SPEED-CHANGE RATES OF PASSENGER VEHICLES

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SYNOPSIS

Three types of speed-change rates representative of normal highway usage were determined by a series of trial runs on six modern passenger vehicles The three types were (a) normal acceleration representing pickup under the normal or unhurried control of typical drivers, (b) full acceleration representing the maximum pickup mechanically possible under control of typical drivers, and (c) motor deceleration representing the slowing down of vehicles governed only by retardation of the motor, with throttle released and without brake application Time data were obtained for speedometer readings up to 70 mph The summary of acceleration rates includes gear shifting manipulations

The information obtained for each of the three types of speed change is presented in form of charts from which the time, distance, or overall rate can be read directly in terms of the upper and lower values of speed ranges up to 70 mph The data herein are compared briefly with recent similar studies by two other investigators While the results obtained are subject to verification by more extensive tests, particularly for the extremes of the speed range tested, it is believed that they may be used as a guide for present factors in highway design

In many investigations to determine highway design practice and principles that are in agreement with normal driver characteristics and probable mechanical limitations of vehicles, it is essential that values for acceleration and deceleration time or distance be known or can be readily calculated In a review of available literature during the summer of 1937, the Division of Design of the Bureau of Public Roads, studying particularly the topics of intersections and sight distance, found little speed-change data available, particularly for speeds above 30 mph Subsequently, brief series of trial runs were made on six passenger vehicles to determine reasonably accurate speed-change values which are characteristic of many passenger vehicles and to arrange these values in usable form Data were obtained for speed-change rates representative of normal operation of the large majority of modern vehicles rather than more precise value for certain limited groups or conditions The data herein are believed to be reasonably accurate for use as a guide in calculating values to be used in highway design, but remain subject to verification or correction by more comprehensive tests Similar tests and analyses on trucks and busses are required to completely cover the range of values needed

Speed-change values were determined for two general accelerating conditions Full acceleration being that governed principally by the mechanical limits of the vehicles and normal acceleration representing the more usual pickup of representative drivers While trials were made for acceleration both through shifting of gears and in high gear, in the analysis all data were combined into representative acceleration without regard to values for separate gears Values also were determined for motor deceleration covering normal slowing down with a completely released throttle but no application of brakes, only the braking action of the motor being effective

As used herein, the full acceleration and motor deceleration values are largely mechanically controlled and are not appreciably affected by the individual characteristics of drivers The normal acceleration values are combined evaluations of the personal element of the several drivers and the mechanical vehicle limitations, and are thus subject to considerably more variation than the above

Data were secured by trial runs on the following six passenger vehicles, all in good operating condition

Vehicle (Fig 1)	Make	Year	Cyl	Model
A	Ford	1936	8	2-door coach
B	Plymouth	1935	6	2-door coach
C	Buick	1937	8	4-door sedan
D	Oldsmobile	1935	6	4-door sedan
E	Studebaker	1937	6	4-door sedan
F	Graham	1937	6	4-door sedan

Each vehicle was operated by three or more drivers over the range of trials Trial runs were made on a relatively flat but slightly curved portion of the Mount Vernon Memorial Highway, paved with portland cement concrete All drivers were relatively skilled and experienced, each regularly driving his personal car, three of which were included in the trials Stop watch readings were recorded for 10 mph increments on the speedometers as the vehicles were changing speed on the prescribed runs One observer read the stop watch and recorded (to closest second only), while the third in the party called the speedometer reading, leaving the driver free for complete control of the vehicle Time readings were started at a given signal after which the operator reacted to start the desired vehicle control, thus including only a fraction of a second of the operator's reaction time Readings were taken successively throughout the run, the speed change being continued beyond the speed of the last reading The deceleration and acceleration runs in high gear were started with the vehicles moving uniformly at the initial speed

Runs for normal acceleration were made for speed ranges of 0 to 30, 0 to 40, 0 to 50, and some 0 to 60 from a standing start to include shifting, and for speed ranges of 20 to 40, 20 to 50, 20 to 60, and 20 to 70 in high gear Runs for full acceleration were made over a range of 0 to 70 to include shifting and from 20 to 70 in high gear Runs for motor deceleration were made for speed ranges of 60 to 20, 50 to 10, 40 to 10, 30 to 10, and some 70 to 20 Each operator made at least two runs for each range of speeds, at least three different operators were used for each vehicle

