DRIVER BEHAVIOR
at
RURAL PARALLEL AND TAPER EXIT RAMPS

TSD - 221 - 73

TRAFFIC and SAFETY DIVISION

DEPARTMENT OF STATE HIGHWAYS
STATE OF MICHIGAN

10058

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KEY WORDS: Driver Behavior, Accidents, Off Ramps, Speed-change Lanes, Speed Differential, Geometric Design

ABSTRACT: The operations of rural parallel and taper exit ramps were compared by observing driver behavior. The parameters used were: speeds, the path of existing vehicles, and accident experience at the ramps. The difference in speeds between exit and thru vehicles was about 7 mph at four parallel ramps and between 9 and 13 mph at three taper ramps; the difference at taper ramps was significantly greater than the difference at parallel ramps. The paths found generally entered the ramp at the beginning of the pavement widening and followed a direct path. There was no difference between the accident rates at the two types of ramps. Both types operated satisfactorily.

REFERENCE: Mercer, Donald J., Driver Behavior at Rural Parallel and Taper Exit Ramps, Michigan Department of State Highways Report TSD-221-73, Lansing, Michigan, April 1973.

Preface

This project began a number of years ago in an attempt to determine which type of exit ramp configuration, the taper or the parallel, should be the standard design. The principal investigator was Lawrence E. Shaw, who conceived the study, designed it, supervised the data collection, and performed the preliminary data analysis.

The author entered the scene at that point. Other than reviewing the work done by other agencies, he did little on this project for several years, until it was reactivated. The project suffers some from the aging of the data and the changing of personnel. Mr. Shaw developed the study with an approach different from that used by the author in analyzing it, thus the data did not always exist in the form desired. But these defects do not invalidate the study: the driving patterns presented here are regarded as true representations of the patterns found at both types of ramps.

Mr. Shaw drew from the Traffic Geometrics Section technician staff, both permanent and temporary, in collecting his data. The electronic speed measurements were taken by personnel in the Traffic Research and Development Section.

To Mr. Shaw goes all credit for the data; to the author comes all the responsibility for the report.

Lansing, Michigan
April 1973

dgm

Driver Behavior at Rural Parallel and Taper Exit Ramps

Figures

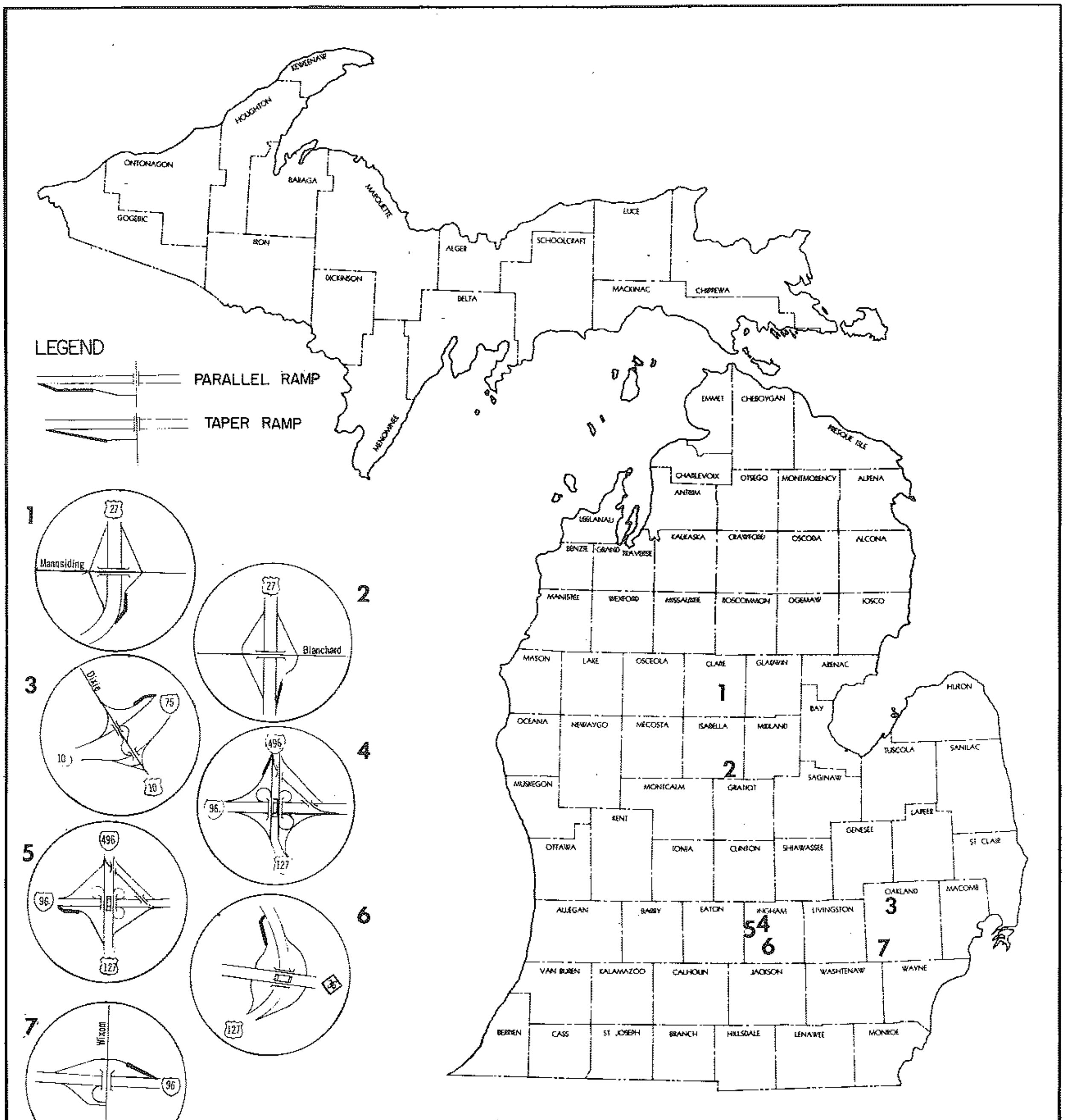

FIGURE 1. *Location Map*

Driver Behavior at Rural Parallel and Taper Exit Ramps

Introduction

PURPOSE OF THE STUDY

This study compares the operations of parallel and taper designs of rural one-lane right-hand exit ramps, on the basis of the typical driven path, speed reduction in the thru lanes and accident experience.

The ideal exit ramp will provide for all deceleration off of the thru lanes, to minimize conflicts between thru and exit vehicles. It will also provide the path that most drivers want to follow, to minimize erratic movements and to reduce the amount of thru traffic that strays onto the ramp.

The parallel design provides abundant deceleration length off of the thru lanes, but the added pavement area can induce the erratic movements. The taper design forces drivers into a stereotype path, but also provides drivers with a small target and may cause drivers to slow excessively on the thru lanes.

For either type of ramp to work properly, adequate sight distance must be provided beyond the gore to give the driver confidence in his ability to negotiate the ramp.

TERMS

In this report the following definitions are used:

1. Deceleration Lane - An auxiliary lane, including the pavement widening, that enables an exiting vehicle to leave the thru lanes and to then adjust its speed as necessary.

2. Pavement Widening - The gradual widening of the ramp pavement, from 0 ft at the edge of the thru lanes. The common name of this feature is "taper", a term not used here to avoid confusion with "taper ramps".

3. Ramp - A roadway providing access from the freeway to another highway. It includes the deceleration lane.

4. Parallel Ramp - A deceleration lane consisting of a pavement widening and a short added lane parallel to the thru lanes.

5. Taper Ramp - A deceleration lane consisting of a pavement widening only, with no added lane.

STUDY METHOD USED

Seven ramps, four of parallel design and three of taper design, were observed.

The vehicle-speed phase of the study was conducted in two steps. Speeds were first measured with an Enoscope for both thru and exit vehicles concurrently at one or more timing zones. The first timing zone was located upstream from the deceleration lane; any additional zones were located within the deceleration lane. At four ramps the speed data was retaken later electronically at two timing zones; the first upstream, the second near the gore. Each exit or thru vehicle timed was timed in both zones but the thru and exit speeds were not taken concurrently. This data is used to determine if the differential between exit and thru speeds correlates with the design of the ramp.

For the vehicle-placement phase, the zone in which the right front wheel of an exit vehicle crossed the edge of the thru lanes was recorded. This data is used to locate where the exit move is taking place.

