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PART I

OVERTAKING AND PASSING REQUIREMENTS AS DETERMINED FROM A MOVING VEHICLE

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SYNOPSIS

By photographic methods observers in a moving car were able to measure the times required by cars overtaking them to pass under various conditions.

It was found that drivers varied widely in the speeds, distances, and times which they needed to overtake and pass another vehicle. Distance needed increased with speed. At 30 miles per hour 650 ft. were required and at 50 miles per hour 1,050 ft. were required by the average driver (median values). In order to take in 80 per cent of the drivers approximately 1,200 ft. would be required at 50 miles per hour for an accelerative type of pass.

The total time required to overtake and pass also increased somewhat as speed increased. Thus, at 30 miles per hour the average driver took 8½ sec. and at 50 miles per hour 9½ sec. to complete an accelerative type of pass (median values). The time varied from a minimum of 6 sec. to a maximum of 20 sec. in individual cases at speeds from 30 to 50 miles per hour.

From the safety point of view it is of interest to see what clearances were allowed by the passing drivers both to the rear and to the front of the vehicle being passed. The clearance to the rear showed a median value of 45 ft. at 50 miles per hour in the accelerative type of pass, and the clearance to the front showed a median value of about 60 ft. However, some drivers approached as close as 10 ft. to the rear and cut in as close as 30 ft. in front of the overtaken vehicle at 50 miles per hour.

The clearance distances were found to be shorter in the New England area, where crooked and hilly roads are the rule, than they were in the open country of the west and midwest, where fairly long clear distances predominate. The drivers in the first area were apparently induced to pass under conditions which were considered hazardous by the drivers in the areas where longer clear distances were frequently available. Thus the importance of providing sufficient clear sight distance on highways is demonstrated.

Those who are charged with the responsibility of designing new highways or redesigning for the improvement of alignment on existing highways are especially concerned with the requirements of overtaking and passing manoeuvers since such measurements furnish a measure of adequate sight distance. Since the great bulk of traffic operation is carried out on 2-lane highways, the problem of adequate passing sight distance becomes especially important in the design of the alignment features of these roads.

PREVIOUS STUDIES

Perhaps the first definite steps taken in recognition of the hazards attendant to overtaking and passing were the drafting and adoption of regulations by various state legislatures which prohibited motorists from overtaking and passing unless certain clear paths were available at the time and place when such manoeuvers were carried out. Unquestionably, factual data concerning the requirements for such manoeuvers were lacking for the preparation of such regulations. This is manifest by a review of vehicle laws in the various states which show a range of prohibition varying from 150 ft. in Arizona to as much as 1000 ft. in Wisconsin.

Other investigators became interested in this problem as early as 1934 and made estimates of the time and distance requirements for overtaking and passing

[1] Bryant R. Burkhard assisted with the photography.

(1) (2) (3).[2] The results arrived at by these previous investigations did not accurately reflect the actual performance of the public and their vehicles under the usual circumstances of operation upon the public ways. In some, certain assumptions were made on driver and vehicle performance; in others, only a relatively few vehicles and drivers acting under specific instructions were involved, while in yet others the complete manoeuver was deduced from a large number of actual cases wherein only a small proportion of the entire manoeuver was recorded, while still others arrived at their conclusions on a completely a priori or computed basis.

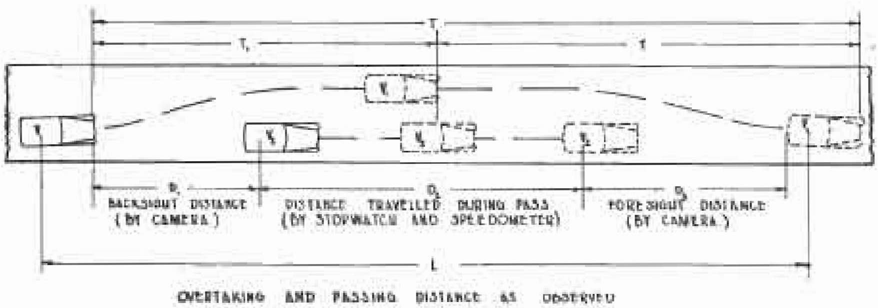

Figure 1. Technique for Measuring Overtaking and Passing Distances

BASIS OF PRESENT INVESTIGATIONS

It was felt that the best way in which overtaking and passing requirements could be determined was by the measurement of the actual performance of drivers found operating on the highway since, admittedly, there is a wide variation among drivers and vehicles.

A new method of investigation was developed, therefore, which could be applied on the open highway under normal driving conditions. This has been described in detail previously (4). Observations were made from a moving vehicle which was overtaken by the vehicle under observation. Distances to the rear and front of the overtaken vehicle at the beginning and end of the manoeuver were obtained by photographic adaptation of stadia methods. (See Fig. 1.) A rapid, serial, snapshot camera was used for recording the distances projected by the tread dimensions of the overtaking vehicle. Because of the approximate uniformity of tread dimensions, errors which arose were negligible insofar as the total distance required for overtaking and passing was concerned. The distance through which the overtaken vehicle moved during the manoeuver was obtained by calibrated speedometer and stop watch. Other pertinent data were recorded by observations entered on a prepared form. Approximately 800 observations were made of as many different drivers and vehicles on highways throughout the New England, mid west, and far west areas.

