ACCELERATION AND DECELERATION CHARACTERISTICS OF PRIVATE PASSENGER VEHICLES

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SYNOPSIS

A study has been made to determine maximum acceleration for passenger cars and their freewheeling and high-gear deceleration under test conditions Investigation was also made of acceleration and deceleration under running conditions Test cars were used in the first instance, without overhaul or special "tune-up", while in the second instance cars were observed under normal driving conditions, without the knowledge of the operators

Second and high-gear maximum acceleration obtained from the test cars were approximately similar, approaching a maximum at speeds between 15 and 25 m p h for second gear and between 20 and 35 m p h for high gear, with an approximate straight-line decrease to zero at maximum speed High-gear deceleration is affected by the same forces affecting free-wheeling deceleration, but with the additional factor of friction and compression of the motor Deceleration increased with speed at a rate greater than the first power of the speed, air resistance being the most responsible factor

Regarding observations of deceleration, only vehicles traveling at the higher speeds exceeded a rate of deceleration of 8 m p h per sec , and 9 m p h per sec appears to be the maximum without discomfort to passengers

Acceleration curves are similar in shape to decleration curves, except that the ordinate values are but half of those for deceleration A high rate of acceleration is used for a short distance from the starting point, decreasing at a gradual rate after shifting into high This shift occurs between 100 and 200 ft from the starting point, with drivers in the lower speed groups shifting into high gear sooner and using a lower rate of acceleration

This study was made for the purposes of determining (a) the maximum acceleration characteristics and both free-wheeling and high-gear coasting deceleration characteristics of motor vehicles, and (b) the manner in which motor vehicles are accelerated and decelerated under running conditions In the first instance, test cars were used without overhaul or special "tune-up " For the second phase of the investigation, observations were made of vehicles operated under normal conditions, the drivers being unaware that they were under observation The report embraces characteristics of passenger cars only

PROCEDURE

Maximum Acceleration

Before making the maximum acceleration and deceleration tests, it was necessary to calibrate the speedometers of the cars used Maximum acceleration tests were made in both high and second gear The vehicles were driven at speeds lower than the increment through which the acceleration was to be measured The throttle was then fully opened and the time required for the vehicle to accelerate through the speed increment was determined by a stop-watch This procedure was repeated through successive ten-mile increments of the entire speed range of the vehicle All tests were made on approximately level grades and straight alignment

Coasting Deceleration

For the coasting deceleration tests the procedure was approximately the reverse of that used in the maximum acceleration tests The vehicles were brought to speeds higher than the increment through which the deceleration was to be measured and then permitted to decelerate

The time required for the vehicle to decelerate through the increment was determined by stop-watch. The procedure was repeated through successive increments until a speed of 10 miles per hour was reached. Lower values were extremely difficult to obtain.

Coasting deceleration tests were made both in high gear and in free-wheeling. High-gear deceleration was measured with the throttle closed and the ignition on. Free-wheeling deceleration was measured with the gears in neutral.

Normal Acceleration

To determine the manner in which vehicles are decelerated to a normal stop and accelerated normally from standing, it was necessary to observe traffic under operating conditions without the drivers of the vehicles being cognizant of the fact that they were under observation.

For the normal acceleration study, observations were made of south-bound traffic at the intersection of S. E. 17th Avenue and McLoughlin Boulevard, Portland, Oregon (Fig. 3). McLoughlin Boulevard, south of this intersection, traverses a sparsely settled urban section with no major street intersections and few minor intersections. Rural highway speeds are permissible and immediately attainable after passing the fixed-time signals which control traffic at the S. E. 17th Avenue intersection.

McLoughlin Boulevard is a four-lane highway consisting of two 20-ft. cement concrete pavements separated by a 4-ft. asphlatic concrete neutral zone, and with 8-ft. macadamized parking lanes between the outer pavement edges and the curbs. The grade is approximately level.

