Drivers' Decisions in Overtaking and Passing

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Drivers' estimations of overtaking and passing distance were compared with actual overtaking distance. Drivers made estimates in a familiar car and in an unfamiliar car, at speeds of 18, 30, and 50 mph. Conclusions were as follows: (a) Drivers were unable to estimate overtaking and passing distances accurately. Mean error ranged from 20 to 52 percent of performance distance. Significantly larger errors were made in the unfamiliar vehicle than in the driver's own vehicle. (b) Negative errors of underestimation, where the maneuver required more space than judged, increased with speed. At 50 mph, 60 percent of the estimates made by drivers in the unfamiliar car, and 78 percent of those made in own cars were underestimations. (c) Overtaking and passing required proportionally more distances as lead car speed increased. (d) Vehicular differences affected passing distance more than did driver variance.

•ON a two-lane rural road, the driver must often overtake and pass a car in order to maintain pace. While many studies have been made of this maneuver, little is known about the driver's decision processes, although the driver is the essential element upon whose judgment the safety of the passing performance depends.

To overtake and pass, the driver must carry out the maneuver in the time or space available. Based on this requirement, the maneuver may be analyzed in terms of four basic quantities:

α is gap time or distance separating the overtaken and opposing vehicles.

α' is the driver's estimate of gap available.

β is the time or distance required by the driver-car combination to perform the maneuver.

β' is the driver's estimate of time or distance required to perform the maneuver

The driver's judgment in overtaking and passing involves a comparison of α' and β'. (The prime notations involve psychological characteristics, which are distinguished from physical variables.) If the outcome is favorable, i. e., the gap available, α, is judged to be longer than the distance required, β, with adequate safety margin, the driver will accept the gap. If not, he will reject it, and wait for a longer gap. With practice, the gap decision becomes habitual and is rapidly made.

The $\alpha\beta$ concept also applies to the driver's gap judgments in merging and in passing an intersection and to other driving decisions as well. When the driver makes a U-turn, the width of the road, α, is related to the turning radius of the car, β. In parking, the driver compares the parking space with the width of the car plus the room required to open the doors.

Both α and β are measured in physical units of time and distance; α' and β' are also measured in physical units, but these quantities are obtained in psychological experimentation. Silver and Bloom (8) measured α' gap size by asking drivers to indicate the

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distance when an opposing car was just 12 sec away; β' may be measured by having the driver indicate the minimum distance at which he can just perform the maneuver. Whether time or distance is used to measure the gap depends on the application. Time is the usual measure of intersection gaps (9, 10), but both time and distance have been used in overtaking studies (1, 8).

PREVIOUS STUDIES

The literature on overtaking and passing has been reviewed by Farber and Silver (2). Early studies were concerned mainly with establishing performance norms for traffic control. Matson and Forbes (5) and Prisk (6) give figures on overtaking distance when the pass was started at the same speed as the car ahead (accelerative pass) and when the following car had an initial speed advantage (flying pass). A distinction is also made between voluntary (unhurried) returns to lane, and those where the overtaking car was forced to return by the oncoming car.

The first psychological study of overtaking and passing was made by Crawford (1), who regarded overtaking and passing judgments as psychophysical. He carried out controlled experiments in which measurements were made of accepted gap distance, overtaking, and safety distances. He also made a validating highway study in which observations were made of overtaking vehicles from the window of a light van. Crawford's findings on overtaking performance and safety distance will be discussed under the section on results

Silver and Bloom (8) showed that the driver could not make accurate judgments. They instructed the driver to indicate when an oncoming car was just 12 sec away, simulating a 12-sec passing time, β. Without specific knowledge of the speed of the oncoming car, drivers gave their passing judgments at the same distance. When drivers were told the speed of the oncoming car, they gave improved estimates of the passing distance associated with the 12-sec gap. Rockwell and Snider have recently shown that the driver does make a limited use of oncoming car speed in making α estimates (7). The present study may be considered the converse of the Silver and Bloom study; α characteristics are here simplified and standardized to test drivers' abilities to estimate β.

The need to consider the α and β characteristics of the overtaking decision is illustrated in a study by Jones and Heimstra (3). Drivers were told to indicate the last moment they could safely pass a lead car and avoid hitting an oncoming car. They indicated the time, but did not actually pass. The lead car speed was 60 mph. Of 190 judgments made during the study, 88 were shown to be unsafe; that is, the actual maneuver required more time than drivers gave it. The time required for the maneuver was determined in preliminary passing trials, with no opposing vehicle. Overtaking was found to be unsafe, but the study does not tell us whether drivers' errors are due to inability to assess the gap, α, or to failure in estimating vehicular passing capability, β, or to both difficulties.