ANALYSIS INTO TYPES OF PASSES

There are two major types of overtaking and passing manoeuvers which may be derived naturally from conditions under which the passes were made. In the first class, will be found the "flying" type of manoeuver, wherein the overtaking vehicle proceeds at constant or nearly constant speed so as to complete the entire pass without slowing down. In the second class, will be found the

[2] Figures in parentheses refer to list of references at end.

type of manoeuver which may be defined as the "accelerative" type, wherein the overtaking vehicle is following behind the overtaken vehicle and by acceleration increases its speed so as to complete the pass.

In both the flying and accelerative types of manoeuver a further classification arises from the manner in which the overtaking vehicle returns to the right half of the roadway. Due to oncoming traffic or short visibility distance the return may be hurried or "forced." Accordingly, both the flying and accelerative types have been further subdivided into forced return and voluntary return.

Figure 2. Flying Pass with Forced Return. Top—Start of Pass, View to Rear from Observation Vehicle. Bottom—Completion of Pass, View to Front Showing Forced Return Due to Counter Traffic.

The general method which was followed in the analysis of the data classified all passes into these four types; 1, flying-forced (Fig. 2); 2, flying-voluntary; 3, accelerative-forced; 4, accelerative-voluntary (Fig. 3).

Analysis of the data showed that the speed of the overtaken vehicle was a controlling element in practically all values of time and distance. Hence, it became necessary to distribute the observations by speed classes ranging by ten mile intervals from 10 to 50 miles per hour. These were the speeds of the overtaken vehicle and should not be confused with the speed of the overtaking vehicle.

Figure 3. Accelerative Pass With Voluntary Return. Top—Start of Pass (View to rear of observation vehicle, showing overtaking vehicle beginning to accelerate after waiting for counter traffic). Bottom—Completion of Pass. (View to front showing free return.)

It further developed that in each speed range for each type of pass there is a rather wide distribution of values. Accordingly, the data are shown in the form of frequency distributions in order to interpret better the values which were obtained. (See Fig. 4.)

Because of the wide range of values and because of the assymetry and lack of continuity found in the distributions, the median was selected for comparative purposes rather than the arithmetic mean. It is generally recognized that the median is preferable where such characteristics prevail.

SPEED DISTRIBUTIONS

A total of 795 completed passes were observed. The speed distribution of these observations, as a whole, was comparable to the usual curve of speed distribution on state highways. The modal value was 40 miles per hour, and the percentage of observations falling at other speeds was nearly congruous with the distribution of speed values shown for a single state in a recent study (5) of speeds on Connecticut highways.

GENERAL SUMMATION OF OVERALL DISTANCES

All passes of passenger vehicles were distributed into the four basic types which included both male and female drivers in the three geographic areas of investigation. This summary is shown in Figures 4 and 5. It will be noted that the median values of overtaking and passing distances fall approximately on a straight line. The values for 30 and 50 miles per hour are given in Table 1. Thus, it is seen that there is only a slight difference between the distances required for the accelerative and flying passes of the voluntary return type. Contrary to expectation, the flying type requires slightly longer distance. A similar situation holds for the forced passes, but the difference decreases at higher speeds.

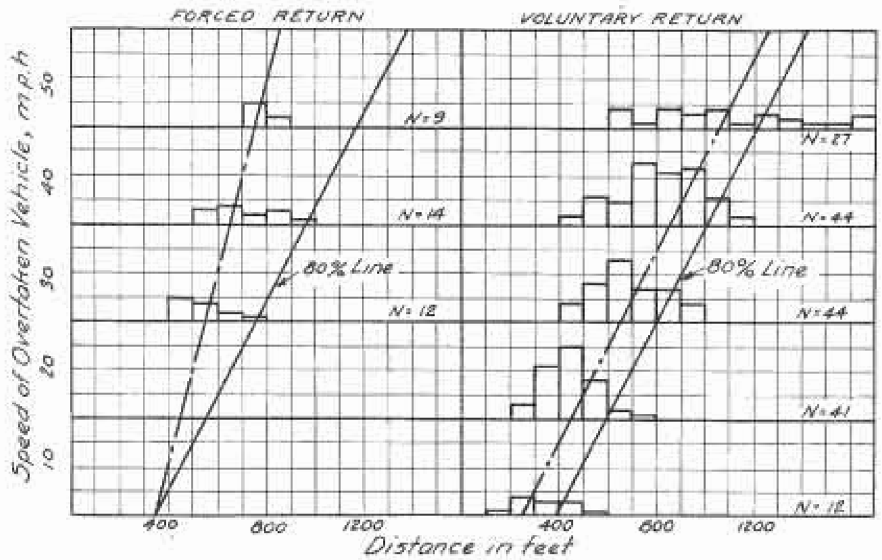

Figure 4. Distance Required to Overtake and Pass, Flying Types, All Areas, All Drivers

