# GAP-ACCEPTANCE CHARACTERISTICS IN FREEWAY TRAFFIC FLOW

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Aerial data were used to determine average spatial and time sizes of the accepted gaps and the lag gaps in gap-acceptance maneuvers for exiting vehicles close to their intended off-ramp and for through vehicles as a function of distance from the off-ramp. Furthermore, an attempt was made to quantify the accident risk that was assumed by each lane changer and the accident risk that was imposed by each lane changer on the lag car of the accepted gap. Results were obtained for an 8-, a 6-, and a 4-lane freeway site and for various flow levels. In general, the average spatial and time gap and lag gap sizes of gaps accepted by exiting vehicles decrease as the exiting vehicles approach the off-ramp. The corresponding average values for through vehicles show less, if any, dependency on distance from the off-ramp. Average gap and lag gap sizes of gaps accepted by exiting and through vehicles decrease with increasing flow levels. Within the assumptions made, it was found that a larger accident risk is accepted by exiting vehicles than by through vehicles in their lane changes, whereas the accident risk imposed on the lag car of the accepted gap is smaller for lane changes by exiting vehicle than by through vehicle.

• THE AVAILABILITY of quantitative data for gap-acceptance characteristics is very important for the understanding of quantitative features of freeway traffic flow. Some rather general results on gap-acceptance characteristics are available (1, 2, 3), but more detailed results are urgently needed. Recently, a methodology was developed (4) that enabled the acquisition of data suitable for this purpose. This methodology involves the application of aerial photographic techniques to obtaining discrete trajectories of vehicles traversing a given freeway site and the subsequent analysis of these trajectories to discern quantitative features of the freeway traffic flow.

In this paper, gap-acceptance characteristics are investigated for exiting vehicles close to their intended off-ramps and for through vehicles. The investigated parameters include spatial and time sizes of the accepted gaps and of the lag gaps in each gap-acceptance maneuver. For each gap-acceptance maneuver, a further attempt was made to quantify the accident risk that was assumed by the lane changer as well as the accident risk that was imposed by the lane changer on the follower of the accepted gap.

## DATA

The 3 freeway sites selected each contained an off-ramp and an upstream section of the freeway. The sites were situated in the Los Angeles area and consisted of an 8-lane freeway (Ventura Freeway, westbound, at White Oak Avenue off-ramp), a 6-lane freeway (Santa Ana Freeway, southbound, at Washington Boulevard off-ramp), and a 4-lane freeway (Newport Freeway, northbound, at Katella Avenue off-ramp).

The data were collected with a 70-mm Maurer camera operated from a helicopter that hovered over the studied freeway site. The camera took pictures at time intervals of 1 sec, and the length of the photographed freeway section was of the order of 1 mile. The pictures were scanned in successive order so as to obtain digitized positions of vehicles. A specialized software system deduced individual trajectories from the digitized vehicle coordinates. The resulting trajectories yield the space-time history of each vehicle within the studied freeway site. They include longitudinal and lateral position and speed for each car in time intervals of 1 sec.

The acquired data were subjected to a statistical analysis to isolate those time periods in which the average flow level remained constant. The length of the obtained time periods ranged from 1.5 to 15 min. The data were aggregated into groups where the average flow levels of the selected time periods differ only within a small range in order to improve the statistical significance of the derived analysis results. Table 1 gives the resulting data groups that were used for this study (more details are given in another report, 4).

## SPATIAL AND TIME CHARACTERISTICS OF GAP-ACCEPTANCE MANEUVERS

In this study of gap-acceptance characteristics as a function of distance from the intended off-ramp of exiting vehicles, each study site was divided into zones of 600-ft lengths starting at the nose of the off-ramp and progressing upstream. In each zone all lane changes of exiting and through vehicles were determined, and for each lane change the leader and the follower of the gap that was accepted by the lane changer were defined. An accepted gap was always assigned to the same zone in which the lane change occurred, even though the leader or follower of the gap or both may have been positioned outside this zone at the moment of the lane change. Figure 1 shows a sketch of a gap-acceptance maneuver and some of the parameters of interest in such a maneuver.