THE STUDY

This research is concerned with how well drivers can judge the distance required to overtake and pass. The decision is simplified by terminating the maneuver at a fixed point on the road rather than by the passing of an oncoming car. In this way, errors in assessing the situation (α errors) are minimized. Estimations were made by drivers in their own cars, and in another phase of the research, in a government vehicle. A comparison of these conditions indicates the effects of driving an unfamiliar vehicle, as well as individual differences in performance.

The Experimental Track

The studies were carried out on the runway of the Beltsville airport (see Fig. 1). A 12-ft length of 2-in. reflectorized tape was placed across the driver's path, 1500 ft from the start of the runway, and another strip was laid down 1000 ft farther. The strips indicated to the driver the starting and the terminal position of the estimation trials.

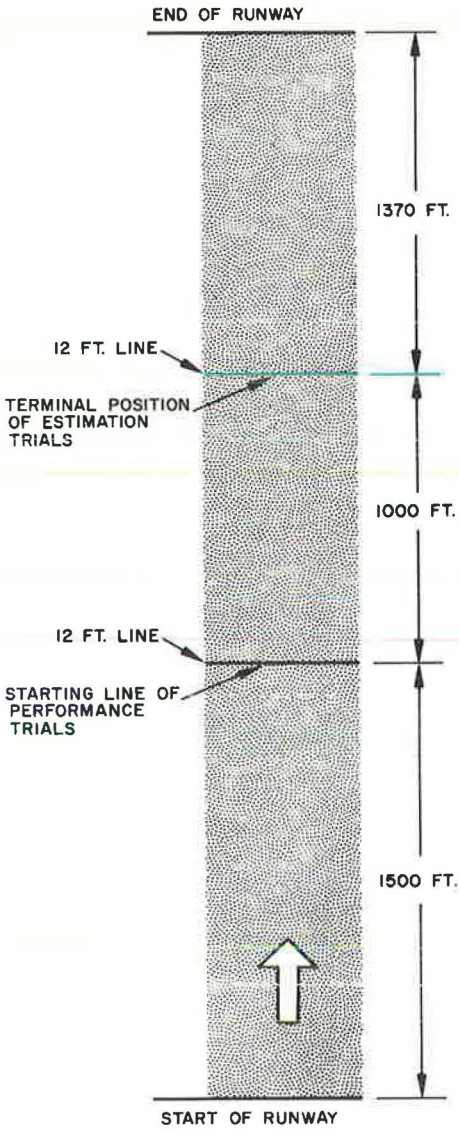

Figure 1. The experimental track.

Each strip was made more conspicuous by placing a 12 by 14-in. white box at its left margin. A numbered scale was laid out on the right edge of the runway.

Vehicles

In the first phase drivers used an unfamiliar 1965 government 6-cylinder, 145-hp Plymouth sedan. In the second phase of the study, drivers used their own cars. No attempt was made to influence selection of the vehicles. All cars completed the tests except a 1959 Volkswagen that could not overtake and pass at 50 mph in the limited runway length.

The Marking Pistol

Positions on the runway where overtaking and passing occured, were indicated by a marking pistol (American Automobile Association detonator) attached to each car's rear bumper. When the driver pressed a button, a solenoid release mechnism fired a shell containing yellow chalk at the runway. In a few instances, the subject's vehicle did not have a 12-volt battery required to activitate the solenoid. In these cases, the experimenter dropped a cloth marker to indicate position.

The Drivers

The 20 drivers who served as experimental subjects were hired from neighboring university and government employment offices. Drivers in the first phase included four males and seven females; ages ranged from 20 to 52 years, with a median of 23 years; driving experience was from 3 to 35 years, with a median of 7 years. Those in the second phase included eight males and two females; ages ranged from 18½ to 46 years, with a median age of 20½ years. Driving experience ranged from 2½ to 26 years, with a median of 4¼ years. Drivers served 4 hours and were paid $2.00 an hour for their work.

METHOD AND PROCEDURE

The overtaking and passing observations were part of a series of tests which also included braking and U-turns. The overtaking and passing procedure was as follows:

Preliminary Practice

Drivers drove to the end of the runway and back twice, to familiarize themselves with the government vehicle. (Familiarization was eliminated in the second phase where drivers used their own cars.)