Attention is further called to the fact that the 80 percentile value of the voluntary type of manoeuver will provide for the large majority of forced passes in both the accelerative and flying types. The use of the 80 percentile values arose from an analysis of clearance times allowed by drivers (6). In this analysis it was found that if a clearance between a vehicle completing the pass and an oncoming vehicle was placed as low as 1 sec. as a common sense minimum safe clearance, approximately 20 per cent of the drivers who attempted a pass in the face of oncoming traffic operated with less than this time clearance value. In fact, 10 per cent or half of these operated with no measurable time clearance or in other words actually forced the oncoming driver to give way on his half of the roadway. This left only 10 per cent who operated with a clearance of 1 sec. or less, and the 80 per cent who operated within apparently reasonable judgment distance required by 80 per cent of drivers at any given speed. Inasmuch as these 80 percentile values practically enveloped the large majority of forced passes in both categories, the practicability of 80 percentile distances is demonstrated.

OVERALL DISTANCES—MALE DRIVERS

Further analysis of distances and time values seemed desirable and in order to eliminate as many variables as possible,

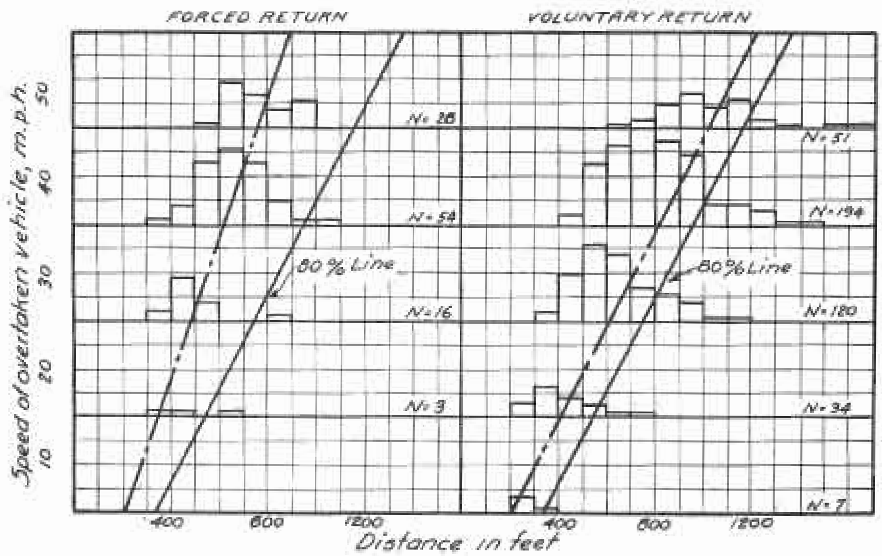

Figure 5. Distance Required to Overtake and Pass, Accelerative Type, All Areas, All Drivers

showed a time clearance value of more than 1 sec.

In parallel fashion it seemed in order to determine the overtaking and passing

TABLE 1

COMPARISON OF OVERALL DISTANCES*

(All Drivers—All Areas—Passenger Vehicles)

Speed in M.P.H.	Flying Passes		Accelerative Passes	
	Forced	Voluntary	Forced	Voluntary
	ft.	*ft.*	*ft.*	*ft.*
30	550	650	450	600
50	750	1050	750	1000

* Median Values.

the following analyses have to deal with male drivers and passenger vehicles only. The distance required to overtake and pass for all areas has been graphically set forth in Figures 6 and 7 according to categories hereinbefore described. Values for both types of passes for 30 and 50 miles per hour are given in Table 2.

It is shown that the median value of the flying-voluntary type was greater than that of the forced return type by about 175 to 400 ft. at the speeds compared. It is seen also that in the accelerative type of pass the voluntary return type required from 100 to 200 ft. more distance than the forced return type on the average.

tendency, however, for the median values to increase slightly when female drivers