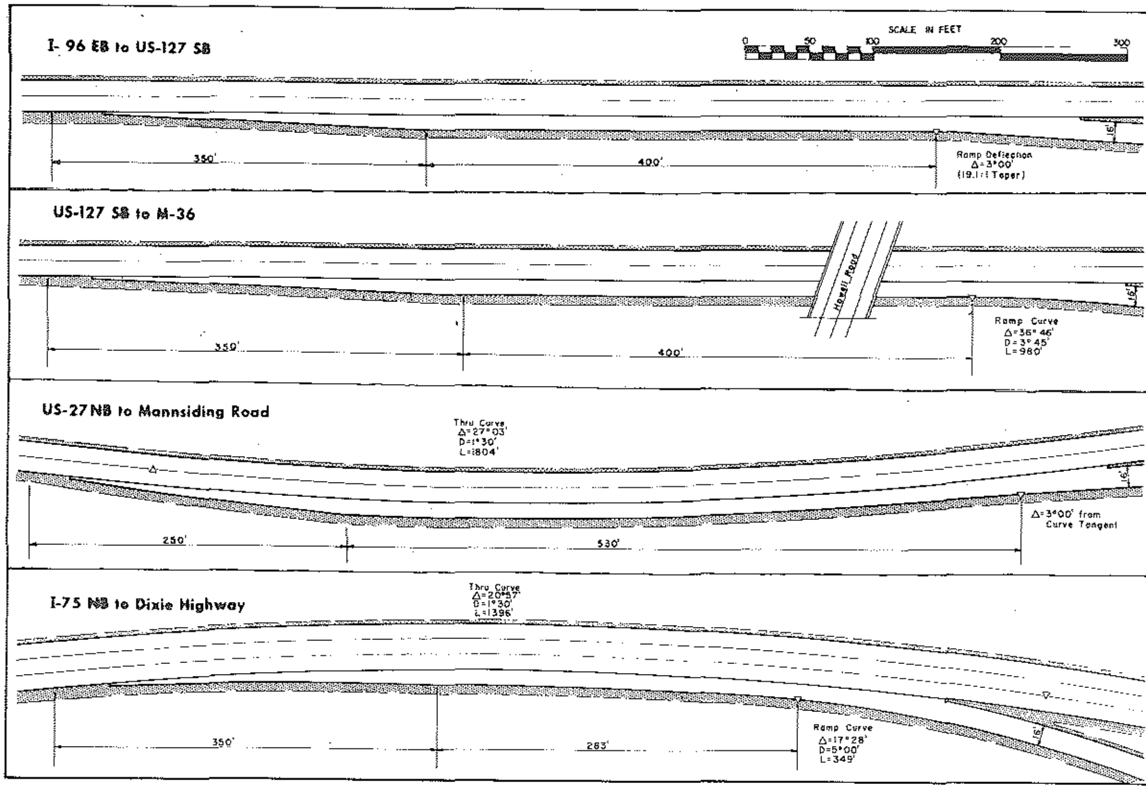

FIGURE 2. Horizontal Alignment of Parallel Ramps

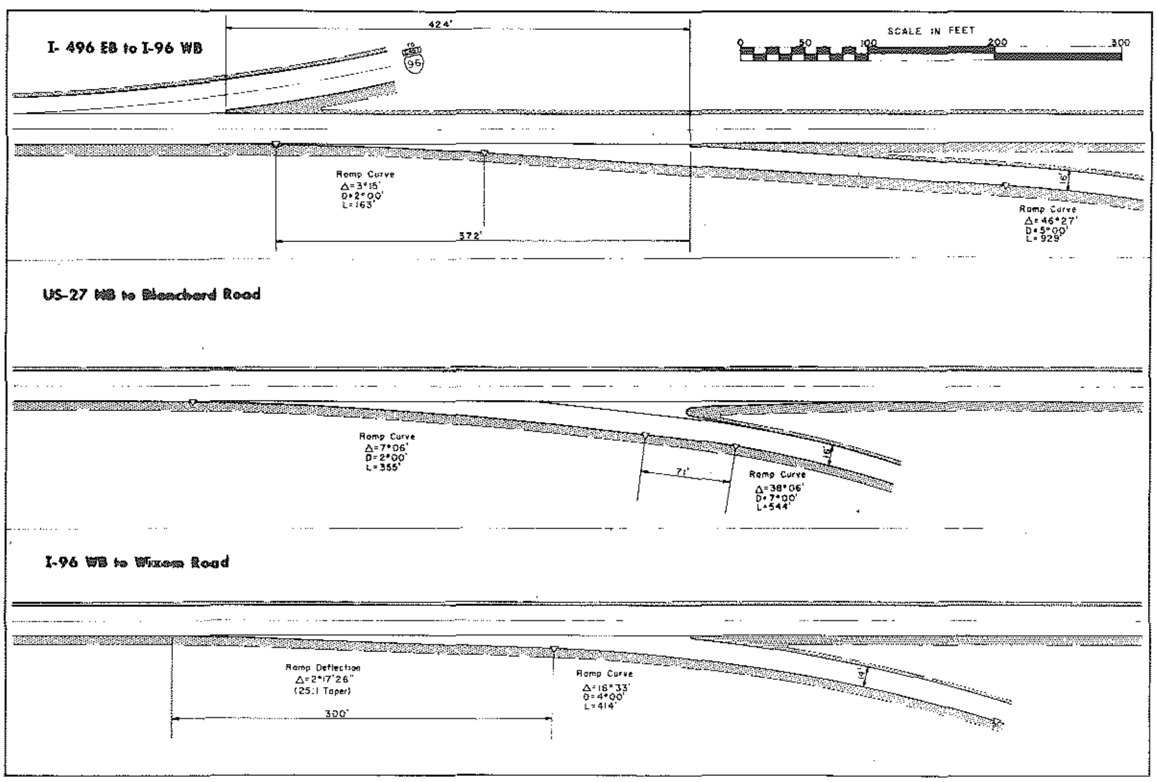

FIGURE 3. Horizontal Alignment of Taper Ramps

The lateral placement of each exit vehicle's right front tire was spotted as it crossed three different points. This data is used to determine the typical exit path.

For the accident phase, the five-year accident histories of the ramps were taken from the Department files. This data is used to determine the types of accidents and the accident rates occurring at the ramps.

LOCATIONS

Each of the seven ramps selected for this study is so designed to allow an exiting driver his free choice of speed and path within the confines of the parallel or taper ramp type configuration. He is able to clear the thru lanes at 70 mph and decelerate at his own rate.

The locations are shown in Figure 1. They are:

Parallel Ramps (Figure 2)

1. I-96 EB to US-127 SB, Ingham County
2. US-127 SB to M-36, Ingham County
3. US-27 NB to Mannsiding Road, Clare County
4. I-75 NB to Dixie Highway, Oakland County

Taper Ramps (Figure 3)

5. I-496 EB (US-127 SB) to I-96 WB, Ingham County
6. US-27 NB to Blanchard Road, Isabella County
7. I-96 WB to Wixom Road, Oakland County

Conclusion

Based on the findings of this study, it is concluded that both parallel and taper rural ramps have satisfactory driving patterns. An operational defect was detected at each type—erratic movements at parallels; excessive slowing at tapers—but neither was so severe to warrant discrediting the ramp configuration on the basis of driver behavior.

Consistency and economy of design favor the taper configuration, as it has been Michigan's standard design for many years and is less expensive to construct. But the designer can choose either type, assuming he provides adequate sight distance and deceleration distance, confident that it will operate satisfactorily.

The observations leading to this conclusion are:

1. Speed Differential. At all ramps, exiting drivers began to slow in the thru lanes before making their exit move. This produced a difference in exit vs thru mean speeds at the start of the pavement widening of -6.7 to -7.7 mph at parallel ramps and -9.0 to -12.9 mph at taper ramps. The larger differential found at the taper ramps is statistically significant.

2. Speed Measurement. The speed differentials found by the Enoscope method were consistently lower than those found electronically. But the relationship between parallel and taper ramps was the same for either method. The speeds found by the Enoscope were 0.2 to 5.7 mph lower than the electronic speeds.

3. Driver Path. At the parallel ramps the exiting drivers chose the most direct path to the ramp. The drivers' points of entering the ramps were concentrated at the pavement widening, but were distributed throughout the deceleration lane. At ramps on tangent the path was a long flat taper (95:1 and 120:1) that began at the start of the pavement widening. Thus the drivers used the full length, but not the full width, of the deceleration lane. At the taper ramps the path followed the edge of pavement; late exits were not observed.

4. Accidents. Erratic movements resulted in several accidents at the parallel ramps. At the high volume taper ramp rear-end accidents were prevalent. The computed accident rates for the two types were nearly identical.

The results of this study concur with the results of the studies by others. The actual tapers driven in those studies were not given in the reports, though Indiana preferred a ramp with a $1^{\circ}30'$ (38:1) taper. The tapers driven at the two parallel ramps on tangent in this study were much flatter, with apparently some reverse curve needed to stay on the pavement. The data collected gave no information for determining the reverse curve. To obtain that path, additional sets of lateral marks were needed, beginning upstream from the deceleration lane and continuing at close spacing through the pavement widening.

The observers (who attempted to stay hidden from traffic) apparently had only a slight effect on driver behavior. At two ramps there was no difference in the speeds measured by the two methods; indicating that at those ramps the Enoscope method was as accurate as the electronic method. The measured paths were all close to the right edge of pavement, indicating that drivers did not shy from the observers.

Recommendations

It is recommended that Department retain its current practice of using taper ramps as standard for rural design with parallel ramps as an acceptable alternate. The data obtained in this study give no justification for changing this policy.

It is also recommended that a broader ramp accident study be initiated, to include parameters beyond the scope of this study:

1. A large number of ramps of each configuration, to encompass different volume categories and to include both configurations on left curves, right curves and tangent. Each study ramp should have adequate deceleration distance and be free of unusual features that could affect the accident experience.
2. Volume counts for both thru and exit flows. The percent of vehicles exiting may be a significant factor.

It is also recommended that a human factors experiment be undertaken to determine what design changes are necessary to induce exiting drivers to maintain their speeds until they have cleared the thru lanes.

If future studies of driver behavior at ramps are conducted it is recommended that they concentrate on the area ranging from 1000 ft upstream to several hundred feet downstream from the start of the pavement widening, to get a clearer understanding of the driver's speed and path as he starts his exit movement.

Vehicle Speeds

GENERAL

The speeds of thru and exiting vehicles were measured at all the ramps to determine first the magnitude of the difference in speed between thru vehicles and exit vehicles and second if that difference was the same at taper ramps as it was at parallel ramps. The speed timing zone was located in the outside thru lane upstream from the deceleration lane. Desirably there should be no difference in speeds at that point; exit vehicles should not begin to slow until they clear the thru lane. But from the results of other studies, some difference in speeds was expected.

The speeds were first measured by Enoscope concurrent with the vehicle placement portion of this study in 1968, using (generally) a 200 ft timing zone. At two ramps speeds were also measured at other timing zones within the deceleration lane. Exit vehicles were timed at the same time as thru vehicles.

The speeds were measured a second time in 1971, using a Hewlett-Packard electronic timer with a 29 ft 4 in timing zone. Three zones were used to obtain two speeds on each vehicle; one zone, upstream from the deceleration lane timed all vehicles, the other two zones were located near the gore, one in the thru lane, the other on the ramp. Due to equipment limitations thru and exit vehicles could not be timed concurrently; they were timed on different days.

The data was analyzed to test the following null hypotheses:

1. H_o: There is no difference between exit speeds and thru speeds at the upstream zone. It was expected that the data would reject this hypothesis and that the alternate, that there is a difference, would be accepted.
2. H_o: There is no difference between the reduction in exit speed found at taper ramps and that found at parallel ramps.
3. H_o: There is no difference between the speed data obtained by the Enoscope and that obtained electronically.

These hypotheses were tested by comparing the arithmetic means (averages) of the two sample populations being considered, at the 95 percent confidence level. See Appendix 1 for a discussion of the method.

The speed distributions were tested for normality by measuring the skewness and peakedness indices. The skewness index (for symmetry) will show non-normality if a disproportionately high number of vehicles in the sample were traveling either above or below the mean speed. The peakedness index (kurtosis) will show non-normality if a disproportionately high or low number of vehicles were traveling at or near the mean speed. Example: suppose a sample distribution, with speeds measured in 2 mph increments, has a mean value of 50 mph and a standard deviation of 10 mph. In a normal distribution, the percent of the sample timed in the 49-51 mph class would be 8 percent; in the 59-61 class, 5 percent; and in the 69-71 mph class, 1 percent. If the sample has significantly different percentages for the class intervals, it is "non-normal." A non-normal distribution indicates increased accident potential, with skewness being the better parameter for determining non-normality (8). Both parameters require a large sample size to show a significant difference from the normal distribution.

The data is presented in the form of cumulative distribution curves. Two curves are shown on each figure, one for thru speeds and one for exit speeds.

At all ramps, the legal range of both thru and exit vehicle speed was 45 mph minimum and 70 mph maximum. All data was collected on dry pavement during the daytime in clear weather.

PARALLEL RAMPS

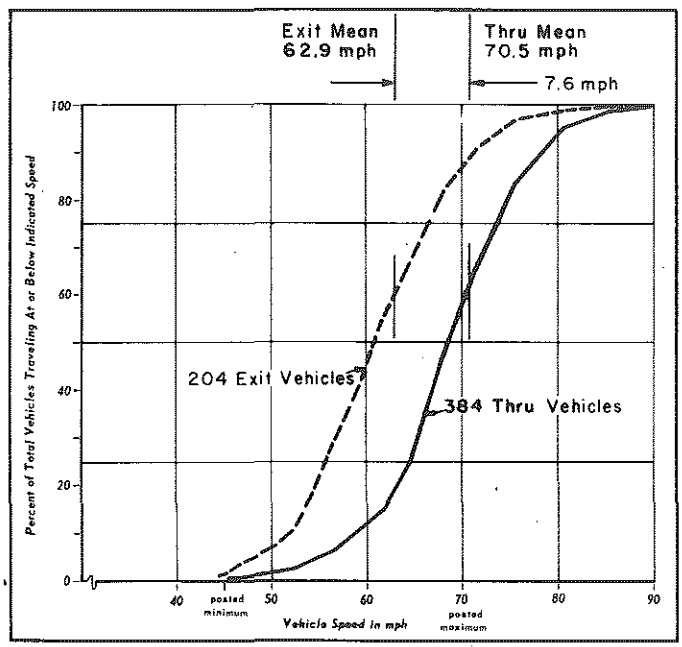

FIGURE 4. Thru and Exit Speeds I-96 @ US-127 (Enoscope Data)

I-96 EB to US-127 SB. The thru lanes are on tangent through this terminal.

Speeds were measured by Enoscope at the upstream zone in September 1968, with additional measurements taken within the terminal in October 1968. Exit speeds only were timed electronically in September (?) 1971.

The Enoscope data showed a significant 7.6 mph difference between thru and exit mean speeds (Figure 4).

The electronic speed data showed exit mean speeds of 62.4 mph upstream and 57.2 mph at the gore, a difference of 5.2 mph.

US-127 SB to M-36. At this ramp the thru lanes are on tangent through the terminal, then curve 2°00' Right about 250 ft after the gore. A structure crosses over US-127 at the deceleration lane.

Speeds were measured by Enoscope in August 1968 and electronically in September 1971.

