U.S. Public Roads, Bureau of.

Studies of driver behavior and vehicle performance by United States Public Roads Administration.

C W Prisk

U.S. Public Roads, Bureau of.

STUDIES OF DRIVER BEHAVIOR AND VEHICLE PERFORMANCE
BY
UNITED STATES PUBLIC ROADS ADMINISTRATION,

Demonstration of Uses of Equipment and Data
Held at Johns Hopkins University, Baltimore, Maryland
October 26-27, 1939

FOREWORD

During the past two years the Public Roads Administration of the Federal Works Agency has designed and constructed special instruments and equipment necessary in connection with studies of driver behavior and vehicle performance.

These instruments are now being used in research work being carried on by the Public Roads Administration in cooperation with a number of State highway departments, the Quartermaster Corps of the United States Army at Camp Holabird, Baltimore, Maryland, the National Bureau of Standards, Johns Hopkins University, and a number of motor truck manufacturers.

The special instruments and equipment were demonstrated at Baltimore, Maryland, on October 26 and 27 before some of the executives of the motor truck industry, safety organizations and governmental agencies and departments primarily for the purpose of acquainting them with the techniques employed in the driver behavior and vehicle performance studies.

Upon completion of the demonstration, Professor J. Trueman Thompson, research specialist for the Public Roads Administration and Professor of Civil Engineering at Johns Hopkins University, presented the following paper summarizing the uses and implications of the equipment and data:

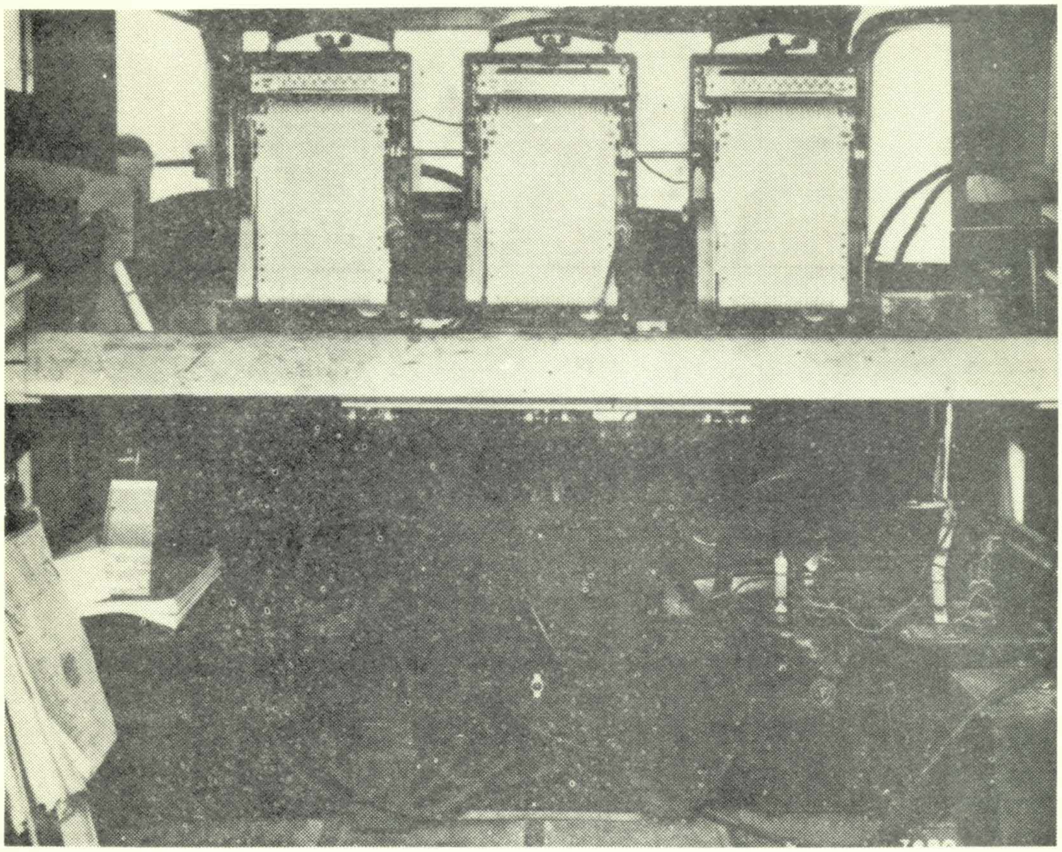
SUMMARY OF USES AND IMPLICATIONS OF EQUIPMENT AND DATA

Paper presented by J. Trueman Thompson, research specialist, Public Roads Administration and Professor of Civil Engineering, Johns Hopkins University, at the demonstration of driver behavior and vehicle performance studies at Baltimore, Maryland, October 27, 1939.

It is realized how confusing it is to be suddenly confronted with an array of apparatus and techniques all dealing with the complexities of traffic movement. But since the devices that have been demonstrated are designed to provide answers to some of the many questions that arise out of the effect of traffic upon such matters as highway and vehicle design, transportation economics, traffic regulation, and highway safety, it is important that all of us shall have a clear understanding of their potential value. The attempt will therefore be made to summarize for you what you have seen and to clarify any confusion that may exist by stating the purposes of the several studies by giving examples, where we can, of the kind of information that is being gathered and its use, and by pointing out how the studies are related and how, in some instances, they supplement one another.

A METER FOR MEASURING VEHICULAR SPEED

Let us begin with the speed studies. A typical experimental set-up consists of two pneumatic tube detectors, 24 feet apart, connected to a speedmeter. An air impulse in the first tube, caused by the wheels of a vehicle striking it, starts the so-called wiper arm of the Strowger switch in the meter to revolve, and an impulse in the second tube stops it. As the wiper arm revolves at a constant speed, the amount of its angular movement in the interval is a measure of the time it has taken the vehicle to move those 24 feet, and hence of the vehicle's speed. Motion of the wiper arm is invariably arrested when the arm is in contact with one of the 50 contact points of the meter; and the contact thus made closes a separate electrical circuit which actuates a particular pen or combination of two pens in a bank of 20 to mark the moving paper tape of the recording instrument. As each contact point of the meter, by virtue of its circumferential position, corresponds to a definite range of vehicular speeds, when the distance between the tube detectors is unchanged, the positions of the pen marks made on the tape indicate the speeds of the passing vehicles within narrow limits. As a mark is made on the record for each passing vehicle and as the record moves at a uniform speed, it is obvious that the device also tallies the total number of vehicles, the time spacing between vehicles, and the number moving in each speed group.



Interior of Truck Containing Speedmeter and Graphic Time Recorders Used For Speed-Placement Studies.

The equipment and techniques that have been developed should lend themselves in the future to a variety of uses. For example, we can learn the effect upon speed of grades, of curvature, of spiraling and superelevation, and of surface type, especially as related to weather conditions. We can find out the extent to which darkness influences speed and how illuminating devices, both on the vehicles and on the roadside, affect it. We can also measure the effectiveness of posted speed limits and of speed zoning.

In Connecticut, police officers, stationed a short distance from the point of speed observation, obtained from each driver information concerning his age, driving experience, purpose and length of trip, and various other items of a personal nature. This further operation, successfully conducted as an experiment this year, will be continued under a variety of road conditions and will eventually yield information that should throw further light on the characteristics of drivers and point the way to driver licensing practices that will exclude the unfit and habitually reckless.

THE TRANSVERSE PLACEMENT RECORDER

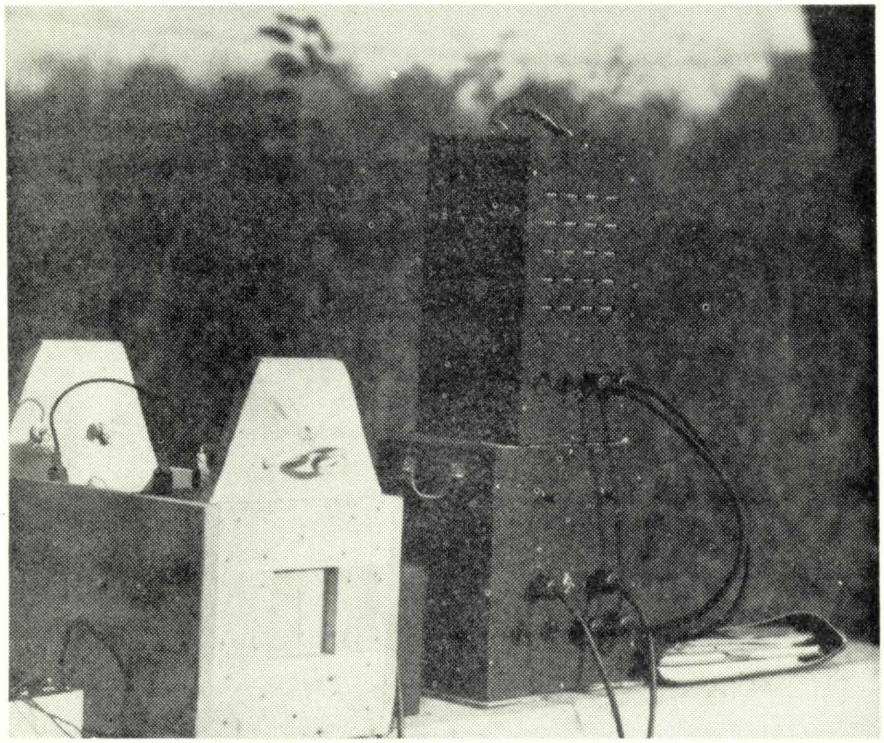
Wherever the speed meter is installed, the position of the passing vehicles transversely on the pavement is also being recorded by means of the transverse placement recorder. This is a segmental mechanical detector made up of alternate dead and live spaces, each of the live spaces being electrically connected to a pen in the recorders. Whenever a wheel passes over one of these segments, an electrical contact is made, moving a pen associated with the particular segment and the position of the wheel is recorded.

This transverse placement equipment was first used last July in Massachusetts, after having been thoroughly tested at Washington and found to be reliable. Studies were also conducted during the past summer in Connecticut, Illinois, and Minnesota. The results of the work thus far are not yet available, but the equipment has functioned smoothly and there is every reason to believe such data will prove exceedingly useful. Results of its further use should serve to establish the normal transverse positioning of vehicles of the various classes and should show how these normal positions are influenced by a variety of conditions. For example, there may be mentioned curvature, spiraling and superelevation, surface width and condition, curbs, center and lane striping, width and condition of shoulders, and the encroachment of objects, such as culvert head-walls. The indicated necessity for widening curves, because of the "tracking-off-line" of long vehicles, may have an important bearing upon regulations governing the length of vehicles and the number of units in combinations.

It is a simple matter to combine the use of speedmeter and position detector. The segmental strip of the latter is merely placed on the pavement about midway between the two pneumatic tubes of the former. The two are used together because it is suspected that speed is a strong determinant in transverse positioning. When so combined, the equipment will be particularly valuable in revealing the effect of speed, traffic volume and the presence of opposing traffic on the lateral position of vehicles.

STUDIES OF HIGHWAY CAPACITY

The highway capacity studies, as the name implies, are directed toward the establishment of the practical and maximum capacities of highways under various conditions of alignment, width and lane arrangement. The term "Capacity" has been used to denote the volume of traffic that can pass over a highway in a given time. Since the accompanying convenience and safety are largely dependent on the amount of congestion which may be present, it is obviously desirable to delimit congestion and to be able to measure it in its varying degrees.



The Speedmeter Being Used in Connection with 20-Bank Counter to Obtain the Cumulative Frequency Distribution of Vehicle Speeds.