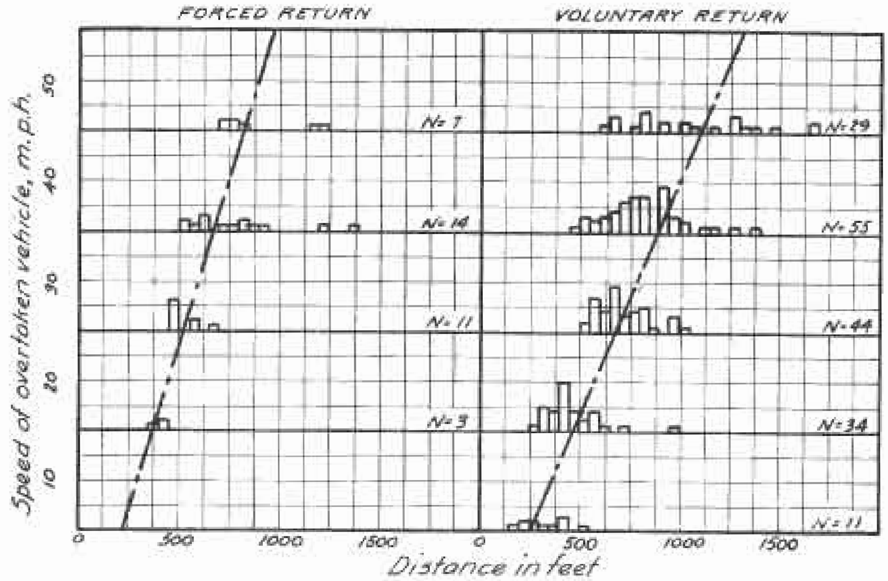

Figure 6. Distance Required to Overtake and Pass, Flying Type, Males, All Areas

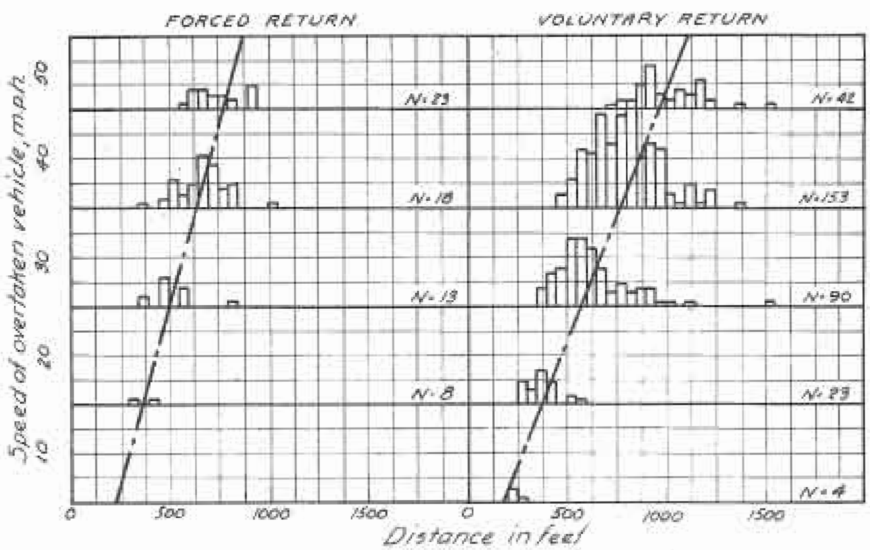

Figure 7. Distance Required to Overtake and Pass, Accelerative Type, Males, All Areas

Comparison of these results with those for all drivers shows that practically the same values were obtained. There is a

are included. Hence, it is reasonable to deduce from these differences that the female drivers as a group required slightly more distance for overtaking and passing than the males.

INFLUENCE OF GEOGRAPHICAL AREA

It was noted in flat terrain where greater sight distances prevail that the natural driving habits of motorists resulted in greater distances for overtaking and passing. Accordingly, all data for male drivers were tabulated into two categories so as to compare the observations made in the hilly terrain of New England with those obtained in the flatter sections of the middle and far western states. These are set forth in Table 3.

It will be noted that the flying-voluntary type of manoeuver observed in the middle and far western areas showed from 100 to 425 ft. greater distance than those for New England. The accelerative-voluntary classification showed a range of 200 to 250 ft. greater distance in the middle and far western areas than were found in New England areas. Since the number of cases for the flying-forced type when separated by areas was too small to be highly significant, it was omitted from the table. For the accelerative-forced type, median distances showed a relationship similar to the voluntary types.

TABLE 2

COMPARISON OF OVERALL DISTANCES*
(Male Drivers Only—All Areas—Passenger Vehicles)

Speed in M.P.H.	Flying Passes		Accelerative Passes	
	Forced	Voluntary	Forced	Voluntary
	ft.	*ft.*	*ft.*	*ft.*
30	500	675	450	550
50	700	1100	750	950

* Median Values.

Thus, it is seen that when there is prevailing limited sight distances and drivers realize that more adequate sight distances do not occur frequently, they will execute passes under strain in face of possible hazard, which would ordinarily be refused where longer sight distances are generally to be found. This interpretation is borne out by reference to the accelerative passes under forced return conditions and also by clearance times previously reported for the two areas. (Op. cit. (6).) If this interpretation is correct, the 80 percentile value from the voluntary conditions should indicate the sight distance which is adequate to include the forced passes under conditions which are generally comfortable. (Note the foregoing discussion of 80 percentile values and forced passes.) Thus, while passes are safely completed under shorter sight distances, the hazards attendant thereto are unquestionably higher.