For each zone, the spatial sizes of all accepted gaps, $s_{g,i}$ (front bumper to front bumper), were determined at the moment of the lane change. For through vehicles and exiting vehicles separately, the gap sizes were classified into 50-ft intervals, and the sample probability density

$$n_k(d)/[N(d) \times 50 \text{ ft}] \tag{1}$$

was computed for each zone, where $n_k(d)$ denotes the number of gaps in the kth gap-size interval in the zone at distance d from the off-ramp, and N(d) denotes the total number of lane changes of through and exiting vehicles respectively in the same zone. For each zone, the estimators of the average gap size

$$\overline{s_g} = (1/N) \sum_{i=1}^{N} s_{g,i} \tag{2}$$

and its variance

$$\sigma_g^2 = 1/\ N(N-1) \sum_{i=1}^{N} (s_{g,i} - \overline{s_g})^2 \tag{3}$$

were also computed.

Analogous procedures were applied to all lag gap sizes, $s_{\ell,i}$.

In addition to this study of spatial gap and lag gap sizes, an analogous study for the associated time gap and lag gap sizes was also performed. For this purpose, the time size of each accepted gap was computed as

$$h_g = s_g/v_\ell \tag{4}$$

and the time size of the lag gap was computed as

$$h_\ell = (s_q/v_\ell) - (s_c/v_c) \tag{5}$$

The meaning of the symbols is shown in Figure 1. For through vehicles and exiting vehicles separately, these time gaps and lag gaps were classified into 0.5-sec intervals, and the sample probability density was computed as

**Table 1. Average flow levels of study sites.**

| Number of Freeway Lanes | Flow | Avg Number of Vehicles/Hour | | Time Period (sec) |
|---|---|---|---|---|
| | | Through | Exiting | |
| 8 | Low | 4,450 | 437 | 1,040 |
| | Medium | 5,520 | 595 | 1,120 |
| | High | 7,320 | 771 | 2,525 |
| 6 | Medium | 4,440 | 484 | 400 |
| | High | 5,680 | 560 | 180 |
| 4 | Medium | 2,520 | 427 | 1,405 |

