	$ 60,987,768.96	$ 28,422,560.05	3572.3	$ 412,262,564.14	$ 185,313,014.62	18745.1	$ 38,130,283.37	$ 15,155,288.75	1949.3	$ 58,381,736.76	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 101,084,663.27 Federal aid $ 45,733,548.42 Miles 4,355.0

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publciation to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

DEPARTMENT BULLETINS

No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370. The Results of Physical Tests of Road-Building Rock. 15c.
386. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
390. Public Road Mileage in the United States, 1914. A Summary.
*393. Economic Surveys of County Highway Improvement. 35c.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463. Earth, Sand-Clay, and Gravel Roads. 15c.
*532. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*555. Standard Forms for Specifications, Tests, Reports, and Methods of Sampling for Road Materials. 10c.
*583. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916. 10c.
*660. Highway Cost Keeping. 10c.
670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691. Typical Specifications for Bituminous Road Materials. 10c.
*704. Typical Specifications for Nonbituminous Road Materials. 5c.
*724. Drainage Methods and Foundations for County Roads. 20c.
*1077. Portland Cement Concrete Roads. 15c.
*1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
No. 1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1259. Standard Specifications for Steel Highway Bridges adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal aid road construction.

DEPARTMENT CIRCULAR

No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS

No. *338. Macadam Roads. 5c.
*505. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *727. Design of Public Roads. 5c.
*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.

OFFICE OF PUBLIC ROADS BULLETIN

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS

No. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
74. State Highway Mileage and Expenditures for the Calendar Year 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D-2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 20, D-4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D-6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

VISION—
in SUPERVISION

A SURETY COMPANY is authority for statistics recently published which seem to confirm the popular belief that highway construction is a hazardous business venture. It is shown that the losses of bond houses on high-type road construction contracts constitute a large percentage of the premiums paid. We assume the figures are correct, although we must confess they depict a far more serious situation than we had believed existed.

BUT WHAT INTERESTS US more than any post mortem figures are the reports received at regular intervals by this bureau from its district engineers, which attribute to bad management one out of every four cases of unsatisfactory progress on Federal-aid projects. Only one other cause appears more frequently—the weather.

NEITHER CONTRACTORS NOR ENGINEERS can be expected to accept responsibility for the weather, although it does appear that a greater amount of time is lost on account of unfavorable weather conditions than there is warrant for in the conditions themselves.

BUT IT DOES SEEM that the cases ascribed to bad management are distinctly up to the contractors; and the evidence of the Federal-aid reports is reinforced by the studies of grading operations recently made by the bureau and published in PUBLIC ROADS. When it is shown that 100 of the 180 seconds required to load, turn, and dump wheelers on an average job represents unprevented preventable delay one is inclined to the opinion that highway construction would be a much less hazardous venture if contractors would put more vision into supervision.