The Enoscope data showed a significant 6.7 mph difference between the thru and exit mean speeds (Figure 5). The electronic data showed a smaller, but still significant, 3.5 mph difference in speeds (Figure 6).

The measured thru

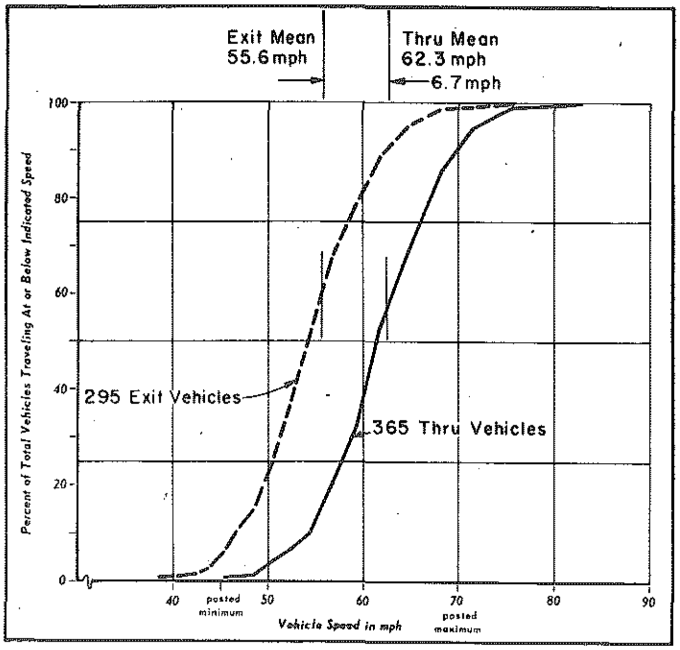

FIGURE 5. Thru and Exit Speeds US-127 @ M-36, (Enoscope Data)

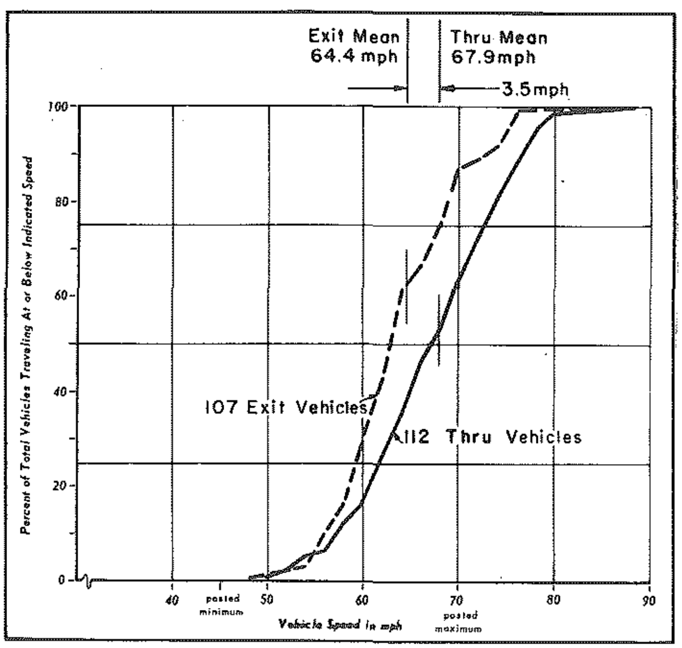

FIGURE 6. Thru and Exit Speeds US-127 @ M-36, (Electronic Data)

speeds increased in the three years between the two timings.

US-27 NB to Mannsiding Road. At this ramp the thru lanes begin to curve 1°30' Left near the start of the terminal.

Speeds were measured by Enoscope in August 1968; they were not measured electronically.

The exit mean speed was a significant 7.7 mph slower than the thru mean speed (Figure 7). Both speed distributions were non-normal (postively skewed).

I-75 NB to Dixie Highway. At this ramp, the thru lanes curve 1°30' Right through the terminal.

Speeds were measured by Enoscope in August 1968 and electronically in October 1971.

For the Enoscope data, the exit mean speed was a statistically significant 7.0 mph slower than the thru mean speed at the upstream zone (Figure 8). The exit

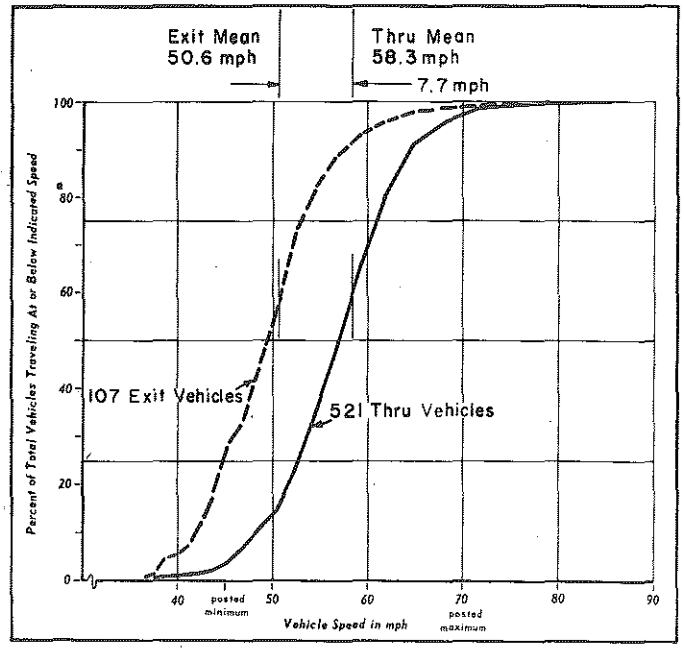

FIGURE 7. Thru and Exit Speeds
US-27 @ Mannsiding Rd. (Enoscope Data)

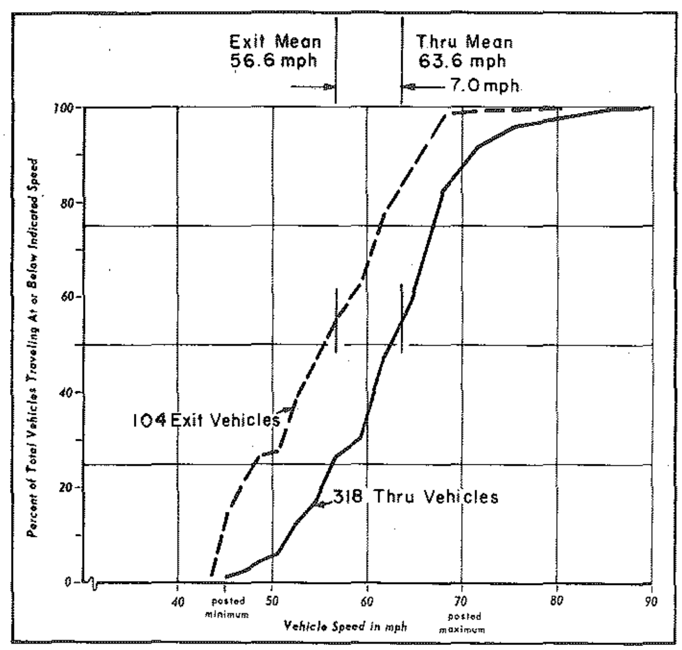

FIGURE 8. Thru and Exit Speeds
I-75 @ Dixie Highway (Enoscope Data)

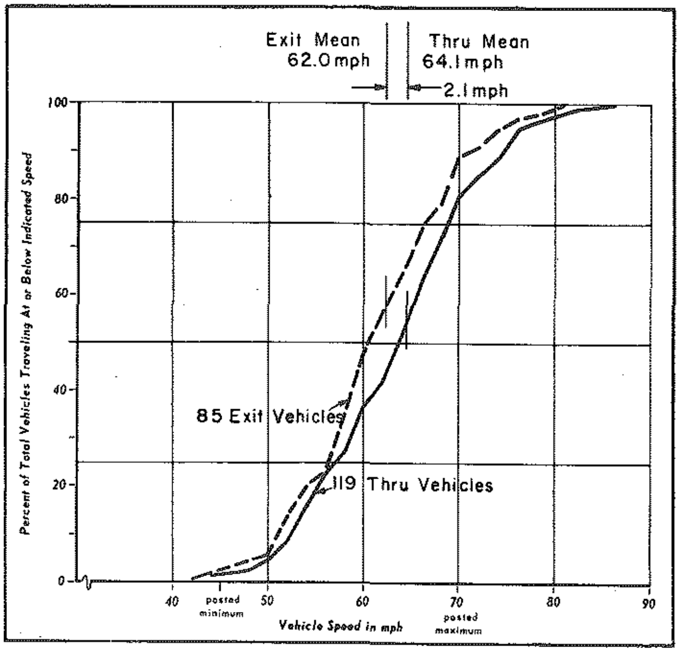

FIGURE 9. Thru and Exit Speeds
I-75 @ Dixie Highway (Electronic Data)

data had a non-normal (negative peakedness) distribution, almost random within the range of speeds, meaning that the arithmetic mean is a poor estimator of the speed of an exit vehicle.

For the electronic data, the difference in speeds was 2.1 mph and was not significant (Figure 9). There was no significant difference in thru speeds between the two measuring methods.

The thru vehicles reduced their speed through this terminal from 64.2 to 60.0 mph. This reduction may be due in part to the fact that the gore is near the crest of a long upgrade. The exit mean speed slowed from 62.0 to 48.3 mph from the upstream point to the gore.

TAPER RAMPS

I-496 EB to I-96 WB. At this ramp, the thru lanes are on tangent; the ramp deflects at 3°15', producing a 370 ft opening. The ramp gore is 420 ft downstream from the gore of a two-lane left-hand exit. Speeds were measured by Enoscope in July 1968 and electronically in August 1971.

For the Enoscope data, the thru mean speed was a significant 9.0 mph faster than the exit mean speed (Figure 10). Both distributions were non-normal. The exit speeds had a negative peakedness and the thru speeds had a positive peakedness.

For the electronic data, the speed differential was less, 3.9 mph, but still significant (Figure 11).

There was no difference between the speeds measured by the two methods. Both thru and exit vehicles slowed through the terminal.

<u>US-27 NB to Blanchard Road (Shepherd).</u> The thru lanes are on tangent at this ramp. The ramp deflects at 7°06' with a 2 degree Right curve at the right edge, providing a 410 ft opening. At the gore a second curve, 7 degrees Right, begins.

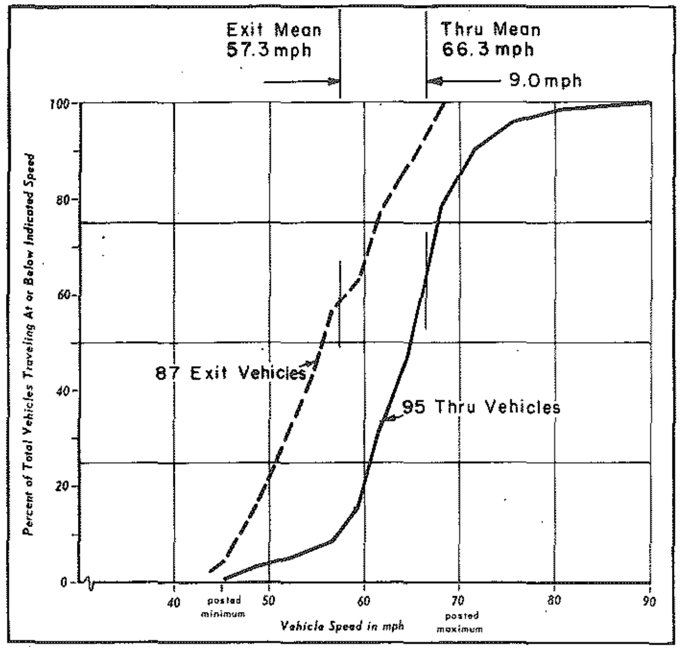

FIGURE 10. Thru and Exit Speeds
I-496 @ I-96 (Enoscope Data)

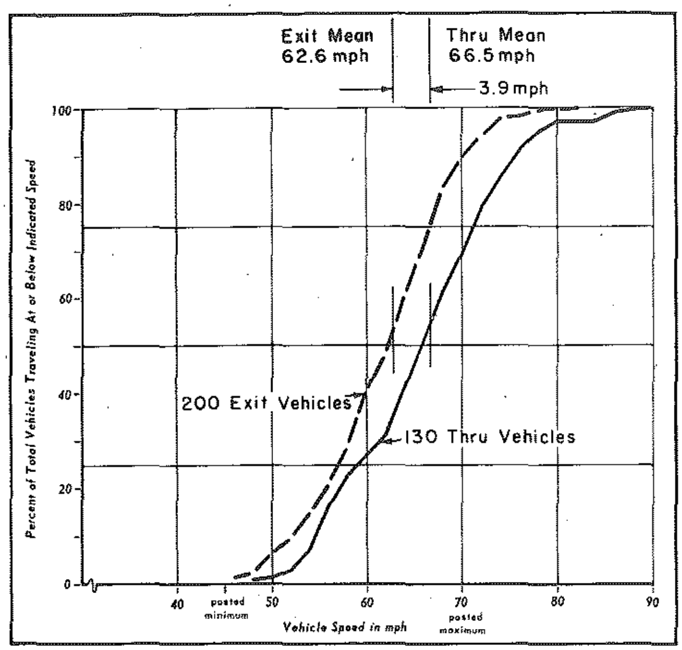

FIGURE 11. Thru and Exit Speeds
I-496 @ I-96 (Electronic Data)

Speeds were measured by Enoscope in August 1968 and electronically in November 1971.