All stop watch readings were made as the speedometer pointer passed the successive 10 mph dial graduations It was necessary to reduce these speedometer readings to actual mile per hour values The speedometers were calibrated by timing each vehicle over a

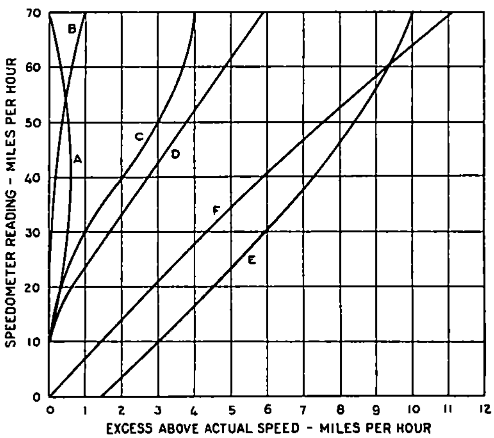

Figure 1 Speedometer Calibration Curves

3600-ft course with the speed held as constant as possible, obtaining actual speeds for the speedometer readings (10 to 70 mph) used in the runs The possibility of further error due to lag of the speedometer indicator was not investigated fully, but appeared to be negligible in the major range of speeds used, 20 to 60 mph

In Figure 1, the speedometer calibration curve for each vehicle shows the corrections made to reduce speedometer readings to actual speeds Two vehicles gave readings within a 2 percent accuracy, two more were 5 to 10 percent in excess, and the remaining two were

15 to 25 percent in excess Note that the speedometers on all six vehicles indicated a speed above that actually being traveled.

The time data were summarized for each type of speed change by plotting a speed-time curve for each vehicle, using the average speedometer interval time values corrected to actual speed values The data from all six curves were then combined into one speed-time curve representative of the group. Figures 2 and 3 present the combined speed-time curves for the several trials made on all six vehicles Some runs to higher

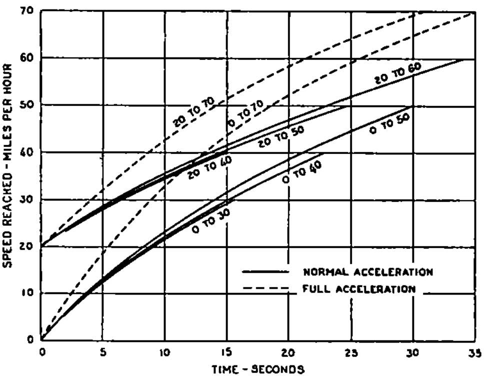

Figure 2. Speed Time Acceleration Curves Trial Run Data (Summary of Acceleration Runs Made on 6 Passenger Vehicles.)

speeds, made only on four vehicles, are not included in these figures Those acceleration runs started in high gear were reduced to zero time at a speed of 20 mph

The data have not been used in this form, but are presented as a summary of the actual speed-time information secured In Figure 2 the normal acceleration curves show a minor difference in values for the three ranges of acceleration The operators were instructed and believed themselves to be "normally" gaining speed at all times for these runs, but the data show slightly higher acceleration rates for higher values of attained speed These differences in rates have been disregarded; such precision was deemed unwarranted in the analyses for which the data were secured These differences in speed-change rates are personal element controls and have little effect on full acceleration or motor deceleration

For the final analysis of the time data secured, all information was combined to determine the average time interval for each 10 mph actual speed increment The average time for each 10 mph increment under each of the three types of speed change was thus determined from 30 to 300 separate time readings for

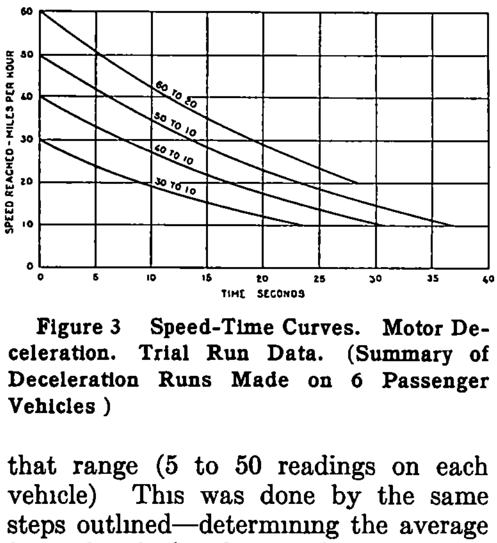

Figure 3 Speed-Time Curves. Motor Deceleration. Trial Run Data. (Summary of Deceleration Runs Made on 6 Passenger Vehicles)