TABLE 3

DISTANCES REQUIRED TO OVERTAKE AND PASS*
(Males—Passenger Cars Only)

Speed in M.P.H.	Flying-Voluntary		Accelerative-Voluntary	
	New Eng. Areas	Mid & Far West	New Eng. Areas	Mid & Far West
	ft.	*ft.*	*ft.*	*ft.*
30	650	750	500	700
40	750	850	650	800
50	825	1250	800	1050
	Flying-Forced		Accelerative-Forced	
30	...	...	450	500
40	...	...	650	675
50	...	...	675	775

* Median Values.

CLEARANCE DISTANCES—REAR

In analyzing the component parts of the total distance required to overtake and pass, it is not without interest to note the range of clearance distances allowed by the driving public both to the rear and the front of the overtaken vehicle. A general summary of all distances which were obtained is set forth graphically in Figure 8. Analysis of the data showed that the clearance distance to the rear of the overtaken vehicle was not influenced by the type of return. In the accelerative type regardless of the type of return the median values of distances to the rear of the overtaken vehicle ranged from 25 ft. at 10 miles per hour to 45 ft. at 50 miles per hour. In the flying type of manoeuver the distances to the rear of the overtaken vehicle were exceptionally constant for all speed classes, being approximately 75 ft. It should be noted that these are median values and that considerable deviation from them occurred. Thus, in the accelerative type the clearance distance to the rear of the overtaken vehicle ranged from as low as 10 ft. to as much as 90 ft. Similar values in the flying type of manoeuver ranged from 20 ft. to 150 ft.

CLEARANCE DISTANCES—FORWARD

The clearance distances allowed in front of the overtaken vehicle show a wide range of distribution. Median values of clearance to the front of the overtaken vehicle for the flying-forced type of pass varied linearly with speed from 75 ft. at 30 miles per hour to 65 ft. at 50 miles per hour. Note in this instance that the clearance distance decreased with increase of speed. This decrease was probably due to lack of accuracy in judgment at higher speeds where oncoming traffic was present and higher relative velocities at lower speeds of overtaking. For the flying-voluntary type the clearance distance to the front showed a practically constant median value from 100 to 120 ft. at all ranges of speed, thus paralleling the constant rear clearance mentioned above.

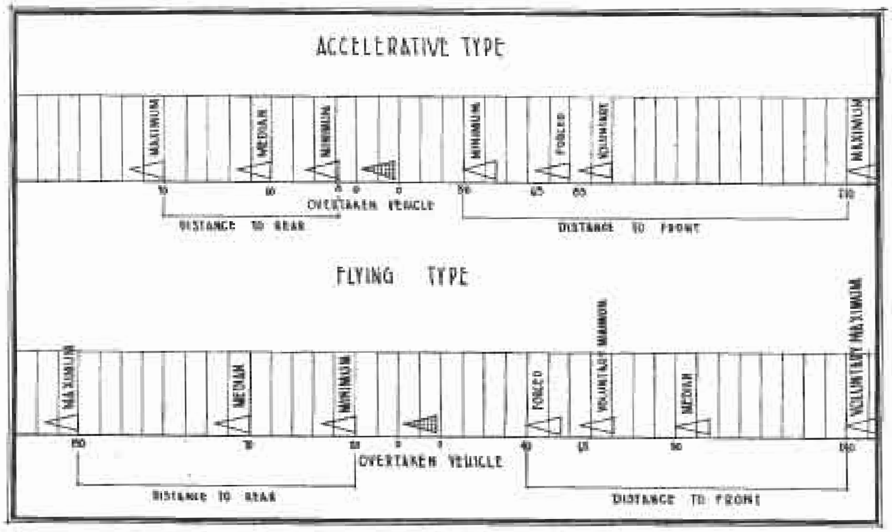

Figure 8. Clearance Distance—Feet

Special significance accrues to the clearance distances allowed in front of the overtaken vehicle under accelerative-forced conditions. Clearance values obtained for this type of manoeuver have been set forth graphically in Figure 9. It will be noted therefrom that the median value of forced return was fairly constant at all speeds at about 60 ft. Isolated values, however, range from 30 to 150 ft. For purposes of comparison the 80 percentile values of the voluntary type of return are also set forth. This shows a fairly constant value of about 110 ft. As was the case for the total distance, the 80 percentile value is sufficient to include nearly all of the forced return type. Here again, it is to be noted that 80 per cent of the motorists voluntarily performed in such a manner as to include practically 100 per cent under forced conditions.