Overtaking and Passing Estimations

Drivers followed the test car at a distance of 55 ft. They were instructed as follows: "You will follow the car ahead and think of passing it. When you come to the

closest point to the line where you can still pass, using maximum acceleration of the car, indicate the spot by pushing the button." The distance between lead and subject cars was maintained by the experimenter's instructions to slow down or speed up. The experimenter aligned a taped spot on the windshield with the hood and rear bumber of the lead car to maintain the 55-ft distance. The speeds of 18, 30, and 50 mph were controlled by the driver of the lead vehicle. An experimenter stationed on the runway recorded the data. After each observation, the marking pistol was reloaded, and the lead and experimental cars were driven to the starting point for the beginning of the next run.

Overtaking and Passing Performance

Performance trials were made after completion of the estimations. The driver followed the lead car at the scheduled pace. Instructions were as follows: "Follow the car ahead at the distance I tell you. When you get to the line, overtake and pass the car ahead, as fast as you can, and come back into the lane. Be sure you swing back into the lane." When the car was fully back in the lane the experimenter in the test car pushed the pistol button. The experimenter on the runway then recorded the position of the chalk mark.

The scheduling of the experiment is outlined in Table 1. Estimation trials followed each other without interruption, as did the performance trials. The entire work was completed in a half-day, after which the driver was paid and dismissed.

TABLE 1

SCHEDULE OF OVERTAKING AND PASSING EXPERIMENT

Series 1 (practice)	Series 2	Series 3
Estimations Trials (following U-turn and braking estimates)		
18 mph	18 mph	18 mph
30 mph	30 mph	30 mph
50 mph	50 mph	50 mph
Performance Trials (following braking performance)		
18 mph	18 mph	18 mph
30 mph	30 mph	30 mph
50 mph	50 mph	50 mph

RESULTS

Performance (β)

Performance results are given in Table 2. Standard deviations are maximum likelihood estimates. The variable error in the table is the mean deviation from the average of the two performances by each driver at each speed. Matson and Forbes, Prisk, and Crawford data are presented for comparison in Figure 2. Each government and own-car point in Figure 2 represents the average of 20 observations. The zero point of 106 ft is the minimum distance required to pass a vehicle parked 55 ft in front of the starting line.

TABLE 2

OVERTAKING AND PASSING PERFORMANCE

Car	18 mph			30 mph			50 mph		
	Mean	S.D.	S.D./M	Mean	S.D.	S.D./M	Mean	S.D.	S.D./M
(a) Overtaking and Passing Performance (ft)									
Government	385.9	53.7	0.139	606.1	77.9	0.129	1023.5	192.8	0.188
Own	440.3	76.7	0.174	628.5	121.3	0.193	1110.8	289.2	0.260
(b) Variable Error (ft)									
Government	12.3	9.8		27.0	15.4		47.3	50.8	
Own	22.0	20.2		32.7	19.9		41.7	34.6	
(c) Variable Error as Percent of Performance									
Government		3.19			4.45			4.62	
Own		5.00			5.19			3.76	

Note: Sign of the error, plus or minus, has been disregarded.

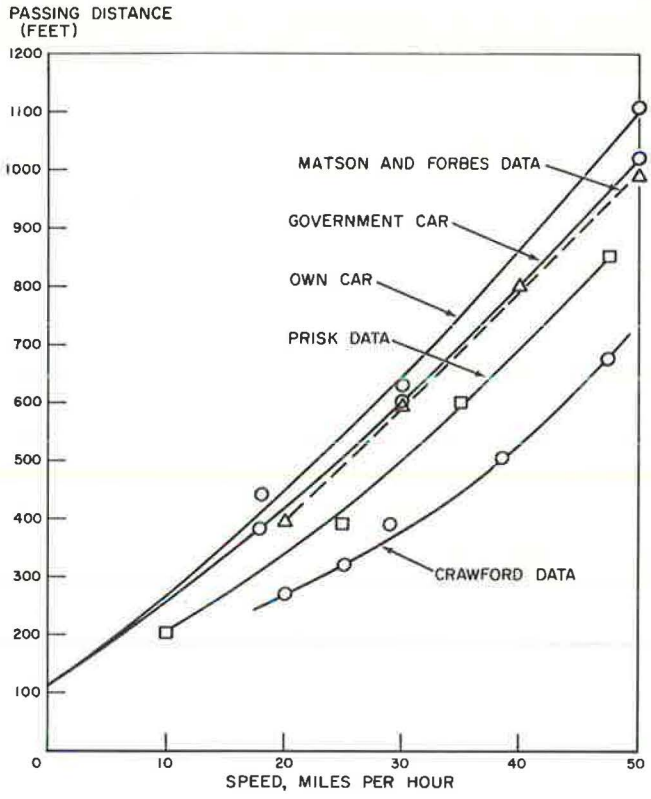

Figure 2. Overtaking and passing distances for various studies.

