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October 11, 1971

H-2-63

MEMORANDUM TO: J. R. Harbison
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report (Interim); "Operational Characteristics of Lane Drops;" KYHPR-70-63; HPR-1 (7), Part II.

The route junctions of I 75 and I 64, northeast of Lexington, and of I 75 and I 71 in northern Kentucky presented geometric design problems which demanded decisions based on insights and foresights beyond established design criteria. If the number of outgoing lanes equals or exceeds the number of incoming lanes at a hub, there are no attendant lane drops. This is a mere mathematical assertion. A split or bifurcation of lanes becomes a lane-drop situation only by paradoxical definition -- that is to say, the sum of outgoing lanes from a cross-type intersection can never be twice the number of incoming lanes without confounding and compounding the multiplicity of lanes at a successive interchange or intersection. This simply means that if a duplicity of lanes is carried through the junction the extra lanes must ramp off at the next interchange or else be carried forward.

Inasmuch as no specific theory or guiding criterion has been advanced heretofore regarding route junctions and lane splits, I submit the following hypotheses:

1. So-called "driving" and "passing" lanes in a rural area simply became destination lanes when approaching Y- or T-type junctions. Lane-assignment signing should begin far enough in advance to permit traffic to weave into the proper lanes. The distance allowed may be proportional to traffic volume and the possibility of needed storage. Extra destination lanes provided in the inbound leg or branch cause no difficulties -- the difficulties arise in the outbound branch -- but then only if a lane is dropped.
2. A lane drop in an outbound direction may indicate that more lanes were carried through the intersection than were needed. Either a single-lane, "off-to-on" ramp would suffice or else all needed ramp lanes should be carried forward to a succeeding destination split preceded by lane-assignment signing.
3. A lane drop, per se, is an entrapment -- justified only by planned, future construction to extend the dropped lane. Signing to indicate which lane ends and which gives information about merging into another lane only alerts the driver to a bad situation ahead.
4. If for some other reason not yet apparent a lane must be terminated, it seems psychologically more tolerable to accomplish it in conjunction with re-confirmation or re-allocation of lane assignment and destination signing.

Indeed, the foregoing statements attempt to disclaim the existence of lane drops as an admissible recourse for design. It is significant to note that the Highway Capacity Manual makes no mention of lane drops, per se. It mentions ramp terminals, acceleration lanes, auxiliary lanes, climbing lanes, and passing bays, etc., but not lane drops. The only reference or allusion thereto concerns a hypothetical case where a two-lane ramp merges with two through lanes; there it is casually mentioned that perhaps a lane might

be dropped; but, even so, an attendant note cautions that the situation described has not been researched sufficiently (the AASHO, **A Policy on Geometric Design for Rural Highways**, 1965, p. 380, portrays this situation as an admissible design).

The hypothetical case is practically identical to the situation at the juncture of I 71 and I 75 in northern Kentucky. There, a two-lane, northbound ramp was built; only one of the lanes was carried ahead. Indeed, complications were foreseen; but the ramp was marked for two lanes; and, in a manner of speaking, no lane assignments were made on inbound I 71.

Privileged overviews and afterthoughts, such as offered here, are not intended in any way to demean Mr. Cornette's report. Whereas a "lane termination" (a true lane drop) may have been considered a necessary design recourse, I merely advance the question now: Is it really necessary? Finally, I am inclined to believe that the future direction of the study should be more toward signing for lane assignment, destination, and lane re-allocations -- if necessary.

We have another current study, (KYHPR-70-61) signing for lane closures, etc. during maintenance operations on high-speeds roads. A similarity between a lane closure and a lane termination seems unavoidable.

Respectfully submitted,

Jas. H. Havens
Director of Research

JHH:sg

Enclosures

cc's: Research Committee

Research Report
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OPERATIONAL CHARACTERISTICS OF LANE DROPS

INTERIM REPORT
KYHPR-70-63, HPR-1(7), PART II

by

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DEPARTMENT OF HIGHWAYS
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in cooperation with the
U.S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

October 1971

INTRODUCTION

A lane drop is defined as a location on a highway where the number of lanes provided for through traffic decreases. For purposes of this study, the broad category of lane drops has been further subdivided into three specific classes: lane exits, lane splits, and lane terminations. These subdivisions are illustrated schematically in Figure 1. A *lane exit* refers to a location where the number of through lanes decreases at an interchange on a multilane roadway. A designation of *lane split* denotes a major fork of a multilane highway where the level of traffic service provided at the terminus of either prong is approximately equal. Thus, the lane split does not have the same exit connotation which is associated with a lane exit. The third category is the *lane termination* which occurs when a lane is simply terminated. A lane termination leaves a driver with no choice, he must merge into the other available lane(s). A lane termination also has no connection with an exiting situation.