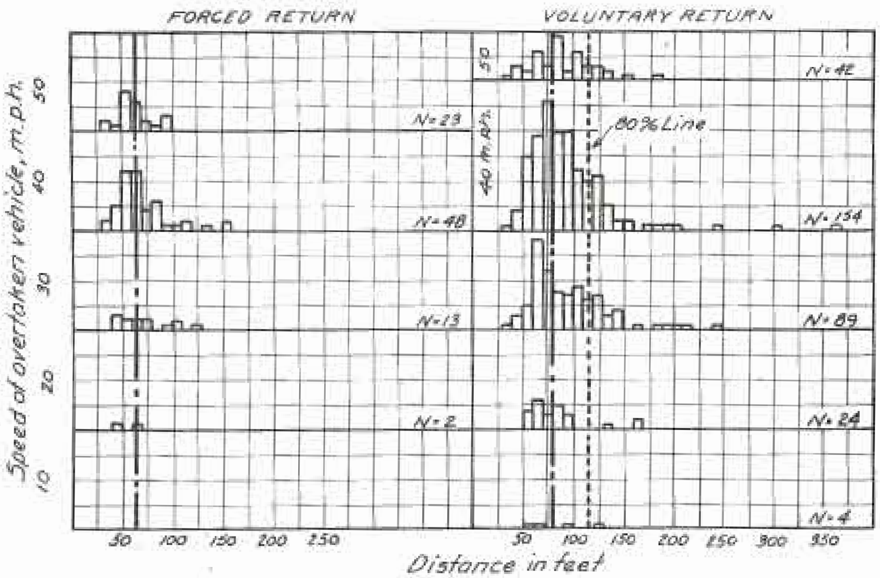

Figure 9. Clearance Distances in Front of Overtaken Vehicles, Accelerative Type

TOTAL TIME REQUIRED TO OVERTAKE AND PASS

While the total distance required to overtake and pass is probably more significant, the total timé required to complete a pass is of particular interest. This holds especially on two lane roadways inasmuch as the entire time spent by the overtaking vehicle in the left hand lane is a time during which extreme hazards are manifest.

Accordingly, the times required to overtake and pass have been analyzed and shown graphically in Figures 10 and 11. In the flying-forced type of manoeuver the time required to overtake and pass is distributed from 5 to 14 sec. Even under the most exacting condition, (the accelerative-forced type of manoeuver) individual time values were distributed from 6 sec. to as much as 16 sec., whereas in the voluntary return type the time required ranged from 6 to 19 sec. Median values are given in Table 4.

Thus, the median times for forced passes vary from 8.0 to 10.5 sec. at the speeds compared, and those for the flying are slightly longer than for the accelerative. Again, attention is called to the use of 80 percentile values for design purposes due to the wide range of individual values found.

TIME REQUIRED TO OVERTAKE

Further analysis was made of the time required for the overtake alone, that is, the time spent by the overtaking driver from the instant he began his manoeuver until the foremost part of his vehicle was opposite the mid point of the overtaken vehicle. Figure 12 shows that for the flying pass both forced and voluntary