Observations of acceleration were made of vehicles as they started to move after having stopped in obedience to the traffic signal. A broad yellow stop line on the pavement indicated the place where vehicles were to stop. Practically all of the vehicles, arriving at the intersection on a red signal, stopped at this line. Measured from the stop line, five successive intervals of 100, 150, 200, 250 and 250 ft. were established. The time required for a vehicle to pass through each interval was recorded. The time delay, or "lag" between the change of the signal to green and the starting of the vehicle, was recorded separately and not included

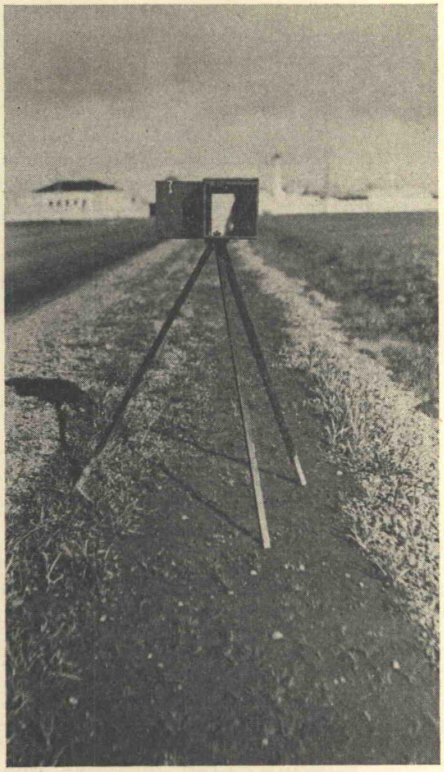

Figure 1. Enoscope

as part of the time required to pass through the first interval. Observations were confined to the first vehicle to start after each signal change.

Two observers were employed. The first was stationed closely enough to the starting point to observe the change of signals, the instant of starting and the passage through the initial interval directly. The second observer was located in the third interval and employed a group of mirror devices ordinarily designated by the term "Enoscope" to determine the passage of the vehicles through the last four intervals.

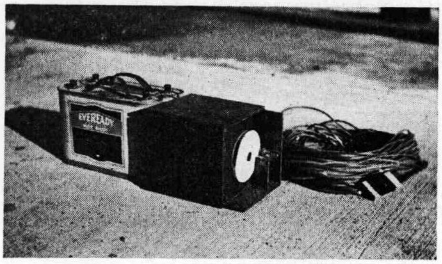

Figure 2. Time Recorder

which could be attached a paper disc. The disc made one revolution in 60 seconds. A spark gap was arranged so that upon pressing a button, a small hole was burned through the edge of the disc. By the use of remote control, the observers were able to cause the spark to burn a small hole at (a) the instant the signal changed, (b) the instant the vehicle started, and (c) the instant it passed each station. A transparent template was then laid over the disc and the time, as represented by the space between each hole, was measured. A separate disc was used for each observation.

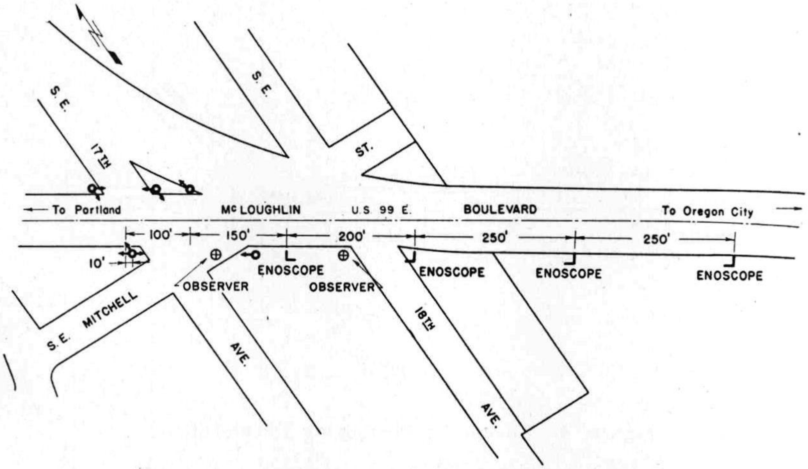

Figure 3. Layout for Measuring Acceleration

The "Enoscope" (Fig. 1) is an L-shaped box, mounted on a tripod, with a mirror installed at 45 degrees to both axes, thus changing the line of sight through 90 degrees. An observer looking parallel to the highway into one end of the Enoscope is thus enabled to see the flash from the mirror as a vehicle passes the apparatus.

The time was recorded by an instrument specially built for this purpose (Fig. 2), consisting of an electric clock from which the hands and face were removed and a small collar substituted to

Normal Deceleration

To determine normal deceleration it was considered advisable to choose a section where vehicles are decelerated to a stop from actual rural highway speeds. For this purpose, the intersection of N. Denver Avenue and N. Union Avenue was selected. At this intersection (Fig. 4), north-bound traffic on N. Denver Avenue is required to stop before entering N. Union Avenue.