**Figure 1. Gap-acceptance maneuver.**

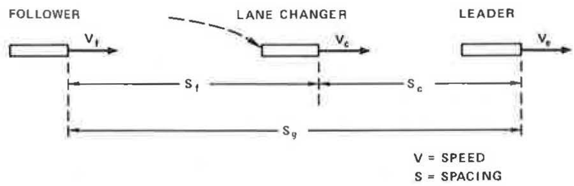



**Figure 2. Spatial size of gaps accepted by exiting vehicles, 8-lane site, high flow.**

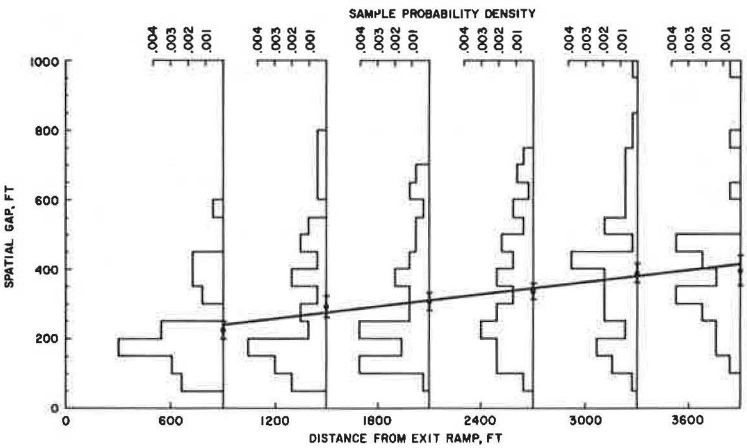
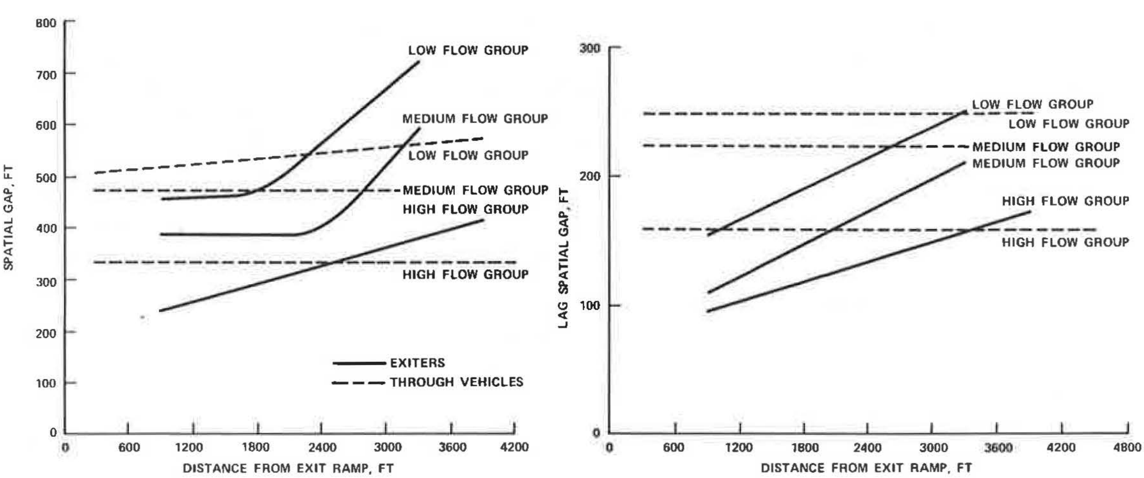



**Figure 3. Estimated average spatial gaps accepted, 8-lane site.**



$$n_k'(d)/[N(d) \times 0.5 \text{ sec}] \quad (6)$$

for each zone, where $n_k'(d)$ denotes the number of gaps in the kth time gap size interval for through and exiting vehicles respectively in the zone at distance d from the nose of the off-ramp. Average time gap sizes and their variances were estimated by equations similar to Eqs. 2 and 3. Analogous results were computed for the time sizes of the lag gaps.

A detailed graphical presentation of the obtained results is given in another report (4, Appendix D). Figure 2 shows an example that is typical of the results obtained for the spatial sizes of gaps accepted by exiting vehicles in the high-flow group on the 8-lane freeway. So that the obtained results could be easily compared, smooth curves were fitted through the average values obtained in each data group, and these curves are shown in Figures 3 through 8.

## ACCIDENT RISK

An attempt was also made to quantify the accident risk involved in the gap-acceptance maneuvers. For this purpose, a computation was made of how long the follower of a gap could delay his braking onset after the leader of the gap had started to brake, such that the follower just barely avoided a collision (this is a modification of the St. John and Kobett time sum concept, 5). In the following these results will be called the "permissible braking delay." For example, the distance between the front bumper of the lane changer and the back bumper of the leader (Fig. 1) is $s_c$ - 17 ft, based on the generally used value of 17 ft for the average car length. It is assumed that the leader starts to brake at time $t = 0$ with a constant deceleration $\ddot{x}$. It is further assumed that the lane changer will decelerate with the same deceleration $\ddot{x}$ when his brakes are activated. In order to just barely avoid a collision with the leader, the lane changer has then the permissible braking delay

$$T_c = [(s_c - 17 \text{ ft})/v_c] - (1/2v_c\ddot{x})(v_1^2 - v_c^2) \quad (7)$$

The permissible braking delay for the follower (Fig. 1) with respect to the lane changer is

$$T_f = [(s_f - 17 \text{ ft})/v_f] - (1/2v_f\ddot{x})(v_c^2 - v_f^2) \quad (8)$$

For this study, the deceleration value, $\ddot{x} = -10 \text{ ft/sec}^2$, was chosen for the computations; this value corresponds to an intermediate risk level (5).