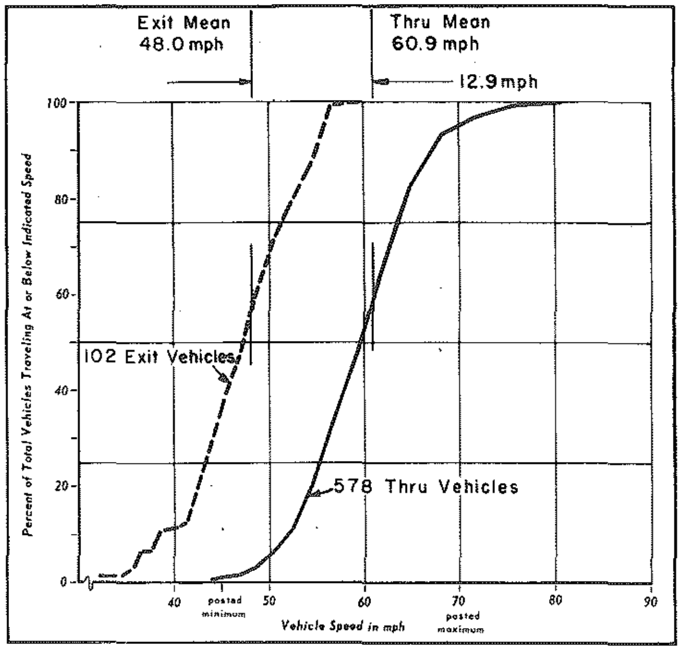

FIGURE 12. Thru and Exit Speeds
US-27 @ Blanchard Rd. (Enoscope Data)

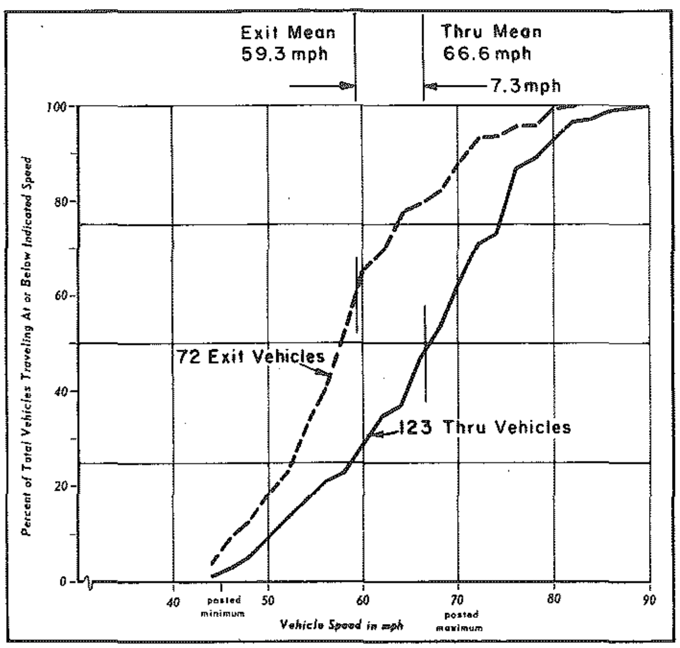

FIGURE 13. Thru and Exit Speeds
US-27 @ Blanchard Rd. (Electonic Data)

For the Enoscope data, the exit mean speed at the upstream zone was a significant 12.9 mph lower than the thru mean speed (Figure 12).

In collecting the data electronically, the exit speeds were measured on two days to obtain a large number of vehicles (72 the first day, 36 the second). At the upstream zone, the first day's exit mean speed was a significant 5.1 mph faster than the second day's, so the two counts cannot be combined. The thru mean speed was significantly faster than the exit mean speed for both days: 7.3 mph faster than the first day (Figure 13), 12.4 mph faster than the second day.

The thru mean speed measured electronically was a significant 5.7 mph faster than that measured by Enoscope. The thru vehicles held their speed constant through the terminal. The magnitude of the speed reduction for exit vehicles was about 10 mph.

I-96 WB to Wixom Road. At this ramp the thru lanes are on tangent. The ramp deflects at $2^{o}17'$, providing a 470 ft opening. A short $4^{o}00'$ Right curve on the ramp begins at about the middle of the widening. The width of the ramp is 14 ft.

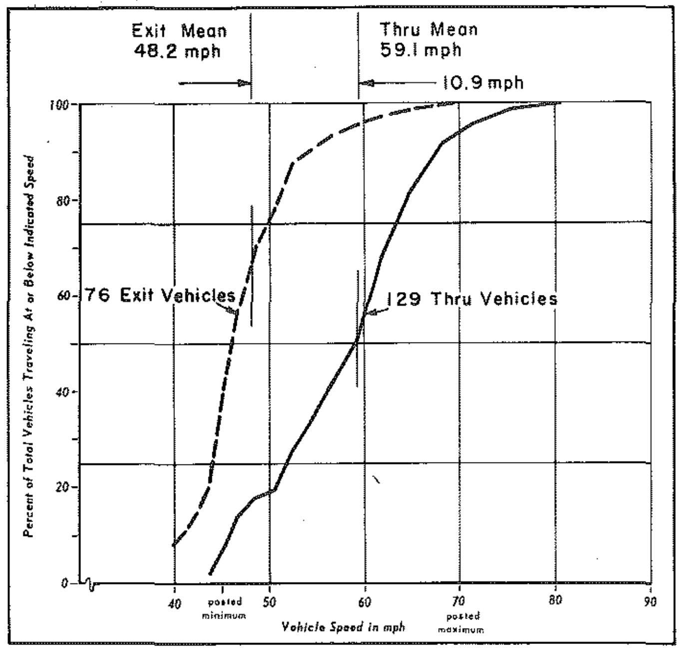

FIGURE 14. Thru and Exit Speeds I-96 @ Wixom Rd. (Enoscope Data)

Speeds were measured by Enoscope in July 1968, with additional measurements taken in October 1968. Speeds were not measured electronically.

The exit mean speed, taken in July upstream from the pavement widening, was a significant 10.9 mph slower than the thru mean speed (Figure 14). Both distributions were non-normal; the thru speeds had negative peakedness and the exit speeds were postively skewed.

The October speed data were obtained at two 300 ft zones; the first was centered 550 ft upstream from the pavement widening, the second zone was the first 300 ft of the pavement widening.

The exit mean speed was significantly slower than the thru mean speed at both zones and the thru vehicles were decelerating between the zones. The difference in mean speeds between the two zones, taken over the 700 ft distance between centers of zones, produces deceleration rates of 0.77 mph/sec for exit vehicles and 0.24 mph/sec for thru vehicles.

SUMMARY

As shown in the table below, the largest speed reduction found at parallel ramps was 7.7 mph (Enoscope data). With this value as the allowed difference in means (δ) for taper ramps, there was still a significant speed reduction at two of the three ramps:

<table>
<tr><th>RAMP</th><th>Thru Mean mph</th><th>Exit mph</th><th>Exit/ Thru</th><th>Δ mean mph</th><th>Δ mean-δ mph</th><th>Z</th><th>Conclusion</th></tr>
<tr><td>I-96 EB @ US-127</td><td>70.5</td><td>62.9</td><td>0.89</td><td>7.6</td><td colspan="3" rowspan="4">δ = Largest Δ mean
= 7.7 mph</td></tr>
<tr><td>US-127 SB @ M-36</td><td>62.3</td><td>55.6</td><td>0.89</td><td>6.7</td></tr>
<tr><td>I-75 NB @ Mannsiding</td><td>58.3</td><td>50.6</td><td>0.87</td><td>7.7</td></tr>
<tr><td>I-75 NB @ Dixie</td><td>53.6</td><td>56.6</td><td>0.89</td><td>7.0</td></tr>
<tr><td>I-496 EB @ I-96</td><td>66.3</td><td>57.3</td><td>0.86</td><td>9.0</td><td>1.3</td><td>1.22</td><td>Accept H_o</td></tr>
<tr><td>US-27 NB @ Blanchard</td><td>60.9</td><td>48.0</td><td>0.79</td><td>12.9</td><td>5.2</td><td>7.97</td><td>Reject H_o</td></tr>
<tr><td>I-96 WB @ Wixom</td><td>59.7</td><td>48.2</td><td>0.82</td><td>10.9</td><td>3.2</td><td>3.19</td><td>Reject H_o</td></tr>
</table>

The tests for normality produced no trends between parallel and exit ramps.

The test of the accuracy of the Enoscope method of speed measurement, compared to the electronic method, gave mixed results. Statistically significant differences were found at two of the four ramps measured electronically; in both the electronic speeds were higher. Because there was a three-year spread between speed timings, it is presumptuous to assign the difference entirely to the data collection methods.

Vehicle Placement

GENERAL

Two types of measurements were taken to determine the paths being driven at the seven ramps.

First, the deceleration lane was divided into zones; six zones for parallel ramps and three or four zones for taper ramps. The length of the zones varied; most were 100 ft long. As each vehicle exited the freeway, the zone in which its right front tire crossed onto the ramp was recorded. This data gives some measure of where the exit maneuver is taking place. Ideally all vehicles would exit in the same zone, near the beginning of the pavement widening. It was expected that at parallel ramps the distribution of the entry points would be scattered. This scattering is undesirable, as it is a measure of potential conflicts. It was also expected that at taper ramps this movement would take place later, at the gore, due to the small target presented to the driver.

Second, at three points along the ramp, the deceleration lane was marked transversely at 2-ft increments, measured from the edge of the thru lane. As each exit vehicle crossed a set of marks, the location of its right front tire, to the nearest 2 ft, was recorded. This data measures the path being driven. At taper ramps, this path is forced; it cannot vary much from being parallel to the edge of the ramp. From studies by others, it was expected that the path at parallel ramps would be a straight line, and would not follow the edge of the pavement.