Approaching the intersection, N. Denver Avenue is constructed on a high embankment with no intersecting roads, residences or business houses for a distance of approximately one and one-half miles The pavement is 30 ft wide between curbs, marked as a three-lane road; the grade is level and the alignment straight, thus affording a view of the stop sign for a considerable distance before the stop must be made A broad yellow line and a metal casting in the pavement bearing the word "stop" mark the point at which the stop should be made A standard stop sign on a post is erected a short distance in advance of the stop line

The method of recording the deceleration was approximately the reverse of that used in recording the normal acceleration Successive intervals of 50, 100, 150, 200 and 200 ft were measured back from the stop line The time required for a vehicle to pass through each interval was observed by means of the Enoscopes and the time-recording device Observations of vehicles which were not brought to a complete stop were rejected

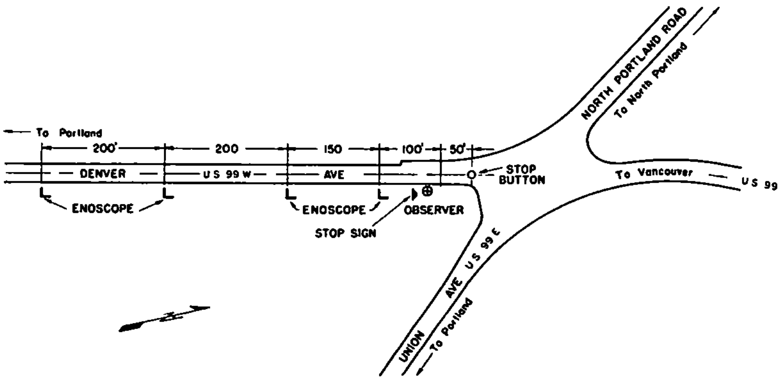

Figure 4. Layout for Measuring Deceleration

RESULTS

The high- and second-gear maximum acceleration characteristics, obtained from the several cars used in the tests, were approximately similar in each case (Fig. 5). The second-gear acceleration curves approached a maximum at speeds between 15 and 25 miles per hour, and the high-gear curves between 20 and 35 miles per hour, with an approximate straight-line decrease to zero acceleration at the maximum speed of the vehicle Any differences in the maximum speeds of the vehicles were due to the differences in the characteristics and condition of repair of the vehicles used No attempt was made to determine the low-gear acceleration because of the lag in the speedometer

The free-wheeling deceleration curves (Fig 6) varied only slightly, with the deceleration increasing with the speed at a rate greater than the first power of the speed Forces tending to retard the vehicle when decelerating in free-wheeling are (1) friction of the moving parts, (2) tractive resistance of the roadway surface, and (3) air resistance which varies approximately as the second power of the speed and directly as the frontal area Air resistance is the factor most responsible for the increased deceleration at the higher speeds

High gear deceleration is affected by the same forces as affect the free-wheeling deceleration, but with an additional factor of friction and pumping of the motor under closed throttle No extreme differences existed between the vehicles used