Permissible braking delays ranged typically from values as low as -3 sec to values of more than 10 sec. An earlier report (4) showed the sample probability densities of the permissible braking delays for the various data groups as a function of distance from the off-ramp. Figure 9 shows a typical example that was obtained for exiting-vehicle lane changes in the high-flow group on the 8-lane freeway site.

Negative values of permissible braking delays indicate very high risk levels because a collision is unavoidable, under the above assumptions, if the leader or the lane changer were suddenly to decelerate 10 ft/sec². However, because typical reaction times are of the order of 1 sec, even all permissible braking delays, $T_c \lesssim 1$ sec and $T_f \lesssim 1$ sec, indicate high risk levels.

With this assumption, the percentage of cars with high accident risks in gap-acceptance maneuvers were obtained for each data group. The results are given in Table 2. The dependency of these percentages on distance from the off-ramp could not be studied because the available data samples were not large enough for this purpose. Because the available sample sizes varied considerably among the various data groups, the accuracies of the percentages given in Table 2 are quite different from one another. A rough indication of the statistical significance of each percentage given is provided by the total number of lane changes from which each percentage was computed.

## SUMMARY AND CONCLUSIONS

Figures 3 through 8 show that the average spatial and time gap and lag gap sizes of gaps accepted by exiting and through vehicles decrease with increasing flow levels.

Figure 4. Estimated average time gaps accepted, 8-lane site.

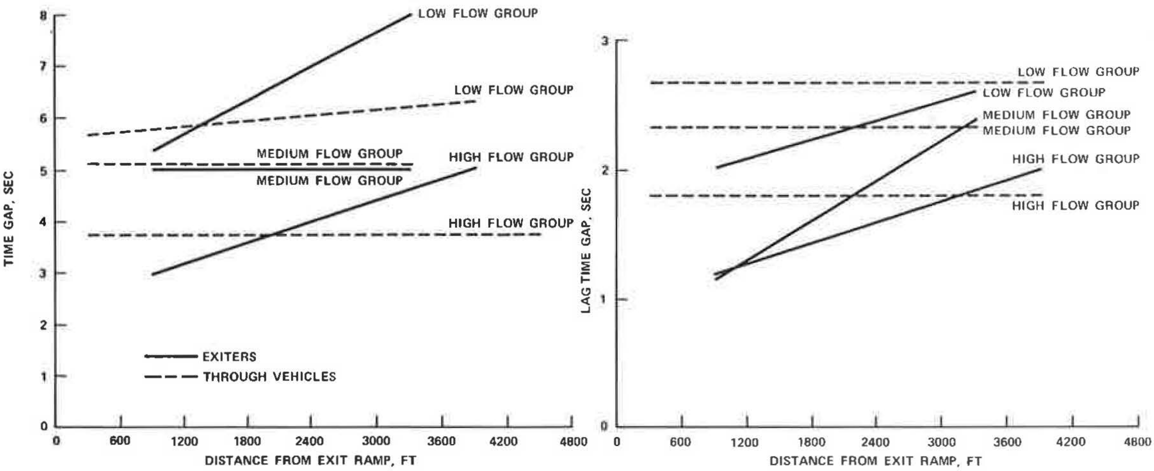



Figure 5. Estimated average spatial gaps accepted by through vehicles, 6-lane site.

