Velocity Thresholds in Car-Following at Night

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•CAR-FOLLOWING is defined as that phenomenon in which a vehicle follows a lead vehicle which is traveling at an arbitrary speed. If the velocity of the lead vehicle is designated by v_1 and the rear vehicle velocity by v_2, then the relative velocity, v, is defined as the difference v_1-v_2. It is the threshold of this velocity that has been investigated. Here velocity threshold is defined as that relative velocity which the driver of the rear vehicle can detect with a 50 percent probability at a given headway for a given presentation time. The headway is taken as the distance from the driver's eyes to the rear bumper of the lead vehicle.

This study is concerned with the determination of velocity thresholds under night driving conditions, and is based on the premise that the information available to the driver of the following car concerning the state of the lead car, is primarily provided by the taillights of the lead car. When a relative velocity exists between the two cars, this visual information appears as a change in the visual angle subtended by the two taillights of the lead car and apparent changes in the brightness and area of the taillights. For the presentation times of relative velocity used in this study, the changes in headway were so small that it was assumed taillight brightness and area could be taken as fixed. Hence, velocity thresholds were obtained by considering only the change in visual angle. This, of course, may not be the only cue of consequence in detecting relative velocities, but it is almost certainly a major one.

Velocity thresholds for daytime driving were obtained in a previous study (1) in which an automobile simulator was also used.

SIMULATION

It was decided to determine the velocity thresholds using an automobile simulator since experimentation on an actual highway presents many problems as far as experimental control and variable measurement are concerned. A block diagram of the simulator is shown in Figure 1. For each given increment of relative velocity v, the switch S_1 is closed by the timer for a time interval T_p, thereby causing the integrator to

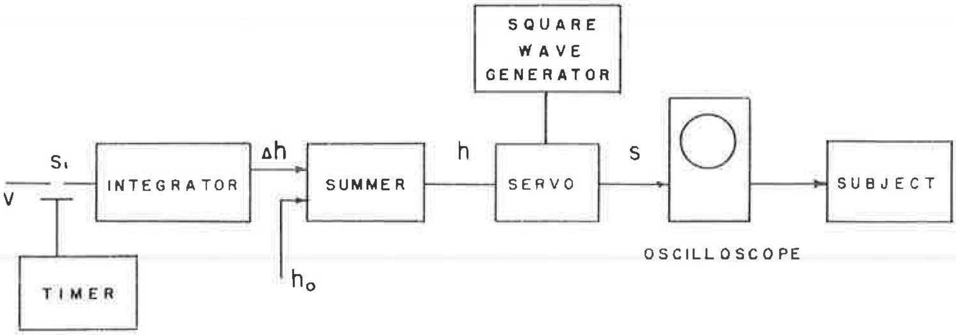

Figure 1. Simulator block diagram.

Paper sponsored by Committee on Driving Simulation.

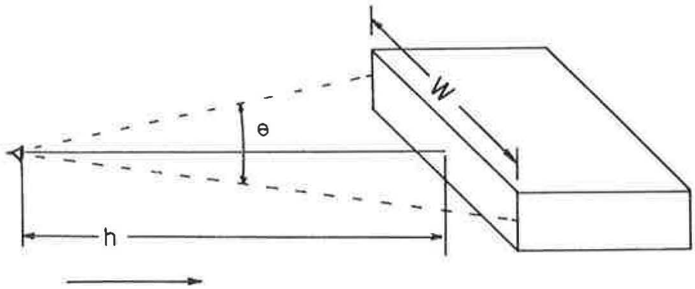

Figure 2. Ray diagram of car-following situation.

integrate v. On integration, v becomes Δh (the change in headway over the time interval T_p), which is added to the initial headway, h_0, to give the instantaneous headway, h. The signal h controls a servomechanism, the output of which is a square wave whose amplitude (S) is inversely proportional to h. However, the horizontal visual angle (θ) subtended by the taillights of the lead vehicle is also inversely proportional to h as $\theta = w/h$ where w is the distance between the taillights of the lead vehicle—w = 7 ft (Fig. 2). Consequently, S is directly proportional to the horizontal visual angle, θ. This signal is then fed into the horizontal input of the oscilloscope which causes 2 spots to appear on the oscilloscope face, representing the taillights of the lead vehicle. Defocusing of the spots was necessary to give a spot whose diameter was equivalent to a taillight diameter of 5.8 in. at h = 71 ft. The diameter of each spot was $^{13}/_{64}$ in. while spot luminance was 4.15 ft lamberts at a contrast of 1.9 percent. The spot size was not varied as the headway changed and the spots were displayed on a 5BPI type cathode ray tube. Lastly, the subject viewed the oscilloscope face from a distance of 30 in. while a headrest was used to insure that his head was always in the same position.