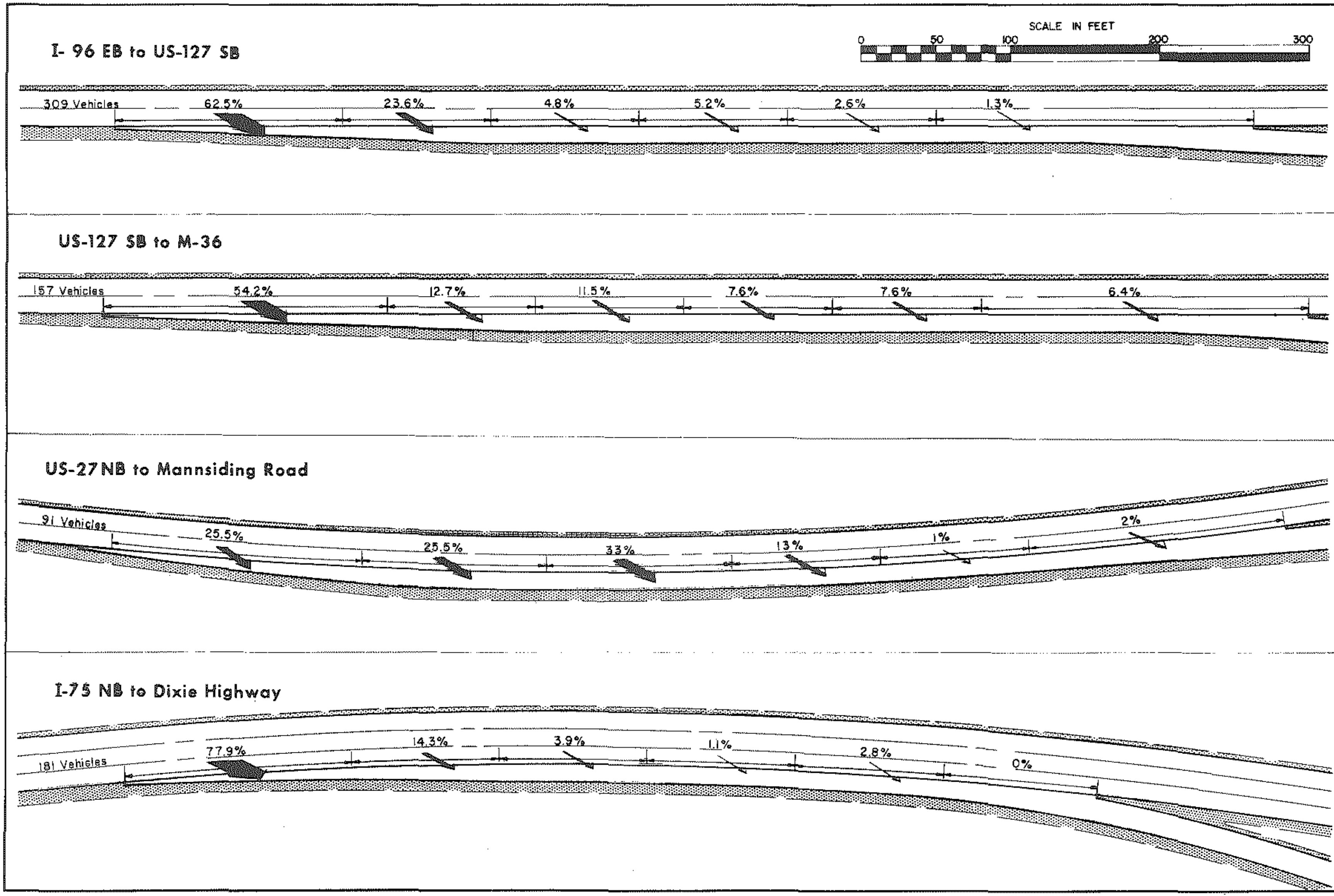

FIGURE 15. Distribution of Entry Zone Data, Parallel Ramps

When the data was taken, only those exit vehicles that crossed the lateral marks were recorded, those that entered the ramp after each set of marks were ignored. This method produced biased data in that it shifted the arithmetic mean to the right of its true value. To compensate for this, lateral placement of the missing vehicles was arbitrarily assigned in this manner: if the vehicle exited in the zone immediately following the set of marks, it was assigned the placement of <u>0</u>; if it exited in a later zone, it was assigned the placement of <u>-2</u>. The data obtained is summarized in Appendix 2.

<u>PARALLEL RAMPS</u>

The distribution of the entry zone data is given in the table below and in Figure 15.

		ZONE					
RAMP		1	2	3	4	5	6
I-96 WB to US-127 SB	Length (ft.)	190	100	100	100	100	210
	No. Vehicles	193	73	15	16	8	4
	Cum. Percent	62.5%	86.1%	90.9%	96.1%	98.7%	100%
US-127 SB to M-36	Length (ft.)	250	100	100	100	100	225
	No. Vehicles	85	20	18	12	12	10
	Cum. Percent	54.2%	66.9%	78.4%	86.0%	97.7%	100%
US-27 NB to Mannsiding	Length (ft.)	182	125	100	100	100	220
	No. Vehicles	23	23	30	12	1	2
	Cum. Percent	25.2%	50.4%	83.4%	96.6%	97.7%	100%
I-75 NB to Dixie	Length (ft.)	196	100	100	100	100	100
	No. Vehicles	141	26	7	2	5	0
	Cum. Percent	77.9%	92.2%	96.1%	97.2%	100%	

On the first two ramps listed, which were adjacent to thru lanes on tangent, the exit movement was concentrated on the pavement-widening (Zones 1 and 2), with the remaining portion (14 and 33 percent) being spread over the last four zones. The US-127/M-36

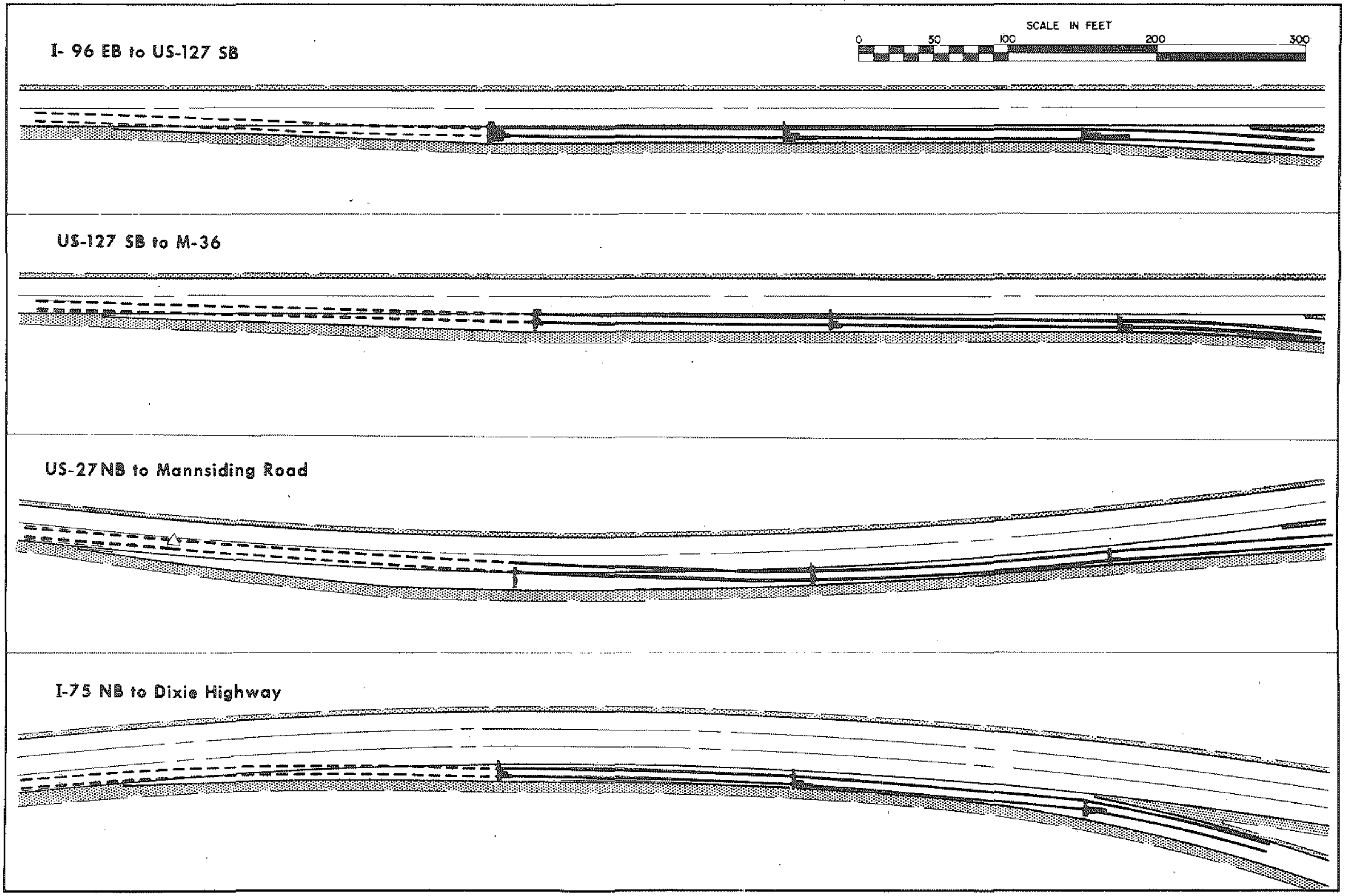

FIGURE 16. Distribution of Wheel Paths and Typical Paths, Parallel Ramps

ramp was the only one studied that had an appreciable number of late exit movements; 14 percent of the vehicles exited in the last 325 ft.

At the US-27/Mannsiding Road ramp, where the thru lanes curve $1^{\circ}30'$ left, the exit move was concentrated near the end of the pavement widening. This is the general area reached if the vehicle continues on tangent rather than following the thru lane curve.

At the I-75/Dixie Highway ramp, where the thru lanes curve $1^{\circ}30'$ right, the exit move was concentrated at the beginning of the pavement widening, indicating that exit vehicles followed the edge of pavement. With this alignment, the pavement widening appears as a smooth connection between the thru and exit curves.

The distribution of wheel paths and the assumed typical path for each parallel ramp are shown in Figure 16.

At the two ramps along tangent thru lanes, the paths did not follow the edge but, as expected, followed a long, flat taper. Between the first two sets of lateral marks, the taper was 95:1 for the first ramp and 120:1 for the second. If these tapers were projected upstream from the 6-ft point of the first set of marks (the modal value for both ramps), the path would run off the pavement. Thus the true path must follow some reverse curve, but there is no data for establishing that path.

At the US-27/Mannsiding Road ramp, the path followed a flat curve or stayed on tangent until it approached the edge of pavement, then it followed the edge.