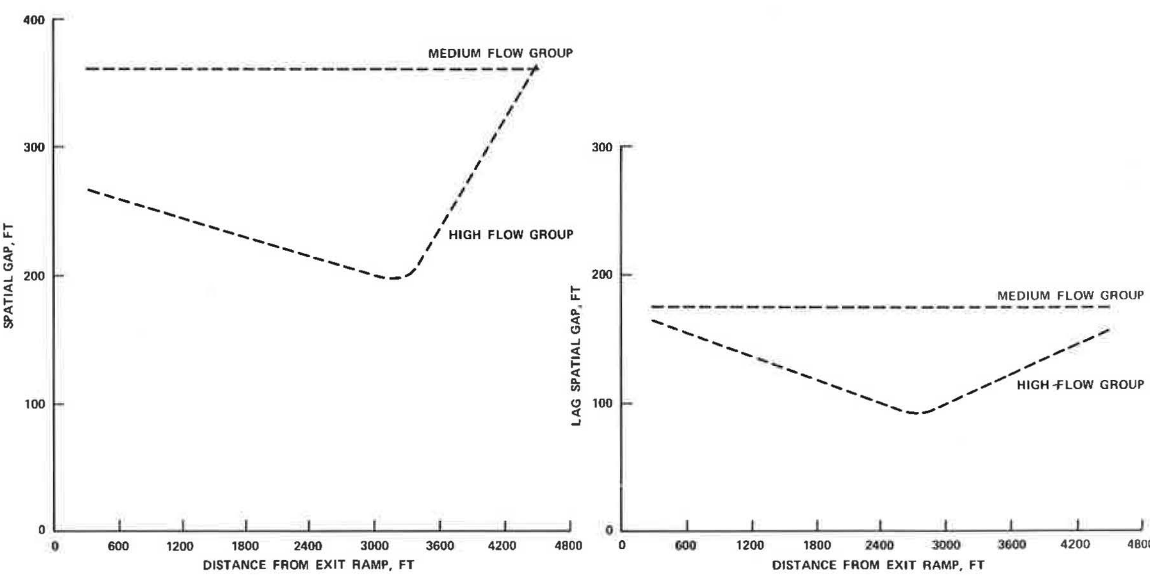
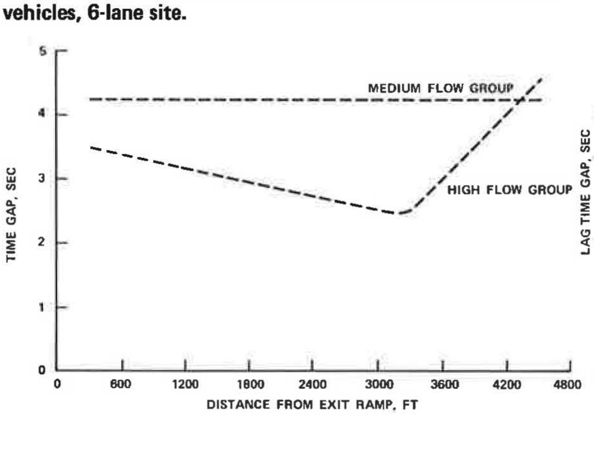



Figure 6. Estimated average time gaps accepted by through vehicles, 6-lane site.



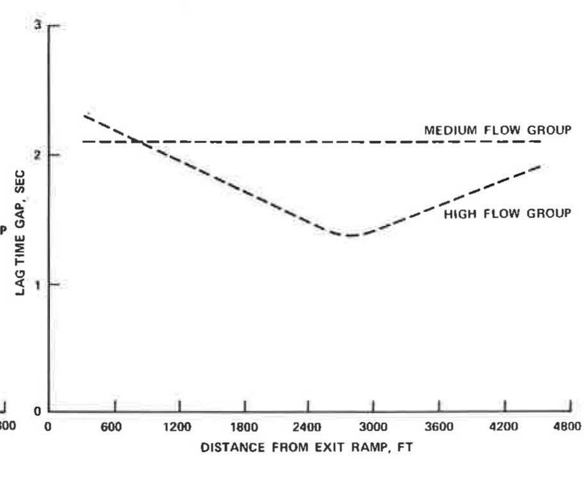



Figure 7. Estimate average spatial gaps accepted, 4-lane site, medium flow.

