Behavior of Drivers Performing a Flying Pass

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•WHEN a vehicle traveling at a given rate encounters a slower moving vehicle, the overtaking driver must decide whether to pass the lead car (LC) or decrease his speed and follow. If no oncoming car (OC) is involved the passing opportunity is limited by the available sight distance and/or local passing zone boundaries. In this case, the correct pass/no-pass decision is a function of the speed of the LC, the overtaking rate of the passing car (PC), and the distance between each of the two cars and the end of the passing zone. The objective acceptability of a passing opportunity depends on whether or not the speeds and distances are such that the PC can complete the pass before the end of the passing zone. The following formula is a convenient way of expressing the relationship of these variables to the validity of the passing decision:

$$\text{Time Difference (TD)} = \frac{\text{DLC}}{\text{LCS}} - \frac{\text{DPC}}{\text{PCS}} - \text{SM}$$

where DLC and DPC are distances and LCS and PCS are speeds from the end of the passing zone of the PC and LC at the time of the encounter, and SM is an arbitrary safety margin left up to the driver. A positive TD predicts that the PC can reach the end of the passing zone ahead of the LC with some safety margin, whereas a negative TD indicates that the passing zone will end before the pass can be safely completed. Obviously this expression is a simplification based on the speed and distance conditions at the time of the passing decision assuming that the starting speeds will be maintained. Clearly, the passing driver may elect to increase or decrease velocity during a pass. However, the maximum acceleration and hence the minimum passing time of which a given vehicle is capable is relatively constant at highway speeds, and the TD can thus be considered as an objective measure of the acceptability of a passing opportunity.

Ideally then, in order to make valid passing decisions—that is, to pass when it is safe to do so and not to pass when it is unsafe—the PC driver would have to consider all of the relevant speed and distance cues and make a decision based on a formula similar in principle to that given. One way of expressing driver decision-making in such passing situations is to plot percent passes as a function of the TD (Fig. 1). If a driver were able to make perfect judgments of all the variables and take each of them into account appropriately he would always pass when the TD was greater than zero and never pass when the TD was less than zero, that is, he would always make a valid decision. In Figure 1, curve A represents perfect decision-making. Curve B is a more realistic prediction of passing behavior: the driver accepts some unsafe passing opportunities and rejects some safe opportunities. The slope of the curve is a measure of the accuracy with which a driver is judging and responding to the TD. The steeper the slope, the more accurate the judgment of TD. Obviously, this is a rather formidable task, involving accurate judgments of speeds and distances in complex combinations.

Considering the importance of the topic, little work has been done in the area. Normann (1) and Whedon (2) report results obtained from observations of highway passing, but data are given only for cars that did pass; thus, no information on the conditions under which drivers will or will not pass is given. The present experiment is the first known to the authors to make a systematic controlled study of passing judgment in situations where sight distance is the limiting factor.

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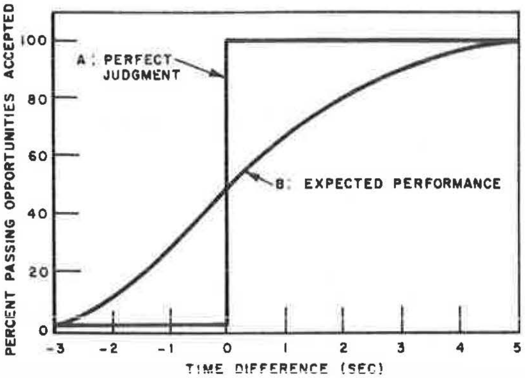

Figure 1. Ideal and expected decision-making plots.

METHOD

The experiment was conducted at the Vineland Speedway, a 1.5-mile closed-road racing circuit in Vineland, New Jersey. The course incorporates a 2600-ft tangent section that terminates in a sharp (25-35 mph) right-hand turn. The passing zone commences at a slight crest located 600 ft from the beginning of the tangent section, at which point the sight distance is 2000 ft. It terminates 200 ft from the end of the tangent section. At the end of the passing zone the sight distance into the curve is 500 ft. Both the beginning and end of the passing zone were marked by rubber cones placed at the right side of the roadway. The roadway was blacktop, 40 ft wide, with sandy shoulders. The layout of the test site is shown in Figure 2.