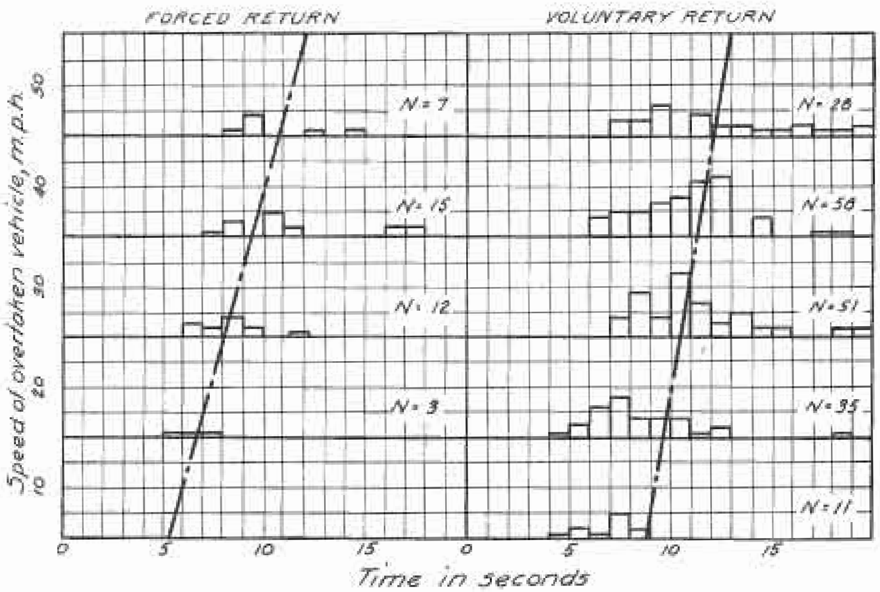

Figure 10. Time Required to Overtake and Pass, Flying Type

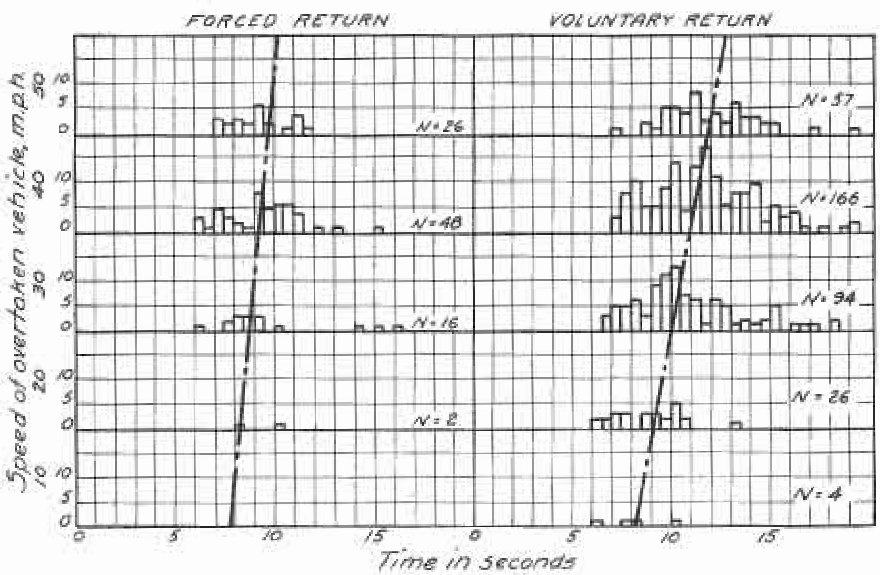

Figure 11. Time Required to Overtake and Pass, Accelerative Type

return types required similar time values. The median time to overtake was approximately $4\frac{1}{2}$ sec.

Similarly, for the accelerative pass the forced and voluntary type of return required equivalent time to overtake. However, the median values of time increased linearly with speed so that at

TABLE 4

COMPARISON OF TOTAL TIMES*

(Male Drivers Only—All Areas—Passenger Vehicles)

Speed in M.P.H.	Flying Passes		Accelerative Passes	
	Forced	Voluntary	Forced	Voluntary
	ft.	ft.	ft.	ft.
30	8.0	10.5	8.0	10.0
50	10.5	12.0	9.5	11.5

* Median Values.

sampling all types of drivers and vehicles. It is felt that this method reflects with sufficient accuracy the variations in driver and vehicle performance, and as has been noted in all of the results, there is a considerable range of individual performance with regard to both time and distance values at any observed speed of operation.

Our previous theoretical calculations based on a reasonable theory of over-

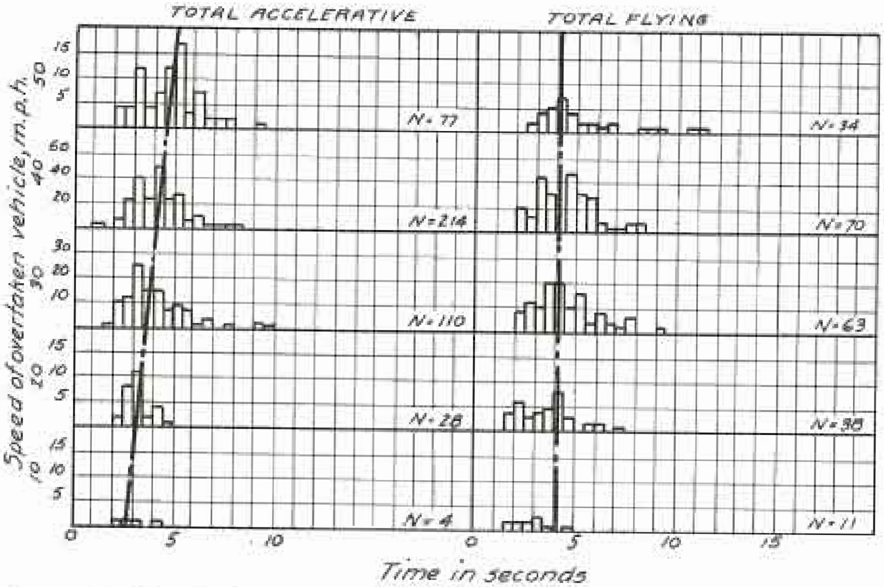

Figure 12. Time Required to Overtake, Forced and Voluntary Returns Together

30 miles per hour approximately $3\frac{1}{2}$ sec. were required and at 50 miles per hour approximately $4\frac{1}{2}$ sec. were required.

DISCUSSION OF RESULTS

General Considerations. The results which have been obtained lead inevitably to a general conclusion that there is a wide difference in the operation of automobiles insofar as overtaking and passing distances and times are concerned. It must be remembered that the results which have been obtained are based on a new method of measuring overtaking and passing distances by taking and passing and common sense estimates showed that the flying type of pass if executed in the shortest distance allowed by physical limitations and driving comfort would be shorter than passes of the accelerative type. It is significant to note, however, in actual operation that this was not the case and that generally speaking the accelerative type of manoeuver required slightly less distance and time. It is to be concluded, therefore, that the average driver does not approach the minimum values which are possible of achievement in the flying pass. This is accounted for largely by the greater clearance distances to the front and rear in the flying types of pass, although they tended to be executed at a higher average speed.