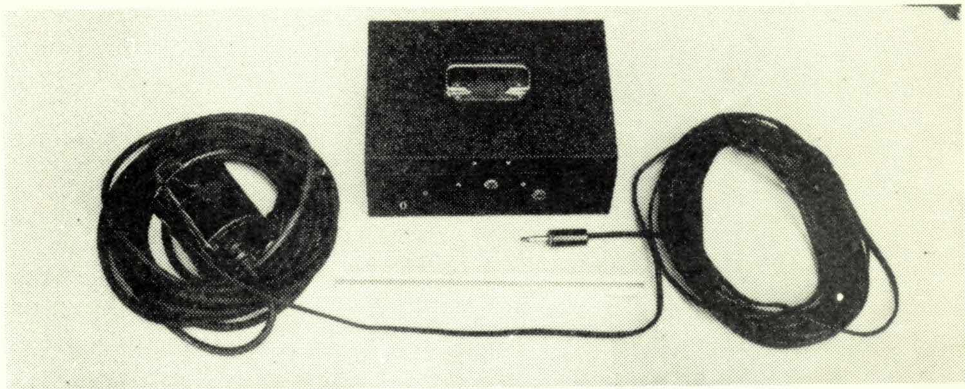
The extreme of "no congestion", of course, corresponds to complete freedom of movement of the individual vehicle. Under this condition each driver travels at whatever speed he chooses, passes vehicles ahead at will, and, in short, uses the highway as though his were the only vehicle present. This condition is approximated, in the experience of all of us, when we travel over stretches of modern multiple lane divided highways in light traffic.

At the other end of the scale is the state of "absolute congestion," in which each individual driver is so sharply governed by the one ahead that he must adopt the latter's speed. When this condition is reached, the difference in speed between successive vehicles in line is zero, and all vehicles are moving at the speed of the slowest.

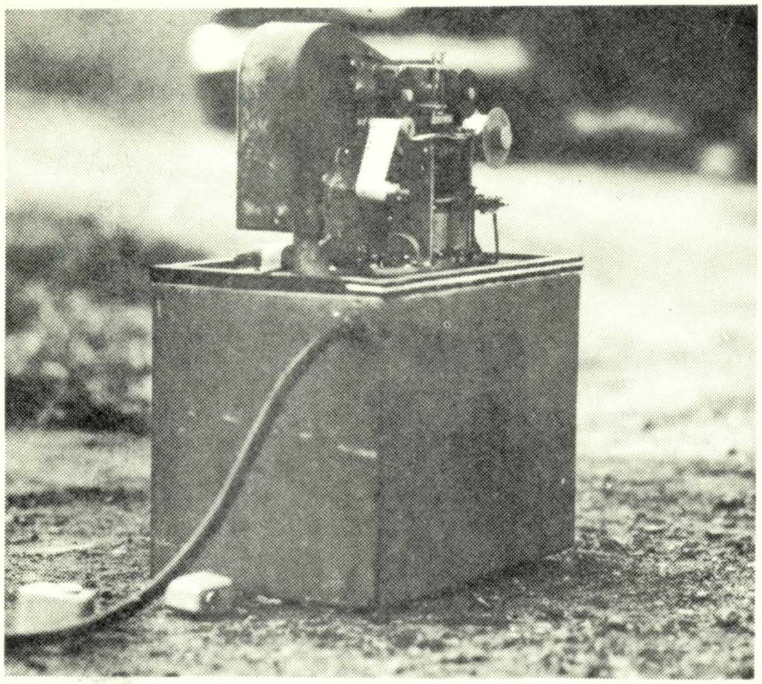
In between these two extremes there are varying degrees of congestion associated with the different traffic volumes which cause them. These depend upon a variety of conditions. Among the more important of these are pavement width, horizontal and vertical alignment, number and arrangement of lanes and, of prime importance, the distribution of the traffic to the lanes and the pattern of that distribution; that is, the number and length of spaces between vehicles in the opposing traffic streams.

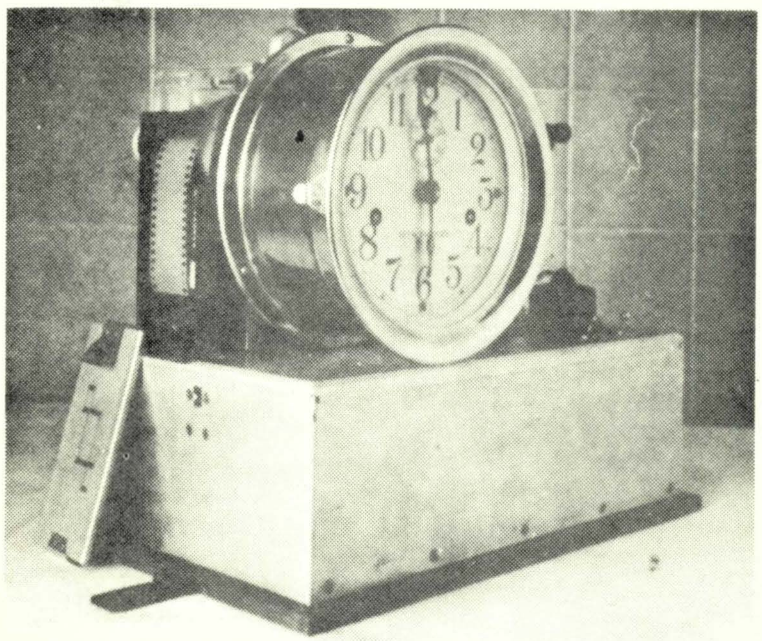
The importance of establishing capacities lies in the fact that traffic volumes are the key to the highway administrator's planned priority of improvement and to an engineering analysis as to whether improvement calls for widening or relocation, and whether or not the number of lanes should be increased.

From what has been said it is apparent that congestion is associated with increasing volume in an important way and, therefore, the detection of its first appearance and the subsequent measurement of its progressive stages is of the utmost importance. As previous experimenters and students of the subject will testify this is a difficult task, but we believe the equipment and techniques which you have seen make this possible for the first time.



Simple Portable Automatic Traffic Counters. Top: Electromagnetic Accumulating Counter with Road Tube, Detector, and Cable. Bottom: 4-Bank Electromagnetic Counter for Use in Obtaining Number of Vehicles Traveling in Each Lane of a 4-Lane Road, or in Connection with Time Clock Switch for Separating the Traffic Count into Any Four Desired Time Periods.





Portable Recording-Type Traffic Counters. Top: Photoelectric Counter Employing a Camera and Film to Record Hourly Readings. Bottom: Counter Employing a Tape to Record the Hourly Readings.

The problem then is to determine what volumes of traffic roads of different kinds can carry without objectionable congestion. In seeking this determination the capacity studies make use of the speed equipment primarily. Not only is the instantaneous value of speed obtainable with this equipment, but also the time and distance intervals between successive vehicles and, of course, the number of each type of vehicle passing the station in a given time.

In figure 1 some of the first results of these studies are shown. The vehicles were examined successively, that is, each vehicle and the one following it were treated as a pair; the time interval between each pair was determined from the record and tabulated and the difference in speed between the pair computed. When all vehicles with a separating time interval of 40 seconds were segregated and their speeds averaged, it was found to be about 39 miles per hour. As the time spacing between vehicles is reduced, the average speed remains unchanged at 39 miles per hour until the spacing falls below 10 seconds. When that point is reached the speed begins to drop as the spacings become shorter until, at a spacing of about $1\frac{1}{2}$ seconds, it is reduced from 39 to 33 miles per hour. Below that spacing the speed increases a little indicating that the following vehicles are now passing the preceding ones. It will be noted that this curve does not offer a sensitive index of congestion.

SPEED CHARACTERISTICS OF VEHICLES TRAVELING AT GIVEN TIME SPACINGS BEHIND PRECEDING VEHICLES

SECTION 3 J - 2 LANE TANGENT

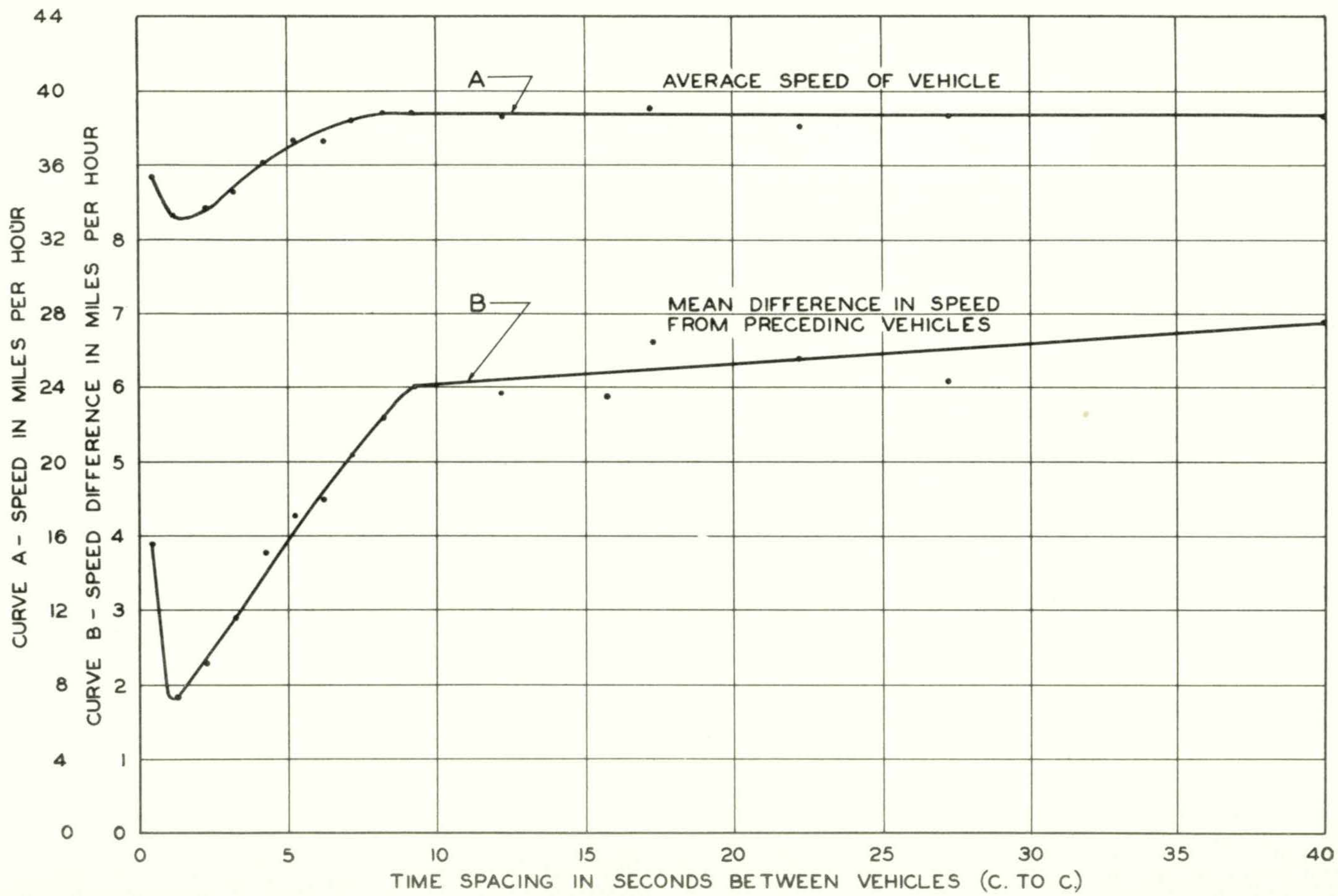


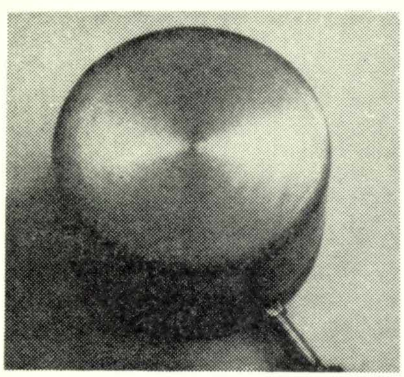
FIGURE 1

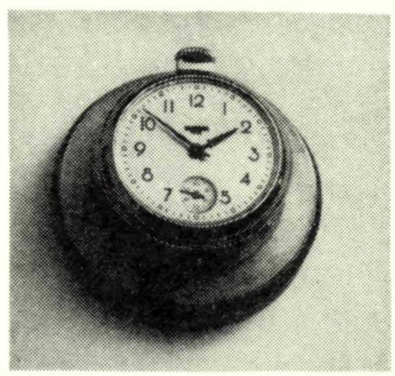
The lower curve uses the same time spacings as abscissae, but for ordinates the mean difference in speed of successive vehicles has been used. For all those in the 40-second spacing group, the mean differences in speed amounted to 7 miles per hour, and as the spacing between vehicles was reduced to 9 seconds the mean difference dropped slightly to 6 miles per hour. Further restriction in the spacing brought a pronounced decline in speed difference until at $1\frac{1}{2}$-seconds spacing it was reduced to less than 2 miles per hour, that is, one vehicle following another at this short interval is so definitely influenced by its predecessor that it is almost forced to adopt its leader's speed. This approaches the point of absolute congestion where all vehicles are forced to move at the same speed and the speed difference is reduced to zero. The sharpness of the breaks in the lower curve leads one to believe that the data, when presented in this form, provide a sensitive and critical index. It should be noted that though the curves seem to be defined by but a few points, they really result from the averages of thousands of moving vehicles.