The performance curves indicate that as speed increased, passing distance also increased, but at an increasing rate. The least-squares fit to the own-car data is

$$D = 112.2 + 15.2\ V + 0.093\ V^2$$

where D is overtaking distance in feet and V is velocity in mph.

The performance on the government car did not differ significantly from that of drivers using their own vehicles. The Matson and Forbes data points fall close to the government car curve, and the Prisk data have the same general form, but distances are about a hundred feet less. Matson and Forbes and Prisk defined passing distance as car travel in the left lane, which is shorter than passing distance as defined here, i.e., from initial driver reaction to return to lane. Crawford's curves show still shorter distances, perhaps explained by his use of trained drivers and by other procedural differences. A complete analysis of these performance curves would take into consideration vehicular accelerations at various speeds, the driver's willingness to use accelerative capacity of the car, and the driver's varying requirements for safety distance.

Drivers differed in their ability to pass, as indicated by the distributions plotted in Figures 3 and 4. (See also standard deviations in Table 2.) These differences are evident even when drivers used the same government car: at 18 mph, driver AR overtook in 284 ft, but driver GR required 455 ft. At 30 and 50 mph variability was larger than at 18 mph. Some causes of these individual differences have already been indicated. Drivers differed in reaction time, in willingness to use maximum acceleration of the vehicle, in safety distance requirements, and they followed different paths in returning to lane at the end of the maneuver.

The vehicle driven had more effect on passing distance than the driver who performed the maneuver. Variance in the own-car condition was significantly larger than in the

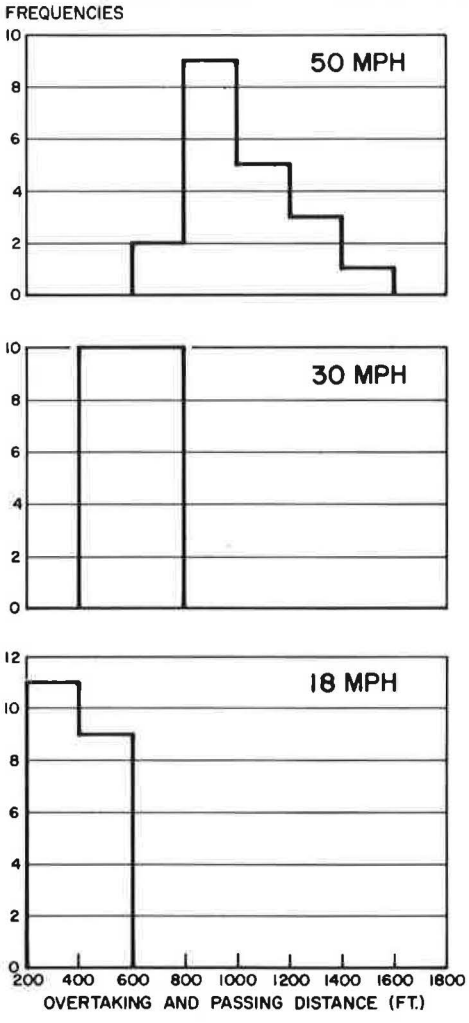

Figure 3. Overtaking and passing distances using government car.

