Driver Interactions and Delays in Freeway Traffic

DONALD A. GORDON, Traffic Systems Division,
U.S. Department of Transportation

The aim of the study was to describe the behavior of individual drivers in normal freeway traffic. An experimental car was driven at slow speeds of 50, 45, and 40 mph along an Interstate highway, causing overtaking drivers to react. Without their awareness, drivers were photographed from a tower and from the experimental vehicle on the road. The photographs were analyzed to show positional relationships of the experimental car and overtaking drivers and to show changes in lead distance between cars as a function of time. A driver who approached in a different lane from that of the experimental car and who was unobstructed passed without slowing. The experimental vehicle did not influence the speed of these passing drivers. Obstructed drivers, who changed lanes to pass, also did not slow down. On the basis of the data, it seems likely that the decision to shift is made at 250 ft of separation distance or less. Nine drivers of the 166 studied were obstructed and appreciably delayed. A typical obstructed driver shows a three-phase response. In the first (approach) phase, the driver moving at his desired pace starts to slow down in anticipation of being blocked. Next follows a delayed phase of from 15 to 35 seconds, where the driver moves to a slightly closer position or matches pace with the car in front. This phase is related to traditional car-following, but drivers' responses are too individualistic to be represented by any simple car-following equation. In the final (passing) phase, the driver assumes his original speed and moves ahead of the car in front. These reactions are partly explained by the driver's motivation to maintain pace and move ahead. Passing drivers and blocked drivers did not slow appreciably. Only when the driver was effectively blocked did he slow down. Traditional car-following did not occur frequently in this study, nor did drivers appear to want to follow the car ahead.

•THE MASONIC TOWER of Alexandria, Virginia, is a well-known landmark of the Washington, D.C., landscape (Fig. 1). For a brief period in the summer of 1969, the observation station of the Tower served as a photographic outlook for the study of freeway traffic reported here.

Characteristically, freeway traffic involves vehicular interaction that is not so severe that movements of the car are completely dictated by the movements of the vehicle in front. Although many studies have been made of highway traffic, little is known concerning the responses of the individual driver who is the active element in the system. Cars and roads do not react; only humans do. The study of the driver's responses and his psychology should reveal important information concerning the detailed mechanisms of traffic flow.

Paper sponsored by Committee on Road User Characteristics and presented at the 49th Annual Meeting.

It was considered important that drivers be observed under operational conditions and be unaware that they were under surveillance. It is doubtful that drivers would have lane-straddled, wobbled, and accepted gaps as they did if they knew that they were being observed in a formal experiment.

A "plant" vehicle was deliberately introduced into the highway stream. This car was driven at a speed slower than that of the traffic stream. Other drivers coming up from behind reacted to the plant. Their responses were photographed from the Tower and simultaneously from the plant vehicle itself.

Figure 1. Masonic Tower from which photographs were made of traffic on Interstate 495, a half mile away.

BACKGROUND OF THE PROBLEM

There is disagreement in the research literature on how drivers interact on the highway. The best known theory is associated with the work of Herman and his co-workers (1, 2). On the basis of experimental observations on a test track and in New York City tunnels, Herman derived the following equation to describe what has been called "car following":

$$\left[(d^2x)/(dt^2)\right]_{n+1} = \alpha_0 \frac{\left[(dx/dt)_n - (dx/dt)_{n+1}\right]}{x_n - x_{n+1}} \qquad (1)$$

where

$(d^2x/dt^2)_{n+1}$ = the acceleration of the following car,
α_0 = a constant related to speed,
$(dx/dt)_n - (dx/dt)_{n+1}$ = the difference in speed between cars, and
$x_n - x_{n+1}$ = the headway distance between cars.

The equation states that the acceleration of the following car is directly proportional to the difference in speed between the 2 cars and inversely proportional to the distance between the vehicles. Herman and Gardels (1) have described the application of the car-following equation as follows:

> Follow-the-leader theory attempts to describe the behavior of a single lane of fairly dense traffic in terms of the detailed manner in which vehicles follow one another in the traffic stream. This condition of one-lane traffic with no passing is more common than the motorist accustomed to multilane turnpikes might think. No-passing situations still exist, in law or actuality, on many stretches of two-way roads and streets, in tunnels and on bridges. Even on multilane highways dense traffic often forces a driver to stay in one lane.
>
> In sum, the follow-the-leader equation works out to show that a driver tries to keep the relative speed between him and the vehicle in front as small as possible, and that the closer he is, the more attention he pays to the problem. If he is far away, he drives in a manner that is more or less independent of what the driver in front is doing.

It may be seen that Herman's equation is intended to describe the reaction of a driver to velocity changes of the car ahead. This follow-the-leader behavior is presumed to be characteristic of very dense traffic, and is possibly applicable to freeways. [A perceptual basis for Herman's equation has been suggested by Michaels (3). He has shown that there is a close relation between the form of Herman's equation and the

angular expansion of an approaching car. The relation suggests that changes in the angular subtense of the vehicle ahead provide a perceptual basis for car-following.

If Herman's equation is integrated, the following relationship is obtained:

$$(dx/dt)_{n+1} = \alpha_0 \log\left[\frac{x_n(t) - x_{n+1}(t)}{L}\right] \qquad (2)$$

where L is the effective length of the following car.

The variables in this equation—velocity of the following car and distance between cars—are convertible to concentration and flow, the master variables of traffic flow. The implication is that Herman has found a basis for traffic flow in the reactions of the individual following driver.

A quite different view of traffic interactions has been presented by Rockwell and Snider, who took film records from commercial trucks, during normally scheduled runs (4). Little evidence of car-following was found in the 40 or more hours of analyzed film:

> When a vehicle would pull in front of the research vehicle, the latter would either immediately pass or else reduce velocity until the influence of the leading vehicle was completely avoided. Car-following, as traditionally described, was observed to occur only when the research vehicle was attempting to pass the leading vehicle. An explanation for this general lack of car-following situations is that the drivers attempted to minimize the influence of leading vehicles upon their own longitudinal control. This is not surprising in view of the fatigue and stress associated with car-following over extended time periods.

Car-following was seldom found, even during peak traffic or behind the experimental car. The authors state that "only a small percentage of vehicles would car-follow, and then only under conditions of extremely large headway."

The results of Herman's study of car-following in tunnels and Rockwell and Snider's study of car-following on the open road seem to be in puzzling contradiction. The differences are partly explained by variances in traffic conditions. But the need seems strongly suggested for further studies of driver interactions in a variety of highway situations.