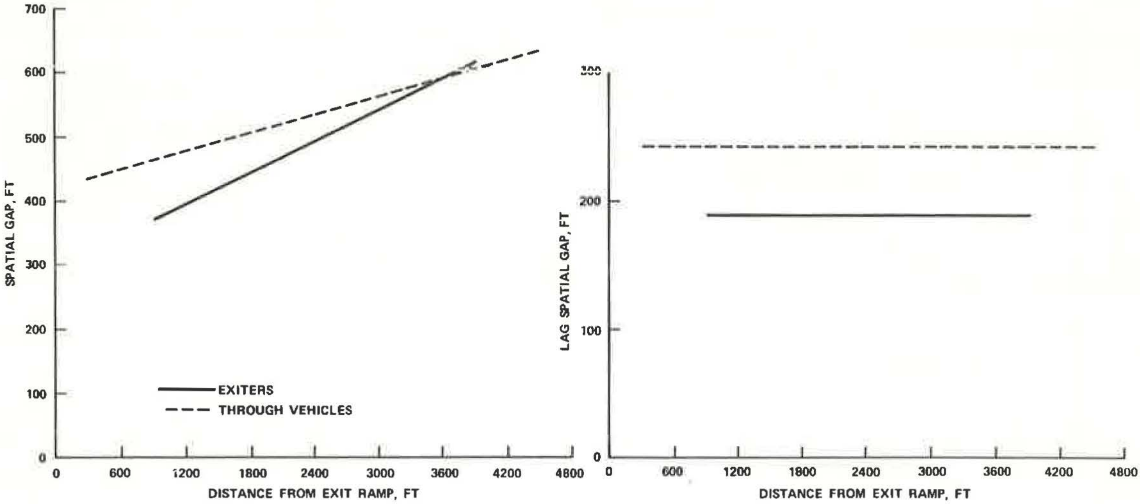



Figure 8. Estimated average time gaps accepted, 4-lane site, medium flow.

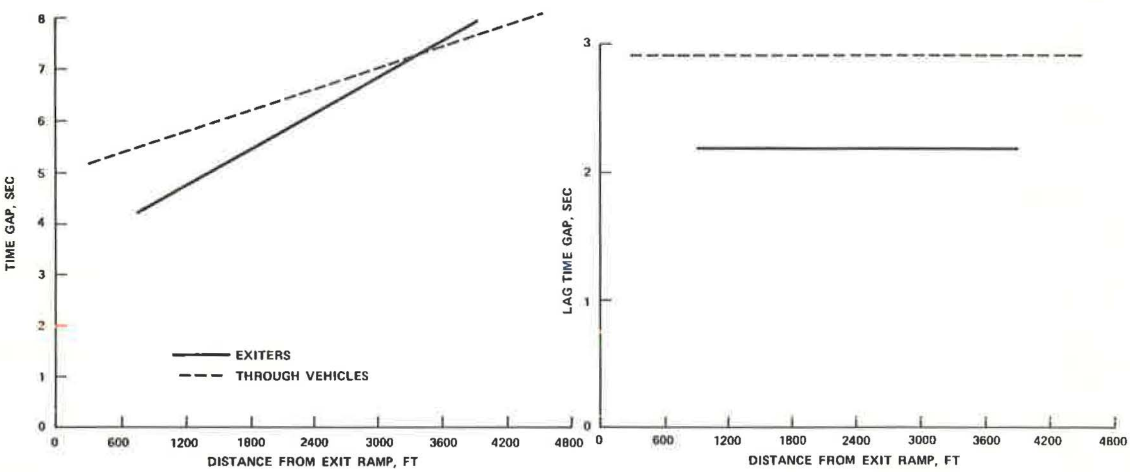



Figure 9. Permissible braking delay of exiting vehicles when accepting gap, 8-lane site, high flow.