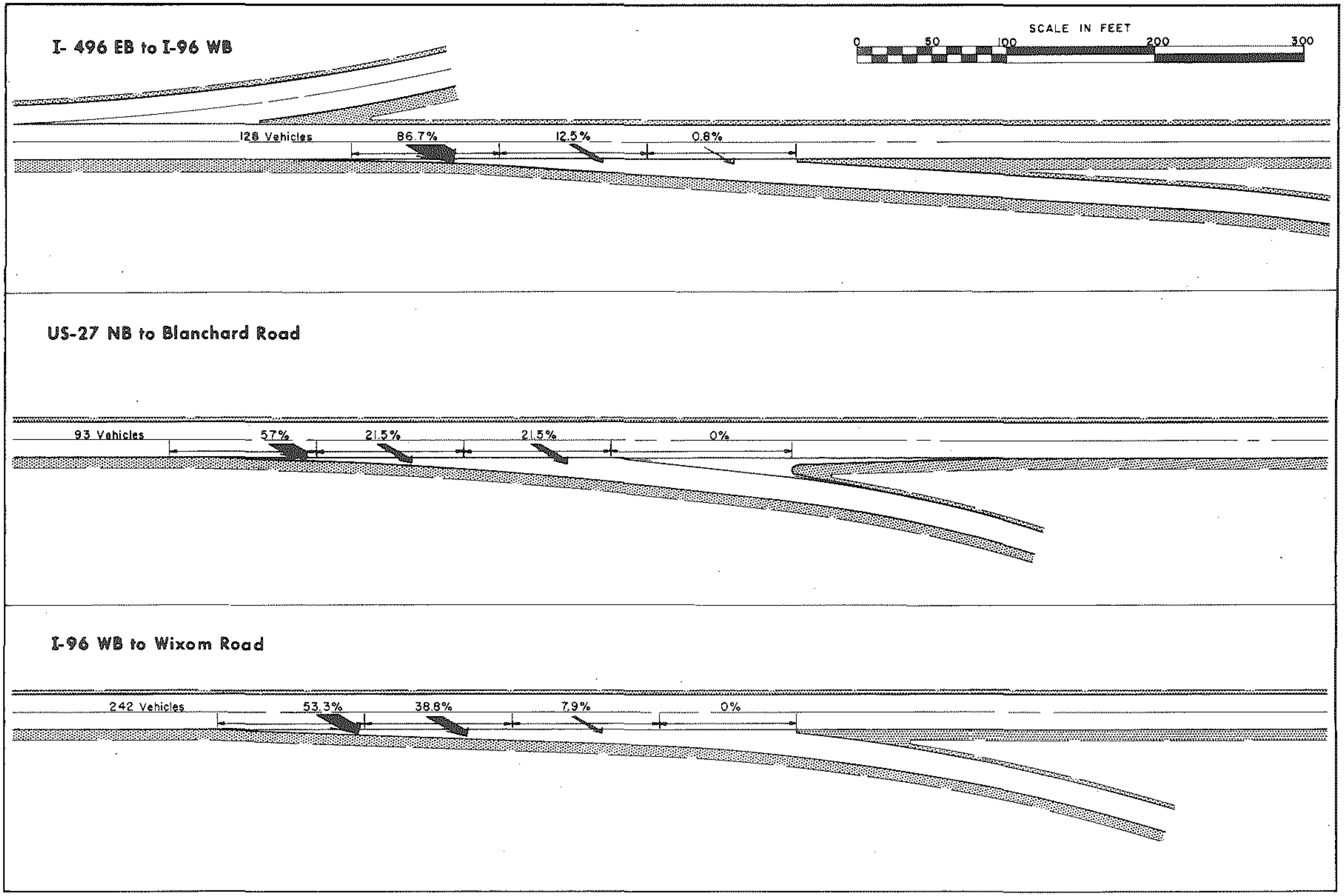

FIGURE 17. *Distribution of Entry Zone Data, Taper Ramps*

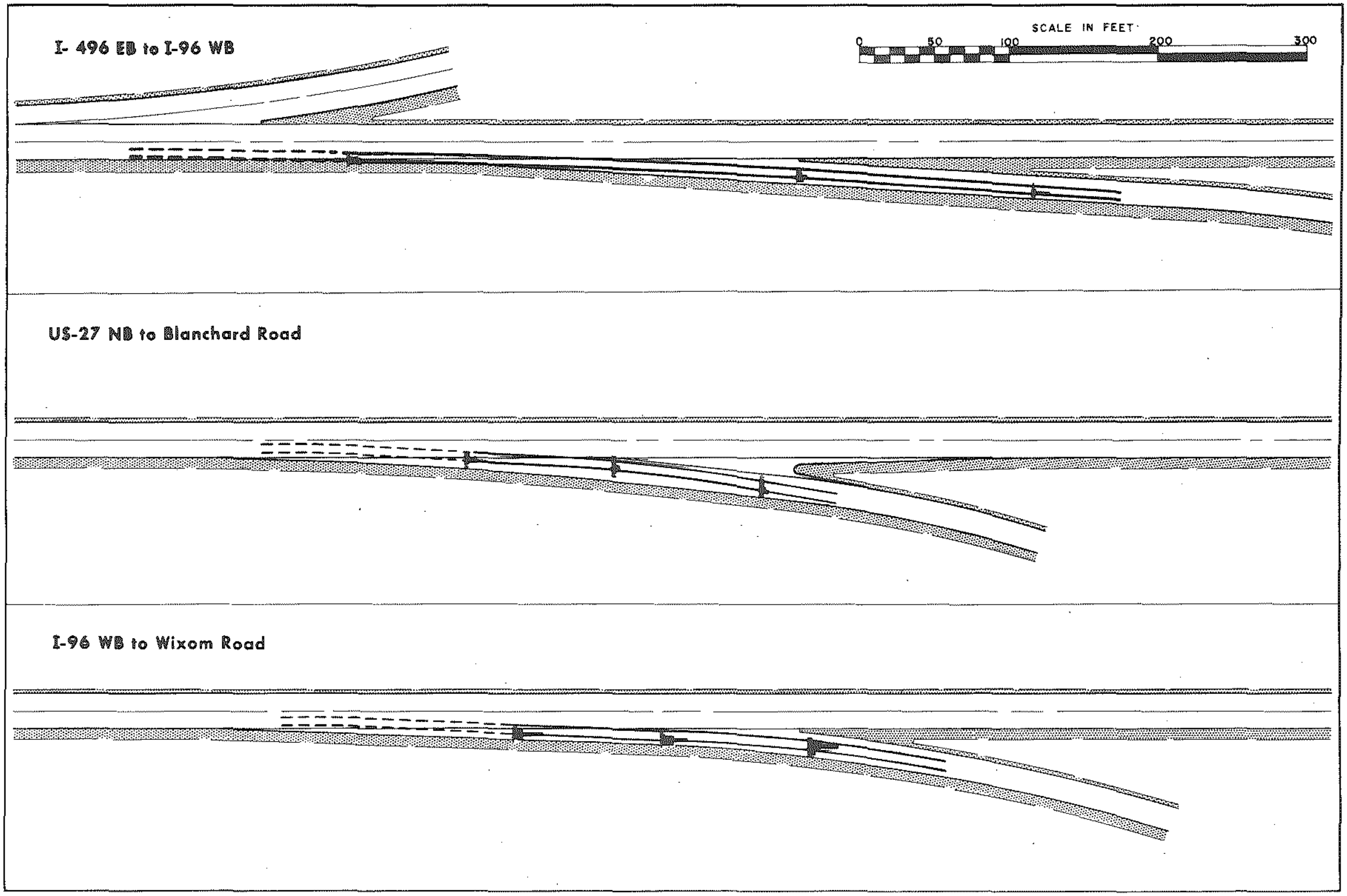

FIGURE 18. Distribution of Wheel Paths and Typical Paths, Taper Ramps

At the I-75/Dixie Highway ramp, the path followed the edge of pavement.

TAPER RAMPS

The distribution of the entry zone data is given in the table below and in Figure 17.

RAMP		ZONE 1	ZONE 2	ZONE 3	ZONE 4
I-496 EB to I-96 WB	Length (ft.)	100	100	100	Not Used
	No. Vehicles	111	16	1	
	Cum. Percent	86.7%	99.2%	100%	
US-27 NB to Blanchard	Length (ft.)	100	100	100	125
	No. Vehicles	53	20	20	0
	Cum. Percent	57.0%	78.5%	100%	
I-96 WB to Wixom	Length (ft.)	100	100	100	90
	No. Vehicles	129	94	19	0
	Cum. Percent	53.3%	92.1%	100%	

The anticipated incidences of late exit movements were not observed at these ramps. Virtually all vehicles exited with at least 100 ft of opening remaining. At each ramp, the majority of vehicles exited in the first 100 ft, even though the ramp was only about 4 ft wide at that point.

The distribution of wheel paths, and the assumed typical path, for each taper ramp is shown in Figure 18.

At two of the ramps, the paths closely followed the edge of the ramp pavement. At the US-27/Blanchard ramp, however, the path follows a curve of about 3 to 5 degrees.

At the I-496/I-96 ramp, the location of the third set of marks is uncertain.

Accident Experience

ACCIDENT TYPES

The five-year accident history, 1967 to 1971, of these seven ramps was reviewed to determine if there is any relationship between ramp configuration and types of accidents.

The accidents occurring on the thru lanes, from 1000ft before the start of the pavement widening, to 500 ft after the gore, were used in this analysis. The size of this zone should be sufficient to include all ramp-influenced accidents.

Of the accidents reported, a number were definitely not ramp-influenced (such as hitting an animal) and some others were recorded on the accident history printout but not found in the files. A brief description of each of the remaining accidents (in which the ramp configuration may have been a factor) follows. Bear in mind that the location given is the generally final location of the vehicle, not the point where the incident began.

PARALLEL RAMPS

I-96 EB to US-127 SB

Date and Time	Distance from Gore	Description
Fr 2-21-69 3 pm	1000 ft before	Vehicle slowing to exit hit in rear by drinking driver traveling at high speed.
Sa 11-14-70 10 pm	1000 ft before	Driver lost control on icy pavement, struck guardrail.
Su 5-24-70 11 am	50 ft before	Driver lost control on wet pavement while attempting to exit.
We 5-28-69 7 am	200 ft after	Driver lost control and rolled over while attempting to exit Driver stated he saw exit at last second.
Mo 6-9-69 9 pm	300 ft after	Driver lost control while passing another vehicle.

US-127 SB to M-36

Date and Time	Distance from Gore	Description
Su 12-1-68 6 pm	670 ft before	Driver lost control on icy pavement, struck median pier.

US-27 NB to Mannsiding Road

Date and Time	Distance from Gore	Description
Fr 1-29-71 11 pm	1300 ft before	Driver blinded by blowing snow; ran off roadway and rolled over.
Su 8-8-71 3 am	40 ft after	Drinking driver attempted to exit abruptly on passenger's advice; lost control, ran off roadway, and rolled over.
Fr 8-13-71 3 am	40 ft after	Driver started to exit, changed her mind, and returned to thru lanes. Trailer jackknifed and vehicle rolled over.

I-75 NB to Dixie Highway

Date and Time	Distance from Gore	Description
Su 8-29-71 3 am	700 ft before	Driver lost control when wind blew camper off edge of pavement.
Su 6-20-71 2 pm	500 ft before	Driver lost control when other vehicle, apparently exiting from inside lane, crossed lane in front of him.
Sa 2-10-68 3 pm	350 ft before	Driver lost control when wind blew vehicle off pavement.
Mo 11-29-71 2 pm	150 ft before	Driver lost control, went in ditch and rolled over.
Sa 3-25-67 Midnight	at gore	Vehicle on ramp was struck in rear.
Sa 4-19-69 10 pm	at gore	Driver lost control and rolled over on ramp.
We 5-14-69 6 pm	at gore	Driver lost control when load in truck shifted.
Fr 6-13-69 6 am	at gore	Driver lost control after tire blew out on ramp.
Fr 3-13-70 Midnight	at gore	Driver lost control on ice, hit other vehicle.
Mo 6-10-68 4 pm	350 ft after	Driver apparently fell asleep, struck other vehicle in rear.
Th 12-3-70 2 pm	350 ft after	Driver lost control when other vehicle pulled in front of him on ramp.
Sa 9-12-70 4 am	350 ft after	Driver lost control while passing when other vehicle swerved in front of him.
We 10-6-71 3 pm	350 ft after	Driver lost control on slippery pavement; tires were in poor condition.

TAPER RAMPS

I-496 EB to I-96 WB

Date and Time	Distance from Gore	Description
Fr 12-11-70 5 pm	500 ft before	Vehicle skidded on wet pavement, struck other vehicle in side.
Th 3-4-71 5 pm	500 ft before	Vehicle sideswiped by other vehicle while passing.
Fr 12-3-71 Midnight	500 ft before	Drinking driver struck other vehicle in rear.
We 2-10-71 Midnight	100 ft before	Driver lost control and hit guardrail while attempting to avoid other vehicle, which had stopped for hitchhiker.
Fr 9-10-71 3 pm	180 ft after	Driver lost control on wet pavement.

US-27 NB to Blanchard Road

Date and Time	Distance from Gore	Description
Th 10-21-71 5 pm	500 ft before	Vehicle struck in rear on thru lanes (pavement wet).
Fr 2-16-68 4 pm	50 ft before	Drinking pedestrian on pavement struck by vehicle.
Th 2-11-71 1 pm	at gore	Driver lost control on wet pavement while exiting.