It is very difficult to compute, from

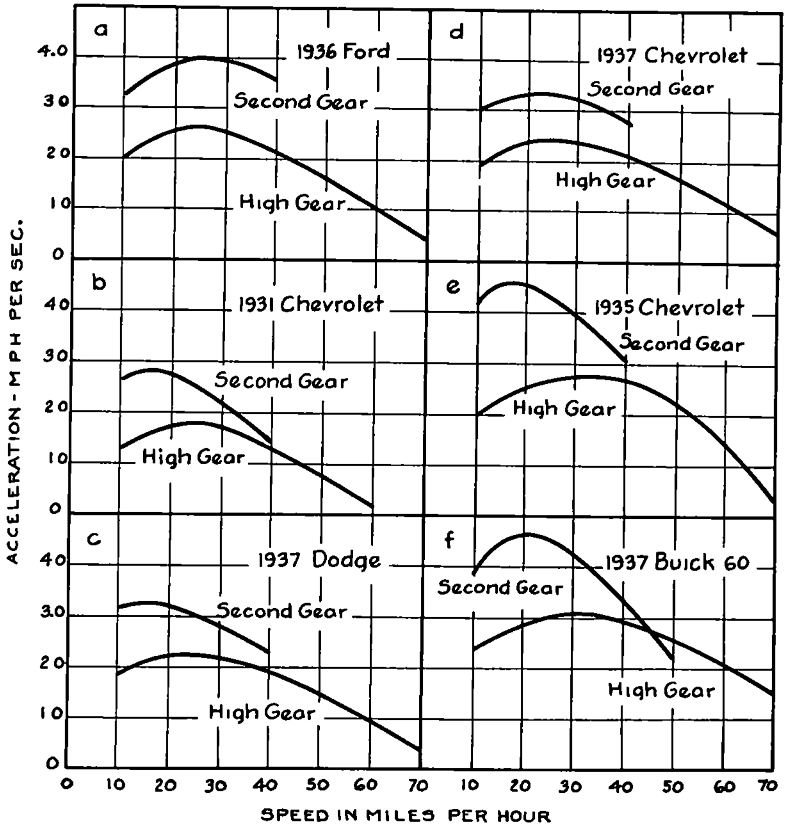

Figure 5. Acceleration Curves

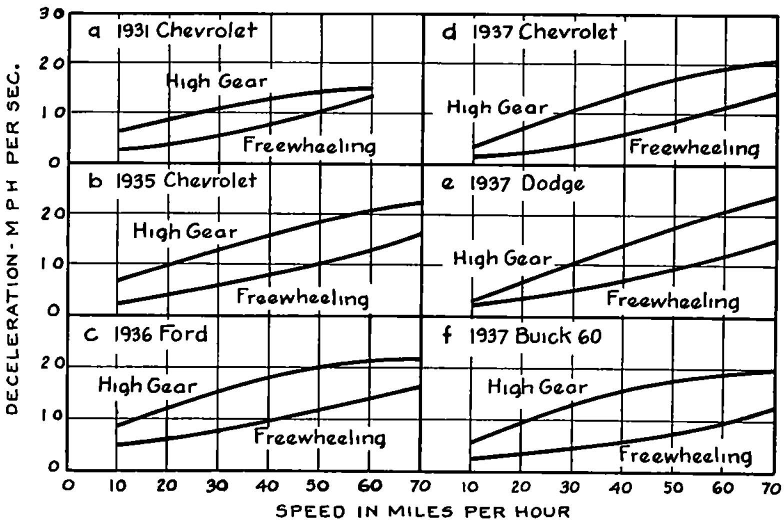

Figure 6. Deceleration Curves

many observations of individual cases, values of deceleration or acceleration that would be representative of those employed by the average driver when stopping his vehicle or accelerating to normal driving speed It is believed that the method employed in this report is as near an approach as is possible

The deceleration data will be considered first In order to determine the speed at which each vehicle was traveling as it entered the test section (Fig 4), its speed through the first interval of the between intervals of the test section In Figure 7, speed and deceleration were plotted as ordinates against distance from the stop line as abscissae

The observations indicated that the vehicles traveling at the higher speeds had been slightly decelerated before entering the test section The deceleration curves show that the cars driven at the higher speeds start decelerating at a greater distance from the stop line and use a higher rate of deceleration throughout the entire maneuver of stopping

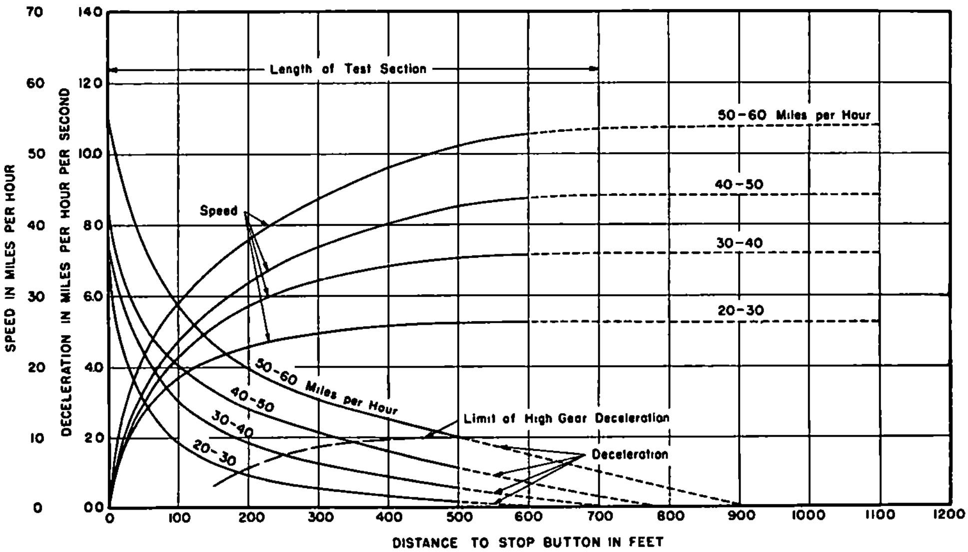

Figure 7 Speed and Deceleration Curves for Vehicle Approaching a "STOP" Sign.