Associated with the first two categories, lane exits and lane splits, is the concept of driver decision. The driver who is confident of his destination and the proper path thereto generally presents no conflict with the flow of traffic. The problem arises largely from those drivers who are inattentive, intoxicated, uncertain of how to reach their destination, and(or) have improper driving habits. It is these individuals, as shown in Figure 2, who conflict with the traffic stream. Therefore, it is imperative that the driver be made aware of the necessity for an early decision regarding his course of travel. The driver who makes an errant decision and abides by it is not as dangerous as the one who makes a delayed decision and attempts, often too late, to correct it. Thus, the driver who perchance takes the wrong branch is likely to resort to desperation tactics and back up or undertake some other maneuver that is illegal or contrary to safety.

The purpose of the study reported herein was to evaluate the operational characteristics of lane-drop situations as they are influenced by various fore-warning, decision-demanding messages. More specifically, the immediate purpose was to discover types of signs, pavement markings, and lane delineations which minimize or reduce erratic movements at existing lane drops. It was also hoped that an optimum design criteria for lane-drop situations might be determined.

Several standard and untried traffic control devices were selected for experimentation. A pilot study at a geographically advantageous location containing three lane splits was conducted. The results of this pilot study are the subject of this report.

HISTORY

The AASHO Special Traffic Safety Committee best described the undesirability of lane drops *(1)* when it said *"lane drops should normally be avoided altogether by original design or later rebuilding, but where this is not practicable, fully adequate advance warning of lane drop situations must always be provided to give drivers sufficient time to maneuver safely into the proper lanes."* Others *(2, 3, 4, 5, 6)* are also critical of the potential hazards (vehicle entrapment, driver indecision, etc.) inherent in most lane-drop situations.

Although recognized by many as an undesirable highway feature, the topic of lane drops is a substantially unresearched area. One lane-drop study is currently being undertaken by the System Development Corporation of California *(7)*. It is essentially a study of traffic operations at several sites utilizing sequential aerial photographs to compute vehicle trajectories. At the present time, insufficient data have been accumulated to reach conclusions. Another lane-drop study by the California Division of Highways *(8)* used accumulations of accident data to evaluate lane-drop situations. Four conclusions of this study were: 1) Accident experience was alike for all three-to-two (three lanes transitioning to two lanes) lane termination types, 2) "Single lane exit without taper" had the lowest overall accident rate of any category, 3) For all two-to-one lane termination types, the situation wherein the shoulder (right hand) lane continued through the lane drop had an accident rate only half as great as those having the higher speed median lane continued through, 4) Traffic volume analysis indicated only a slight trend toward an accident rate that increased as the volume of traffic increased.

No completely satisfactory manner of signing lane-drop situations has yet emerged *(1)*. In an attempt to determine improved methods of signing and pavement delineation at lane-drop locations, and thereby improve traffic flow and lessen driver confusion, a thorough study of the technical literature was made. Two studies concluded, insofar as nighttime conditions are concerned, that a carefully planned and executed delineator treatment is highly accepted (by drivers), easily followed, and generally helpful *(9, 10)*. The **Manual on Uniform Traffic Control Devices** *(11)* also attests to the merits of a proper reflective treatment.