that range (5 to 50 readings on each vehicle) This was done by the same steps outlined—determining the average for each vehicle, plotting the summation speed-time curve on an actual speed scale, and from the six of these deriving a final average curve From the final curve for each type of speed-change the differences of the time values for successive 5 mph speed intervals were used as the basic rate data Table 1 presents this information The rate, used as miles per hour per second herein, is the average for the 5 mph interval The distance was calculated on the basis of the time elapsed and the average speed for each 5 mph interval The remaining charts are varied presentations of the data in Table 1 speeds 1 5 to 2 0 times the above The smoothness of the time curves was not

TABLE 1

TIME, RATE AND DISTANCE OF SPEED CHANGE FOR 5 MPH INCREMENTS
(Basic Data Derived from Trial Runs on 6 Modern Passenger Vehicles)

Speed Mph	Normal Acceleration			Full Acceleration			Deceleration In Gear		
	Time, Sec	Rate, Mphps	Distance, Feet	Time, Sec	Rate, Mphps	Distance, Feet	Time, Sec	Rate, Mphps	Distance, Feet
0-5	1 7	2 9	6	1 3	3 9	5	—	—	—
5-10	2 0	2 5	22	1 4	3 6	15	—	—	—
10-15	2 3	2 2	42	1 5	3 3	28	7 8	0 65	143
15-20	2 7	1 9	70	1 6	3 1	41	6 2	8	159
20-25	3 0	1 7	99	1 7	2 9	56	5 2	95	172
25-30	3 4	1 5	137	1 9	2 6	77	4 5	1 1	182
30-35	3 7	1 35	176	2 1	2 4	100	4 0	1 25	191
35-40	4 1	1 2	226	2 3	2 2	126	3 6	1 4	196
40-45	4 5	1 1	280	2 6	1 9	162	3 2	1 55	199
45-50	4 8	1 0	335	2 9	1 7	202	2 9	1 7	202
50-55	5 2	95	400	3 3	1 5	254	2 6	1 9	203
55-60	5 6	9	473	3 8	1 3	321	2 4	2 1	203
60-65	5 9	85	541	4 4	1 1	403	2 2	2 3	202
65-70	6 3	8	624	5 1	1 0	505	2 0	2 5	198

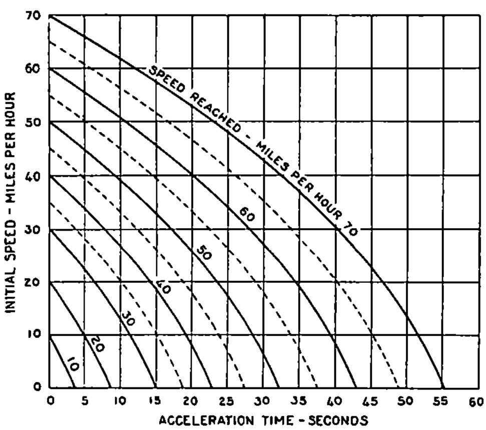

Figure 4 Normal Acceleration Time for a Range of Speeds

During the runs for normal acceleration from a standing start it was observed that the shift from low to intermediate gear was made at speeds of 8 to 14 mph , and from intermediate to high at speeds of 18 to 24 mph , depending on individual driving characteristics Under full acceleration the shifting points were at

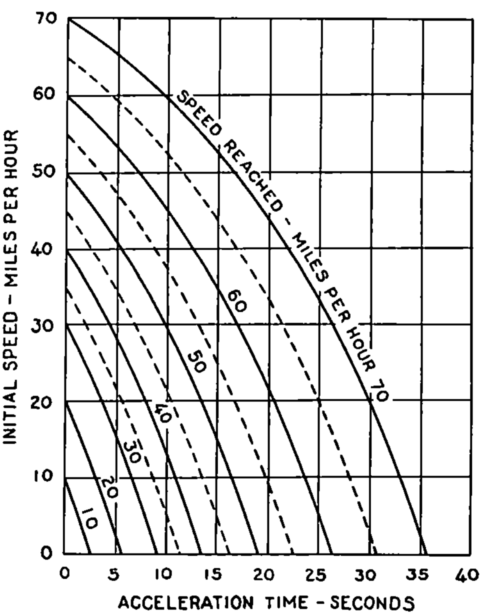

Figure 5. Full Acceleration Time for a Range of Speeds

appreciably affected by shifting It thus may be concluded that the precise manner and time of shifting do not affect values derived for general use.