EQUIPMENT AND PROCEDURE

Photographic Procedure

The highway around the plant was photographed simultaneously from the Tower and the plant itself. The Tower view is approximately 400 ft above Interstate 495 (Fig. 2). Both sides of the highway can be seen from the Tower, except where the line of sight is obscured by 2 apartment houses.

Photographs were also taken through the rear window of the plant, with a 16 mm camera equipped with 14.5 mm wide-angle lens (Fig. 3). The backwards field of view was wide enough to cover all lanes and showed complete lane shifts of passing cars. The photographer in the plant car did not reveal to approaching drivers that pictures were being taken. He looked forward and did not touch the camera until told by radio communication from the Tower to start or stop picture-making.

Figure 2. Traffic on I-495 photographed from Tower.

Experimental Vehicle

The plant was a gray 1965 Dodge sedan equipped with speed governor. It was marked for identification by tape bands

on its roof, hood, and trunk. These bands could be seen from the Tower, but were hardly visible to approaching drivers.

Figure 3. Traffic on I-495 photographed from experimental car.

Experimental Course

The plant car shuttled on I-495 between exits 1N and 3. Photographs were taken on the stretch of highway 2.1 miles long between the Linnean overpass and exit 1N (Fig. 4). At closest, this highway is 0.6 mile from the Tower and, at farthest, 1.6 miles. The course has 3 lanes, except at Telegraph Road where exit lanes leave and entrance lanes come in. Posted speed limit is 65 mph. Traffic during the runs would probably be classified as "medium".

Schedule of Runs

Photographs were made on 6 round-trip runs from the Linnean overpass to the 1N exit and back. During each round trip, a fixed speed was maintained. The first run was at 50 mph, followed by runs at 45 and 40 mph. This sequence was again repeated to give a total of 6 round trips. It will be noted that the plant traveled at speeds below the 65 mph limit, causing approaching drivers to react. The plant driver stayed in the first lane and shifted only when the first lane exited from the freeway. During the 6 runs, photographs were simultaneously taken from the Tower and the plant car.

ANALYSIS OF DATA

To an observer, the moving traffic stream appears as a bewildering confusion of passing, following, and shifting vehicles. It was necessary, therefore, to devise some

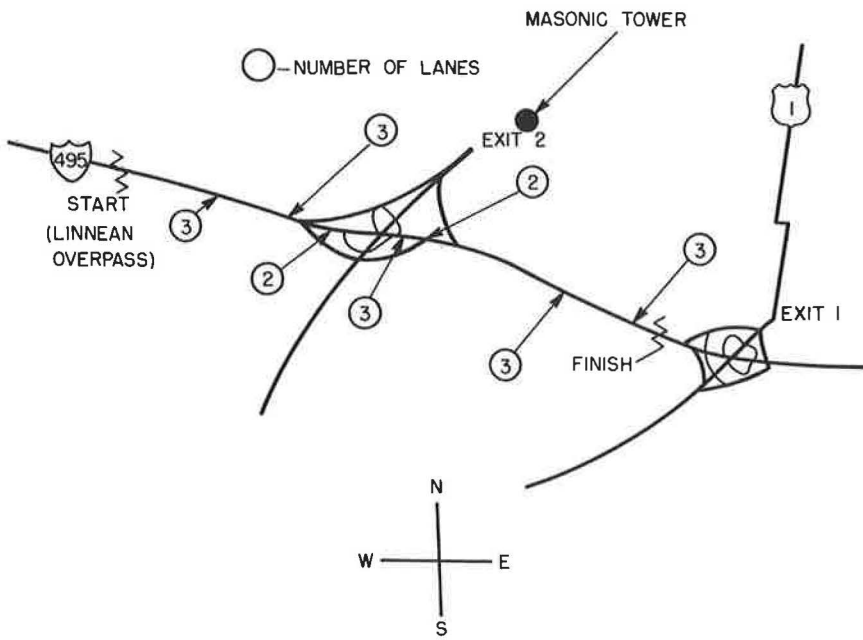

Figure 4. Experimental course.

method of classifying and analyzing individual driver reactions. The analysis was accomplished by means of occupancy diagrams, interaction summaries, and positional plots.

Occupancy Diagrams

Occupancy diagrams indicate the consecutive positional relationships of plant and interacting driver. Figure 5 shows occupancy diagrams modified from records of the sixth run. In diagram a, at the start of the run, vehicle A in the second lane passes the plant in lane 1 (right lane), without shifting lanes. In diagram b, vehicle B passes both the plant and vehicle C, which is behind and in the same lane as the plant. In diagram c, vehicle C shifts from the first to the second lane and passes the plant. In diagram d, the plant shifts to avoid being caught in the exit lane; vehicle D, which has been following, passes on the right. The occupancy work sheet also noted the lanes occupied by plant and vehicle, described the interacting car, i. e., "cream Volkswagen," and provided a letter designation for it. This letter identified the vehicle in all subsequent tabulations and charts.

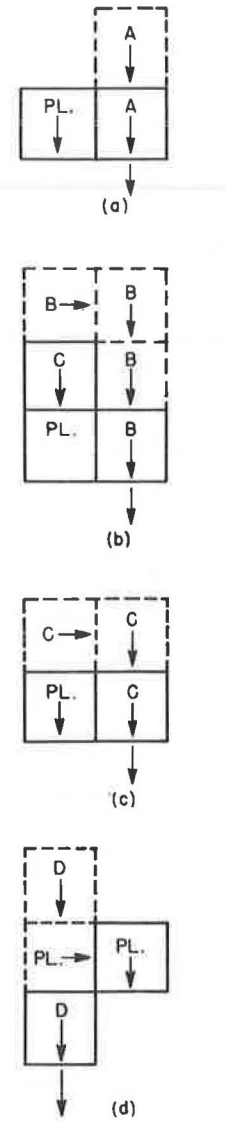

Figure 5. Occupancy diagrams.

Interaction Summary

The interaction summary included all driver interactions and their resolutions. Situations were classified as those where the approaching car was in a different lane from the plant and hence was not obstructed; or in the same lane and obstructed. If not obstructed, the vehicle passed by simply moving ahead. The obstructed cases were resolved by the subject car shifting to another lane or by the plant shifting. In some instances, the subject car was blocked and appreciably delayed. These cases are of special interest and were given a complete analysis.