It appears that when the time spacings have been reduced to 9 seconds, at which point the speed differences are 6 miles per hour, the lower limit of free and relatively uninfluenced movement is reached and that thereafter rapidly increasing congestion will occur. These two figures are therefore important and will be used in a later connection as an index of this lower limit of free movement.

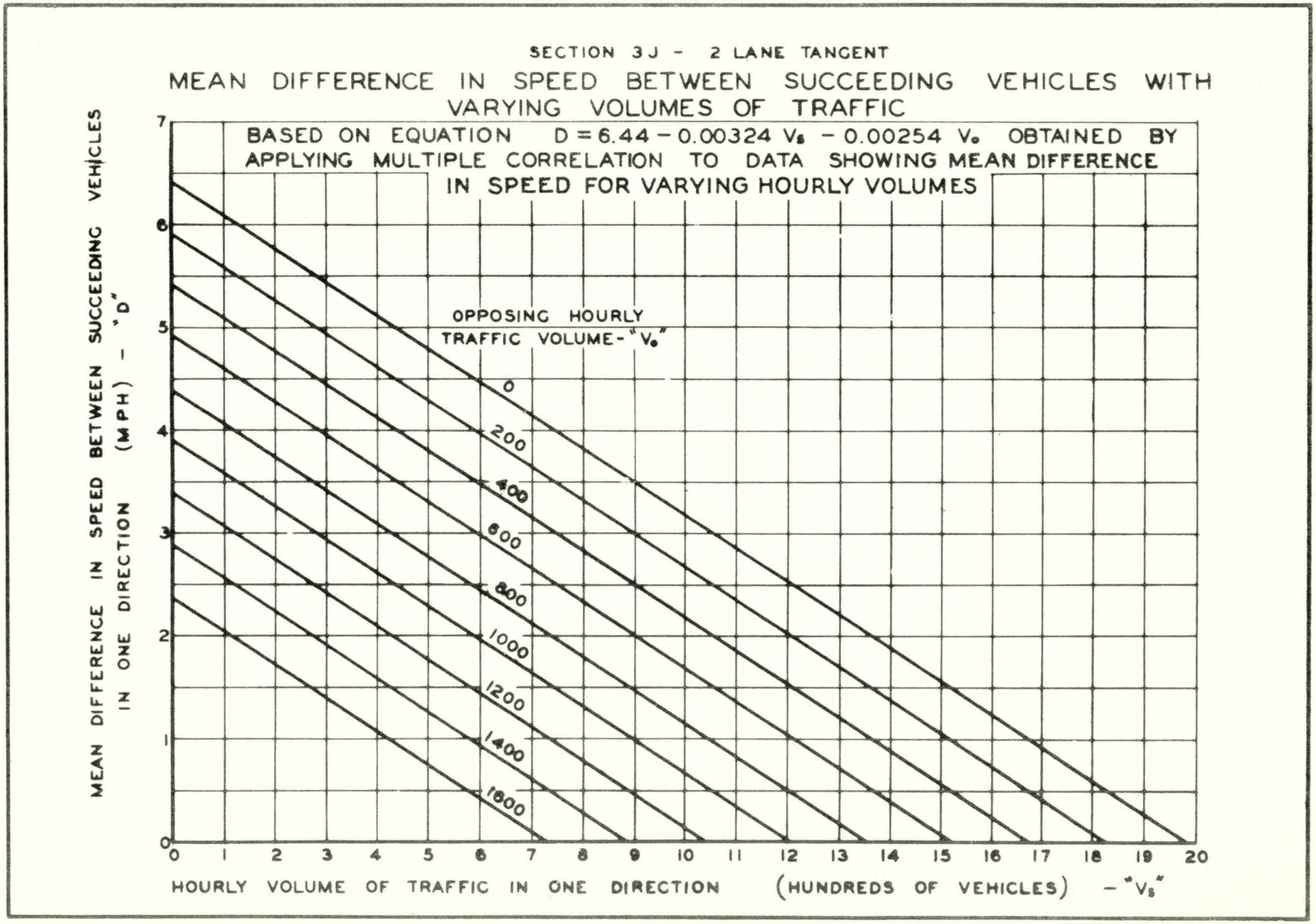
It should be stated that these data refer to but one road, a 2-lane tangent stretch, and therefore use of these significant figures in connection with other alignments and lane arrangements cannot be made without qualification.

Just one more example of how the capacity data may be used. In figure 2 they have been arranged so as to relate the hourly volume in each direction with the speed differences just discussed. Points along the topmost line all correspond to zero traffic in one direction. As we move down this line, volumes in the other direction increase while speed differences decrease. At the very bottom the speed difference falls to zero, that is, absolute congestion is reached and all vehicles are forced to move at the same speed. The hourly volume is then shown to be around 2,000 vehicles. Other combinations of hourly volumes in the two directions will likewise cause absolute congestion such as 600 and 1,500 or 1,200 and 1,050. Absolute congestion is rare, of course, and the volumes that cause it exceed any that could be used as a basis of design.





Simple Portable Mechanical Traffic Counter Employing Inexpensive Watch as the Counting Unit. Left: With Cover. Right: With Cover Removed.



SECTION 3J - 2 LANE TANGENT
MEAN DIFFERENCE IN SPEED BETWEEN SUCCEEDING VEHICLES WITH VARYING VOLUMES OF TRAFFIC
BASED ON EQUATION D = 6.44 − 0.00324 Vs − 0.00254 Vo OBTAINED BY APPLYING MULTIPLE CORRELATION TO DATA SHOWING MEAN DIFFERENCE IN SPEED FOR VARYING HOURLY VOLUMES
OPPOSING HOURLY TRAFFIC VOLUME-"Vo"
0
200
400
600
800
1000
1200
1400
1600
MEAN DIFFERENCE IN SPEED BETWEEN SUCCEEDING VEHICLES IN ONE DIRECTION (MPH) - "D"
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
HOURLY VOLUME OF TRAFFIC IN ONE DIRECTION (HUNDREDS OF VEHICLES) - "Vs"

FIGURE 2

Figure 1 showed that the traffic moved freely at nearly 40 miles per hour until such volumes were reached as to cause a reduction in speed difference to 6 miles per hour, and that thereafter increasing volumes caused a rapid increase in congestion. From figure 2 it may be seen that this point of incipient congestion corresponds to an hourly volume of less than 100 vehicles in each direction. When the volumes have increased to 400 in each direction, the differences are perforce reduced to almost 4 miles per hour; when they are 800 in each direction, differences are under 2 miles per hour; and finally absolute congestion is reached at about 1,100 vehicles per hour in each direction.

Other analyses, which are too involved to permit detailed examination in the time available here, bring out the significance of the frequency and lengths of the gaps between successive vehicles in the opposing traffic. We find for example that a vehicle passing one just ahead of it must be in the opposing traffic stream for a minimum of about $7\frac{1}{2}$ seconds. If the two streams are moving past one another at the same speed, a gap in the opposing traffic of 15 seconds must be available to the passing vehicle, provided it is able instantly to take advantage of it.

The dotted lines in figure 3 show the percent of time in which gaps of various durations are available for different hourly traffic volumes. The topmost one is for gaps 15 seconds long, or longer, and indicates that with an hourly volume of 200 vehicles in each direction, a vehicle moving in one direction is opposite gaps of at least this duration in the stream of opposing traffic for about 90 percent of the time. But it must be remembered that both the vehicle considered and the gaps in the opposing traffic are moving, and moving in opposite directions. The vehicle may be imagined as passing by the spaces or gaps, so that as it proceeds that portion of each gap ahead of it continually decreases. For purposes of passing a vehicle in its own lane, the vehicle can utilize only that portion of the gap in the opposing traffic lane that is ahead of it at the moment when passing is begun. If that portion is less than 15 seconds long a passing requiring a 15-second gap for completion cannot be safely begun. Consequently, the vehicle which is opposite gaps of 15 seconds or longer in the opposing traffic stream nearly 90 percent of the time, can actually utilize these passing gaps to begin a passing requiring a 15-second space during only a considerably smaller part of the time.