test section was computed These data were then grouped into speed increments of 10 miles per hour viz, 20-30, 30-40, 40-50, and 50-60, according to the speed at the beginning of the test section Each of these groups was then treated separately. The average of the total time from the beginning of the test section was then computed for each observation point These average values were then used to compute the speed through each interval of the test section The decelerations were computed from these computed speeds and the elapsed time The limits of high-gear deceleration as determined from the test cars have been indicated for the average of each speed increment Above these points deceleration must be accomplished by the use of brakes In each group, maximum deceleration occurred in the last few feet of the stopping maneuver, the greater rate being used by the higher speed drivers However, only vehicles in the higher speed groups exceeded a rate of deceleration of eight miles per hour per second Indications were that nine miles per hour per second might be considered the maximum rate of deceleration that can be used without discomfort to the passengers It is noted that other observers have found that a deceleration rate of eleven miles per hour per second can be attained without discomfort This represents probably the range of minimum discomfort

The deceleration time through the test

lyzed in very much the same manner as the deceleration data The observations were grouped in 10-mile-per-hour increments according to the speed in the last interval of the test section The averages of the total elapsed time from the starting point were computed for each of the observation points and these values

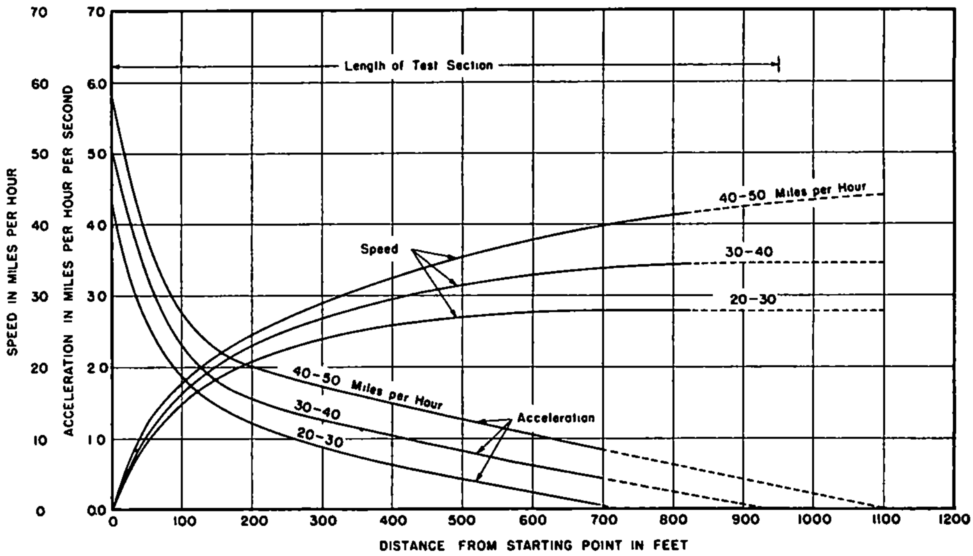

Figure 8. Speed and Acceleration Curves for Vehicle Leaving a Traffic Signal

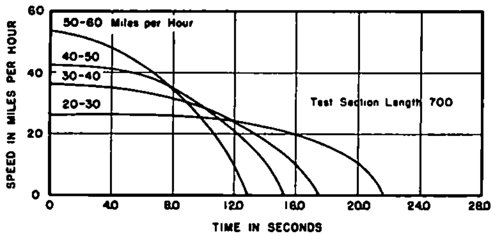

Figure 9. Deceleration Time Through Test Section

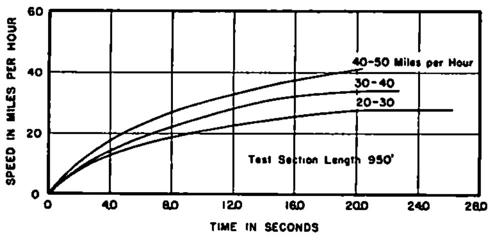

Figure 10 Acceleration Time Through Test Section

section, for the average speed of each speed increment group, is shown in Figure 9, the total elapsed time required to travel through the test section to a stop being 12 9, 15 4, 17 5, and 21 6 sec for the speed increment groups of 50-60, 40-50, 30-40, and 20-30 mph respectively