Relative Position Graphs

A quantitative description of vehicular interactions was obtained by plotting the distance between the plant and overtaking vehicles as a function of time. A $^5/_6$-sec interval, representing a sampling rate of 1 frame in 20, was used in plotting the positional graphs.

In the analysis of the Tower photographs, screen image distance between cars was calibrated by reference to the known distance between the plant's hub caps (10 ft 1½ in.). Distances in the plant car photographs were calculated from perspective changes. As a vehicle approached the plant, its angle and the related image on the screen increased inversely with distance. The relationship is expressed in the following formula:

$$d = k/\beta$$

where

- d = the distance from the focal plane of the plant camera to the front of the observed vehicle;
- β = the angle of some particular dimension, such as the distance between headlight centers, as represented by the measurement on the screen; and
- k = a constant related to the size of the vehicular feature, the focal length of the camera and projector lenses, and the distance from projector to the screen.

This approximation of the tangent function is justified because the angles of interest are almost all less than 6 deg. The formula was applied by measuring the screen size β

with the distance d to the observed vehicle known and thus determining k. Once constant k was known, the distance associated with any β could be found.

Distance to the vehicle was first obtained by measuring the length on the screen between lane markers at the front of the approaching vehicle. The constant k was calibrated in this way at several distances and an average value selected. The change in dimension between the top of the roof to the shadow between the tires was used to measure β. A correction of 7 ft was subtracted to correct for camera to rear bumper distance.

RESULTS OF EXPERIMENT

A total of 166 "incidents" were recorded in which approaching drivers reacted to the slower moving plant (Table 1). It may be seen that 151 drivers (91 percent of the cases) were either unobstructed or escaped obstruction by simply shifting lanes. In 9 cases (5.4 percent of the incidents) the following car was appreciably delayed. More interactions occurred at the 40-mph plant speed than at more rapid speeds. An incident occurred on the average of once every 8.9 sec on 40-mph runs, every 11.1 sec on 45-mph runs, and every 19.4 sec on 50-mph runs. The number of incidents is related to the relative velocity of plant and highway traffic. A vehicle moving at 10 mph less than the traffic stream will encounter twice as many interactions, on the average, as one moving 5 mph slower than traffic.

Unobstructed Passes

Unobstructed passes are those that are made when the approaching driver is on a different lane from the plant and simply passes. An unobstructed pass was randomly chosen for analysis, from each of the 6 runs (Figs. 6 through 11). The identification of the vehicles follows that of the occupancy diagrams. For example, the first vehicle, which bears the notation 1K, was the kth (eleventh) vehicle in the first run. Plant speed was 50 mph in the first and fourth runs, 45 mph in the second and fifth runs, and 40 mph in the third and sixth runs. Lead distance in the figures is reckoned from the rear bumper of the plant to the front bumper of the oncoming car. Separation is zero when the bumpers are even with each other. The record for vehicle 6J may be seen to lack a zero point as the Tower view was obscured when this vehicle passed.

In none of these records does the driver change pace in passing. Except for vehicle 4K, all records show either straight lines of constant velocity or smooth curves of very slowly changing velocity. Vehicle 4K shows a dither response, which may well have been a personal idiosyncrasy. It appears that the typical unobstructed highway pass does not entail a slowing down or an increase in speed.

Obstruction Resolved by Driver Shifting Lanes

Obstructed drivers most frequently resolved the predicament by shifting lanes. Six cases that involved only the plant and the shifting vehicle are shown in Figures 12 through 17. These figures show that lane-shifting did not generally involve a change in

TABLE 1

SUMMARY OF DRIVER INTERACTIONS

Run	Speed (mph)	Subject Unobstructed and Passed	Subject Obstructed in Same Lane as Plant			Total
			Subject Shifted	Plant Shifted	Subject Delayed	
1	50	11	3	1	1	16
2	45	25	6	0	1	32
3	40	26	18	2	1	47
4	50	10	0	1	3	14
5	45	21	4	1	2	28
6	40	17	10	1	1	29
Total		110	41	6	9	166
Percent		66.3	24.7	3.6	5.4	100

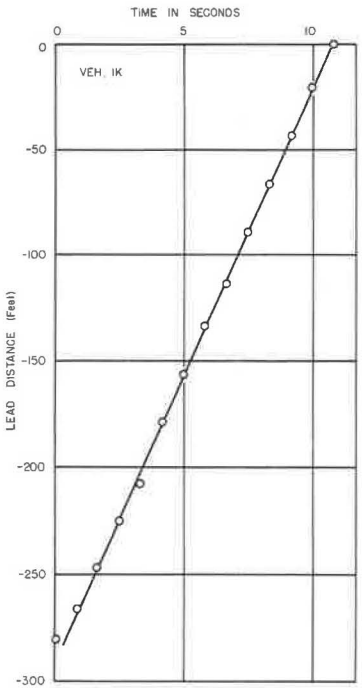

Figure 6. Lead distance of vehicle 1K in unobstructed passes.

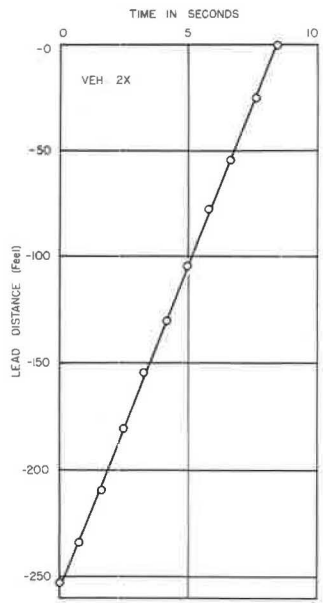

Figure 7. Lead distance of vehicle 2X in unobstructed passes.

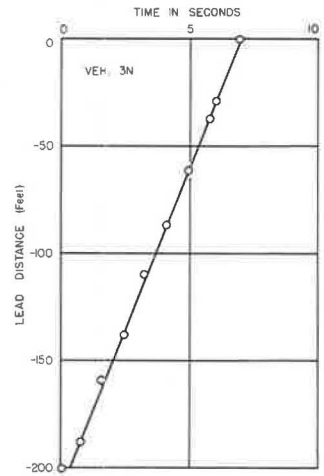

Figure 8. Lead distance of vehicle 3N in unobstructed passes.