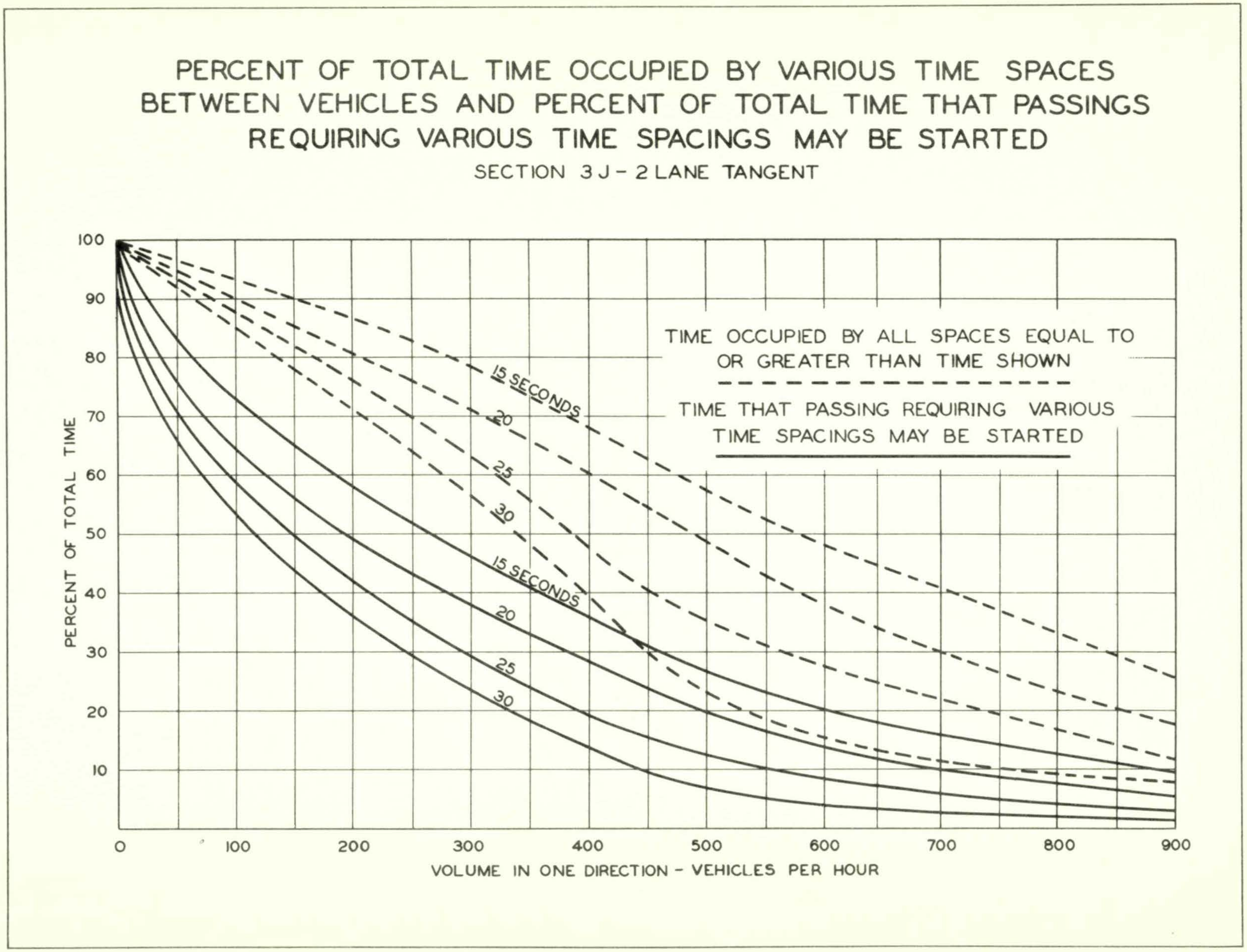

PERCENT OF TOTAL TIME OCCUPIED BY VARIOUS TIME SPACES BETWEEN VEHICLES AND PERCENT OF TOTAL TIME THAT PASSINGS REQUIRING VARIOUS TIME SPACINGS MAY BE STARTED
SECTION 3 J - 2 LANE TANGENT
TIME OCCUPIED BY ALL SPACES EQUAL TO OR GREATER THAN TIME SHOWN
TIME THAT PASSING REQUIRING VARIOUS TIME SPACINGS MAY BE STARTED
15 SECONDS
20
25
30
15 SECONDS
20
25
30
PERCENT OF TOTAL TIME
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
800
900
VOLUME IN ONE DIRECTION - VEHICLES PER HOUR

FIGURE 3

When analyzed in this light, the actual availability of 15-second gaps long enough to begin a $7\frac{1}{2}$-second passing is shown by the topmost solid line to be reduced to less than 60 percent of the time for an hourly volume of 200 vehicles in each direction. These data were gathered on tangent sections; when less favorable sight distances are involved, operators are less likely to be able to perceive and take advantage of gaps, and their actual availability for a given volume of traffic will decrease and the resulting congestion become greater.

THE PASSING STUDIES

Intimate information about passing practices is implied by the statements just made. Such detailed information is beginning to be supplied by the passing studies which you have seen demonstrated. These make use of tube detectors laid 50 feet apart over a half-mile stretch of highway. Each tube is plugged at its center so that each half of it serves as a detector for one lane. The contacts of wheels with detectors are recorded at three synchronized stations involving in all 120 recording pens. The paper charts on which the pens record move through the machines at a uniform rate so that measurements along them can be reduced to time. The presence of any vehicle moving outside its normal traffic lane is easily distinguishable from those moving in their proper lanes. This enables a continuous automatic record of the instantaneous positions of all vehicles moving in the half-mile test section.

Graphic Recorders Employed in Field Studies of Vehicle Passing Practices and Random Truck Performance.

The equipment is thus seen to provide, for the first time, accurate information of what actually takes place in a stream of moving traffic, and this is in sharp contrast to the fruits of speculation and theoretical geometry with which we have hitherto had to content ourselves.

Several States are already cooperating in the passing studies and others will later join in the work; and though the analysis of the data is necessarily slow, we should before long be able to tell how much time and distance is normally required for one vehicle to pass another and how these times and distances are affected by speed, sight distance, and other factors. The interplay of traffic volume and the frequency and length of gaps in opposing traffic streams as they affect the number of passings will also be illuminated by these studies. The special effect of highway alignment on passings will be used to determine whether certain types of alignment in themselves create hazardous driving practices.

A Group of Officials Attending the Demonstration Viewing the Operation of the Equipment Used for the Passing Practice and Random Truck Performance Studies.

Besides providing information in regard to the characteristics of passing maneuvers, the same equipment also gives promise of yielding more complete and exact information concerning the behavior of traffic and the causes of accidents than can be obtained in any other way. The records left on the charts constitute a virtually complete picture of the behavior of all vehicles passing through the half-mile test section. Some sections can be selected to represent any number of typical highway situations, with variables of curvature, grade, sight distance, pavement width, surface type, light condition, etc. With transverse placement detectors added, the record of behavior is completed; and the combined records will show exactly how every passing vehicle behaved through the test section for as long a period as may be desired. It is possible that such records may show the actual occurrence of accidents, but they will throw a powerful light upon the causes of accidents even if no accidents occur. It is the special advantage of these records that they will permit the study of potential as well as actual accidents, under conditions that admit of no dispute; and, used in this way, they are certain to prove extremely valuable in the campaign for greater safety.

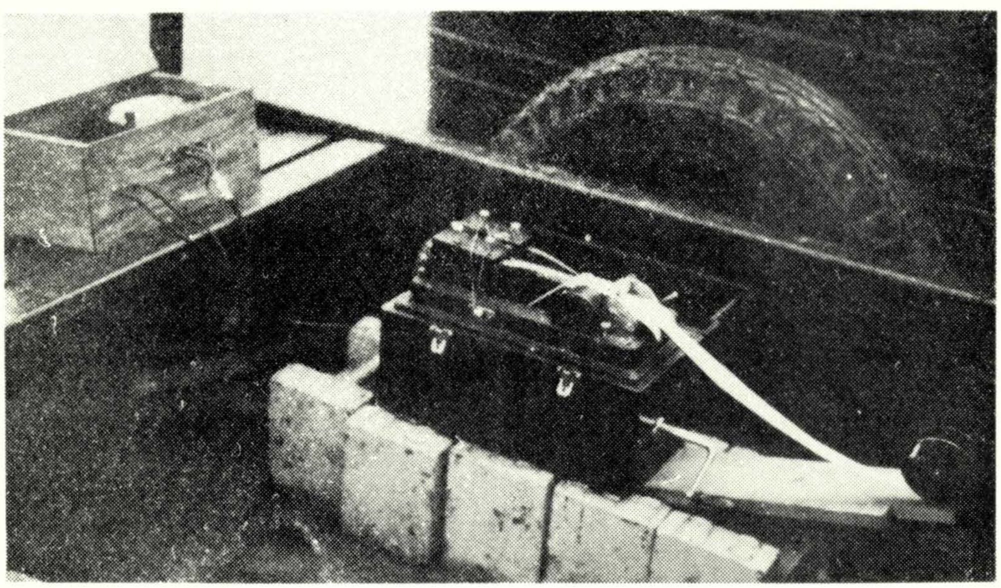
HILL-CLIMBING STUDIES

The final item of this discussion, the hill-climbing studies, has to do directly with both the efficiency and convenience of traffic movement and with safety. Nearly all rural roads today are 2-lane roads. The great majority will always remain 2-lane roads. The presence in the traffic stream on such a road of vehicles moving at speeds substantially less than the average speed of the stream, whether such vehicles be trucks or passenger cars, is a cause of inefficiency, inconvenience, and accident hazard. The problem created is a serious one, and the public is genuinely concerned.

What to do to improve matters; whether to widen the roads, or speed up the vehicles, or both; and what measures, either singly or in combination will give the greatest relief at the least total cost, are questions that require answers; and it is to these questions that the hill-climbing studies are addressed.

Overloaded Trucks Obstructing the Free Flow of Traffic and Creating Hazardous Driving Practices.

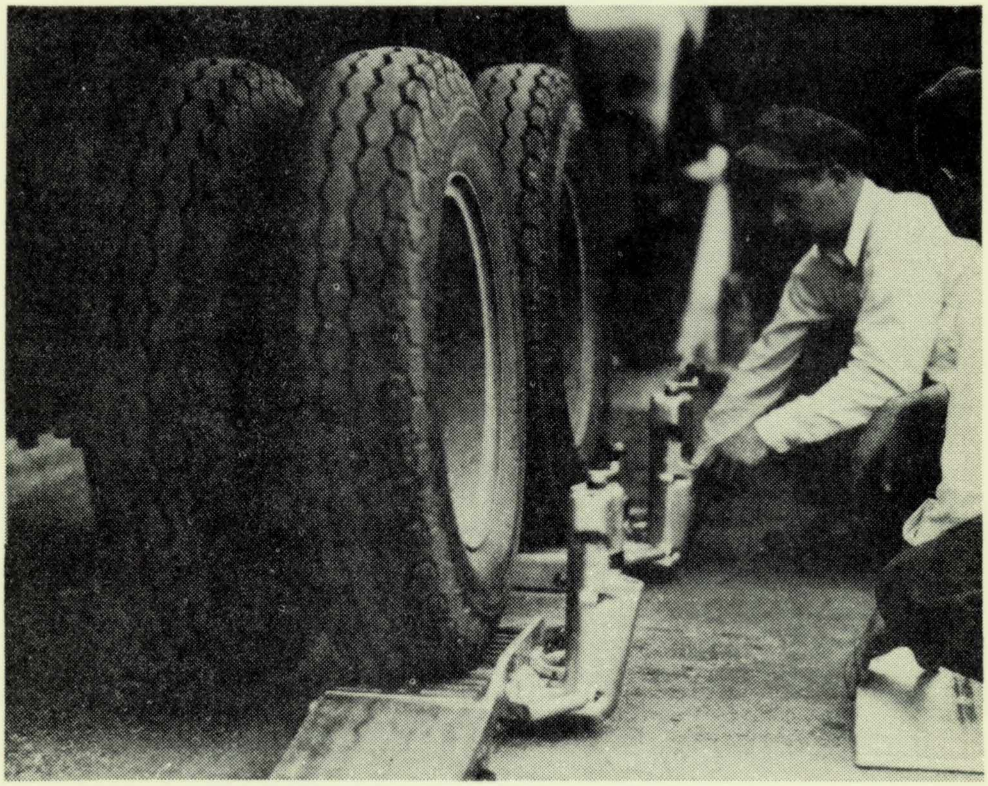
In the case of passenger cars, slow speed is usually a matter of the driver's habits or choice. The cars themselves are usually capable of higher speeds. In the case of trucks and tractor-trailer combinations, slow speed on hills is often a matter of the design or loading of the vehicles. The vehicles are capable of no greater speed under the existing conditions of load and grade, etc. To deal intelligently with the problem created by the presence of such vehicles in the traffic stream it is obviously necessary to know, within reasonable limits, the speeds of which they are capable under various grade conditions; and it was for this purpose that the hill-climbing tests were undertaken.



The Chronograph Used to Determine Instantaneous Speeds on a Grade is Mounted Behind the Cab of a Test Truck.

At the beginning of the undertaking we had only a realization of the variables involved. We believed that a material number of vehicles travelled at such low speeds, particularly on hills, as seriously to interfere with the normal movement of traffic, with attendant exasperation and resulting hazard. How many or what kind of vehicles they were, and under what conditions of grade, load, and alignment they were more prone to bog down - we did not know. Nor did we know at what minimum speed they should be capable of moving in order to improve conditions. We knew that grade, speed, and gross weight were involved as variables, but there was considerable doubt as to precisely how they were related through such factors as tractive resistance, engine power, gear ratios, mechanical efficiency, and rolling radii. We were aware that we could not base our judgment on the performance of new vehicles alone - that the effect of service wear and tear would have to be evaluated; and, finally, we realized that after all the data were studied and correlated we would still be faced with decisions as to the measures of relief to be employed.

Accordingly, a program was adopted which consisted of three major parts - the precise and detailed examination of the grade performance of a limited number of new chassis, a similar study of a number of used trucks of the same models whose record of use and maintenance would be known to us, and finally a study of the hill-climbing practice of a large number of vehicles chosen at random from the general traffic.



Truck Being Weighed After Negotiating the Grade
Selected for the Random Truck Studies.