The total distance required to overtake and pass was considerably affected by the type of return. Both in the accelerative and flying type of manoeuver the voluntary return utilized more distance, the difference of median values amounting to 250 ft. at 50 miles per hour for the accelerative types and 300 ft. for the flying types.

Design Speed. Without exception all results for all types of passes show that the overtaking and passing distance becomes greater for higher speeds. Thus, it is readily seen that the overtaking and passing distance which is chosen in designing for modern traffic speeds is intimately bound up with the design speed of the roadway. In connection therewith, it is significant to note that the 80 percentile distance found in the accelerative-voluntary type included practically all passes of the forced types, including the flying-forced type. It is felt that this is especially important from the design point of view for it is believed that whenever there is any doubt in a motorist's mind as to whether he can successfully complete a pass or not, he will reduce speed to a point comparable to that of the vehicle ahead and therefore establish any pass which he makes thereafter as the accelerative type. Moreover, it seems from the design point of view that the fact that the accelerative type proves shorter makes it desirable to use values obtained from that type of manoeuver when discussing or considering overtaking and passing requirements. In view of the fact that the 80 percentile provides for the large majority of forced passes, it seems especially significant in considering design values. Based on the data which have been gathered, the overtaking and passing distance, which includes 80 per cent of all accelerative-voluntary passes, amounts to approximately 1150 ft. at 50 miles per hour, 950 ft. at 40 miles per hour, and 750 ft. at 30 miles per hour.

Areas. The results obtained for New England and the more open areas of the middle and far western sections show that under prevailing limited sight distances motorists will pass under conditions which would be considered hazardous by motorists travelling under conditions of prevailingly greater sight distance.

Clearances. Consideration of the median clearance distances allowed in the flying types of pass showed that the average motorist allowed himself approximately 70 ft. headway before starting a manoeuver. In the accelerative types the motorist allowed himself from 25 ft. at 10 miles per hour to 45 ft. at 50 miles per hour. These latter values seem absurdly low from the safety viewpoint and reflect the questionable amount of caution which is exercised under the conditions attendant to the accelerative-forced type of pass.

On the other hand, the average motorist when forced to return to the right half of the roadway in front of the overtaken vehicle allowed an average clearance distance of about 60 ft. This clearance value was increased to an average of 110 ft. under voluntary return conditions. The differences in drivers under varying conditions is especially indicated in these clearance values inasmuch as isolated cases showed a range of distribution from as low as 10 ft. to the rear to a minimum of 30 ft. to the front of the overtaken vehicle.

Times. For purposes of computing sight distances the amount of time required for overtaking and passing seems especially pertinent. The results show that the total time required to overtake and pass increased with speed. For the lower speed of 30 miles per hour the accelerative-forced type required 8½ sec. to complete a pass. In the accelerative-voluntary type the median value of the time required at 50 miles per hour amounts to 11⅓ sec. To this value of the time required to overtake and pass must be added some additional time clearance values for the computation of sight distance. In a previous paper (Op. cit. (6)) it was shown that 80 per cent of the drivers allowed a clearance of 1 sec. or more when passing in the face of oncoming traffic. It is beyond the scope of this paper to discuss the various other factors involved in the computation of a safe passing sight distance.

SUMMARY

1. Actual distances and times required to overtake and pass by the driving public were measured. A total of 795 observations were obtained in New England, mid western and far western states.

2. A photographic method was developed for use from a moving vehicle.

3. Four types of passes were developed for the purpose of analysis.

4. Distances and times increased linearly with speed. At 50 miles per hour drivers executing a "following" pass required a median distance of 1000 feet and 80 per cent of them passed in less than 1150 ft.

5. The corresponding median time value was 11.5 sec.

6. The 80 percentile values provide adequate distance for practically all observed passes under pressure. It is, therefore, suggested for design purposes.

7. Conditions of terrain apparently influenced driver behavior. Clearances to rear and to front have been analyzed, together with corresponding time values.

8. The results emphasize the fact that traffic studies of this sort involve the inherent variability of the human factor as represented by the performance of the driving public. The wide range of values obtained necessitates the simpler type of statistical treatment developed for the analysis of biological and human data. Failure to recognize this range and variability leads to conflicting and erroneous interpretations.

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DISCUSSION ON OVERTAKING AND PASSING REQUIREMENTS

Dr. B. D. Greenshields, *College of the City of New York:* It is gratifying to know that the authors' results agree so closely with those I arrived at by an entirely different method. (Proceedings, Highway Research Board, Vol. 15, pp. 332–342.)

Of significance is the fact that the time I found was the clearance time required on the opposite lane, and that it apparently agrees with the total time for passing. This indicates that drivers allow themselves very small margins of safety. Perhaps it should be added that due to the method of analysis, the time I found to be required for passing was the minimum average for all drivers and should be compared with the 80 percentile value found by Forbes and Matson.