DESCRIPTION OF EXPERIMENT

The subject was presented with a view of only the taillights of a vehicle. The separation of the taillights was initially set to correspond to some real world constant headway, representing the real situation of a lead vehicle being followed by a rear vehicle at some constant headway (i.e., both vehicles' speeds are identical and v = 0). The relative velocity was then changed from 0 to v. This change causes a proportional change in the spot separation, either an increase or a decrease depending on whether v is negative or positive. The subject observes the simulated taillights and reports whether he perceived an increase, decrease, or no change in the spot separation.

Three male subjects with normal vision were used in the experiment. All subjects had driving experience and ranged in age from 24 to 30 yr. The experiment was performed in a dark room and a visual adaptation time of 15 min was required before experimentation began. Communication between the experimenter and subject was maintained by a telephone headset.

PROCEDURE

The taillight separation was initially set to correspond to some real world headway. The subject was then instructed to observe the oscilloscope when the command "observe" was given. A fraction of a second later a signal corresponding to a step change in relative velocity, v, of duration equal to T_p was fed into the simulator. After this presentation the subject was given the command, "report." On this command he reported whether or not he had detected any motion of the taillights. If he had detected motion during the interval T_p, he was also to report the sense of the motion (i.e., did the taillights separate or draw closer together). After the subject had reported his observation, the taillights were removed from the oscilloscope screen and the taillight separation reset to its initial value. Then the spots were restored on the oscilloscope

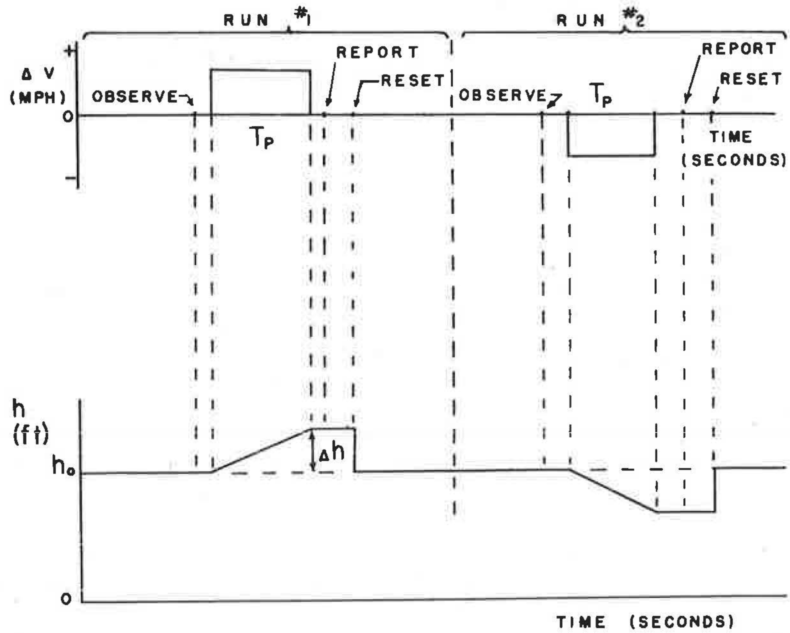

Figure 3. Event diagram of experimental procedure.

and another run made. The sequence of events as well as the behavior of the variables v and h are shown in Figure 3. Fifty such runs were made at one setting. For the presentation times used, this took about 15 min. After a reset period of 5 min another 50 runs were made and so on until a total of 200 runs were completed. The rest periods were found necessary to minimize fatigue.

The subjects were presented with 9 different incremental velocities, v, for a given set of steady-state conditions. These velocities had positive, negative, and zero magnitudes and were presented to the driver in a random sequence. Two hundred runs per subject were made for each combination of steady state headway h_0 and presentation time T_p. Headways of 71, 129, 188, and 276 ft were used and the presentation times T_p were 0.3, 1.0, 2.0, 3.0, and 5.0 sec.

RESULTS

Velocity Perception Curve

Each set of 200 runs was used to plot a velocity perception curve which is a plot of the probability of velocity detection vs the incremental velocity, v. The probability of velocity detection for a given velocity increment was determined by dividing the total number of runs in which the subject detected motion correctly (i.e., the subject had to not only determine if motion had taken place but also the sense of the motion) by the total number of runs at that velocity increment and expressing the result as a percentage. Figure 4 shows the average velocity perception curve obtained when the three subjects' velocity perception curves are summed and averaged for a given h_0 and T_p. The other values of h_0 and T_p used, yielded similar curves.

Threshold Velocity Characteristics

The relative velocity threshold is dependent on both the headway and presentation time of the relative velocity stimulus. For each value of headway and presentation time, there exists both a positive and negative threshold velocity.