The trial runs for motor deceleration proved that retardation from a speed of 40 mph or faster severely taxed driver patience to reach a speed of 25 mph or lower without resort to braking It was evident that most drivers usually begin to apply brakes at speeds above 25 mph, depending upon their initial speed and the stopping conditions. Thus most full deceleration is done at rates much higher than those measured in these trials

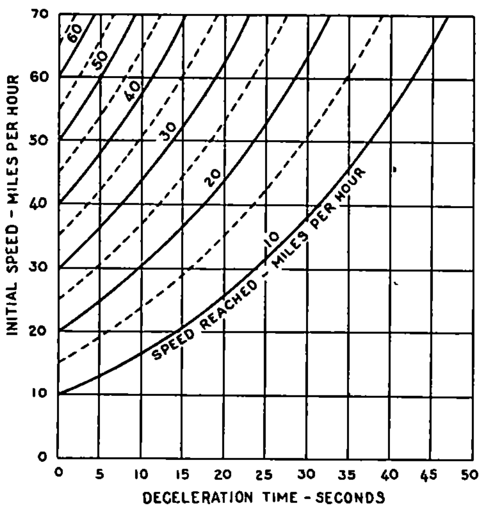

Figure 6. Motor Deceleration Time for a Range of Speeds

For general use it is convenient to apply speed-change values that are applicable for a given range of speed, as from 20 to 60 mph, 60 to 40 mph, etc Figures 4, 5, 6, 7, 8, 9 and 10, 11 have been prepared in such form that values for time, distance and rate, respectively, may be read directly for various speed ranges In each case separate charts have been prepared for (A) normal acceleration, (B) full acceleration, and (C) motor deceleration The left scale indicates the initial speed, the sloping lines the speed reached and the lower scale the desired value of time, distance, or overall rate for the range of speeds

The overall rates presented in Figures 10 and 11 have been determined on a total time—total mile per hour basis Speed-change distances calculated from a uniform rate effective over the whole of a range of speeds are subject to increasing percentage of error as the speed-change range increases Therefore, in Figures 10 and 11 the overall speed-change rates are given only for ranges of 0 to 30 mph which result in an error less than 5 per-

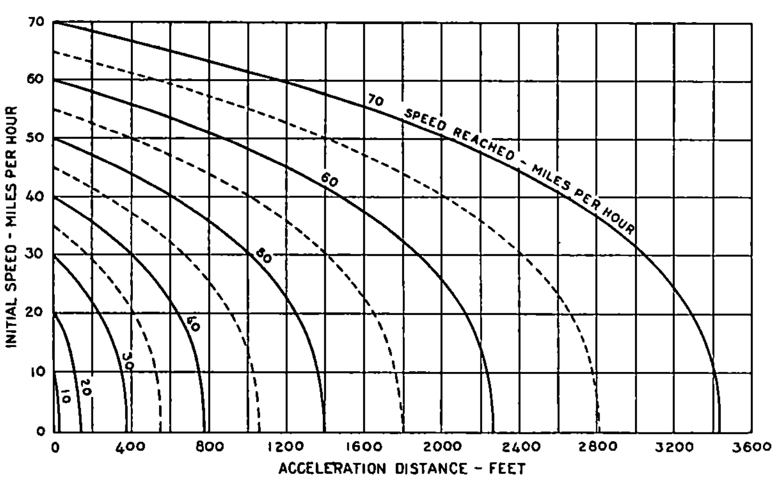

Figure 7. Normal Acceleration Distance for a Range of Speeds

cent for calculated distances Values for larger ranges of speeds may be calculated readily in two or more steps The distance traveled may be represented