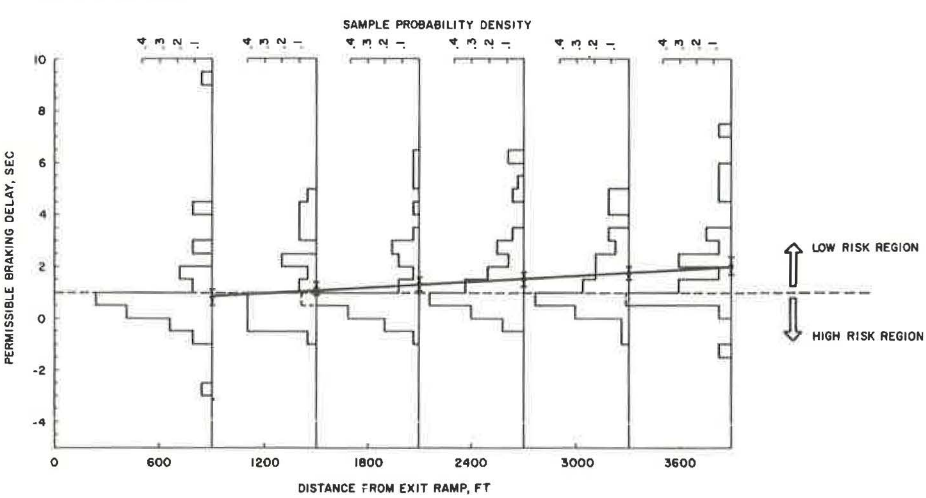


**Table 2. Permissible braking delays less than 1 sec for lane-changing vehicles and for lag cars.**

| Number of Lanes and Flow | Vehicles Changing Lanes | | | | Vehicles Accepting Gaps of Lag Cars | | | |
|---|---|---|---|---|---|---|---|---|
| | Exiting | | Through | | Exiting | | Through | |
| | Percent | Number | Percent | Number | Percent | Number | Percent | Number |
| 8, low | 34 | 87 | 22 | 379 | 9 | 87 | 18 | 379 |
| 8, medium | 32 | 75 | 22 | 500 | 21 | 75 | 23 | 500 |
| 8, high | 55 | 271 | 29 | 1,399 | 19 | 271 | 34 | 1,399 |
| 6, medium | 31 | 26 | 16 | 93 | 12 | 26 | 34 | 93 |
| 6, high | 86 | 7 | 16 | 50 | 29 | 7 | 46 | 50 |
| 4, medium | 30 | 50 | 14 | 246 | 14 | 50 | 22 | 246 |

Figures 3 and 4 show that, for the 8-lane freeway, the spatial and the time average sizes of the gaps accepted by exiting vehicles decrease with decreasing distance from the off-ramp. The only possible exception to this general trend may occur for the time sizes of gaps accepted by exiting vehicles in the medium-flow group; but here, the statistical accuracy of the data points is especially poor (4). Figures 3 and 4 also show that the corresponding spatial and time lags in the gap-acceptance maneuvers of exiting vehicles exhibit also a substantial decrease with decreasing distance from the off-ramp.

For the 4-lane freeway, Figures 7 and 8 show a decrease in spatial and time average size of gaps accepted by exiting vehicles for decreasing distances from the off-ramp. However, in this case, the spatial and time lag in gap-acceptance maneuvers of exiting vehicles does not change with distance from the off-ramp. Unfortunately, because of a lack of a sufficiently large data sample, no graphs are available for gap-acceptance maneuvers of exiting vehicles on the 6-lane freeway site.

The corresponding average values for through vehicles show less, if any, dependency on distance from the off-ramp. Figures 7 and 8 show that through vehicles accept, on the average, shorter gaps with decreasing distance from the off-ramp for the medium-flow group of the 4-lane site. Figures 3 and 4 show a similar, although weak, trend in the low-flow group of the 8-lane site. No such trend is apparent in the medium- and high-flow groups of both the 8-lane and the 6-lane sites. The spatial and time lags in gap-acceptance maneuvers of through vehicles do not depend, on the average, significantly on distance from the off-ramp for any of the data groups, with the exception of the high-flow group of the 6-lane freeway. Figures 5 and 6 also show that, for the high-flow group of the 6-lane freeway, the average values for through vehicles exhibit a special and unique dependency on distance from the off-ramp.

Data given in Table 2 show that, as expected, a substantially larger accident risk is accepted by exiting vehicles than by through vehicles in their lane changes. Furthermore, the accident risk of exiting vehicles in their lane changes tends to increase with increasing flow levels. Somewhat unexpected, however, is the finding that the accident risk imposed on the lag car of the accepted gap is substantially smaller for exiting-vehicle lane changes than for through-vehicle lane changes.

## REFERENCES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