The dependence of threshold velocity on headway was first determined. Figure 5 shows the relation between the positive threshold velocity, v_t, and the headway, h,

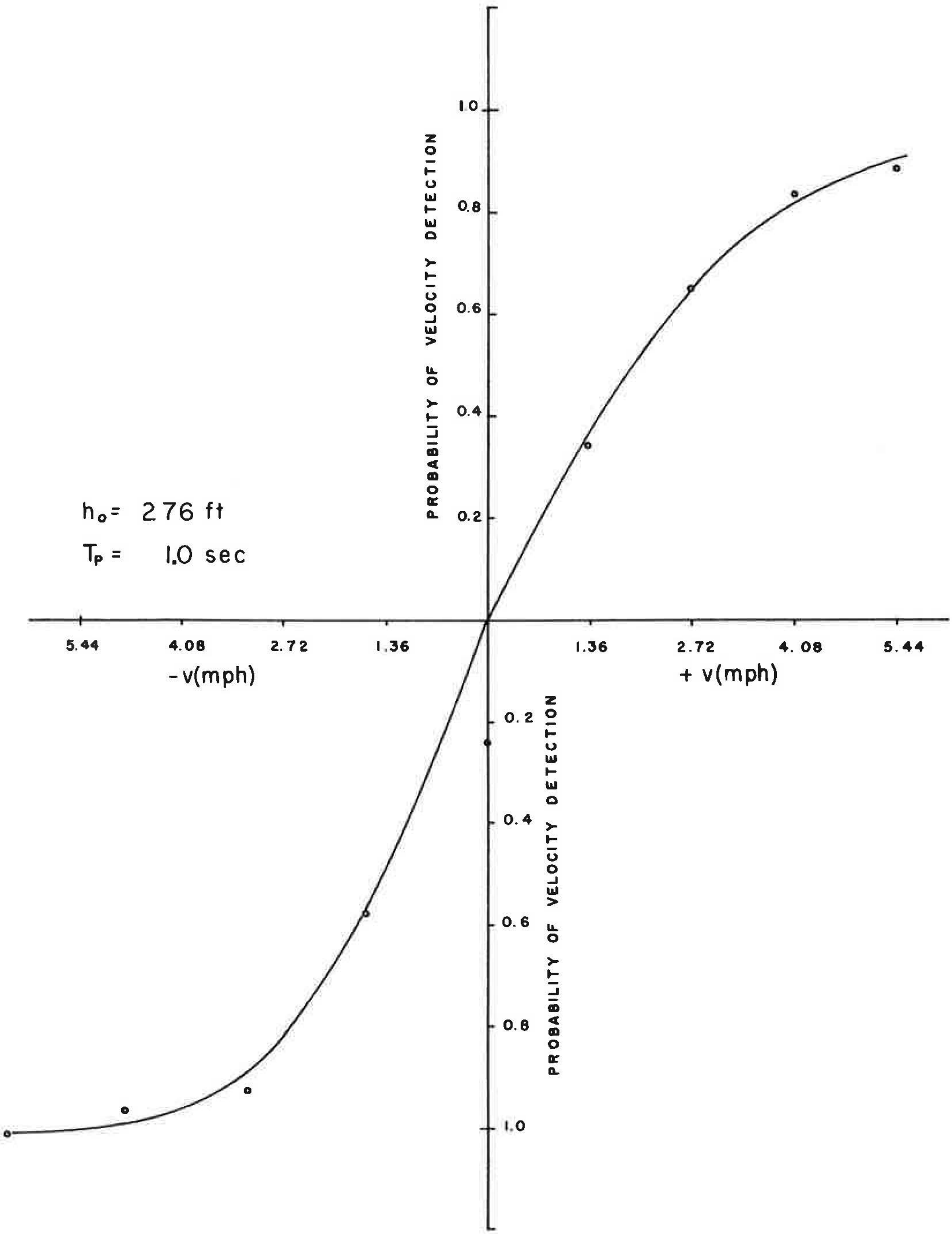

Figure 4. Average velocity perception curve.

where T_p is a parameter. The method of least squares was used to obtain the best linear approximation to the data points for each headway. The equations of these curves have the general form $v_t = Kh^n$ where the parameters K and n are dependent on T_p and have the values given in Table 1.