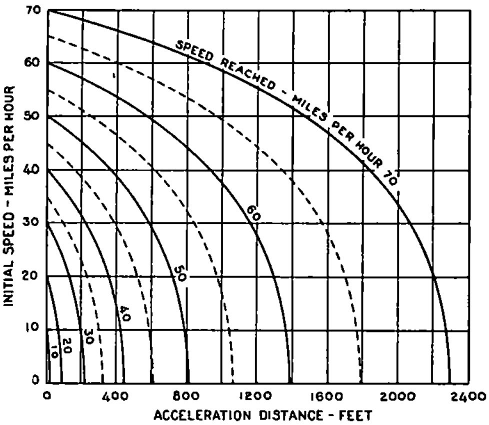

Figure 8 Full Acceleration Distance for a Range of Speeds

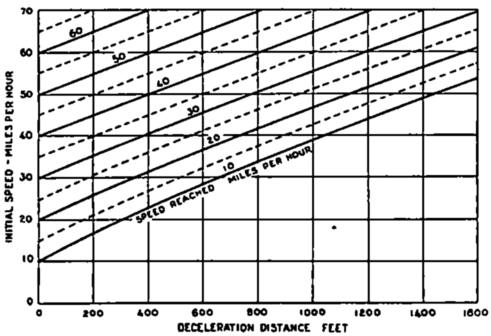

Figure 9. Motor Deceleration Distance for a Range of Speeds

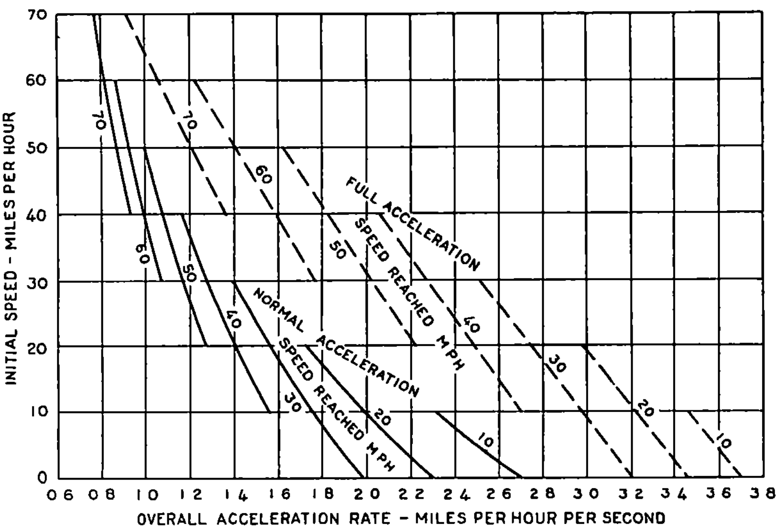

Figure 10 Normal and Full Acceleration Overall Rate for a Range of Speeds

by the formula $S = \frac{0\ 733}{a} (V^2 - V_0^2)$ in which S is the distance in feet, and V and V_0 are the higher and lower speeds in miles per hour and a is the overall rate of Figures 10 and 11 in miles per hour per second

The solid line curves A, B and C of Figure 12 represent instantaneous speed-change rates as found herein These curves were prepared by plotting the rates in Table 1 at the midpoints of the 5 mph increments Such curves are particularly useful for comparison with other test data.

The remaining curves in Figure 12 represent rates recently determined by two other investigations Curve D is a study of acceleration in high gear made on 20 passenger sedans at the General Motors proving grounds. Curves E and F are acceleration rates in high gear and second gear, respectively, as found by the

Oregon State Highway Commission on six passenger vehicles Curves G and H are rates for deceleration in high gear and in freewheeling, respectively, of the same vehicles

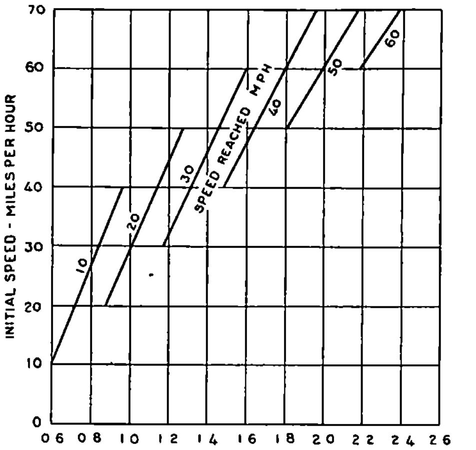

Figure 11. Motor Deceleration Overall Rate for a Range of Speeds

and curve B represents two 1935, one 1936 and three 1937 models The higher values of curve D, in addition to elimination of earlier and slower models, doubtless are largely due to the more exact driving and mechanical conditions of proving ground tests Curves B and E, both representing a range of models, are in substantial agreement in the range of 30 to 65 mph High speed values are subject to less precise measurements in field tests, the form of curve E at 70 mph seems the more correct theoretically Little direct comparison of acceleration rates can be made below the 30 mph speed Curves D and E are the rates for high gear only and curve F is the rate for second gear only, whereas curve B represents usual acceleration with successive shifting through three gears Curves of the type of D, E and F cannot be used directly to represent acceleration from a standing start as performed by the normal highway user