I-96 WB to Wixom Road

Date and Time	Distance from Gore	Description
Fr 9-5-69 5 pm	1200 ft before	Driver lost control and left roadway while attempting to change lanes.
Fr 5-30-69 1 pm	400 ft before	Rear-end accident on median shoulder. Both drivers entered shoulder to evade other vehicles stopped on thru lanes.
Tu 6-4-68 3 pm	100 ft before	Vehicle struck in rear on thru lanes.
Mo 10-27-69 6 am	at gore	Vehicle struck in rear on ramp.
Su 11-30-69 Noon	at gore	Driver lost control while exiting, due to wind.
We 11-18-70 8 pm	at gore	Vehicle struck in rear on ramp.
We 7-29-70 8 pm	300 ft after	Driver lost control on wet pavement.
Tu 3-30-71 10 pm	400 ft after	Pedestrian on pavement struck by vehicle.

A breakdown of these accidents, by type and by time of day, follows:

TYPE OF ACCIDENT		4 PARALLEL RAMPS Number	Day/Night	% of Acc.	3 TAPER RAMPS Number	Day/Night	% of Acc
Rear End or Side Swipe		4	2/2	18%	8	5/3	50%
Loss Control	Erratic Driving	6	3/3		1	0/1	
	Weather Pavement or Vehicle	9	4/5		4	4/0	
	No cause given	3	1/2		1	1/0	
	Sub Totals	18	8/10	82%	6	5/1	38%
Pedestrian		0			2	1/1	12%
TOTALS		22	10/12		16	11/5	

The percentage breakdown for the taper ramps closely agrees with those found in another study (3): 57 percent rear-end or sideswipe, same direction; 34 percent single vehicle; 9 percent other. That study, which looked at 2100 off-ramp accidents (both urban and rural) occurring on the pavement widening and added lane, did not differentiate between parallel and taper ramps. A study (6) of taper ramps found a greater proportion of single-vehicle accidents, 51 percent; two vehicles, 43 percent; three or more vehicles, 6 percent. The comparable percentages for freeways were 28 percent, 53 percent, 19 percent. The author concludes that, because the single-vehicle percentage is considerably higher at ramps, "off-ramp geometry is difficult to maneuver". Michigan does not have a similar breakdown of accidents by type for freeways.

ACCIDENT RATES

The relative accident rates for the seven ramps were computed, based on (1) all accidents occurring within the influence zone and (2) the average one-way thru vehicle ADTs, determined from

1970 and 1971 ADTs. Because these are one-way accidents and flows, the computed rates below are not directly compatible with the two-way accident rates:

RAMP	Influence Zone length (ft.)	One-Way ADT	Number of Accidents	Acc/ 100MVM	Acc/ MV
I-96/US-127 (P)	2250	10,750	11	130	0.56
US-127/M-36 (P)	2250	5,200	5	120	0.53
US-27/Mannsiding Rd. (P)	2280	5,450	5	120	0.50
I-75/Dixie Hwy (P)	2175	7,950	18	300	1.24
I-496/I-96 (T)	1870	10,100	7	110	0.38
US-27/Blanchard Rd. (T)	1775	5,400	7	210	0.71
I-96/Wixom Rd. (T)	1970	17,200	16	140	0.51

The rates in accidents per million vehicles are biased toward the tapers, since the influence zones for the parallel ramps are about 20 percent longer than those for the tapers. Thus the parallel ramp data includes more of the non-ramp influenced accidents that occurred within the influence zone by chance.

DISCUSSION

Half of the accidents at the taper ramps were rear-end or sideswipe accidents, and half of those occurred at the high volume I-96/Wixom Road ramp, which had a large differential between exit and thru mean speeds.

One-third of the loss-of-control accidents at the parallel ramps resulted from an erratic movement by the vehicle involved or another vehicle. Several of these were late exits, even though the driver had a span of more than 20 sec (at 70 mph) to make his move. "Lost control" is a generalization that may mask important causative factors. The degree of influence of the ramp configuration on these accidents cannot be accurately measured.

The parallel ramps had a higher proportion of accidents at night than did the taper ramps. This can be traced to the loss of control accidents blamed on weather or slippery pavement; five of the six such accidents at the parallel ramps, occurred at night, while all of the four at taper ramps occurred during daylight.

The average accident rate computed for the parallel ramps was slightly, but not significantly, higher than the average rate for the taper ramps.

Both types of ramps operated satisfactorily. The two trends that developed, rear-end accidents at tapers and erratic driving at parallels, were expected. Neither type was frequent enough to be considered a problem.

Other Studies

Five other studies have also attempted to determine the best operation of some aspect of off-ramp design. These are all real-world experiments in which the subjects did not know they were being tested. Oregon and Texas attempted to compare taper and parallel designs; Toronto studied the operation of parallels only; Indiana studied tapers only; and California studied the length of ramp tangent on tapers.

OREGON

Historically, the first attempt to compare the operating characteristics of the two types of ramps was Conklin's 1959 (1) study of two different off-ramps, one of each type. Both ramps leave a 70 mph rural freeway at approximately level grades.

The taper ramp deceleration lane at a diamond interchange was 527 ft long at a 4°10' deflection. An edge line was painted for a distance of 247 ft, leaving a 280 ft opening. Just beyond the gore the ramp curved 4°12' right.

The parallel ramp deceleration lane in advance of the structure at a partial-cloverleaf interchange, was 470 ft long. Slightly upstream of the gore the ramp curves 41.5° (138-ft radius) right over a central angle of 73°57'. At the end of the curve the ramp becomes half of a two-way ramp.

Conklin measured speed by radar, lateral placement by photo and sand pattern. He found the following 85th percentile speeds:

	Taper	Parallel
Thru Passenger Cars	62.5	63.0
Exit Vehicles		
Start of Widening	49.0	45.5
Middle	47.5	37.0
Gore	46.0	23.5

On lateral placement, he found that at the midpoint of taper ramp deceleration lane virtually all vehicles were off the freeway lane, while at the midpoint of the parallel ramp deceleration lane more than half of the vehicles were still partly or completely in the freeway thru lane. The path at the taper ramp followed the paint lines very closely. On the parallel ramp, only 20 percent of the vehicles left the thru lanes in the first 200 ft, as the ramp is designed. Another 47 percent made a direct connection to the deceleration lane in the middle 140 ft. The other 33 percent made a delayed entrance into the lane in the last 130 ft, apparently to make a more direct approach to the curve. Thru vehicles often moved into the median lane to avoid conflict with the exiting traffic.

From his study, Conklin concludes that the taper ramp was "definitely superior" (1, p. 16) to the parallel ramp, both in speed of operation and the placement of vehicles.

INDIANA

The speed and lateral placement of vehicles on the various designs of acceleration and deceleration lanes used in Indiana were studied to correlate these designs with traffic behavior to determine which types provide the most efficient and safest operation (5). Speed and lateral placement data were obtained from motion pictures; radar was used to measure spot speeds of thru traffic.

Five rural off-ramp designs were studied:

1) 1200 ft taper (3 locations)
2) 250 ft taper, 50 ft parallel, curve (3 locations)
3) Curve from thru edge of pavement (3 locations)
4) 400 ft taper (1 location)
5) 200 ft taper, curve before gore (3 locations)

The authors projected a plot of ramp speed to determine where the ramp speed equaled the thru speeds. They found that at all but one ramp, the exit traffic began to decelerate on the thru lanes more than 1000 ft ahead of the ramp. When the thru lanes curved left, as opposed to being straight or curving right, the drivers used less of the ramp and entered the deceleration lane later and at lower speeds. The authors theorize that drivers "desired to follow a natural straight path of exit with a minimum of maneuvering" (5, p. 51). They felt that the 1200 ft taper ramp design operated the best. This design is actually a double taper, the off-ramp deflects at $4^{\circ}00'$ (13:1 taper) 344 ft ahead of the gore. The second taper begins 500 feet ahead of the first, deflects at $1^{\circ}30'$ (38:1) and intersects the first taper at the gore. The authors also found that ramps with almost identical geometrics had different patterns of vehicle behavior. They concluded that a large number of drivers do not know how to use the ramps properly, and the driving public must be better informed.

TORONTO

To assess the adequacy of, and driver behavior on, existing off-ramps, six rural ramps on the Highway 401 beltline around Toronto were studied (2) by a motion picture technique similar to that used in the Indiana study. The headways, speeds, lateral placements, and deceleration rates were measured from the film.

All of the ramps were parallel ramps with length of added lanes ranging from 320 to 440 ft (in one case 1015 ft). The lanes were 11 ft wide. Ahead of the gore the right edge of ramp pavement curved right, widening the ramp to 21 ft (in one case to 30 ft) at the gore.

The point of entrance to the ramp was defined as the "location where the right front wheel of the vehicle crossed the imaginary line separating the deceleration lane from the outside lane".

Except for the location with 1015 ft lane, between 88.2 and 97.3 percent of the vehicles entered the lane before the pavement widening reached full width. There was undesired two-lane operation at diamond off-ramps, but the drivers stayed in a single file at loop off-ramps.

The vehicles did not move to the right immediately, as the ramp is designed, but rather moved directly toward the inside of the ramp curve, similar to a taper ramp path.

In the speed measurement portion of the study, the pace of exiting vehicles included between 51 and 85 percent of the vehicles; the speed ranges between exits varied from 25 to 40 mph, with a top speed of 67.5 mph at one ramp. The vehicles tended to decelerate until they reach the ramp curve, then accelerate slightly through the curve, then decelerate again. The 85 percentile speed through the curve at four ramps was 0 to 5 mph above the design speed, indicating that the drivers are willing to accept side friction factors higher than those recommended by AASHO. At the end of the pavement widening, the speed of the ramp vehicles was about 7 mph below the speed of the thru vehicles.

The deceleration rates measured were in all but one case well below the AASHO rates for "in gear" deceleration, indicating that the deceleration lanes provide a considerable margin of safety for speed changes.

The authors conclude that the deceleration lanes are not being used as intended. Vehicles were not clearing the thru lanes before decelerating and seemed to be aiming toward the ramp curve. Therefore, "A direct-taper type of exit would seem to be indicated since it would appear to fit the vehicle paths better than the taper plus added parallel deceleration lane" (2, p. 72). Also, "The exit with the least amount of curvature would appear to satisfy motorists best" (2, p. 73).

TEXAS

A similar motion-picture technique was used on ten ramps, both on-ramps and off-ramps, in Texas (7).

Although this study concentrates on entrance ramps, the authors point out that at a parallel ramp 5 percent of the vehicles used the ramp as designed, 35 percent followed a taper-type path to the ramp curve, and the remaining 60 percent made a delayed move into the ramp, perhaps to increase their turning radius. The authors felt that "This lack of usage (of the added lane) is related to the exit ramp driver's desire to follow a natural and easy path. Use of parallel deceleration lane requires a reverse curve movement, which represents additional maneuvering to the driver" (7, p. 57). They also state that careful consideration must be given to the deceleration distance and the sight distance beyond the gore, so that the drivers can judge conditions and adjust their speed as needed.

CALIFORNIA

California (4) studied the length of the tangent portion of taper ramps to "determine whether the length of the ramp tangent approaching the ramp curve has any effect on ramp speed, and if it does, what the optimum length of such a tangent is" (4, p. 17).

The speeds at eight existing taper ramps in urban areas were taken with road tubes placed at various spots along the ramp. The only ramp data used was that obtained when the average thru speed was 45 to 50 mph.

The authors found that the speed of an exiting vehicle is the function of three factors: the speed of the thru vehicles in the outside lane, the length of the tangent available for deceleration, and the degree of ramp curvature. They also found that exiting vehicles begin to decelerate 135 to 220 ft ahead of the beginning of the ramp. If the length of tangent available is greater than the length needed to decelerate, the vehicles maintain a steady speed for the first part of the ramp and decelerate in the last part. However, the authors found that where alignment is not a control "it appears that there is a psychological maximum of about 46 mph" (4, p. 21) on the ramps.