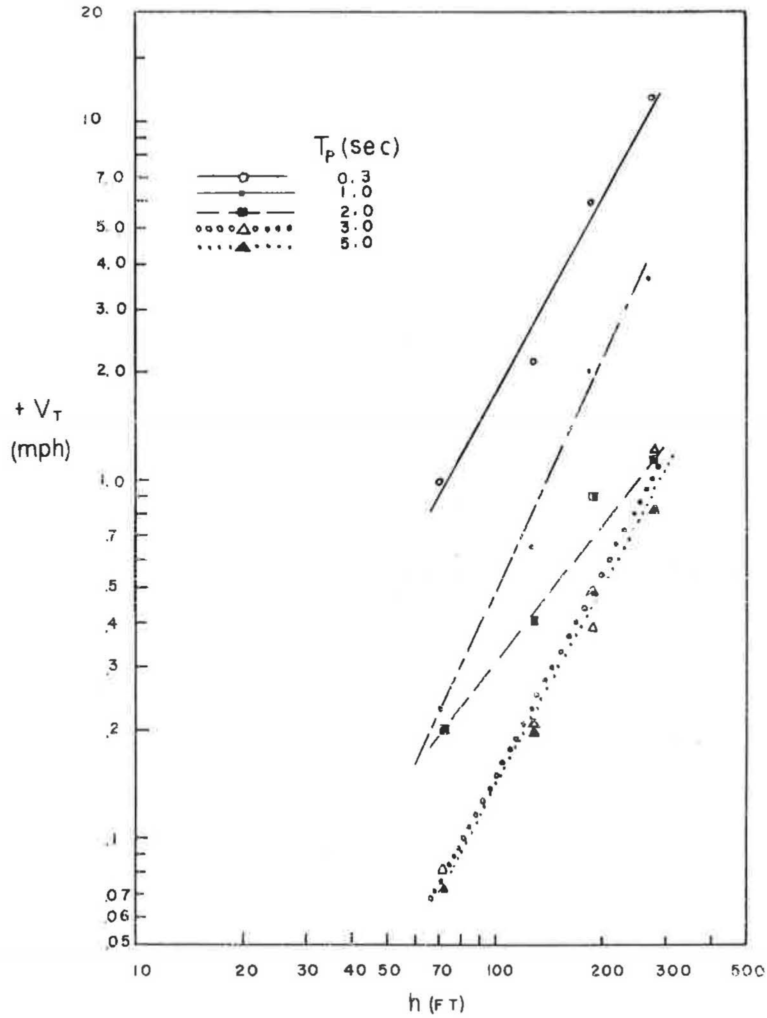

Figure 5. Positive velocity threshold characteristics for simulated nighttime driving.

TABLE 1

Dependence of K and n on T_p.

T_p (sec)	K (mph)	n
0.3	3.16×10^{-4}	1.86
1.0	2.82×10^{-4}	2.10
2.0	6.73×10^{-4}	1.34
3.0	2.17×10^{-5}	1.91
5.0	2.87×10^{-5}	1.84

Figure 6 shows the relation between the negative velocity threshold, v_t, and the headway h where T_p is a parameter. Again the curves have the general form $v_t = K_1 h^m$ where K_1 and m are dependent on T_p and have the values given in Table 2.

These velocity threshold characteristics hold only for simulated night driving. In a previous work (1) the velocity threshold characteristics were determined for simulated day driving (Figs. 7 and 8). Comparing Figures 5 and 6 with Figures 7 and 8, the night and day characteristics are

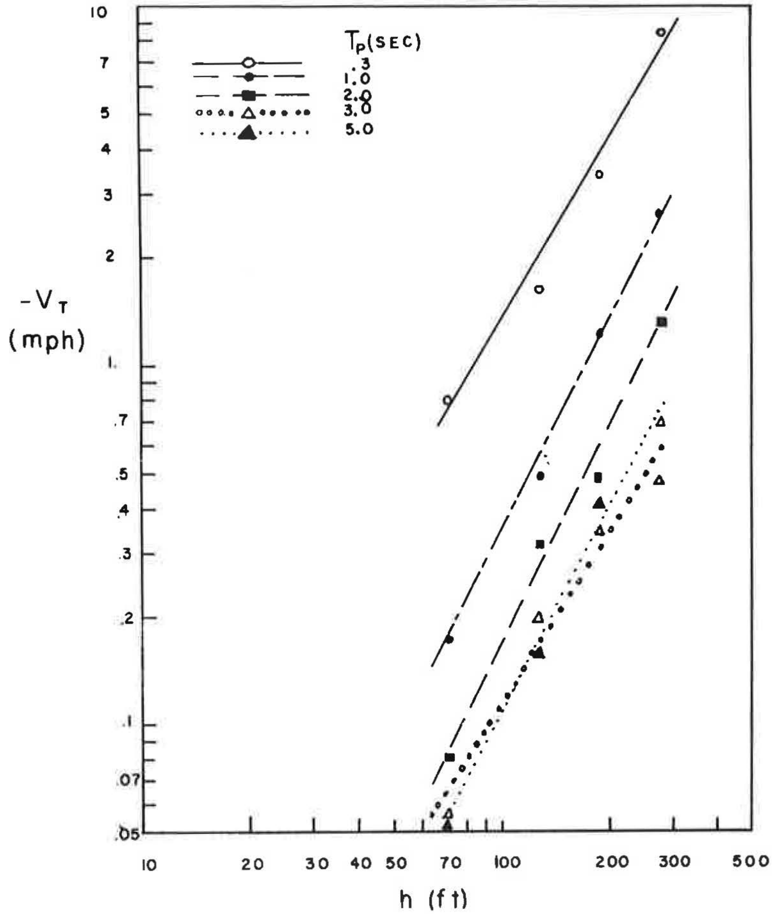

Figure 6. Negative velocity threshold characteristics for simulated nighttime driving.

TABLE 2

Dependence of K_1 and m on T_p

T_p (sec.)	K_1 (mph)	m
0.3	4.73×10^{-4}	1.72
1.0	2.72×10^{-5}	2.04
2.0	1.71×10^{-5}	1.99
3.0	6.98×10^{-5}	1.60
5.0	1.37×10^{-5}	1.94

similar. The only significant difference between the two types of thresholds is that the night velocity threshold is generally smaller than the day velocity threshold. This difference is quite possibly because the observer was presented with fewer extraneous visual stimuli at night than during the day; however, it may be a consequence of the environment in which the experiment was performed. In any event, it appears that the process of relative velocity detection was the same in both experiments.