Two vehicles were employed in the experiment, a passing car (PC) and a lead car (LC). The PC was a 1965 Ford Galaxy sedan with a 352-cu in. V8 engine, automatic transmission, and power steering. The PC and LC were each equipped with fifth wheels to provide speed and fine distance information. Rough distance information was obtained by means of photocells mounted under the cars that sensed transverse white tape strips every 400 ft on the pavement. The PC had additional instrumentation providing continuous analog tracings of longitudinal and lateral acceleration, lateral position, yaw rate, brake pressure, throttle position, and steering-wheel position. The speed and distance data were subsequently used to determine the true positions and velocities of the test cars at various points in the passing maneuver. Throttle and steering-wheel position and brake-pressure records were used to determine at what point in a trial the subject decided whether or not to pass. The lateral-position record was used to determine at what point in the passing zone the PC regained the right lane at the completion of a pass.

The subjects in the experiment were 24 Philadelphia Yellow Cab Co. drivers, ranging in age from 26 to 58, with a minimum of 9 years of driving experience.

Procedure

Throughout a block of trials, the PC continuously circulated the track. On each lap, as the PC reached a specific point on the curve leading into the straightaway, a start signal was given to the LC, parked on the shoulder of the pavement at a preassigned point on the straightaway. On the start signal the LC pulled onto the straightaway in front of the PC and accelerated to a constant preassigned velocity. The PC driver was

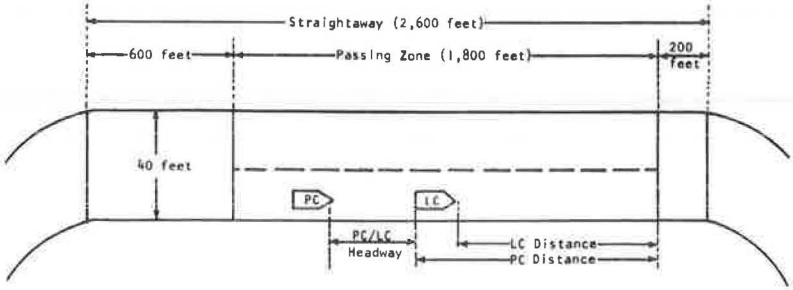

Figure 2. Vineland Speedway test site.

TABLE 1

EXPERIMENTAL DESIGN

Speed (mph)		TD (sec)					
LC	PC	-3	-1	0	1	3	5
25	45						
35	45						
40	60						
50	60						

instructed to maintain a constant assigned speed on the straightaway until he overtook the LC, at which time he was to decide whether he could pass safely. A safe pass was defined for the subject as one that could be completed at or before the end of the passing zone (200 ft from the end of the tangent section). The subject was permitted to increase his speed during the pass if he desired. If he chose not to pass, he was to slow down and follow the LC.

Experimental Design

The independent variables were (a) the speed of the PC (PCS); (b) the speed advantage or closing rate of the PC (CR); and (c) the TD as defined above, controlled by manipulating the LC starting point. Vehicle speeds and TD's are shown in Table 1. Each subject had two blocks, each block consisting of one trial at each of the 24 independent variable combinations. The primary dependent variable was whether or not the subject passed. Since desired safety margins may vary from driver to driver, no safety margin was used in computing the starting conditions required to produce the tabled TD's. A zero TD in this experiment means that the passing driver arrives at the end of the passing zone just as the right lane is regained at pass completion.

RESULTS

Data were taken from the trial records at two points: at the moment of the pass/no-pass decision and at the point of maximum PC speed on those trials in which a pass took place. The pass/no-pass decision point was determined by examining the analog records and noting when the PC began a pass, as indicated by throttle and steering-wheel position traces, or when it began to slow and follow, as indicated by the throttle position, brake pressure, and speed traces. The distance and speed data taken from the records at these points were used to compute TD's. All of the data given below were averaged across subjects.