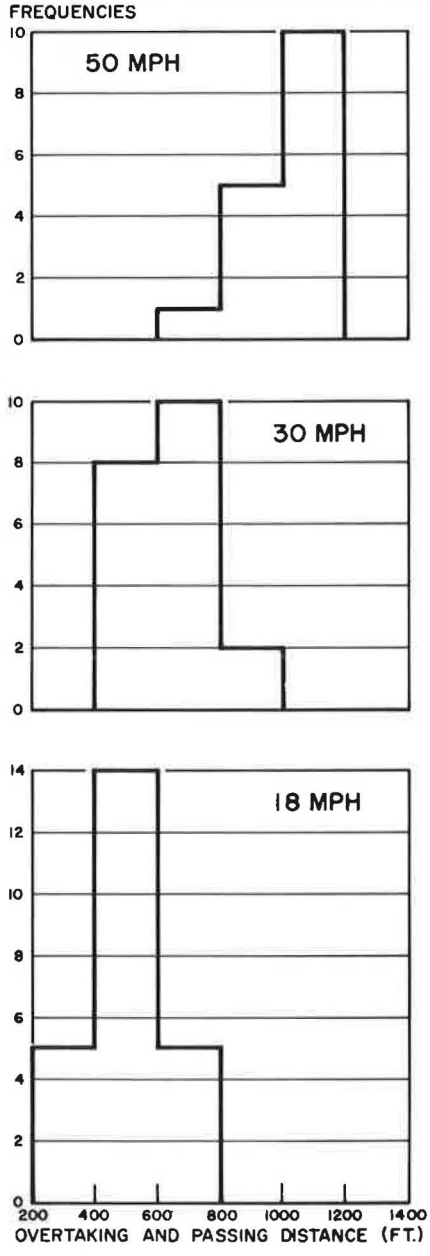

Figure 4. Overtaking and passing distances using own car.

government-car phase where the same automobile was used (F test, .05 level, all speeds). Residual variance of own car minus government car is larger than government-car variance at all speeds. These variance calculations involve the squared standard deviations of Table 2a. The importance of vehicular effects may also be seen in the individual records. The difference in performance between the highest powered car, driven by a 46-year-old woman, and the lowest powered car, driven by a 19-year-old boy, was larger than any set of driver differences on the same (government) vehicle. These vehicular and individual differences relate to the groups studied and do not necessarily apply to the universe of cars and drivers on the road.

TABLE 3

OVERTAKING AND PASSING ESTIMATION ERRORS

Car	18 mph		30 mph		50 mph	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
(a) Constant Error (ft)						
Government	197.2	179.5	312.2	205.5	317.9	208.7
Own	136.9	111.9	129.6	120.5	237.5	176.1
(b) Variable Error (ft)						
Government	42.5	30.5	52.7	40.1	29.9	14.4
Own	40.8	33.4	63.6	41.8	50.9	44.7
(c) Constant Error/Variable Error						
Government	4.63		5.92		10.63	
Own	3.36		2.04		4.67	
(d) Constant Error/Overtaking Performance						
Government	0.511		0.515		0.311	
Own	0.309		0.206		0.214	
(e) Underestimation Errors						
	N	%	N	%	N	%
Government	4	20	7	35	12	60
Own	2	10	7	35	14	78
Crawford data (interpolated)		7		39		76

Note: Sign of the error, plus or minus, has been disregarded.

Drivers' Errors

The errors made by drivers are analyzed in Table 3. Constant error listed for each speed is the difference between each estimate and the mean of the two performances by the driver at that speed, averaged over all drivers. Variable error is the deviation of each driver's constant error from his mean constant error, averaged over all drivers. The underestimation errors listed in Table 3e occur when the constant error is negative. Frequency distributions of errors made in the government and own car are plotted in Figures 5 and 6. Each chart includes the 20 errors made at a particular speed.

It may be seen from Table 3a and Figures 5 and 6 that drivers are not able to estimate passing distance accurately. Constant error varies from about one-fifth to one-half of actual overtaking distance (Table 3d). Constant error exceeds variable error at all speeds at the .01 significance level. It appears that drivers estimate their overtaking performance consistently, but in an erroneous manner.

Drivers predict their overtaking performance better in their own cars than in an unfamiliar vehicle (Table 3a). Errors in own car are significantly less ($p = .05$) than in the unfamiliar car ($\underline{4}$ Fisher combination of experiments statistic). This implies that estimating vehicular performance (β') may be a learned aspect of driving skill. The finding also suggests that the driver's ability to estimate braking, U-turns, parking, and car-following requirements may furnish a useful measure of his skill and effectiveness. Little is known concerning the nature of driving skills.

Negative errors of estimate involving underestimation of maneuver distance are dangerous. Negative errors occur at all speeds, but are particularly frequent at high speeds (Table 3e and Figs. 5 and 6). At 50 mph, 60 percent of government-car estimates and 78 percent of those in own car would have been dangerous in the operational situation. The finding that underestimation is most frequent at high speeds where accidents are most serious is in close agreement with Crawford's results (Table 3e, or $\underline{1}$, Fig. 9).