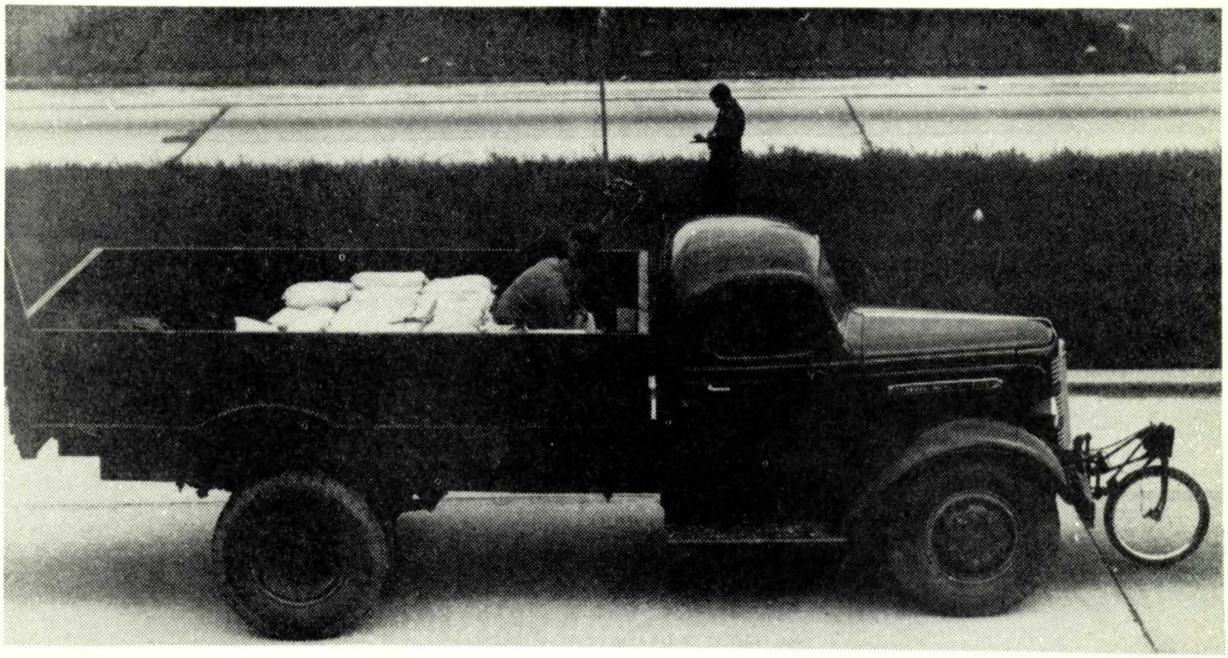
The new chassis phase, completed this summer, will serve as the basic foundation of optimum performance on which will repose our ultimate ideas of a reasonable minimum speed. The used chassis phase which is just being begun should enable us to determine the effect of use on the original or new power characteristics, and thus to modify intelligently or discount them. The random studies will reveal which vehicles move slowly, where they do it, and why they do it; and by making use of the passing study equipment on grades we will be able to record the length of the queues forming behind vehicles travelling at low speeds. A plot of the length and pattern of these queues against the speed of slow vehicles causing them will permit a determination of the resulting interference with traffic and indicate the worth and necessity of measures for the avoidance of such interference. Similarly the equipment will automatically measure added exposure to danger introduced by the formation of these queues since it is capable of recording attempts of vehicles in the queues to move ahead to more favorable positions often in the face of oncoming traffic.

Without going into much technical detail we may discuss briefly the tests we have just completed on new chassis. The first question which naturally arose in our minds and is perhaps in yours is, "Why go to all the trouble and expense of actual field tests? Surely, there must be available a means of computing from the specified characteristics of trucks, what they will do on hills." To answer this question, the automotive engineers have a formula. It is:

$$GVW = \frac{T \times 12 \times e \times R}{r\left\{\frac{g}{100} + f\right\}}$$

where: GVW = Gross vehicle weight, in pounds.
T = Torque at a given engine speed, in foot-pounds.
e = Over-all efficiency of vehicle.
R = Total gear reduction.
r = Rolling radius, in inches.
g = Percent grade, in feet of rise per 100 feet.
f = Coefficient of rolling resistance, in pounds per pound of weight.

This formula is known to be valid from the point of view of simple mechanics. It expresses the gross vehicle weight that can be carried at any given speed in terms of measurable quantities. The grade, the radius of tires, and the gear reduction are easily obtainable. The power output can be determined by putting the engine in a cradle dynamometer and developing its torque curve. We have done this for each engine in the laboratories which the authorities at Camp Holabird made available to us along with a number of other facilities.

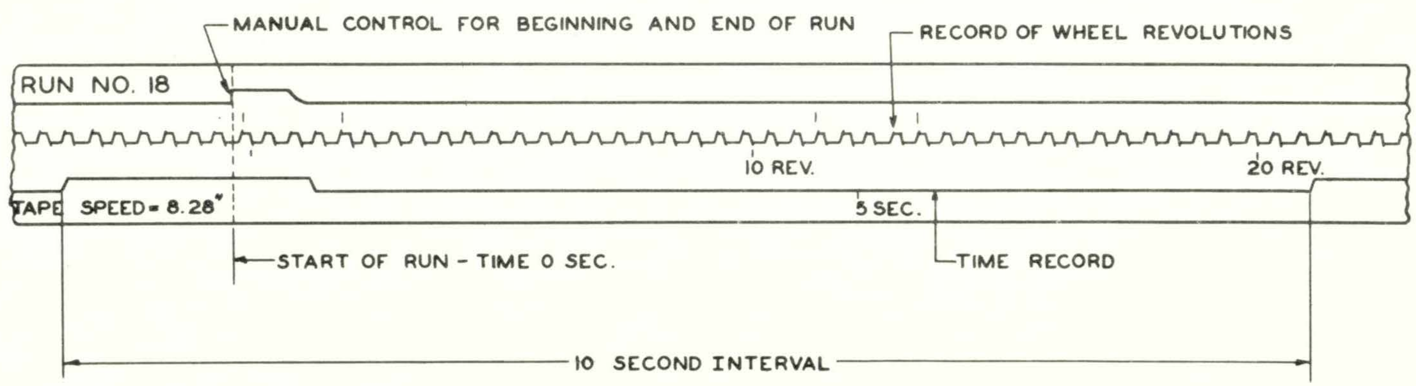


Test Truck on Grade During the
Motor Truck Grade Ability Test.

But there are two other terms which are much more difficult to measure, and which are quite variable depending upon conditions. In consequence average values have generally been assumed for them when such computations have been made in the industry. These terms are the resistance which the vehicle meets in pushing through the air and in rolling over the highway surface, and the mechanical efficiency of the transmission of the engine power to the driving wheels.

Because we were unable to discover any consensus as to the limits and variations of these terms we could not rely upon the customary average values, particularly since these new chassis tests formed the basis of our future work and a high degree of accuracy was desired. So we decided to develop empirically the relationships expressed by the formula. An important contribution of our efforts has been the incidental development of resistance and efficiency figures which, as time went on, helped us speed up our work materially, and should be of great future use to the automotive industry.

You have seen one of these vehicles being tested and understand that we find by trial the speed which can be steadily maintained up the test hill at full throttle with a known gross load. On the next run the load is varied and the changed crawl speed again recorded. This process is repeated for each available gear ratio until a series of curves can be plotted showing the variation of speed with load for each gear. The load is, of course, a function of the number of sand bags on the vehicle, while its speed and the consistency with which it is maintained is obtained from an office analysis of the fifth wheel chronograph record shown in figure 4.

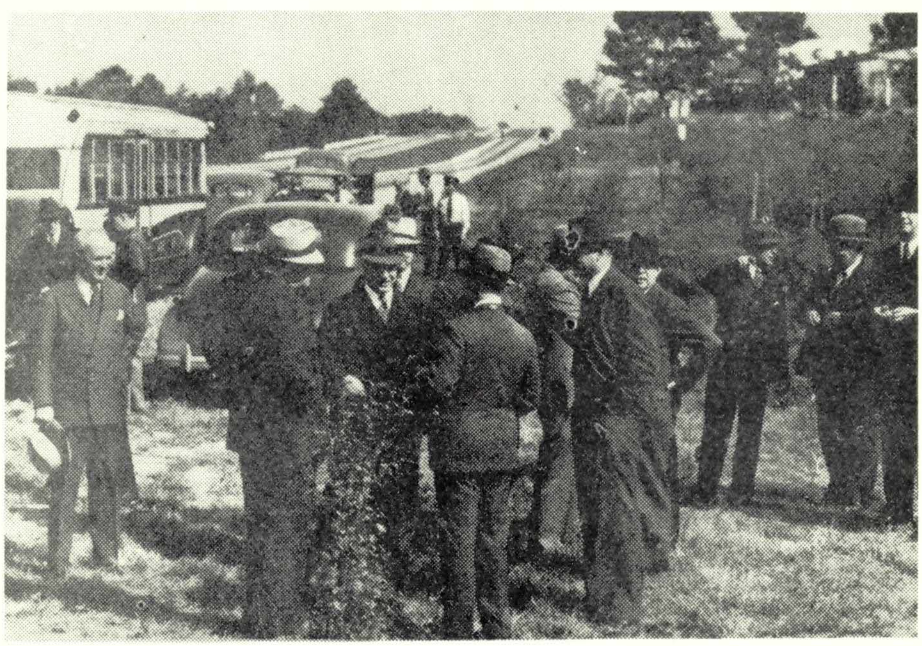


CHRONOGRAPH TAPE RECORD

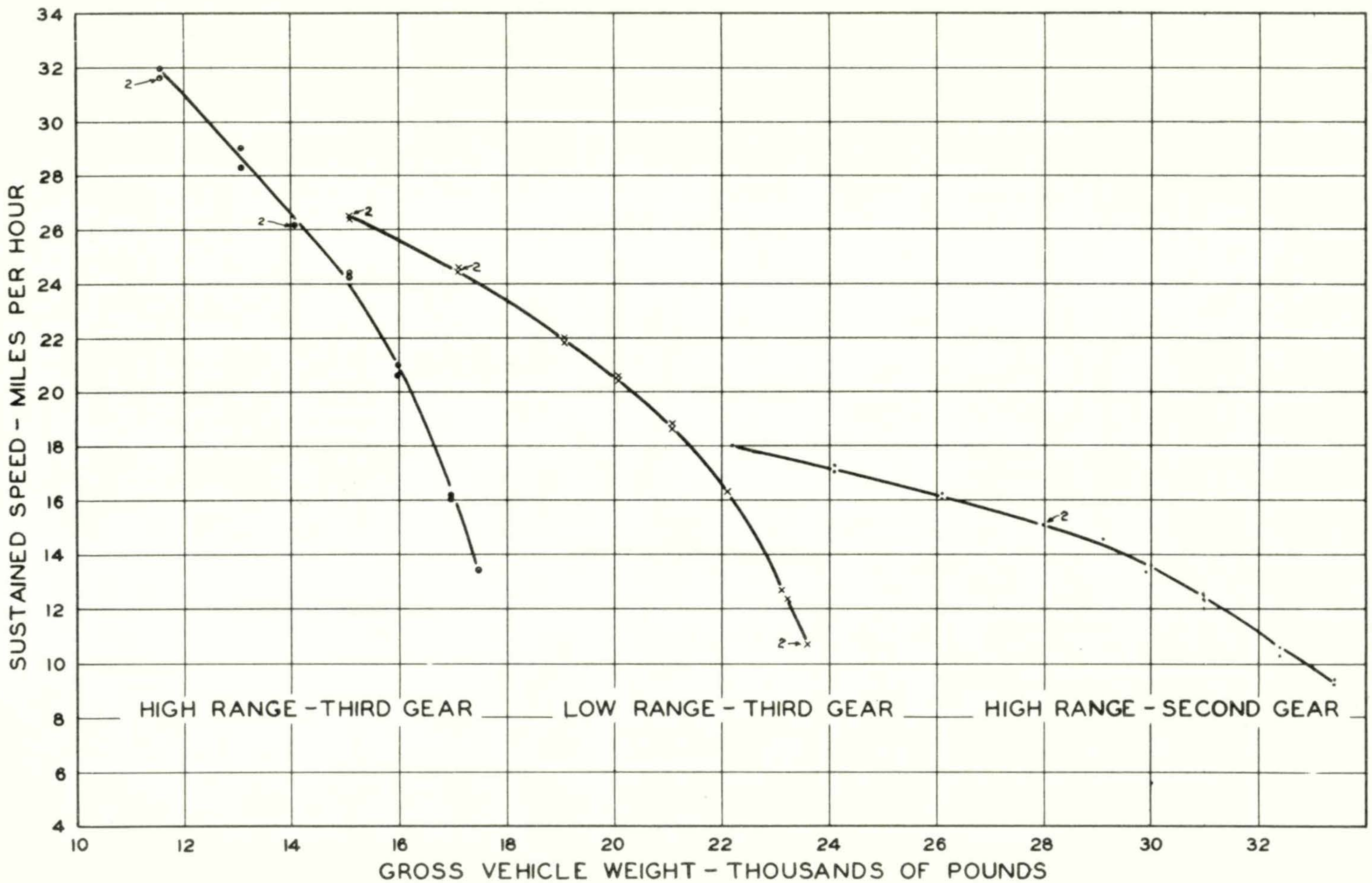
FIGURE 4

Figure 5 shows a typical set of these speed-load curves for one of the chassis on a $4\frac{1}{2}$-percent grade. From it we see that if a speed of 20 miles per hour was desired on this grade, its high-range second gear would be useless; it would use its low-range third gear and could carry a little over 20,000 pounds gross at the desired speed.