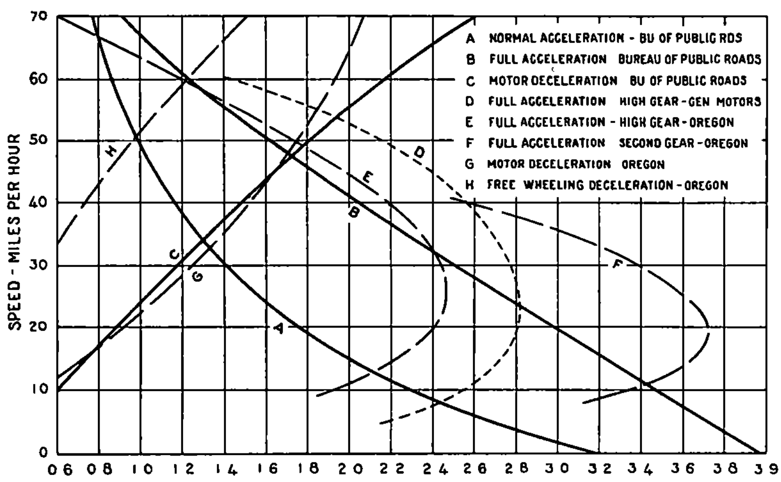

Figure 12 Speed Change Rates at Various Speeds

Curves D, E, and the upper portion of curve B all are measures of maximum acceleration in high gear The values for curve E include one 1931, one 1935, one 1936 and three 1937 models Curve D is the average for twenty 1936 vehicles,

The motor deceleration curves, C and G, compare closely in speed ranges of 50 to 20 mph Here again the differences at higher speed values probably are due to the difficulty of securing accurate readings at these speeds

Figure 13 presents speed-distance curves for comparison of Oregon observations on vehicles accelerating from an intersection stop (drivers unaware of observations) and the two acceleration rates determined herein The vehicles observed in the Oregon studies were summarized in three groups, according to the speeds reached at the end of a 950-ft test section The normal acceleration compares favorably with the faster group In order to compare directly it is necessary to round off the normal acceleration values, into the form of the Oregon data, to the ultimate travel speed reached. Inasmuch as the first three readings in the Oregon studies were made at 100, 250, and 450 ft from the starting point, and in our tests at successive 10 mph increments, the shorter distances of the latter curves appear to be the more accurate for the lower speeds

Deceleration studies made at a stop sign in other Oregon tests prove to be measures of brake application for the most part The values thus are not directly comparable to the Motor Deceleration rates herein, with the possible exception of an indefinite portion at the beginning of the deceleration, before foot brakes are applied

The two types of acceleration used herein were selected to simulate actual driving conditions of present-day drivers The motor deceleration is less representative of actual driving practice, but is an evaluation of the maximum rate attainable without resort to braking For any highway deceleration the driver reacts to release the throttle, either gradually or at once, and proceeds at decreasing speeds until the particular conditions suggest the extent of braking that he must do to control his vehicle properly He probably applies brakes gradually, except in emergencies Thus his deceleration rate varies from a very gradual motor retardation at the beginning to a full braking rate as the vehicle is stopped. Obviously rates for full deceleration from various speeds are subject to such wide variation in driver control that, except for emergency stops, the use of any value as "representative" may be questioned The full motor deceleration rates herein are not directly applicable in retardation involving braking, although they may be used as the equivalent of gradual motor deceleration and initial or light braking However, the values determined herein may be used as a guide in determining warning or vehicle control distances, such as sign posting distances or lengths of deceleration lanes, for highways of a given design speed

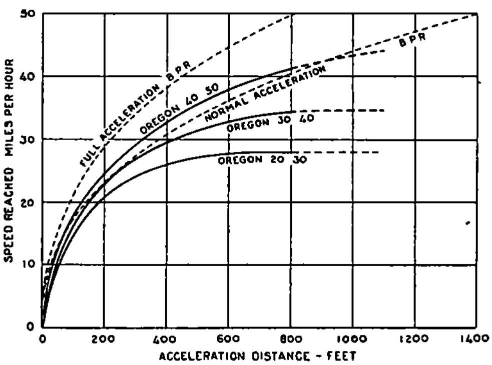

Figure 13 Comparison of Acceleration Distances

The full acceleration rate, while subject somewhat to variations of individual driver shifting manipulation, represents the maximum pickup of the six passenger vehicles tested. It thus can be used as a guide to determine the minimum acceleration time or distance that highway design should provide, as for safe passing sections or acceleration lanes