One study of lane-termination signing done in California tested drivers' reactions to various signs shown on film or slides. The study indicated that a rectangular four-foot by eight-foot sign bearing the message **LANE ENDS - MERGE LEFT** was significantly better understood than four other signs or sign combinations

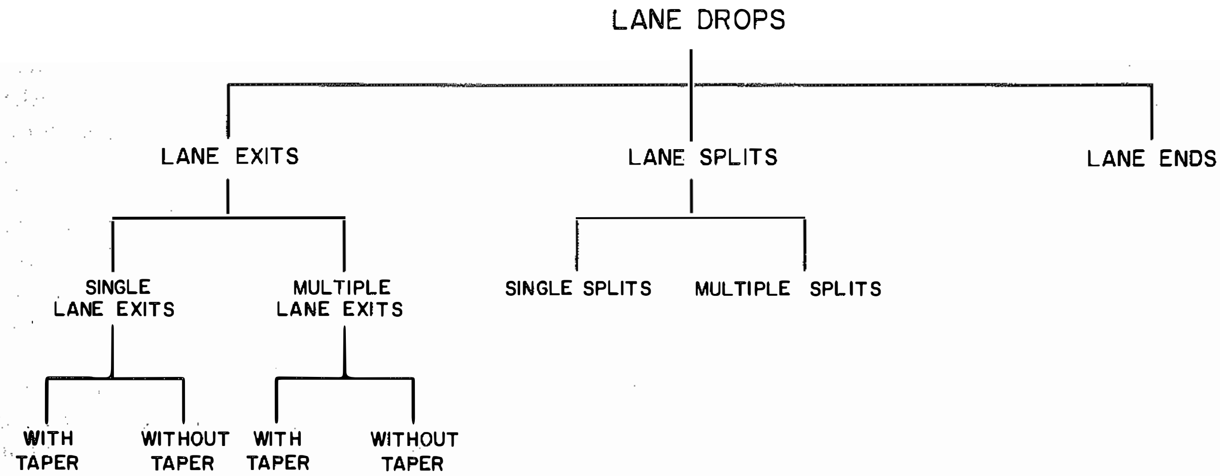

FIGURE 1. LANE-DROP TYPES

used in the study *(12)*. Another study done in Michigan indicated some reduction in driver confusion with a "color coding" system, consisting of edgemarking, delineation and signing *(13)*. A study conducted by the Michigan Department of State Highways *(14)* disclosed that certain significant reductions in lane changes and erratic movements (70 and 78 percent decreases, respectively) can be attributed to the use of a black-on-yellow **EXIT ONLY** panel and that the continued use of this panel for lane-drop situations is advisable.

From two studies *(15, 16)* of the effectiveness of pavement edge markings, it was concluded that edge markings reduced both the number of fatalities and the number of accidents at intersections during both daytime and nighttime conditions. To explain these findings, it was suggested that edge markings encourage drivers to look farther ahead and thus become more aware of vehicle movements ahead. Other studies describe the beneficial psychological effects on driver confidence provided by edge marking *(17, 18)*. Another study *(19)* related the usefulness of pavement markings in reducing hazardous lane changes where roadways diverge.

Two recent studies *(20, 21)* indicate that it is possible to objectively measure the accident potential of a given area using the traffic conflict criterion, i.e., to evaluate the area dynamically, not waiting for an accident history to evolve. These studies also indicated that the traffic conflict technique provides a relatively quick test, in the form of "before and after" conflict counts, for determining the effectiveness of traffic engineering changes. Furthermore, the traffic conflict technique, according to these same studies, resulted in accurate measures of accident potentials, provided an understanding of the basic causes of accidents and should ultimately lead to a reduction of traffic accidents.

PROCEDURE

A pilot study was conducted at the I 64 - I 75 interchange in Fayette County. This interchange, shown in Figure 3, is a standard three-leg interchange of directional design with a three-level structure *(3)*. At the time this interchange was designed, projected traffic volumes and existing safety design standards did not indicate an immediate need for constructing two-lane ramps on the legs. Therefore, this interchange provided three lane splits (Figures 4 through 6) which could be investigated as a pilot effort. The single-lane aspects of the legs provided an excellent example of the necessary decisions drivers must make.