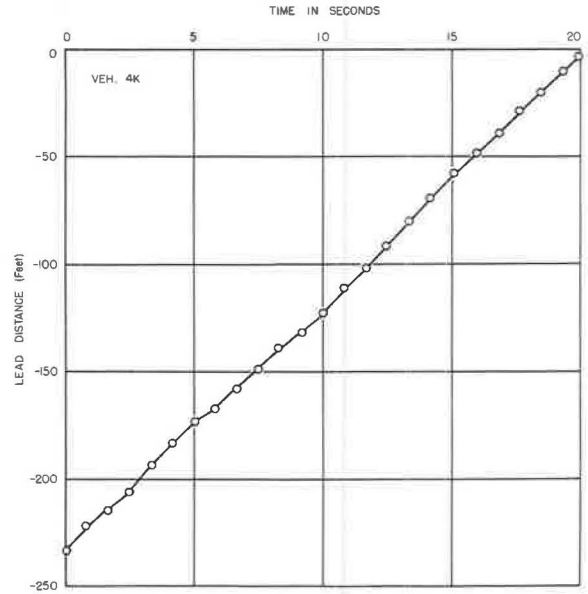

Figure 9. Lead distance of vehicle 4K in unobstructed passes.

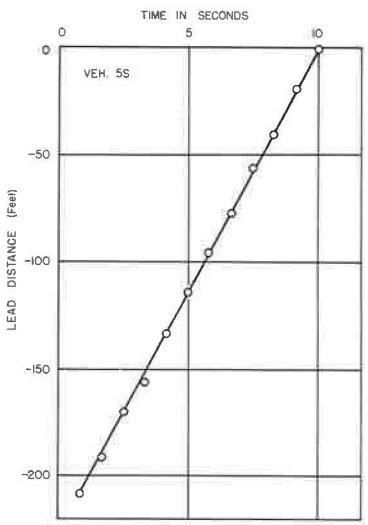

Figure 10. Lead distance of vehicle 5S in unobstructed passes.

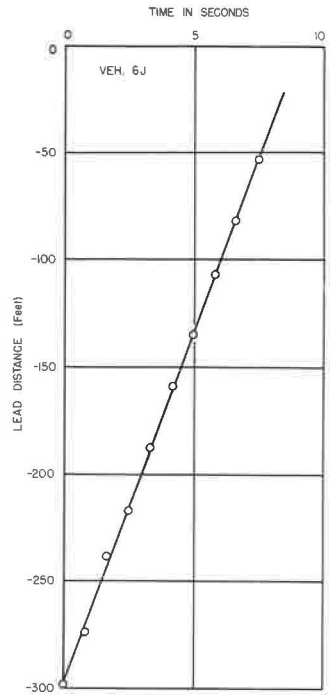

Figure 11. Lead distance of vehicle 6J in unobstructed passes.

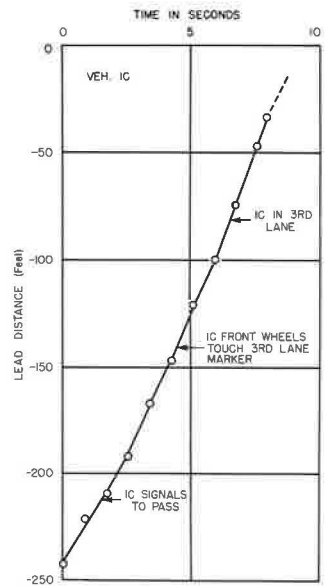

Figure 12. Lead distance of vehicle 1C in lane shifts.

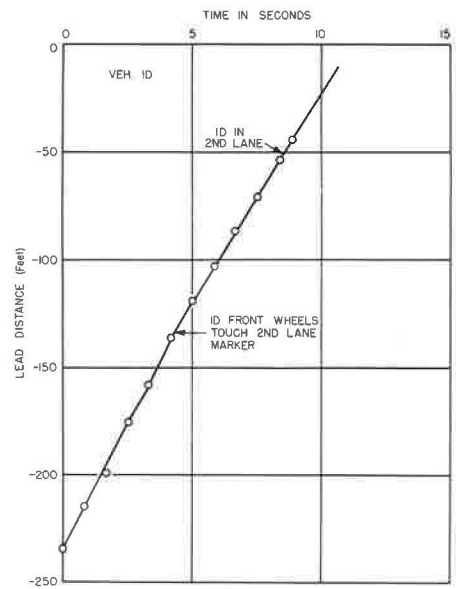

Figure 13. Lead distance of vehicle 1D in lane shifts.

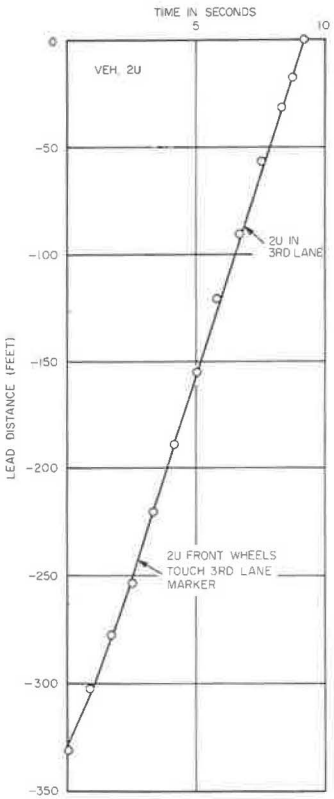

Figure 14. Lead distance of vehicle 2U in lane shifts.

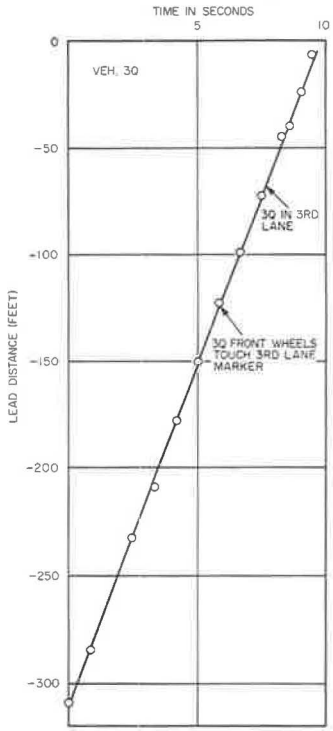

Figure 15. Lead distance of vehicle 3Q in lane shifts.