General Velocity Threshold Equations

In the determination of the day velocity threshold it was found that two equations could be used to interrelate accurately the velocity threshold with the variables of headway and presentation time (1). The same approach was applied to the night velocity threshold. Figures 9 and 10 show plots of plus and minus v_t vs T_p on log-log graph

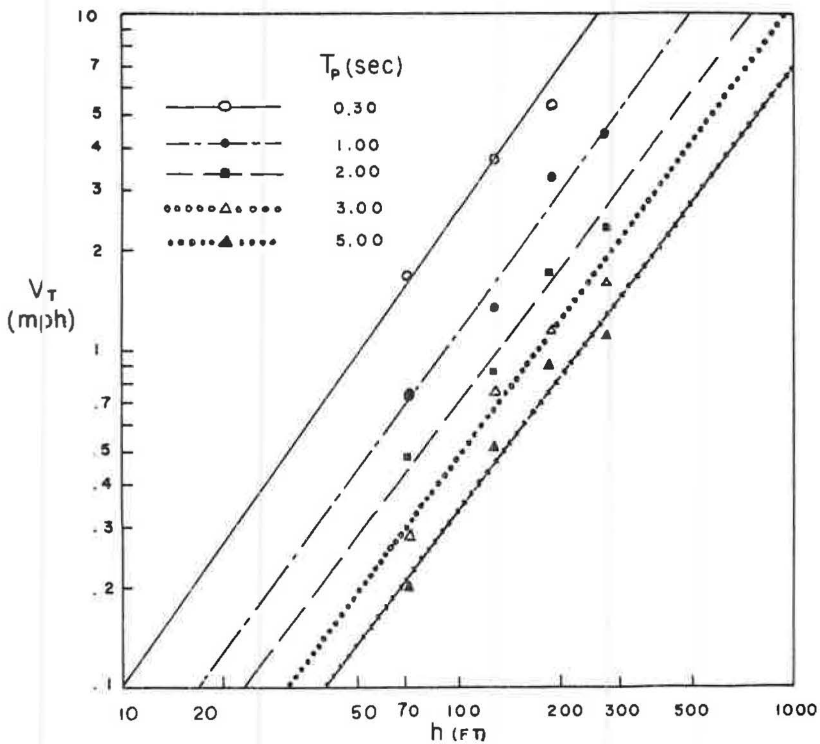

Figure 7. Positive velocity threshold characteristics for simulated daytime driving.

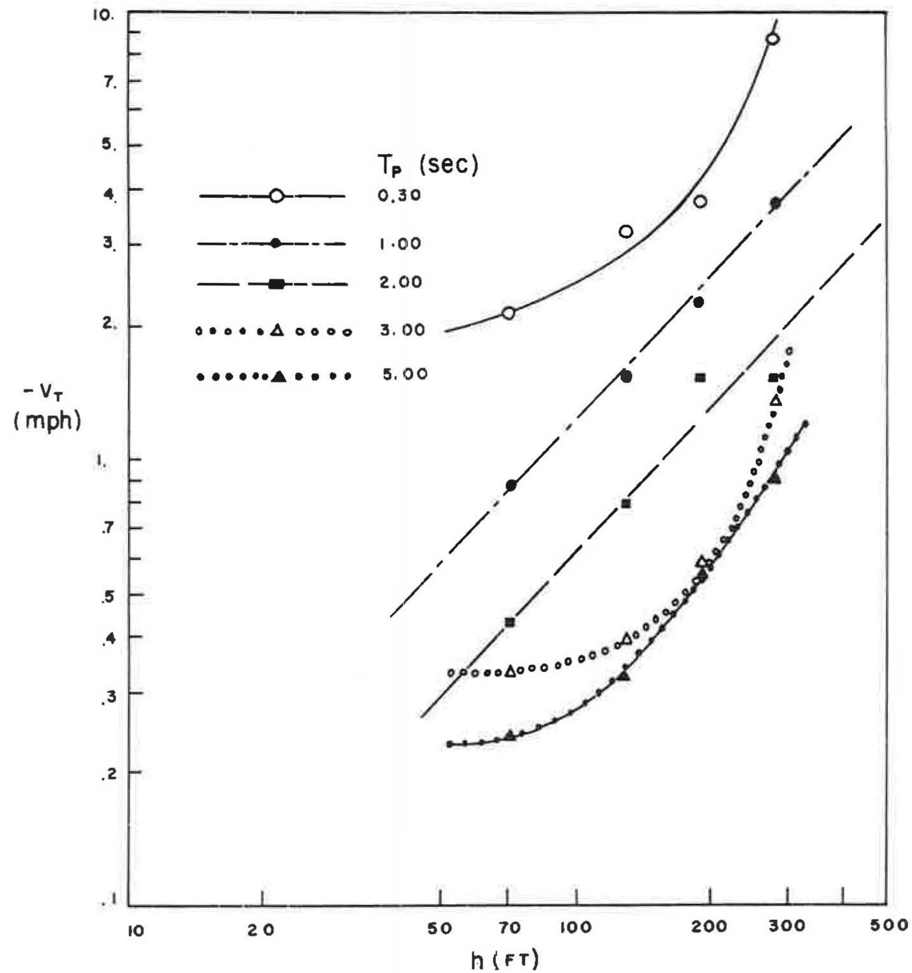

Figure 8. Negative velocity threshold characteristic for simulated daytime driving.