Conflict studies, spot-speed studies, and volume counts were conducted at each of the three approaches. Conflict studies were originally of 12-hour duration: nine hours of daytime conditions and three hours of nighttime conditions. The day and the hours were selected to provide a wide range of traffic volume and lighting conditions. Thus, at the I 75 northbound gore area, a study was conducted from noon to midnight on Sunday, the highest traffic-volume day in this direction. At the I 75 southbound gore area, the study was made from noon to midnight on Friday. The I 64 westbound lane-split study was conducted on Tuesday because no exceptionally heavy traffic-volume day existed there. Furthermore, the extremely light volume of traffic at

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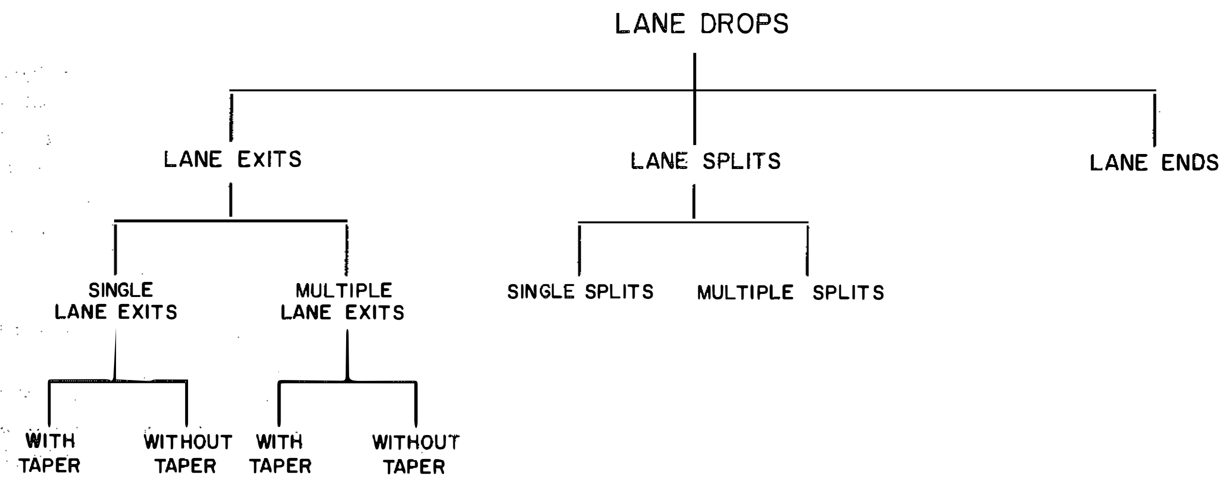

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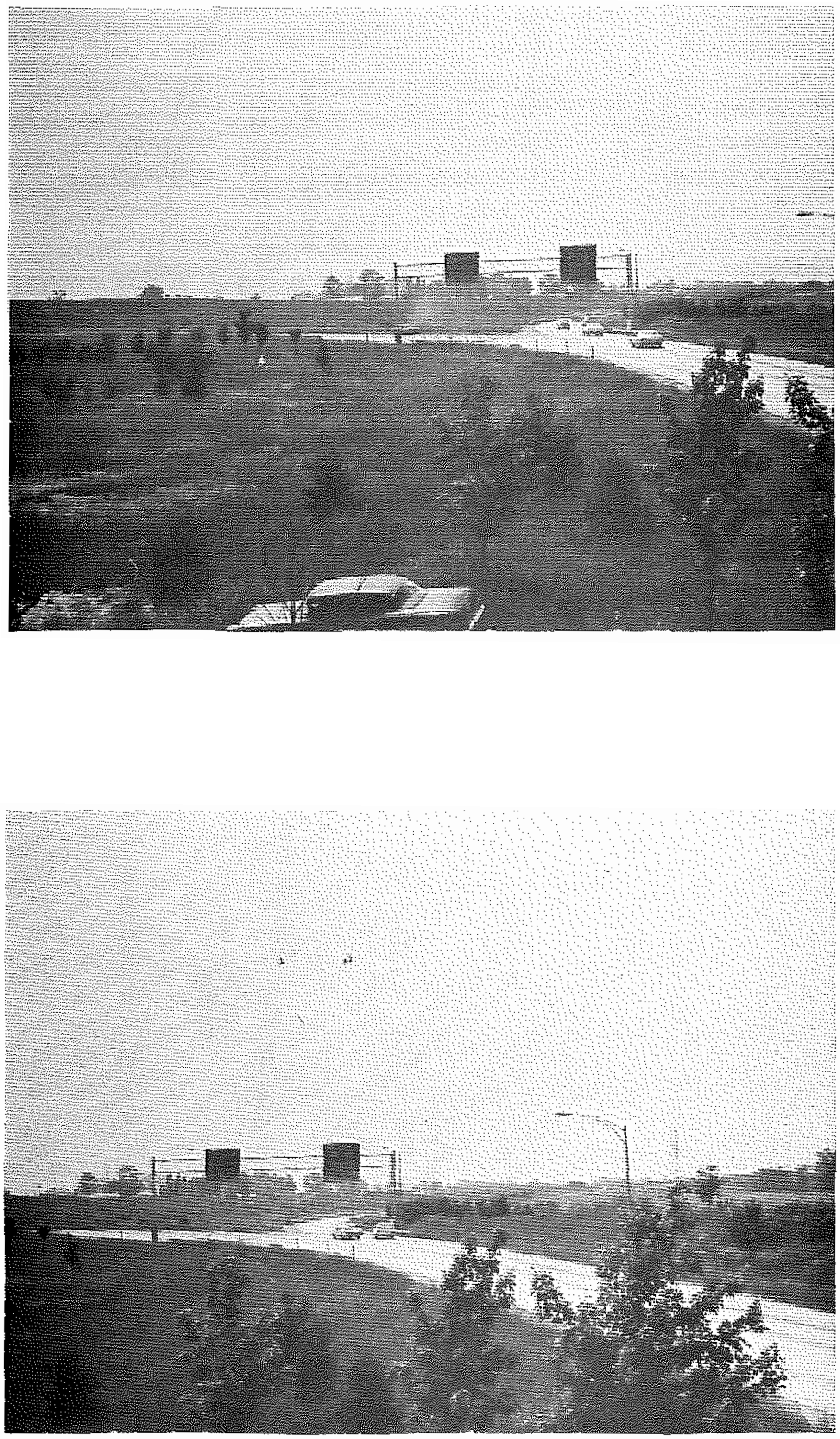