The normal acceleration runs were made at what the drivers believed to be their usual pickup rates Figure 12 shows that the normal rate, an average of the personal variations of the different drivers tested, is about two-thirds the full rate The normal rate as measured may be somewhat greater than actual highway usage inasmuch as the drivers tested were conscious of their acceleration, but the results compare favorably with the Oregon tests on actual highway usage It is believed that the normal rates determined are sufficiently below the full acceleration rates to be used as a guide in determining reasonable design values that cover the driving characteristics of most all drivers now using the highways

The two general types of acceleration rates determined and summarized herein are believed to represent types of speed change in common use, representative of "average" or "usual" driver manipulation The deceleration study proves to be of limited use but indicates the desirability of future studies to determine decelerating values representative of vehicles approaching slow signs, stop signs, or signal control lights While all values determined are subject to verification by more extensive tests, particularly for the higher speeds, it is believed that they may be used as a guide for present factors in highway design This study indicates that these data can be presented in a form that is directly usable in the design of highways for stated speeds

DISCUSSION ON SPEED CHANGE RATES

DR B D GREENSHIELDS, *College of the City of New York*· Mr. Loutzenheiser states that the normal acceleration as obtained from trial runs (Table 1) decreases from 2 9 miles per hour per second at 0–5 miles per hour to 1 5 miles per hour per second at 25–30 miles per hour. These ratios are contrary to those I obtained in Michigan in 1933 Observations of passenger cars starting up after having been stopped by a traffic light showed a corresponding acceleration range of 1 mile per hour per second at 0–5 miles per hour to 2 3 miles per hour per second at 25–30 miles per hour. (Proceedings of Twentieth Annual Highway Conference, University of Michigan, p. 16, Feb 13–15, 1934)

While I think that Mr Loutzenheiser is justified in his belief that the results he gives may be used as a guide for factors in highway design, I suggest that further studies in which the recordings are made at much shorter intervals of time might yield worthwhile information. The method used in 1933 proved to be satisfactory from the standpoint of both accuracy and cost

MR J A BUCHANAN, *Bureau of Public Roads.* Our primary concern is to move traffic rapidly and without accidents. In our technical discussions we customarily use "foot" units when considering distances and this probably coincides with driving practices We use "miles per hour" in our speed conceptions and this also is customary in driving habits For our acceleration units, however, we ordinarily think in terms of "feet per second per second." Such changes in our fundamental units—from feet to miles in displacement and from seconds to hours in time—are not the best practice in technical studies nor are they conducive to quick and safe thinking on the part of the driver.

If speeds were defined as "feet per second" rather than as "miles per hour" much could be gained The technical advantages are obvious The psychological or driver advantages are as great or even greater from a safety viewpoint. The driver is more likely to correlate the distances involved in traffic maneuvers with his speed if the units are readily related, i e , feet for distances and feet per second for speeds. If he realizes how fast he is going in *feet per second* he is much more likely to correlate his speed with respect to the number of *feet* he has available and the number of *seconds* which would be involved.

By way of example, let us assume a speed of 50 miles per hour and a perception plus reaction time of one-half second, which is quite conservative The vehicle is traveling 75 ft per sec (approximately) and moves 37 ft during the perception and reaction time. This is more than the entire width of many intersecting streets and roads and has been traversed before the driver has started to apply his brakes —stopping distances are extra Had the driver been aware of his speed in feet per second rather than miles per hour he possibly would have been more cautious in approaching a situation where split seconds are precious and an accident averted by a matter of feet rather than miles Furthermore, this change in conception of speed from miles per hour to feet per second would probably be reflected by a change in attitude in traffic cases brought to court

It is realized that education and readjustments would be necessary The change could be made, however, without confusion by a simple replacement of speedometer dials For a year or two both the old and the new units could be shown on the same dial The idea should be tried out on experimental groups and the best method for effecting the change determined It is quite possible that the benefits which would result would repay the cost many times.