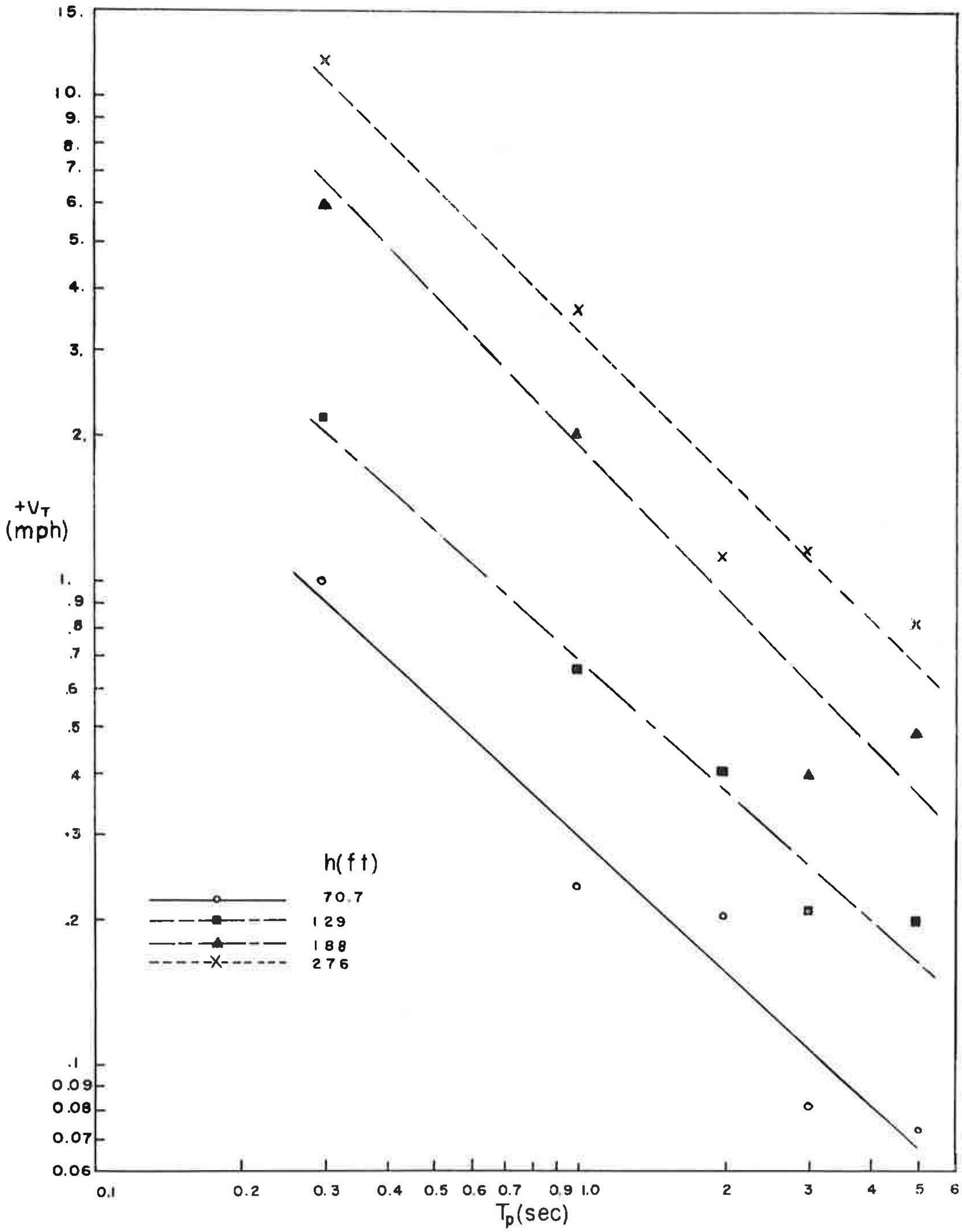

Figure 9. Positive velocity threshold characteristics (v_t vs T_p).

paper. The method of least squares was used to obtain the best linear approximation to the data points for each headway. It is evident from the curves that the describing equations are of the form $v_t = K_2(h)\,T_p^{-n}$. Evaluation of the constants yields the following two invariant threshold equations:

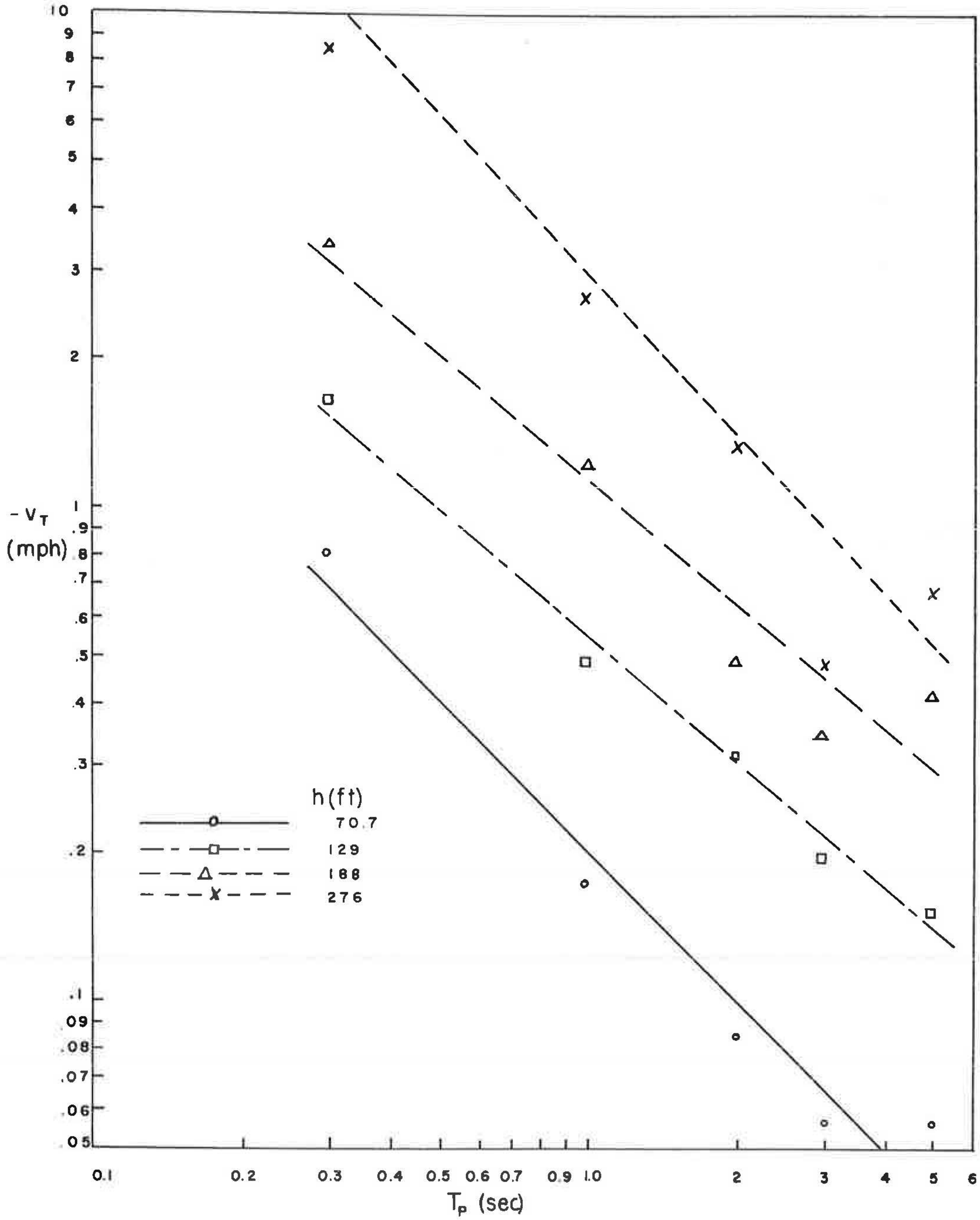

Figure 10. Negative velocity threshold characteristics ($-v_t$ vs T_p).

$$v_t \text{ positive} \quad v_t T_p^{0.963} h^{-1.85} = 1.065 \times 10^{-4} \tag{1}$$

$$v_t \text{ negative} \quad v_t T_p^{0.946} h^{-1.96} = 4.375 \times 10^{-5} \tag{2}$$

where h is in feet, T_p in seconds, and v_t in miles per hour. Eqs. 1 and 2 are valid only for the following range of variable values:

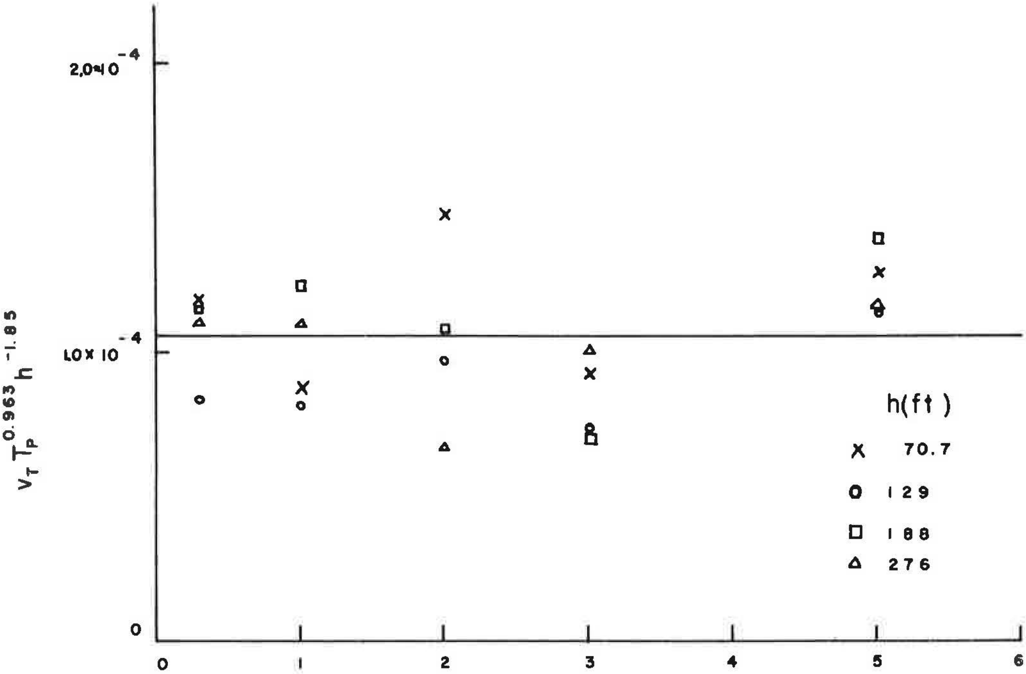

Figure 11. Dependence of the positive velocity threshold on T_p.

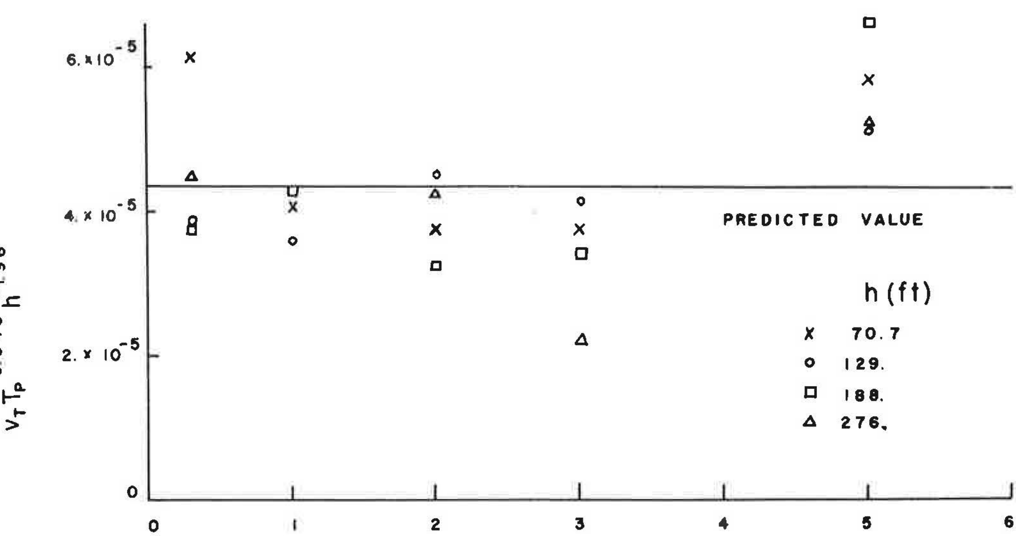

Figure 12. Dependence of the negative velocity threshold equation on T_p.

$$0.07 \text{ mph} \le +v_t \le 11.7 \text{ mph}$$

$$0.05 \text{ mph} \le |-v_t| \le 8.5 \text{ mph}$$

$$0.3 \text{ sec} \le T_p \le 5 \text{ sec}$$

$$71 \text{ ft} \le h \le 276 \text{ ft}$$

The same test for invariance of the general velocity threshold equations was made as before (1). That is, the left-hand portions were calculated on the experimental data and the result plotted as a function of T_p (Figs. 11 and 12). These plots show that the general velocity threshold equations are, in fact, almost invariant in that there is no consistent trend of the data points with T_p.

CONCLUSIONS

This experimental investigation of the driver's night velocity threshold, using a simulator, has yielded the driver's velocity threshold as a function of headway and presentation time of the relative velocity. Two general velocity threshold equations were derived which interrelate the velocity threshold with the presentation time and headway for the simulated situation. It is simple to calculate the positive and negative night velocity thresholds if the headway and presentation time are known. A comparison was made between day and night velocity thresholds, both obtained from automobile simulator experiments, with the result that the night velocity threshold is generally smaller than the corresponding day velocity threshold. This deviation is due, of course, to the modification of the environment. In one case the complete vehicle and roadway are observed on the TV screen, whereas in the night driving case only the two spots are visible.

REFERENCE

1. Todosiev, E. P. Velocity Thresholds in Car-Following. Presented at 43rd Annual Mtg. of the Highway Research Board, 1964.