But while such information is of special interest to the manufacturer of that particular vehicle, we were concerned with a more general use of the data. We therefore grouped together the light, medium, and heavy chassis and rearranged the data as shown in figure 6 which is for light trucks only, that is, trucks with a rated capacity of $1\frac{1}{2}$ tons. From it we can see at a glance the interrelationship of grade, speed, and gross load.



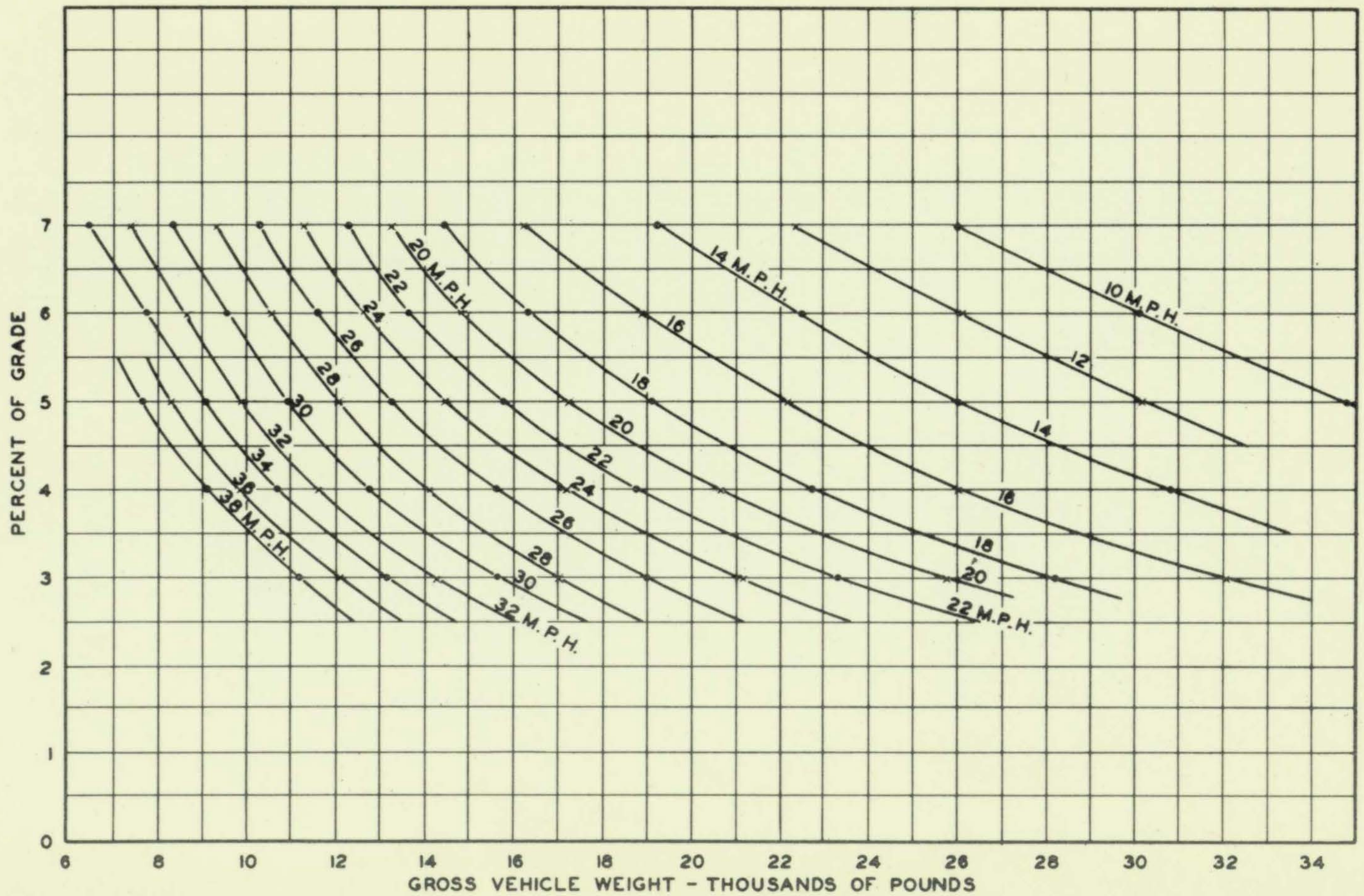
A Few of the Officials that Attended the Field Demonstration of Equipment Used for Driver Behavior and Vehicle Performance Studies.



PERFORMANCE OF TYPICAL TRACTOR TRUCK WITH SEMI-TRAILER ON 4.5% GRADE - WITHOUT GOVERNOR

AT STANDARD ATMOSPHERIC CONDITIONS

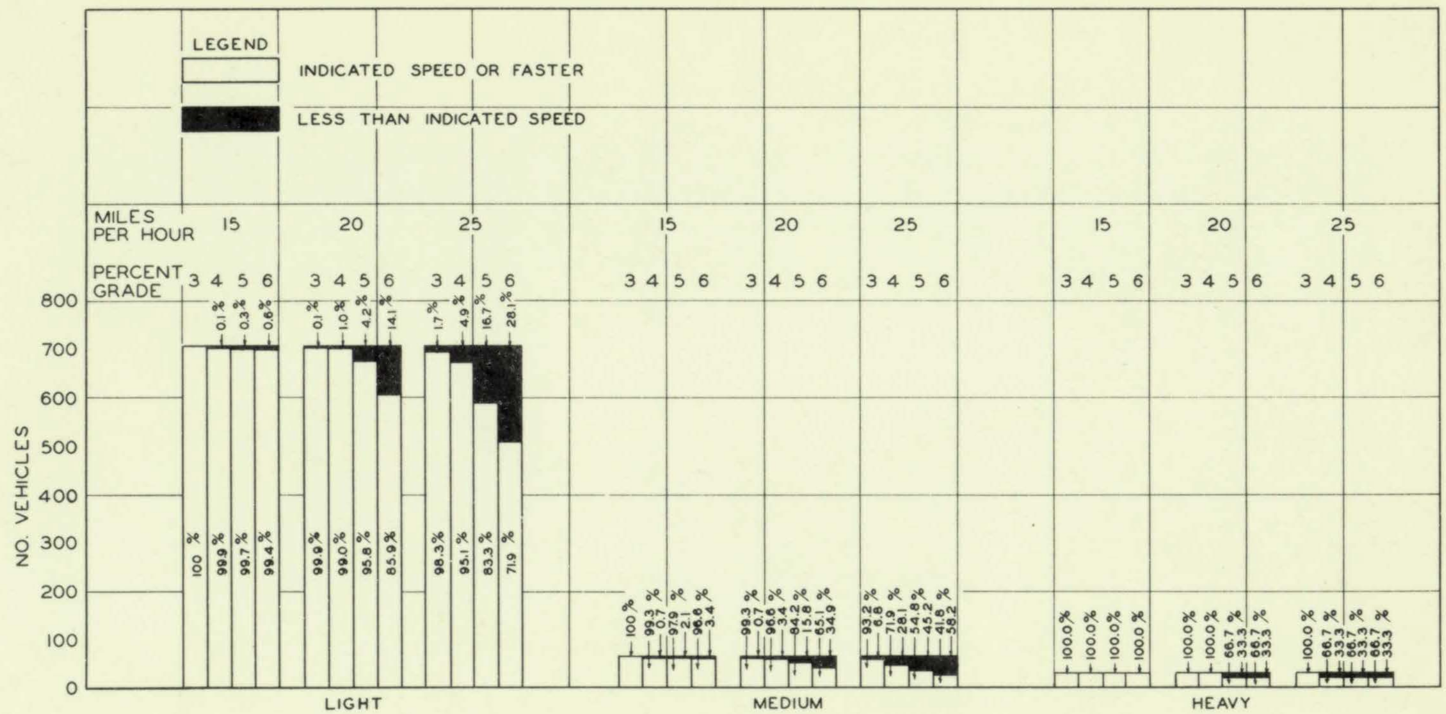
FIGURE 5



GRADE ABILITY OF LIGHT TRUCKS AND TRACTOR - TRUCKS (WITHOUT GOVERNOR)

FIGURE 6

The manner in which this and related information may be used in arriving at reasonable performance standards and in correlating these standards with highway design and motor vehicle operation may be illustrated by the following which is offered merely as an example. A section of U S 1 between Richmond and Fredericksburg was considered, a distance of about 50 miles. The data gathered at planning-survey weight stations give the number of trucks in the light, medium, and heavy classes involved in average daily traffic. They also give the average weights carried by each class. Knowing the abilities of vehicles in each class from the data in the diagram just shown, it is possible to picture in figure 7 the speed of which these vehicles would have been capable. Note that these are trucks, not tractor trucks and semitrailers. Note also that, because no information is yet available for used trucks, these figures are based on the optimum performance of new trucks.