The normal acceleration data were ana-

used to compute the speed and acceleration curves In Figure 8, speed and acceleration have been plotted as ordinates against distance from the starting point as abscissae

It was impossible, with the equipment available at the time, to extend the test section for a sufficient distance to observe all vehicles traveling less than 30 miles per hour or more than 40 miles per hour. Further, such observations as were made of vehicles traveling in the 20-30 and 40-50 mph groups were close to the upper and lower limits, respectively This results in a poor distribution in those groups

The acceleration curves are quite similar in shape to the deceleration curves except that the ordinate values are but half of the ordinate values for the deceleration curves The curves indicate that a high rate of acceleration is used for a short distance from the starting point, decreasing at a gradual rate after shifting into high until constant speed is reached The drivers who eventually attained the higher speeds used a greater rate of acceleration throughout the maneuver and maintained it over a greater distance Most drivers traveled only a short distance in low gear, with the greater part of the acceleration occurring in second and high gear The shifting into high gear occurs between 100 and 200 feet from the starting point Drivers of cars in the lower speed groups, shift into high gear sooner than those in the other groups

The acceleration time through the test section for the average speed of each speed increment group is shown in Figure 10 The average time required to traverse the test section was 20 5, 22 6, and 26 2 seconds for the speed increment groups of 40-50, 30-40, and 20-30 mph , respectively As mentioned before, the test section was not long enough for each speed group to reach a constant driving speed, with the exception of those driving between 20 and 30 miles per hour The average speed for the latter group was 27 8 miles per hour through the last part of the test section Those in the 40-50 and 30-40 speed groups left the test section at average speeds of 41 5 and 34 0 miles per hour, respectively, but attained higher speeds than these after leaving the test section

The time interval, from the instant the traffic signal turns to the green until the operator has the vehicle in motion is a summation of (1) the perception and reaction time of the driver, (2) the mechanical lag in the vehicle's mechanism, and (3) in some instances, the inattention time of the driver The perception and reaction time is that time which elapses from the instant the driver first sees the green signal until he starts the necessary movements to put his car in motion Psychologists have given the reaction time for visual stimulation as 0 15 to 0 20 second, and as 0 12 to 0 16 second for audible stimulation [1] Apparently no information is available as to the time consumed by the mechanical lag of the vehicle, but, from the limited tests made by the authors of this report, it was found that the time required normally to engage the clutch is approximately 0 5 sec , and approximately 0 5 sec additional to shift from neutral into low gear Using 0 2 sec , the upper limit of visual reaction time, and adding to it 0 5 sec for engaging the clutch, results in 0 7 sec as the minimum time required to put the vehicle into motion If it is first necessary to shift into gear, a minimum of 1 2 sec is required

"Inattention" time of the driver is variable From observations of delay time at a traffic signal having only visual (lights) indication of signal change, and with amber following the green only, the following results were obtained

Delay greater than 2 0 seconds	13%
Delay 2 0 seconds or less	87%
Delay 1 0 second or less	38%
Starting early ("jumping")	12%

Of these observations in the 13 per cent having a delay greater than 2 0 sec , a maximum of 8 2 sec was recorded The attention of the driver in this case was finally attracted by the blowing of the horn of the vehicle behind his Of these

[1] "Greater Experiments in Psychology," by H E Garrett.

delays greater than 2 0 sec , the majority were observed not to be watching the signals The arithmetical mean of all delays of less than 2 0 sec was 1 0 sec This value is within the theoretical limits of the minimum-delay time when no inattention time is included The arithmetical mean of all delays was 1 3 sec

As stated previously in the report, acceleration was computed only from the instant the vehicle started to move and the foregoing discussion of delay time need not be considered with reference thereto

This study was conducted under the auspices of the Oregon State Highway Department, Mr R H Baldock, State Highway Engineer The field work and analysis of the data necessary for the compilation of this report were very ably performed by Mr Kenneth M Klein and Mr. W J Brown of the Traffic Engineering Department, Oregon State Highway Department