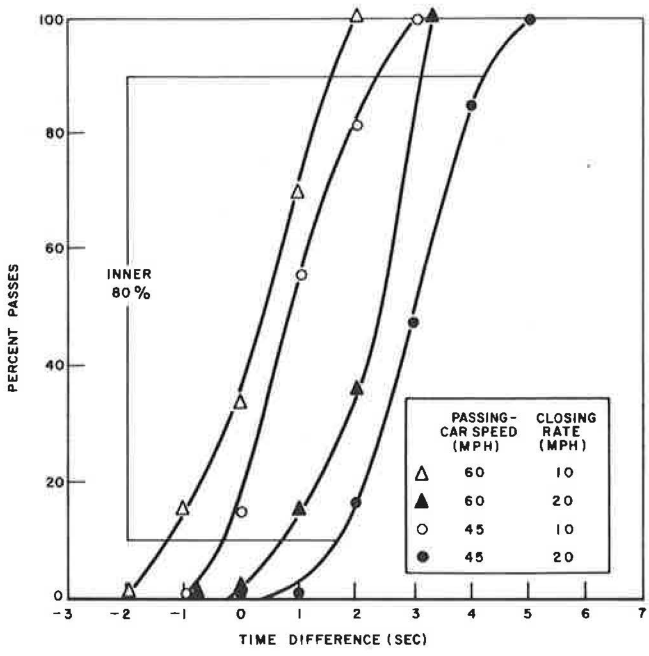

Figure 3. Percent passes as a function of TD at different PC speeds and closing rates.

Figure 3 shows percent passes as a function of the TD obtaining at the moment of the pass/no-pass decision for each of the four LC-PC speed combinations. Each curve is quite steep through the middle portion. The inner 80 percent of each curve falls within a TD range of 2.7 sec or less; within each curve very few subjects passed when the TD was more than 1.5 sec less than the threshold and very few failed to

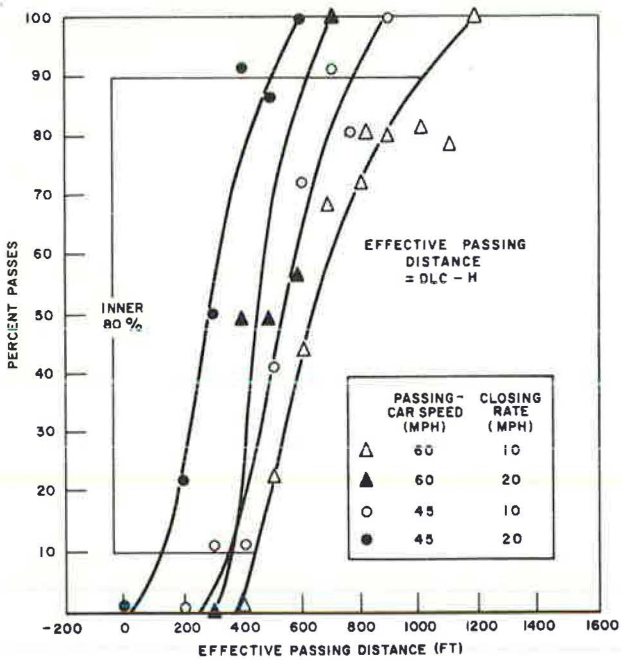

Figure 4. Percent passes as a function of EPD at different PC speeds and closing rates.

pass when the TD was over 1.5 sec more than the threshold. (The threshold TD is defined as that TD above which 50 percent of the drivers passed.) In the two 10-mph speed-advantage conditions a number of passing opportunities characterized by negative TD's were accepted. This means that, had the drivers maintained a constant speed through the pass, they would not have been able to complete the pass before the end of the passing zone. In fact, as will be seen later, most drivers did accelerate when they passed and very few passes were completed beyond the end of the passing zone.