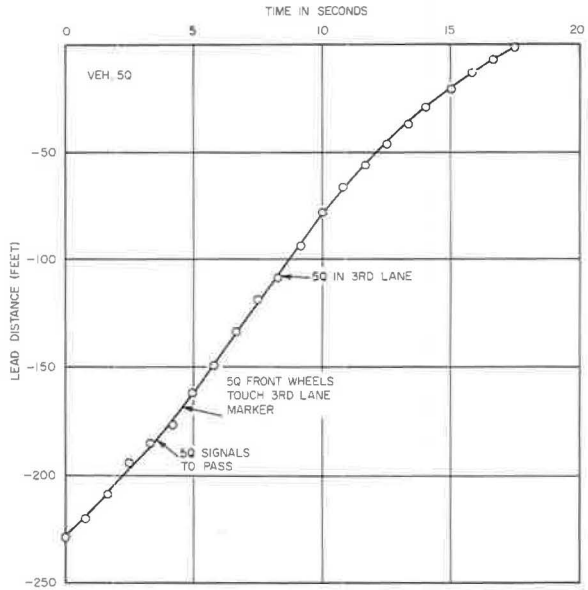

Figure 16. Lead distance of vehicle 5Q in lane shifts.

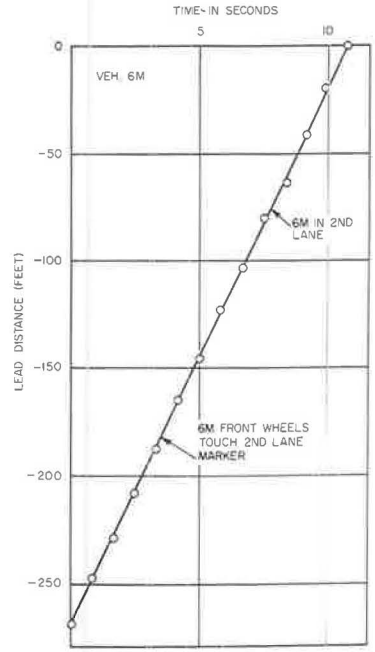

Figure 17. Lead distance of vehicle 6M in lane shifts.

pace. The driver of vehicle 5Q did speed up when the front wheels touched the lane marker at 168 ft, and he slowed down at a 106-ft distance from the plant. This driver's truck was loaded with bottled beverages, which may have accounted for his cautious approach.

The distances at which various phases of lane-shifting took place are shown in Figure 18. Eight drivers signaled before shifting. The signal was given at a median distance of 202½ ft, a range from 78 to 314 ft. The start of the shift, indicated by contact of the front tire with the lane marker, based on 30 overtaking drivers, occurred at a median distance 34.7 ft closer to the plant. The range was from 7 to 66 ft. Median lane contact was 148½ ft. The shift from tire contact to "in-lane" position required 2.2 sec (median). The range was from 1.08 to 5.58 seconds. [For comparison, Worrall and Bullen (5) give 160 and 110 ft as the mean (not median) distances for tire contact and in-lane position. Their figure for the average time required to shift is 2.91 sec. Because the distributions of distance and time are skewed, the results of the 2 studies are roughly comparable.]

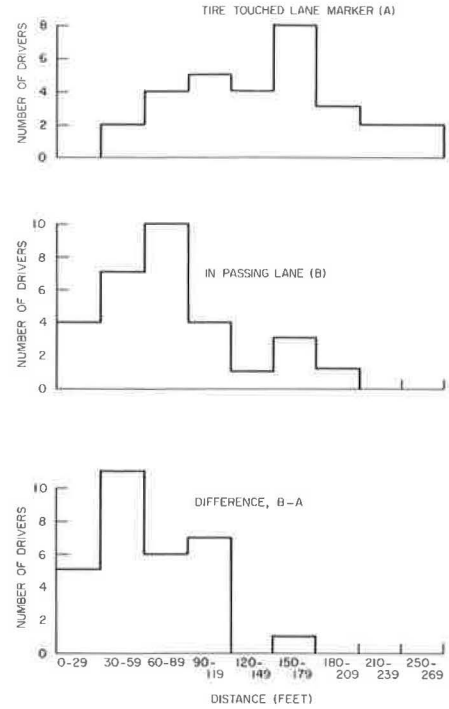

Figure 18. Distribution of lead distances of vehicles in lane shifts.

From these calculations, it appears that drivers start to react to an overtaken vehicle at distances of 300 ft or less. Lane-shifting quickly follows the signal to pass, and is completed at a distance of about 100 ft from the car in front. The distributions of Figure 18 indicate considerable variability associated with driver, vehicle, and traffic condition differences.

Vehicles Appreciably Delayed

Nine drivers (1 in 18 of those observed) were appreciably delayed by the traffic situation near the plant. The approaches of these 9 drivers to the plant are shown in Figures 19-27. The detailed characteristics of these records are as follows (Table 2):

1M—The record starts with 1M coming out of a merge, moving more slowly than the plant. 1M started to shift to the second lane to pass, but was blocked by the plant's move to the second lane. 1M slowed down to match pace and was then blocked by fast-moving 1K and 1L in the third lane. Later, 1M signaled, shifted lanes, and passed. The movements of 1M are seen to be in response to complete blockings by vehicles in addition to blocking by the plant. 1M matched pace and passed as soon as the opportunity afforded itself.

2E′—The record also starts with the subject car coming out of a merge, moving more slowly than the plant. For a period of about 10 sec, 2E′ followed the plant without attempting to shift and pass. 2E′ was then blocked by 2 trucks and matched pace with the plant, gaining about 10 ft in 13 sec. After an obscured period, 2E′ moved to the second lane and accelerated. The record shows an adaptive response to the merging, entry, and blocked situations; 2E′ passed when able. The approach phase is missing because 2E′ came from a merge.

3K′—The driver of 3K′ intended to leave the highway at exit 2. Vehicles 3I′ and 3J′ prevented him from passing the plant and entering the exit lane occupied by plant. The response of driver 3K′ was to move close to the plant and pass when the plant moved to the second lane. The record shows approach obstructed, and passing phases. The obstructed phase shows closing rather than a matching of pace with the plant.