The authors also feel that drivers do not differentiate between small radii curves, and many drivers enter a 130 ft radius at a speed safe for only a 250 ft radius. They conclude their study with a table of deceleration distance, measured between the 12-ft point and the start of the ramp curve. This distance is a function of the curve radii, varying from 450 ft for a 400-ft radius to 750 ft for a full stop. For radii larger than 1000 ft, no deceleration is needed, but the alignment must cue the driver that he is approaching an off-ramp.

In the lateral placement portion of the study, the authors found that gore striping, when used, tended to guide the vehicles using the ramp.

DISCUSSION

The Oregon study is actually comparing a normal taper ramp with a very substandard parallel ramp. The author excuses his choice of ramps with the statement "An inherent feature of a parallel lane type off-ramp is a relatively sharp horizontal alignment on the direct taper type off-ramp is normally much less severe" (1, pp. 14-15). It is true that most loop ramps are introduced by a parallel ramp; however, parallel ramps can also be used to introduce diamond ramps. The author is comparing not only the ramps up to the gore, as his report indicates, but also the curvature beyond the gore.

The 1200 ft taper ramp used in Indiana presents the most convincing argument of all the ramps studied. It allows the drivers to take the path that the other studies found that the drivers naturally followed on parallel ramps, while also giving the drivers a good reference line in the edge of pavement. This study gives no evidence for comparing parallel ramps to taper ramps.

The Toronto study provided more evidence that the path designed into a parallel ramp is not followed. The drivers were choosing an extremely long taper that provided them with more than enough deceleration distance.

The conclusions concerning off-ramps reached in the Texas study appear to be the authors' own opinions, based on their own experience and readings of other reports and are not substantiated by their data.

Speeds might have been reduced somewhat in the California study, since the speeds were measured by tubes across the pavement. The authors state that the deflection of the ramp should be about 5° (11:1), to give the drivers a cue as to which is the thru lanes and which is the ramp. This angle is much sharper than the drivers choose for their free-path turns on parallel ramps.

Appendix 1
Statistical Analysis of Speed Data

COMPARISON OF MEANS

The hypotheses on page 10 were tested with the z-statistic for comparison of the arithmetic means (averages) of the two sample populations being considered, at the 95 percent confidence level. If the z-statistic falls within the critical range, it is assumed that the two samples come from the same population, and the null hypothesis is accepted. Otherwise it is rejected. The equation of the z-statistic for comparison of means is:

$$Z = \frac{\bar{X}_1 - \bar{X}_2 - \delta}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

Where $\bar{x}_i$ = mean of sample population i.

δ = allowed difference in means for the null hypothesis (a constant).

σ_i^2 = variance of population i. When $n_i > 30$, s_i^2 can be used to to approximate σ_i^2

n_i = size of sample population i.

Z = z – statistic. At the 95 percent confidence level the critical region is $-1.96 \leq Z \leq +1.96$.

PARALLEL RAMPS
I-96 EB to US-127SB

H_o:	$\bar{x}_1$ mph	$\bar{x}_2$ mph	$\Delta\bar{x}$ mph	Z	Conclusion
Enoscope: Exit = Thru	62.9	70.5	–7.6	–10.8	Reject H_o
Electronic Exit, Gore = Upstream	57.2	62.4	–5.2	–5.4	Reject H_o

On three different days in October 1968, speeds were timed at three 200 ft zones within the general area of the terminal:

Date	ZONE 1 Centered 600 ft. Upstream from Terminal	ZONE 2 First 200 ft. of Added Lane	ZONE 3 Last 200 ft. before Ramp PC
Monday Oct. 7	Thru: $\bar{x}$ = 60.7 mph (140 Veh.) No exit data	Thru: $\bar{x}$ = 68.5 mph (128 Veh.) Exit: $\bar{x}$ = 59.3 mph (11 Veh) $\Delta \bar{x}$ = 9.2 mph	Thru: $\bar{x}$ = 60.4 mph (130 Veh.) Exit: $\bar{x}$ = 48.9 mph (17 Veh.) $\Delta \bar{x}$ = 11.5 mph
Tuesday Oct. 15	Thru: $\bar{x}$ = 62.5 mph (148 Veh.) Exit: $\bar{x}$ = 60.6 mph (14 Veh.) $\Delta \bar{x}$ = 1.9 mph	Thru: $\bar{x}$ = 59.7 mph (112 Veh.) Exit: $\bar{x}$ = 54.4 mph (18 Veh) $\Delta \bar{x}$ = 5.3 mph	Thru: $\bar{x}$ = 64.9 mph (126 Veh.) Exit: $\bar{x}$ = 55.1 mph (120 Veh.) $\Delta \bar{x}$ = 9.8 mph
Wednesday Oct. 23	Thru: $\bar{x}$ = 60.3 mph (48 Veh.) Exit: $\bar{x}$ = 56.3 mph (70 Veh.) $\Delta \bar{x}$ = 4.0 mph	No Data	No Data

The data cannot be tested for statistical significance. The accuracy of the data is questioned; note that on the first day the mean thru speed in zone 2 was recorded as being 8 mph higher than at the other two zones, which is an unlikely pattern.

US-127 SB to M-36

H_o:	$\bar{x}_1$ mph	$\bar{x}_2$ mph	$\Delta \bar{x}$ mph	Z	Conclusion
Enoscope: Exit = Thru	55.6	63.3	–15.4	–15.4	Reject H_o
Electronic, Upstream: Exit = Thru	64.4	67.9	–3.5	–3.8	Reject H_o
Thru: Electronic = Enoscope	67.9	63.3	4.6	6.0	Reject H_o
Electronic Thru: Gore = Upstream	66.8	67.9	–1.1	–1.2	Accept H_o
Electronic Exit: Gore = Upstream	50.5	64.4	–13.9	–16.5	Reject H_o

US-27 NB to Mannsiding Road

H_o:	$\bar{x}_1$ mph	$\bar{x}_2$ mph	$\Delta \bar{x}$ mph	Z	Conclusion
Enoscope: Exit = Thru	50.6	58.3	–7.7	–10.6	Reject H_o

I-75 NB to Dixie Highway

H_o:	$\bar{x}_1$ mph	$\bar{x}_2$ mph	$\Delta \bar{x}$ mph	Z	Conclusion
Enoscope: Exit = Thru	56.6	63.6	–7.0	–7.6	Reject H_o
Electronic, Upstream: Exit = Thru	62.0	64.1	–2.1	–1.8	Accept H_o
Thru: Electronic = Enoscope	64.1	63.6	0.5	0.6	Accept H_o
Electronic Thru: Gore = Upstream	60.0	64.1	–4.1	–3.6	Reject H_o
Electronic Exit: Gore = Upstream	48.3	62.0	–13.7	–11.9	Reject H_o

TAPER RAMPS
I-496 EB to I-96 WB

H_o:	$\bar{x}_1$ mph	$\bar{x}_2$ mph	$\Delta \bar{x}$ mph	Z	Conclusion
Enoscope: Exit = Thru	57.3	66.3	–9.0	–8.5	Reject H_o
Electronic, Upstream: Exit = Thru	62.6	66.5	–3.9	–4.5	Reject H_o
Thru: Electronic = Enoscope	66.5	66.3	0.2	0.2	Accept H_o
Electronic Thru: Gore = Upstream	64.1	66.5	–2.4	–2.4	Reject H_o
Electronic Exit: Gore = Upstream	56.8	62.6	–5.8	–8.5	Reject H_o

US-27 NB to Blanchard Road

H_o:	$\bar{x}_1$ mph	$\bar{x}_2$ mph	$\Delta\bar{x}$ mph	Z	Conclusion
Enoscope: Exit = Thru	48.0	60.9	−12.9	−19.8	Reject H_o
Electronic, Upstream Day 1: Exit = Thru	59.3	66.6	− 7.3	− 5.0	Reject H_o
Thru: Electronic, Day 1 = Enoscope	66.6	60.9	5.7	5.7	Reject H_o
Electronic Exit Upstream: Day 1 = Day 2	59.3	54.2	5.1	3.0	Reject H_o
Electronic Thru, Day 1: Gore = Upstream	67.1	66.6	0.5	0.4	Accept H_o
Electronic Exit, Day 1: Gore = Upstream	48.4	59.3	−10.9	− 7.7	Reject H_o

I-96 WB to Wixom Road

H_o:	$\bar{x}_1$ mph	$\bar{x}_2$ mph	$\Delta\bar{x}$ mph	Z	Conclusion
Enoscope: Exit = Thru	48.2	59.1	−10.9	−10.8	Reject H_o
Oct Upstream: Exit = Thru	57.0	59.8	− 2.8	− 3.5	Reject H_o
Oct Taper: Exit = Thru	50.1	57.8	− 7.7	− 9.1	Reject H_o
Oct Thru: Taper = Upstream	57.8	59.8	− 2.0	− 2.2	Reject H_o
Oct Exit: Taper = Upstream	50.1	57.0	− 6.9	− 9.0	Reject H_o

TESTS FOR NORMALITY

Ramp		Thru Skewness	Thru Peakedness	Exit Skewness	Exit Peakedness
I96/US127 (P)		-0.196	0.442	0.279	0.147
US127/M36 (P)	Enoscope	0.025	0.084	0.238	0.185
	Electronic	0.115	-0.472	0.346	0.470
US27/Mannsiding (P)		0.643(N)	3.477(N)	0.873(N)	1.997(?)
I75/Dixie (P)	Enoscope	0.085	0.203	0.165	-0.804(N)
	Electronic	0.126	-0.197	0.085	-0.210
I496/I96 (T)	Enoscope	0.291	2.236(N)	-0.044	-0.970(N)
	Electronic	0.206	-0.240	-0.122	-0.280
US27/Blanchard (T)	Enoscope	0.097	0.108	-0.396(N)	-0.196
	Electronic	-0.293	-0.477	0.387	-0.287
I96/Wixom (T)		0.001	-0.944(N)	1.152(N)	1.129(?)

(N) = Non-normal at 95% Confidence Level
(?) = Sample size too small to test for normality

Appendix 2
Distribution of Wheel Paths

PARALLEL RAMPS

I-96WB to US-127SB

Lateral Mean (ft.)	-2	0	2	4	6	8	10
First Lateral	(28)*	(22)	22	75	98	70	1
Second Lateral	(3)	(8)	7	29	70	149	49
Third Lateral			1	8	83	213	10

US-127SB to M-36

Lateral Mean (ft.)	-2	0	2	4	6	8	10	12
First Lateral	(34)	(18)	12	30	46	17		
Second Lateral	(10)	(12)	15	13	40	58	7	
Third Lateral			3	7	14	62	63	2

US-27 NB to Mannsiding Road

Lateral Mean (ft.)	-2	0	2	4	6	8	10	12
First Lateral	(15)	(30)	11	7	17	9	1	
Second Lateral	(3)	(12)	9	10	18	25	11	3
Third Lateral				3	12	12	54	10

I-75 NB to Dixie Highway

Lateral Mean (ft.)	-2	0	2	4	6	8	10	12	14
First Lateral	(7)	(7)	14	25	46	63	18	0	1
Second Lateral		(5)	0	5	13	52	95	9	2
Third Lateral				1	6	102	52	20	

TAPER RAMPS

I-496EB to I-96WB

Lateral Mean (ft.)	-4	-2	0	2	4	6	8	10	12	14
First Lateral	6	56	54	2	1					
Second Lateral						6	29	54	33	1
Third Lateral						2	4	17	77	21

US-27 NB to Blanchard

Lateral Mean (ft.)	-2	0	2	4	6	8	10	12	14	16
First Lateral	(20)	(20)	53							
Second Lateral		(20)	1	7	36	28				
Third Lateral				1	0	16	25	37	14	

I-96WB to Wixom

Lateral Mean (ft.)	0	2	4	6	8	10	12
First Lateral	(19)	44	132	44	3		
Second Lateral			8	56	116	55	4
Third Lateral				62	138	9	31

*Numbers in parentheses are assigned values.

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