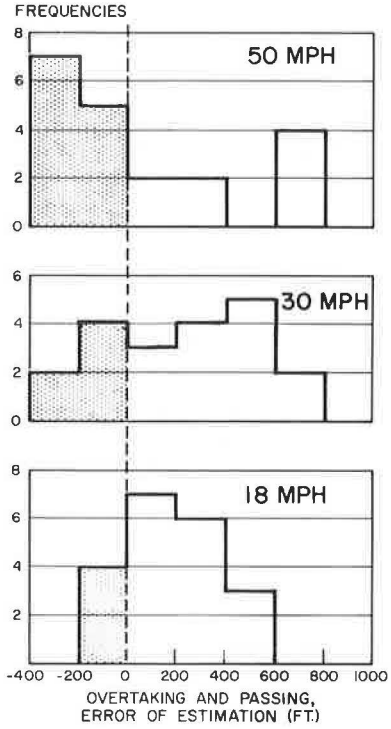

Figure 5. Estimation errors in overtaking and passing using government car.

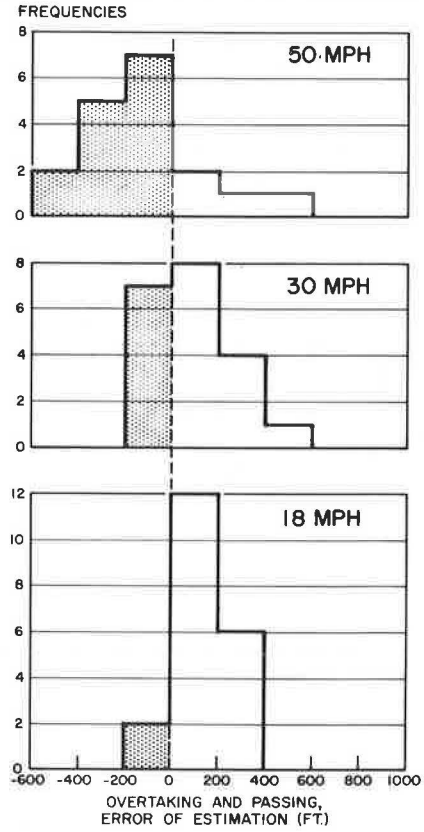

Figure 6. Estimation errors in overtaking and passing using own car.

Driver's errors and underestimations in overtaking and passing may perhaps be explained by the difficulty of the judgment. Overtaking distance varies with speed. There are as many overtaking distances as vehicular speeds. The driver cannot perform by simply learning a fixed distance, as might be the case in U-turns, or parking. The underlying speeds, accelerations, and distances are themselves subject to estimation error. For example, at 50 mph, overtaking requires about a thousand feet. An opposing vehicle, coming toward the driver at the same speed, would be twice as far away when the decision was made. The driver cannot be expected to make precise spatial judgments at such large distances.

The precise cause of underestimations at high speeds is not known. One explanation might be that the driver is not fully aware of how performance requirements (β) increase with speeds, and he may continue to act as he did at slower speeds. Whatever its cause, high speed underestimation remains a pertinent fact that highway engineers must contend with in dealing with the overtaking and passing maneuver.

Nonetheless, overtaking and passing accidents are not very frequent since several safety factors are inherent in the situation. The driver may avoid danger by not passing at high speeds, and he may insist on an adequate safety distance. If a wrong decision is made, he may drop back into lane, and the overtaken and oncoming cars may slow down and move to the shoulder. Traffic controls such as passing zones and signs also aid the driver.

APPLICATIONS

The finding that the driver is unable to estimate accurately his overtaking and passing requirements and that underestimations are frequent at high speeds implies that the maneuver requires guidance. Possible aids to the driver include the following:

1. Passing areas, and "no passing" signs (traditional aids to overtaking and passing).
2. Speed limits and other speed regulations particularly in passing zones.
3. Driver education not to pass at high speeds and to cooperate with the overtaking driver.
4. Road design modification, such as wide shoulders and addition of lanes.
5. Traffic planning to minimize use of two-lane rural roads.
6. Electronic devices informing the driver when it is safe to pass.

(Such devices are currently under development in the Traffic Systems Division, U.S. Bureau of Public Roads.)

The $\alpha\beta$ concept provides a theoretical framework that may be useful in studying driver decisions in intersection and merging gap acceptance, and in such maneuvers as U-turns, braking, parking, and car following. The $\beta'\beta$ comparison may be useful as a measure of driving effectiveness in studying learning and driving performance.

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