Within a given OC-LC speed condition, all of the variation in the TD's presented to the subjects is associated with variations in the distances of the two vehicles from the end of the passing zone. If subjects were responding solely to TD, i. e., if they were taking PC and LC speeds accurately into account, there would have been little or no separation between the curves. However, this was not the case. The greater the CR and the less the PCS, the fewer the passes at a given TD. For example, in the PCS 45, CR 20 condition no drivers passed at a TD of zero, while in the PCS 60, CR 10 condition almost 35 percent of the drivers passed. The separation between these curves was found to be significant when the data were subjected to analysis of variance. This consistent separation of the curves indicates that at the greater speed advantage (20 mph) of the 25-45 and 40-60 conditions the drivers did not fully use their speed advantage in deciding whether or not to pass. Figure 3 also shows somewhat more conservative behavior at the lower PC speed (45) than at 60 mph at each speed advantage. This indicates that the subjects were not completely compensating for their own speed. Nevertheless, the spread of the curves is not nearly as large as would be anticipated if drivers were completely ignoring speed and speed advantage.

That drivers were taking speeds into account to a large extent is indicated in Figure 4, which shows percent passes as a function of effective passing distance (EPD), which is given by DLC - H, where H is headway, the distance between the PC and LC. This parameter is used rather than DLC or DPC as it takes the relative positions of the two vehicles into account. The figure is based on the EPD's that obtained at the moment of the passing decision. Although the points show considerably more scatter than in Figure 3, the curves show clear separations, indicating that with a high speed advantage subjects tended to pass more at shorter distances. The figure also shows that subjects responded to lower PC speeds by passing more frequently at shorter distance. Table 2 compares the empirical threshold EPD's with EPD's based on a TD of 2.0 sec, i.e., the EPD's that would have obtained had drivers always passed with a TD of 2.0 or more and never passed at TD's less than 2.0. A TD of 2 sec was chosen for this purpose because it is close to the overall threshold TD. The table shows generally good correspondence between empirical and ideal performance. If drivers had passed according to the ideal TD expression, the two sets of numbers would have perfect proportional correspondence. The correspondence is obviously not perfect; nevertheless, the table indicates that drivers were able to a large extent to judge and take into account the speed of the lead car and the overtaking rate in making the decision whether or not to pass.

TABLE 2

ACTUAL AND IDEAL THRESHOLD EPD's AT MOMENT OF PASSING DECISION FOR EACH PC-LC SPEED COMBINATION

Speed (mph)		Threshold EPD (ft)[a]	
PC	LC	Empirical	Ideal
60	50	640	650
60	40	450	350
45	35	530	500
45	25	190	175

[a]Based on a TD of 2.0 sec.

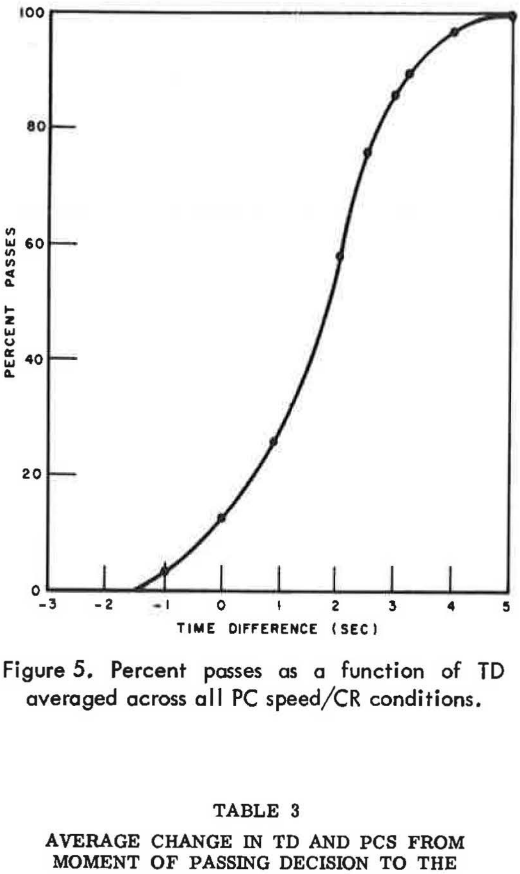

Figure 5. Percent passes as a function of TD averaged across all PC speed/CR conditions.