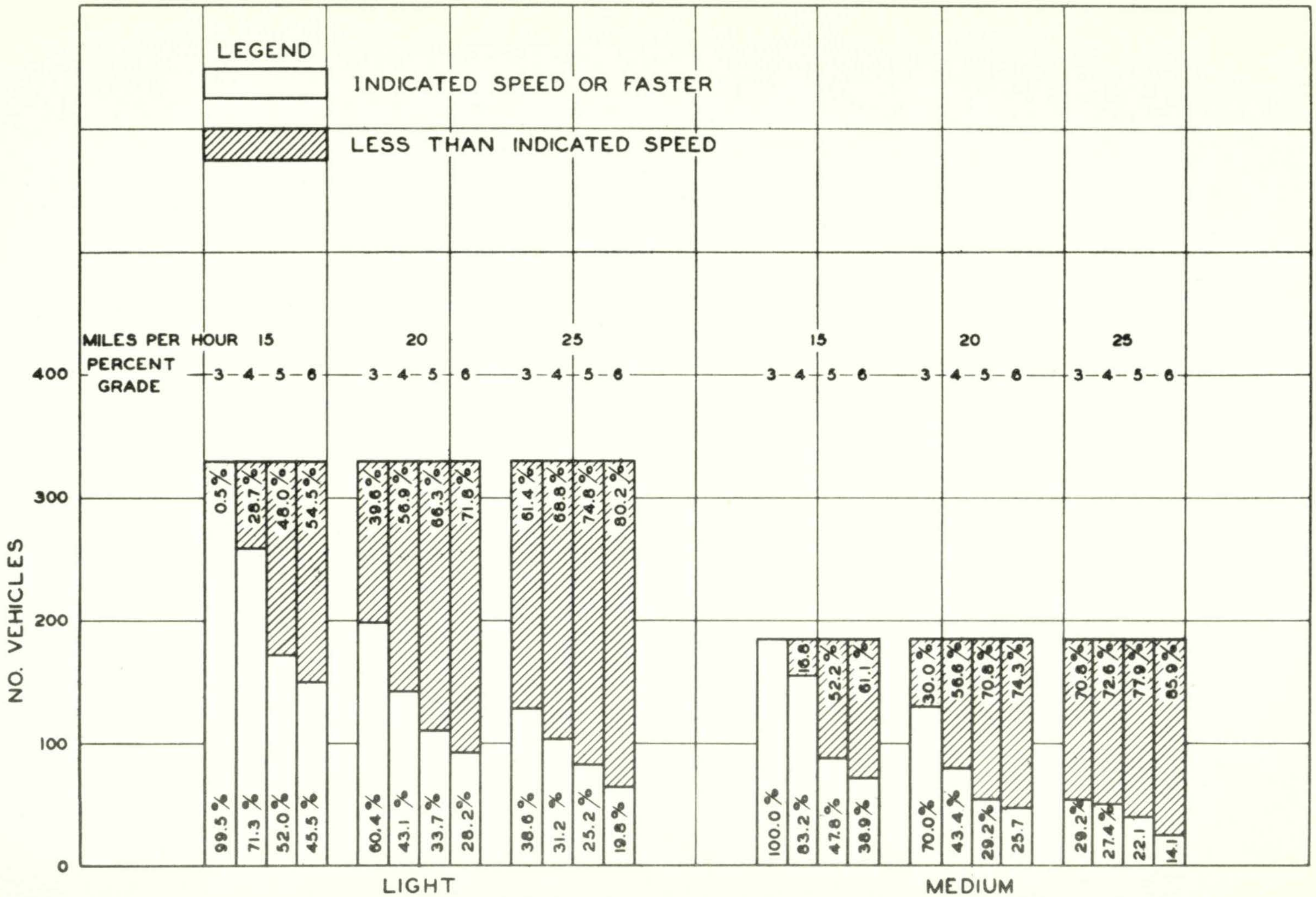
GRADE ABILITY OF SINGLE UNIT TRUCKS
24 HOUR DAILY AVERAGE TRAFFIC BETWEEN FREDERICKSBURG
AND RICHMOND, VA. ON U. S. ROUTE 1

FIGURE 7

From figure 7 we see that all the light trucks included in the traffic on this road would have been capable of a speed of at least 15 miles per hour on the 3-percent grades, had all of them retained the power they possessed as new trucks. Few would have been reduced to less than 15 miles per hour, even on grades as steep as 6 percent. Only a few of these trucks would have been reduced to less than 20 miles per hour on 3- and 4-percent grades, and only a few more to less than that speed on 5 percent grades. On 6-percent grades a substantial percentage of the total number would have been incapable of 20 miles per hour. On this grade 14 percent would have been unequal to that minimum speed. While this percentage may not appear large, it must be recognized that the light trucks, as a class, constitute about 80 percent of the total number of trucks on this road, so that, of the total of 124 trucks that would be incapable of 20 miles per hour, 100 or 81 percent were light trucks. As would be expected, the third group of bars representative of the light trucks shows that somewhat larger percentages of the total numbers would have been incapable of a speed of at least 25 miles per hour on the several grades, rising to as many as 28 percent for 6-percent grades.

The general patterns of the bar charts representative of the medium and heavy truck groups are much the same as for the light groups, except that the percentage of these larger vehicles incapable of each minimum speed on the several grades is somewhat larger than in the case of the light trucks. But, even so, the actual numbers of the heavier trucks unable to make the several desired speeds is far less than those of the light vehicles similarly incapable.

Figure 8 shows the same kind of information for tractor trucks and semitrailers. It will be seen at once how vastly different the light group looks when contrasted with the light trucks. Here large percentages are deficient for all but the least requirements. Nearly half of them could not negotiate a 5 percent grade at even 15 miles per hour. On a percentage basis the medium tractors are even worse off, though because of their relatively smaller number they actually produce many less deficiencies.

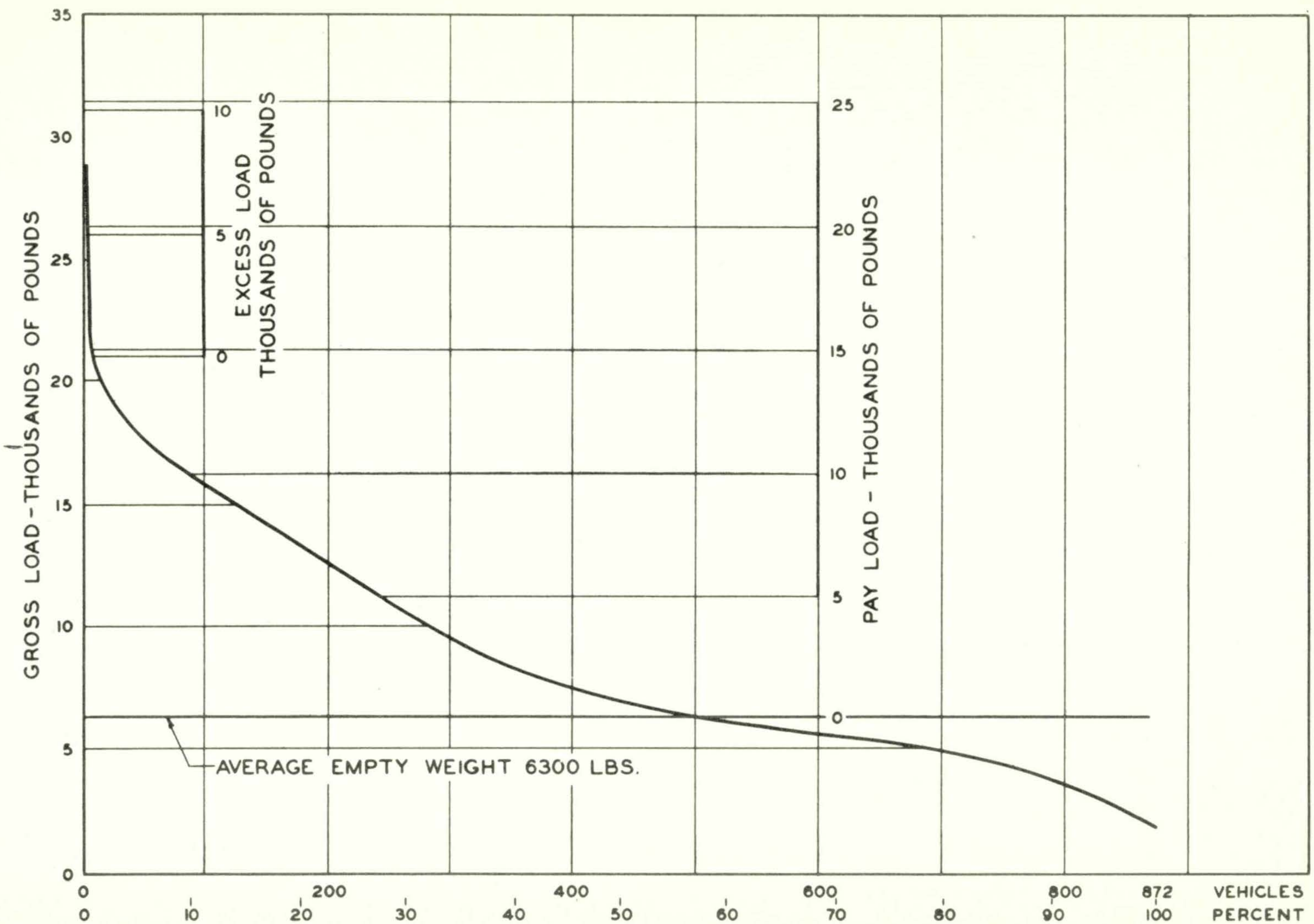


GRADE ABILITY OF TRACTOR TRUCK SEMI-TRAILER COMBINATIONS
24 HOUR DAILY AVERAGE TRAFFIC BETWEEN FREDERICKSBURG
AND RICHMOND, VA. ON U. S. ROUTE 1

FIGURE 8

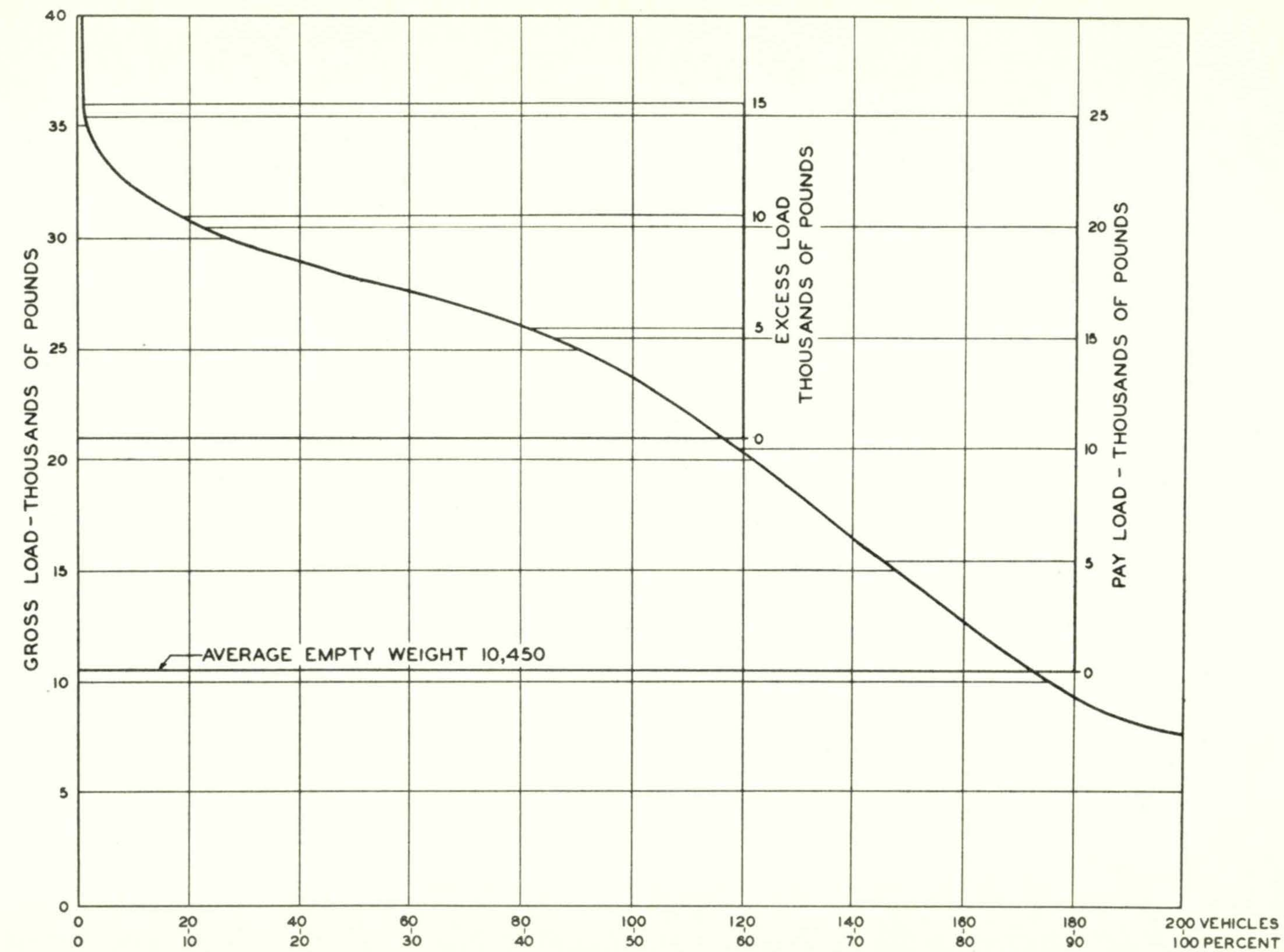
Figure 9 shows how the information derived from the truck tests may be used in the field of the economics of truck operation. This figure presents a frequency distribution curve of gross weights as actually measured at the weighing stations on the Richmond-Fredericksburg road. From it one sees that about 60 percent of the light trucks on this route are loaded and 40 percent empty; that 40 percent have gross weights of 8,000 and pay loads of less than 2,000 pounds; that 20 percent have gross weights of 13,000 and pay loads of 7,000 pounds, and so on. Since from the truck performance tests we know that not even new models in this light class can carry more than about 21,000 pounds gross on a 4-percent grade at 20 miles per hour, anything over that figure is an excess which would have to be avoided if it were desired to operate at such a speed on grades of that percentage. Of course, this is merely an example of use; any other level of performance may be imagined. Note that about 10 or only 1 percent of these light trucks carried excessive loads as measured by this standard.