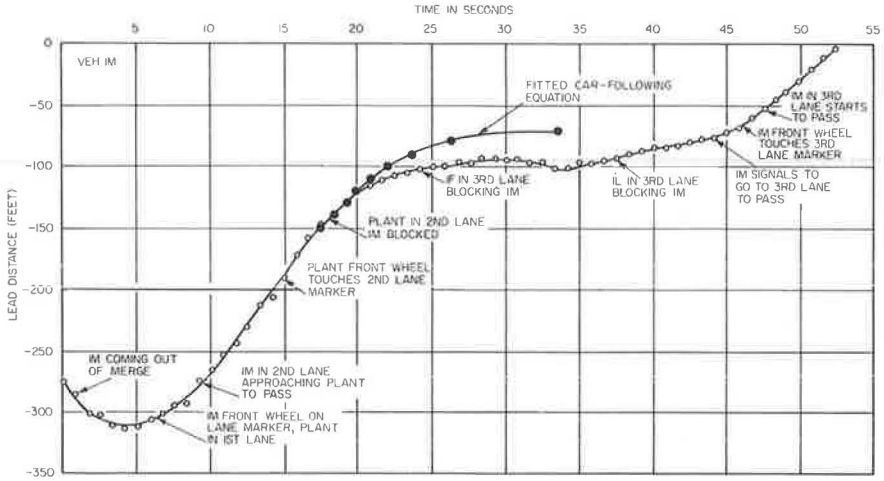

Figure 19. Lead distance of delayed vehicle 1M.

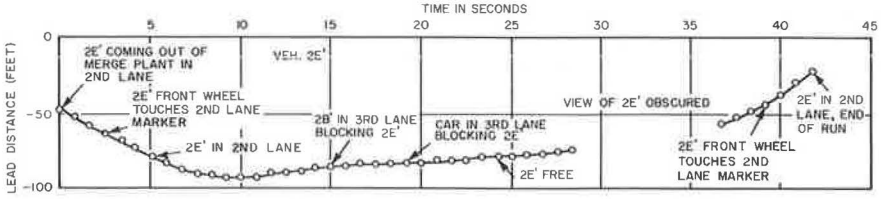

Figure 20. Lead distance of delayed vehicle 2E'.

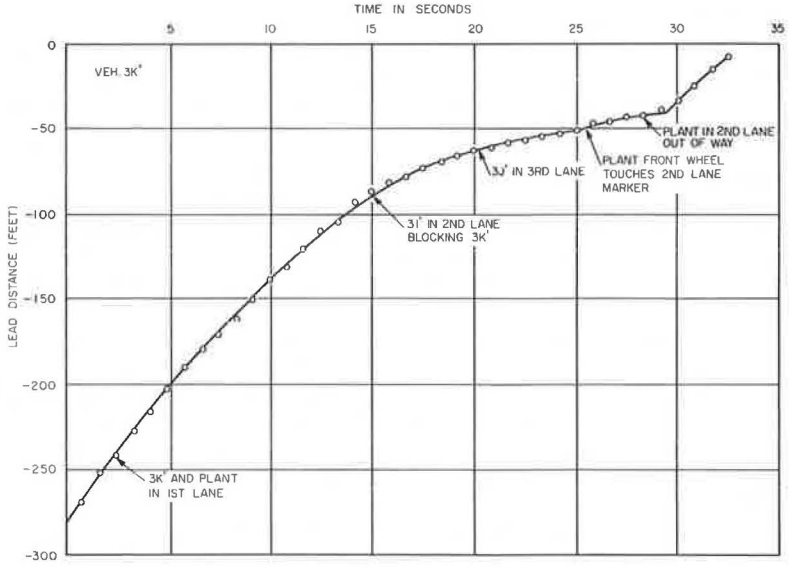

Figure 21. Lead distance of delayed vehicle 3K'.

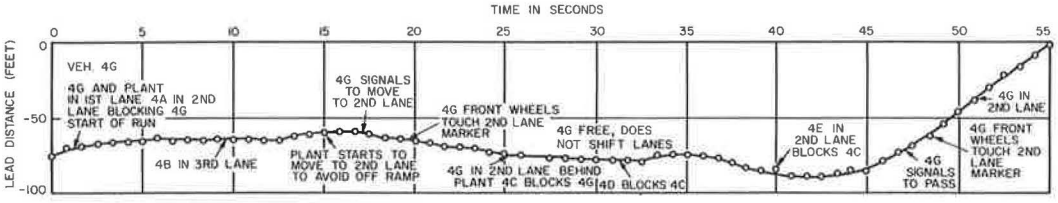

Figure 22. Lead distance of delayed vehicle 4G.

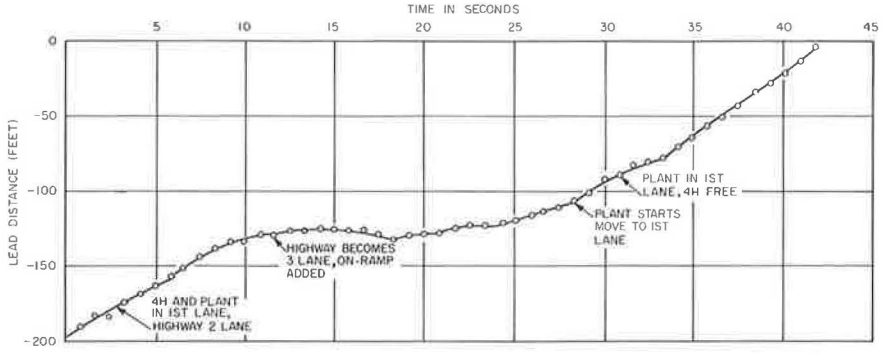

Figure 23. Lead distance of delayed vehicle 4H.

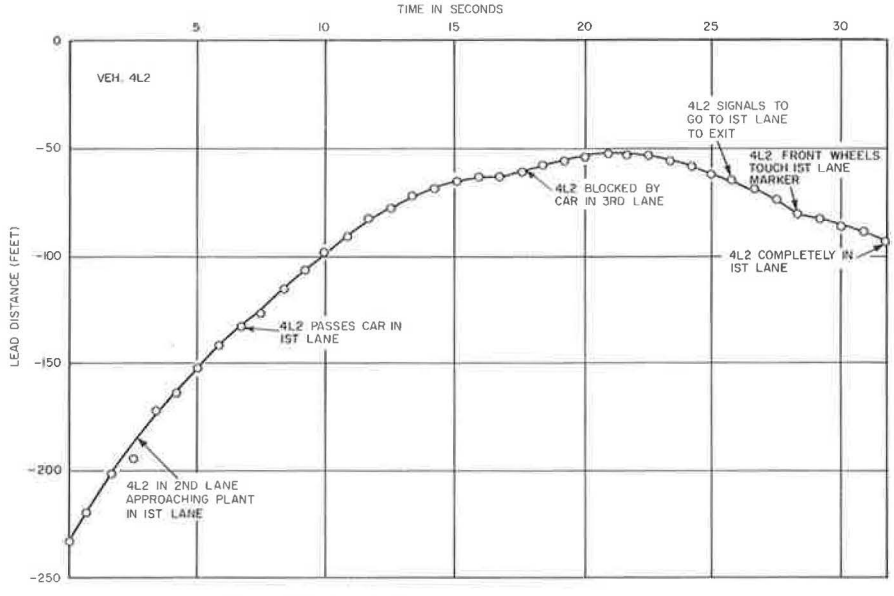

Figure 24. Lead distance of delayed vehicle 4L2.