TABLE 3

AVERAGE CHANGE IN TD AND PCS FROM MOMENT OF PASSING DECISION TO THE POINT OF MAXIMUM PCS

Speed (mph)		ΔPCS (fps)	ΔTD (sec)
PC	LC		
60	50	12	1.8
60	40	8	1.1
45	35	14	2.2
45	25	10	1.4

The spread of each of the curves in Figure 2 reflects several sources of variability: errors in driver judgment of EPD; differences between drivers, and trial-to-trial differences in the same driver in what they judged to be an acceptable EPD; and finally, despite the fact that the curves empirically separate into PCS-CR groups, some of the variability within each curve is due to errors in judging and taking into account the PC speed and CR. Hence judgment of distance is certainly no worse than can be estimated on the basis of the variability within the EPD curves. Further, if it is assumed that distance and headway judgment per se is independent of CR and PC speed, then distance judgment was no worse than what can be estimated on the basis of the curve exhibiting the least variability. Thus in the PCS 60-CR 20 condition, all of the passes took place within an EPD range of only 400 ft, i.e., no passes took place when the EPD was less than 300 and no EPD's in excess of 700 ft were rejected. Considering the fact that several other sources of variability contributed to this spread, this suggests excellent distance judgment accurate to within ±200 ft at distances up to 2000 ft.

The subject drivers did a good job in taking all of the variables into account. Figure 5 is a plot of percent passes as a function of TD averaged across all PC speed/CR combinations. The figure shows that 80 percent of the drivers passed within only ±1.75 sec of the overall threshold TD (1.8 sec) and 95 percent passed within ±2.25 sec of the threshold.

Figure 3 shows one somewhat surprising result: the threshold TD's are generally quite low, ranging from about +0.2 to 3.0 sec. However, as noted above, the TD expression does not take acceleration into account. Table 3 gives, for subjects who passed, the average change in TD and PC speed from the moment of the passing decision to the point of maximum PC speed for each of the speed combinations. The changes in TD's are consistent with the changes in PC speed. As might be anticipated, the increases were greatest at the low PC speeds and speed advantages. Thus the TD's obtained at the moment of maximum PC speed range from 1.5 to 4.0 sec. These values should not be considered as representative threshold TD's in actual highway situations. Subjects under the experimental conditions were probably considerably less conservative than they would have been on the public roads.

CONCLUSIONS

The experiment was conducted to determine which cues a driver is sensitive to in making a pass/no-pass decision in a flying pass situation in which remaining sight distance is the limiting factor. The results indicated that drivers are responsive to all of the variables that determine the validity of the passing decision: the speed of the passing car, the passing car-lead car closing rate, the distance of the passing car from the end of the passing zone, and the passing car-lead car headway.

It was not possible to determine exactly the ability of drivers to judge distance and headway, but the results suggest that their judgment of these variables was adequate and therefore not in need of remediation. While drivers were not able to compensate perfectly for speed and closing rates, it is clear that they did respond appropriately to these variables by passing more at shorter distances when passing-car speed was low and closing rate was high. Further, drivers were able to compensate partially for errors of judgment by increasing their speed and passing in less time when a marginal (low TD) passing opportunity was accepted. The data suggest that there would be little to gain by reducing the variability associated with distance and headway judgment. Further, the passing car speed information already available to drivers from the speedometer probably cannot be improved. The only remaining critical variable that could be considered for remediation is closing rate. Despite the fact that drivers responded appropriately to CR, their accuracy in judging and compensating for CR was not known from this experiment; this problem is addressed in more detail in another experiment that is concerned with judgment of closing rate in overtaking situations (3).

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