Figure 10, however, shows that a very different situation prevails with respect to the light tractors on this route. It shows that they travel much less frequently empty, since only about 14 percent of them are unloaded as against 40 percent in the previous class. Also, we see that instead of 1 percent, nearly 60 percent would have had to reduce their loads in order to qualify, were they required to perform at 20 miles per hour on a 4-percent grade.



AVERAGE PAY LOAD AND EXCESS LOAD FOR LIGHT TRUCKS ON 4% GRADE AT 20 M.P.H.
U.S. ROUTE 1 BETWEEN RICHMOND AND FREDERICKSBURG, VA.

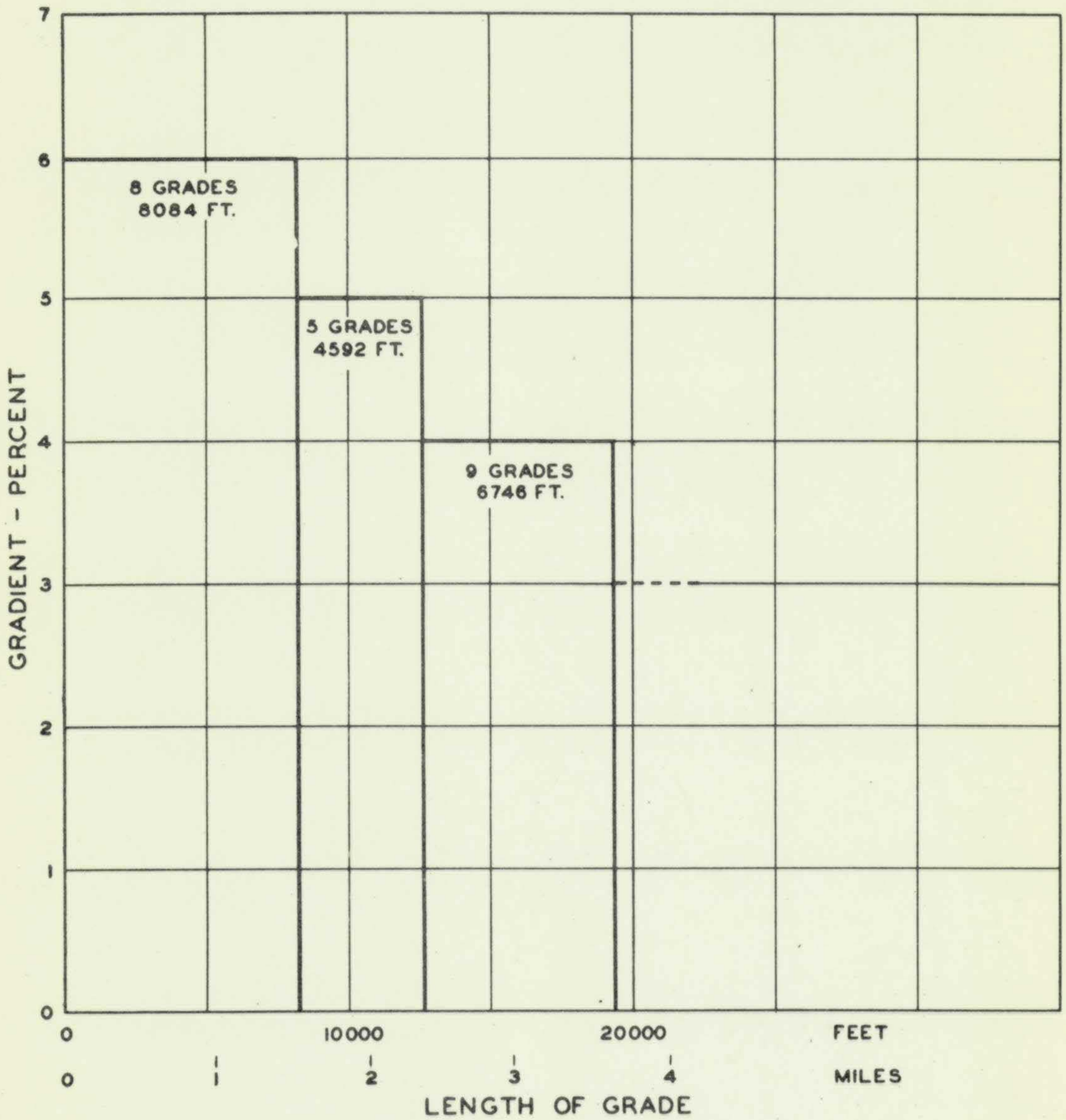
FIGURE 9



AVERAGE PAY LOAD AND EXCESS LOAD FOR LIGHT TRACTOR TRUCK SEMI TRAILER COMBINATIONS ON 4% GRADE AT 20 M. P. H.
U. S. ROUTE 1 BETWEEN RICHMOND AND FREDERICKSBURG, VA.

FIGURE 10

Of the 52 miles from Richmond to Fredericksburg more than $3\frac{1}{2}$ miles consists of stretches of at least 500 feet on grades of 4 percent or greater. (See fig. 11.) More than 2 miles of the route is made up of grades of 5 percent or more in sections 500 feet or longer, and $1\frac{1}{2}$ miles is composed of 6-percent grades of at least 500-foot length. If reduction of grades were contemplated as a means of improving the speed performance of the trucks and tractors using this route, these data would give an idea of the extent of the reconstruction that would be necessary. It is easy to imagine how this simple concept could be elaborated to show in cubic yards of excavation or in dollars of cost the magnitude of the road construction cost involved.



APPROXIMATE LENGTH OF GRADE
EXCEEDING VARIOUS GRADIENTS

(INCLUDING ONLY GRADES 500 FT. OR MORE IN LENGTH)
U.S. ROUTE 1 - RICHMOND TO FREDRICKSBURG, VA.
52 MILES

FIGURE 11

ATTENDANCE

Demonstration of Driver Behavior and Vehicle Performance
Baltimore, Maryland, October 26 & 27, 1939

Motor Truck Committee, A.M.A.

- Chairman, Black, Robert F., President, The White Motor Company.
- Babcock, I.B., President and General Manager, General Motors Truck and Coach Division, Yellow Truck & Coach Manufacturing Company.
- Butler, Arthur C., Secretary, Motor Truck Committee.
- Fenner, David C., Vice President, Mack-International Motor Truck Corporation.
- Fish, W. E., Manager, Commercial Car Department, Chevrolet Motor Division, General Motors Corporation.
- Moulder, P. V., Motor Truck Sales Manager, International Harvester Company.
- Page, Robert P., Jr., President, The Autocar Company.

Automotive Safety Foundation

- Damon, Norman, Director.
- Hoffman, Paul G., President, The Studebaker Corporation

Automobile Manufacturers Association

- Cope, James, Secretary, Public Relations Committee.
- Johnson, Pyke, Executive Vice President
- McGaughey, Wm. H., Editor, Automobile Facts.
- Romney, George W., Manager, Detroit Office.

Engineers, Other Representatives of Motor Truck Companies, and Guests

- Bachman, B. B., Vice President, The Autocar Company.
- Bishop, T. S., Engineering Department, Mack-International Motor Truck Corporation.
- Bock, Carl J., General Motors Truck and Coach Division, Yellow Truck & Coach Manufacturing Company.
- Cass, Robert C., Ass't Chief Engineer, The White Motor Company.
- Coale, H. M., Vice President, The Autocar Company.
- Conway, W. C., The Studebaker Corporation (New York)
- Cunningham, H. M., Ford Motor Company, Alexandria, Virginia.
- Green, George A., Vice President, General Motors Truck & Coach Division, Yellow Truck & Coach Manufacturing Company.
- Horner, F. C., Assistant to Chairman, General Motors Corporation.
- Jeffries, S. A., Chief Truck Engineer, The Studebaker Corporation.

Josephs, L. C., Jr., Vice President-Chief Engineer, Mack Manufacturing Corporation (Allentown, Pa.)

Kynoch, C. W., Motor Truck Engineer, Dodge Division, Chrysler Corporation.

Lautzenhiser, Fred B., Transportation Engineer, International Harvester Company.

Morrison, R. L., General Manager, Bendix Westinghouse Automotive Brake Company.

Orphal, Geo. A., Assistant Director of Sales, Dodge Division, Chrysler Corporation.

Powell, E. E., Black and Decker Company.

Reese, W. D., Chief Motor Truck Engineer., International Harvester Company.

Schamehorn, A. J., Director, General Motors Proving Ground.

Winans, E. W., Chief Engineer, Federal Motor Truck Company.

Wuerfel, R. B., Engineering Department, Chevrolet Motor Division, General Motors Corporation.

American Automobile Association	Allgaier, Earl, Washington Marsh, Burton, Washington
American Road Builders Association	Upham, Chas. M., Washington
Association of American Railroads	Feldman, E. R., Washington
Highway Education Board	James, Stephen, Washington
Interstate Commerce Commission	Blanning, W. Y. Kelly, H. H.
Motor Vehicle Officials	Elgin, W. Lee, Maryland Georger, R. C., New York Morony, Louis R., Secretary, Association of Motor Vehicle Commissioners Schroeder, D. Marshall, Maryland
National Bureau of Standards	Bruce, C. S.
National Education Association	Hubbard, Dr. Frank W., Washington
National Highway Users Conference	Gray, Chester H., Washington
National Safety Council	Baker, J. S., Chicago

Society of Automotive Engineers	Blanchard, Donald, New York Warner, John A. C., New York
State Highway Departments	Ballard, Wilson T., Maryland Childs, W. F., Maryland Cutler, T. H., Kentucky Kennedy, D. D., Maryland Lewis, G. N., Jr., Maryland Mack, W. W., Delaware Ruthowski, W. J., Maryland Van Wagoner, M. D., Michigan
War Department	Atwell, Maj. Richard N. Johnson, Maj. W. B. Lawes, Lt. Col. H. J. Smith, Thomas W.
Yale University	DeSilva, Dr. Harry R.
Federal Works Agency	Allen, Forrest, Chief, Information Division
Public Roads Administration	MacDonald, Thos. H. Commissioner Hewes, Dr. L. I., Chief, Western Region
Division of Highway Transport	Coffman, S. F. Craig, R. E. Hilts, H. E. Holmes, E. H. LaBell, O. J. Montgomery, R. A. Normann, O. K. Prisk, C. W. Saal, C. C. Taragin, Asriel Tuttle, L. S. Walker, W. P. Werner, R. A.
Division of Information	Fairbank, H. S., Chief Hillers, J. K. Royall, R. E.

Division of Tests	Kelley, E. F., Chief Gemeny, A. L. Reymer, S. E. Teller, L. W.
Division of Design	Toms, R. E., Chief Barnett, Joseph
Research Specialist	Thompson, Prof. J. Trueman Professor of Civil Engineering, Johns Hopkins University