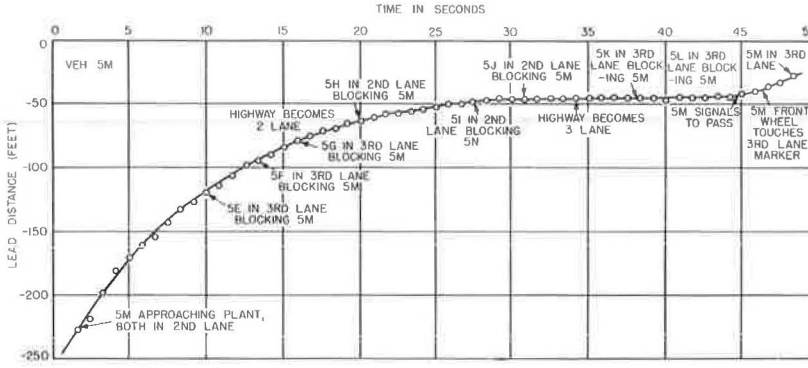

Figure 25. Lead distance of delayed vehicle 5M.

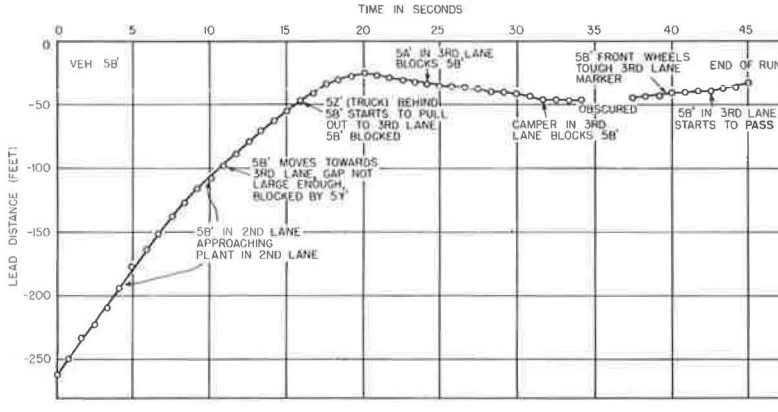

Figure 26. Lead distance of delayed vehicle 5B'.

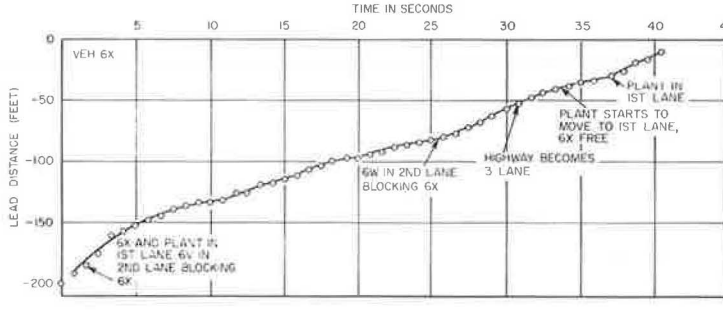

Figure 27. Lead distance of delayed vehicle 6X.

TABLE 2

RESOLUTION OF VEHICLE DELAYS

Vehicle	Original Speed (mph)	Cause of Delay	Delay Length (sec)	Time Lost (sec)	Distance Lost (ft)	Resolution
1M	60.4	Blocked by vehicles	20	3.96	351	Lane shift
2E′	51.1	Blocked by vehicles in passing lane	27	2.79	209	Lane shift
3K′	54.0	Blocked by vehicles in passing lane and by plant in exit lane	15	3.33	249	Plant shift
4G	60.2	Blocked by vehicles in passing lane	45	4.67	412	Lane shift[a]
4H	54.2	Badly loaded truck	20	1.44	114	Plant shift
4L2	61.4	Blocked by vehicles in passing lane and by plant in exit lane	15	4.34	391	Stayed behind in same lane as plant
5M	55.9	Blocked by vehicles in passing lane	30	6.49	532	Lane shift
5B′	56.4	Blocked by vehicles in passing lane	25	6.52	539	Lane shift[b]
6X		Blocked by vehicles in passing lane	30			Plant shift[c]
Total				33.54	2,797	
Avg	56.3[d]			4.19	349.6	

[a]Close to plant when record starts.
[b]Record ends before passing completed.
[c]It is not certain that this vehicle was delayed.
[d]Does not include vehicle 6X.

4G—The record starts at the beginning of the fourth run, with 4G and the plant moving at about the same speeds. 4G is blocked successively by 4A, 4C, and 4E, and could not pass on the right of the plant because this first lane became an off-ramp. There was a period of about 5 sec, between the passing of 4C and blocking by 4D, when 4G could have passed easily but did not. The final portion of the record shows acceleration to pass the plant.

4H—This truck was precariously loaded with 3 oil barrels piled end-to-end. The driver seemed to have his load in mind. The record shows a slow approach and pass when the plant shifted from the second to the first lane. There is no blocking by other vehicles. The approach was very slow, as the plant was moving at 40 mph. The record seems to indicate a reluctance on the part of the driver to make abrupt longitudinal or lateral movements.

4L2—This vehicle approached the plant close to the 1N exit. 4L2 was blocked from shifting by a vehicle in the third lane, and by the plant who occupied the exit lane. The response of 4L2 was not to pass—he followed the plant preparatory to exiting. The approach and obstructed phases are shown on the record, but not a passing phase.

5M—5M was an underpowered foreign car. As he approached the plant, he was blocked by 8 more rapidly moving cars in the passing lane. The end of the record shows the beginning of an acceleration to pass the plant. The trajectory is fairly flat during the time 5M is blocked.

5B′—After approaching, the driver of this car was blocked successively by 4 vehicles in the third lane and by a large moving van in the first lane. The driver started to move ahead when he had the opportunity. The record shows a conventional approach and a flat trajectory during blocking. The record does not show the final pass phase.

6X—This vehicle was exposed to the plant when a truck in front of it shifted lanes. 6X was blocked by 6V and 6W, moving at about the same speed in the third lane. The record shows that 6X moved slowly toward the plant and ahead when the plant shifted lanes. Vehicle 6X was blocked, but it is not certain that it was delayed.

Typically, these obstructed drivers show distinct approach, delayed, and passing phases (Figs. 19, 21, and 23). In the approach phase, the driver can see that traffic is massed ahead, but he is still far enough away not to have to react. He maintains pace or slows down slightly. In the second delayed phase, the driver is blocked by the plant and other vehicles. He matches pace or slowly approaches to within 50 to 100 ft of the vehicle in front. Individual reactions differ considerably. Driver 5M showed an almost constant spacing of about 55 ft for a full 20 seconds; 1M and 4H showed patterns of acceleration followed by slowing down; and 2E′ showed almost steady approach. Of the 9 drivers, 6 drivers decelerated gradually between the approach and delay phases, perhaps because they anticipated a blocked situation ahead. In 3 other cases, the transition

to blocking was abrupt and immediate. In the final passing phase, the driver increased speed to get ahead of the plant. In the cases of drivers 1M, 3K′, and 4H, final speed seems to match the initial speed of approach. Generally drivers' responses appear too individualistic to be well represented by a simple car-following equation—whatever the applicability of such an equation to other, high-traffic density conditions. A comparison of results with the predictions of Herman's car-following equation has been made in Figure 19.

A car-following equation of the form

$$(dx/at)_{n+1} = \alpha_0 \frac{\log\left[X_n(t) - X_{n+1}(t)\right]}{L}$$

was fitted to the data of vehicle 1M, under the condition that LM pass 150 ft behind the plant 17.5 sec after the start of the run, and match speed with the plant at 70 ft. The required equation, solved for α_0 and L, is

$$(dx/dt)_{n+1} = 46.4 \log\left[X_n(t) - X_{n+1}(t)\right] - 85.6$$

This equation is represented by the filled circles of Figure 19. It may be seen that the car-following equation does not give a good fit to the approach of vehicle 1M. The equation appears to describe responses to velocity changes of the car in front rather than the approach of a rear driver. In the fitted equation, the rear car (1M) cannot approach closer than 70 ft unless the lead car itself slows down.

Traffic Delays

Vehicular delays may be evaluated by comparing delayed performance with the progress that would have been made if the car had not been slowed. [For example, if a vehicle originally moving at 88 ft/sec (60 mph) is slowed behind the plant to 66 ft/sec (45 mph) for a period of 10 sec, it has been delayed 10 x (88 - 66) = 220 ft. The time delay is 220/88 = 2.5 sec.] Delays are given in terms of time and distance in Table 2 for 8 of the 9 obstructed vehicles (vehicle 6X's record was not complete). Total delay of the 8 vehicles due to obstruction is 33.54 sec in the half hour of film record examined. While these lags may have been an annoyance to the drivers, they do not represent a very serious loss of time. Traffic flow would be speeded more by wider use of freeways and hurrying the slow driver than by eliminating the sort of transient delays encountered here.

DISCUSSION OF RESULTS

These findings clearly reveal the driver's motivation to keep moving at elected speed and to avoid being blocked. Only when the driver had no choice but to accept the situation did he slow down. Passing drivers and blocked drivers who escaped by shifting lanes did not slow up appreciably. Only 9 cars of the 166 observed were so trapped. When blocked, the driver slows, matches pace with the driver in front, and prepares to pass. As soon as blocking is removed, he moves ahead again.

This goal-directed view of driver motivation is in accord with the observations of Rockwell and Snider (4). Their study concerns the important case where the plant is moving at close to traffic stream speed and the oncoming driver is not greatly slowed if he has to follow. Under these circumstances the authors note that drivers did not follow, but immediately passed or else reduced velocity until the influence of the leading vehicle was completely avoided.

The driver's intention to move ahead is not compatible with instructions given in many car-following experiments to "follow at minimum safe distance" (or words to that effect). If the lead vehicle gets out of the way, the driver does not follow but keeps his course and possibly moves ahead. The intention of the driver is to move toward his destination, not to follow the vehicle in front. (Genuine car-following may be said to occur in funeral processions, in situations where the driver follows a preceding car in fog, or where the driver is being guided by the one in front to an unfamiliar address.)

While a typical delayed driver curve could be chosen for simulation purposes from Figures 19-27, such a curve would be something of an abstraction. Although drivers share a common motivation to move ahead, they execute their intentions in quite different ways. Furthermore, the driver is reacting to an entire situation and not merely to the vehicle in front. The film records show numerous instances of drivers moving toward the edge of the lane preparatory to shifting, and then moving back when they saw that a gap was not available. Although the driver's intention to move guides the maneuver, his moment-to-moment revisions of strategy, based on the changing situation, are also evident.

ACKNOWLEDGMENT

The author wishes to express his thanks to Kirk Reuyl, head of the Optical Physics Department, Aberdeen Proving Grounds, for helpful suggestions concerning the photographic techniques used in this study. He also wishes to express his appreciation to W. E. Manson and M. E. Fowler for permission to use the Masonic Tower in photographing traffic.

REFERENCES

1. Herman, R., and Gardels, K. Vehicular Traffic Flow. Scientific American, Vol. 209, No. 6, Dec. 1963, pp. 3-11.
2. Herman, R., and Potts, R. B. Single Lane Traffic Theory and Experiments. In Theory of Traffic Flow (Herman, R., ed.), Elsevier Publishing Co., New York, 1961, pp. 120-146.
3. Michaels, R. M. Perceptual Factors in Car Following. In Proc. 1963 Second Internat. Symp. on Theory of Traffic Flow (Almond, J., ed.), Organisation for Economic Co-Operation and Development, Paris, 1965, pp. 44-60.
4. Rockwell, T. H., and Snider, J. N. An Investigation of Variability in Driving Performance on the Highway. Systems Research Group, Ohio State Univ., Rept. RF-1450, Sept. 1965, pp. 17-31.
5. Worrall, R. D., and Bullen, A. G. R. Lane-Changing on Multi-Lane Highways. Federal Highway Administration, final rept., Aug. 1969.