FIGURE 2. TYPICAL EXAMPLES OF DRIVER CONFUSION AT LANE-DROP LOCATIONS

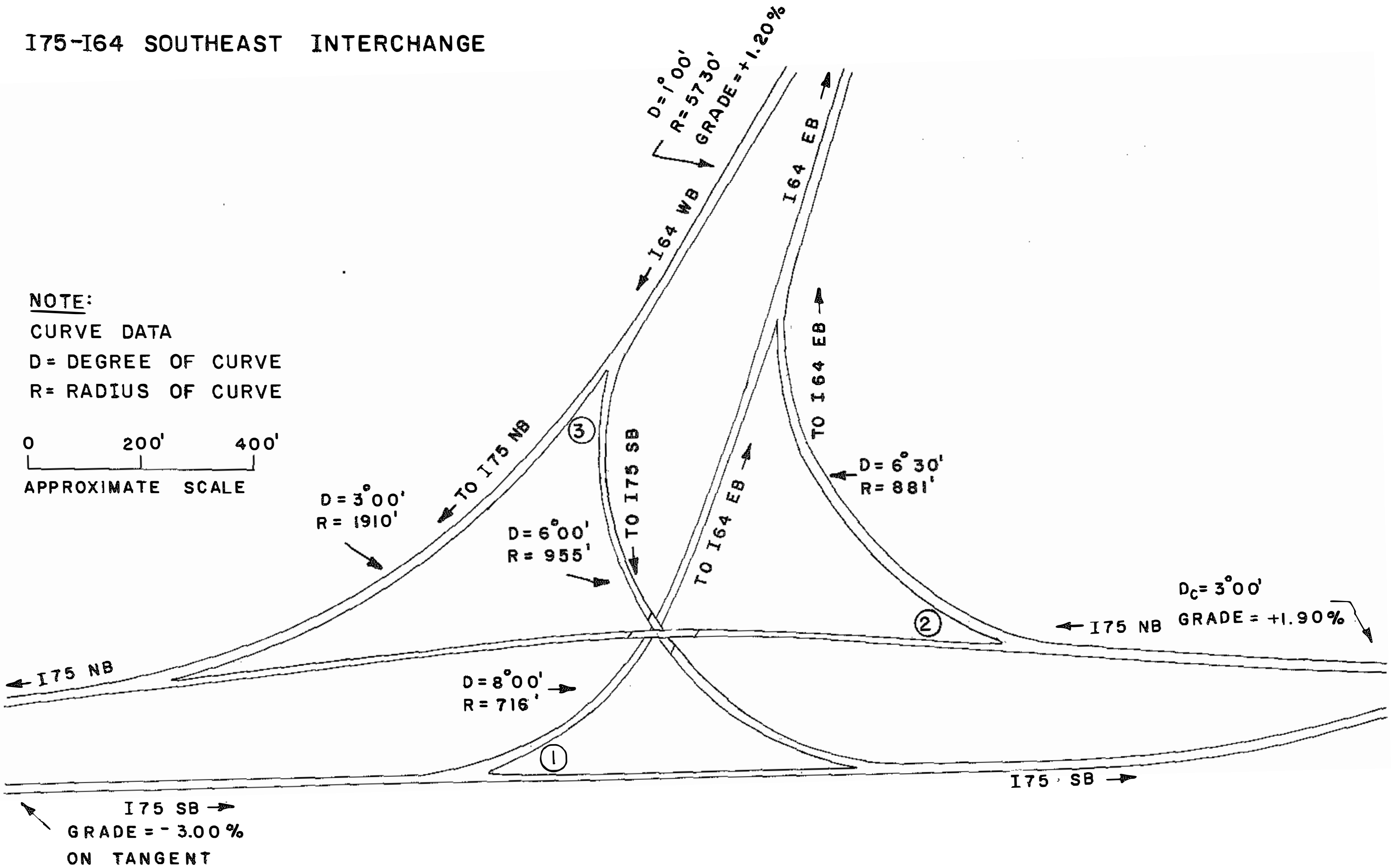


FIGURE 3. ROADWAY GEOMETRICS OF THE PILOT STUDY SITES

FIGURE 4. I 75 SOUTHBOUND - I 64 EASTBOUND LANE SPLIT

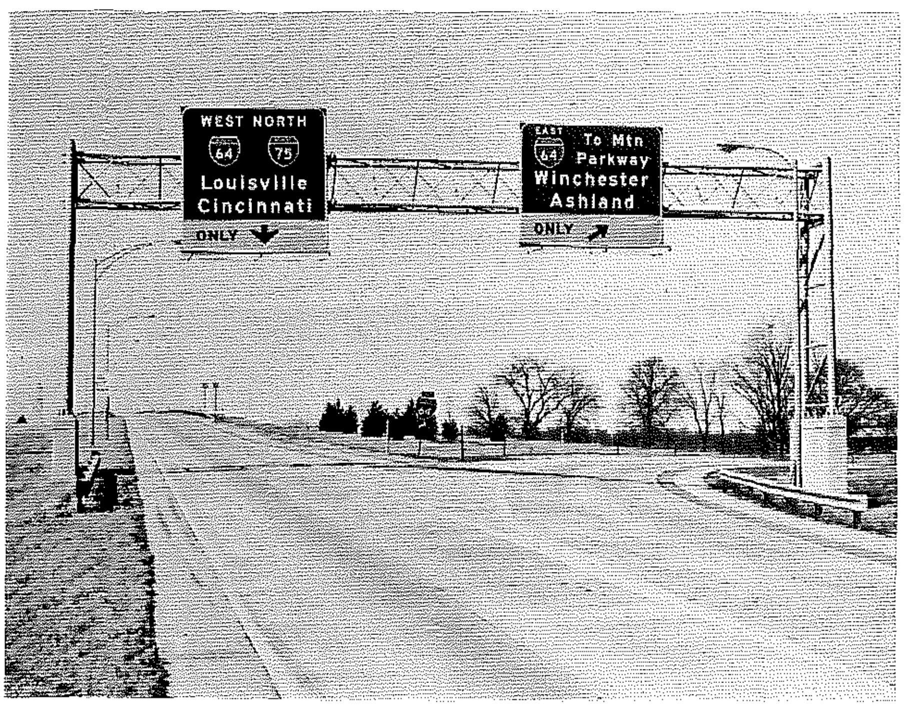


FIGURE 5. I 75 NORTHBOUND - I 64 EASTBOUND LANE SPLIT

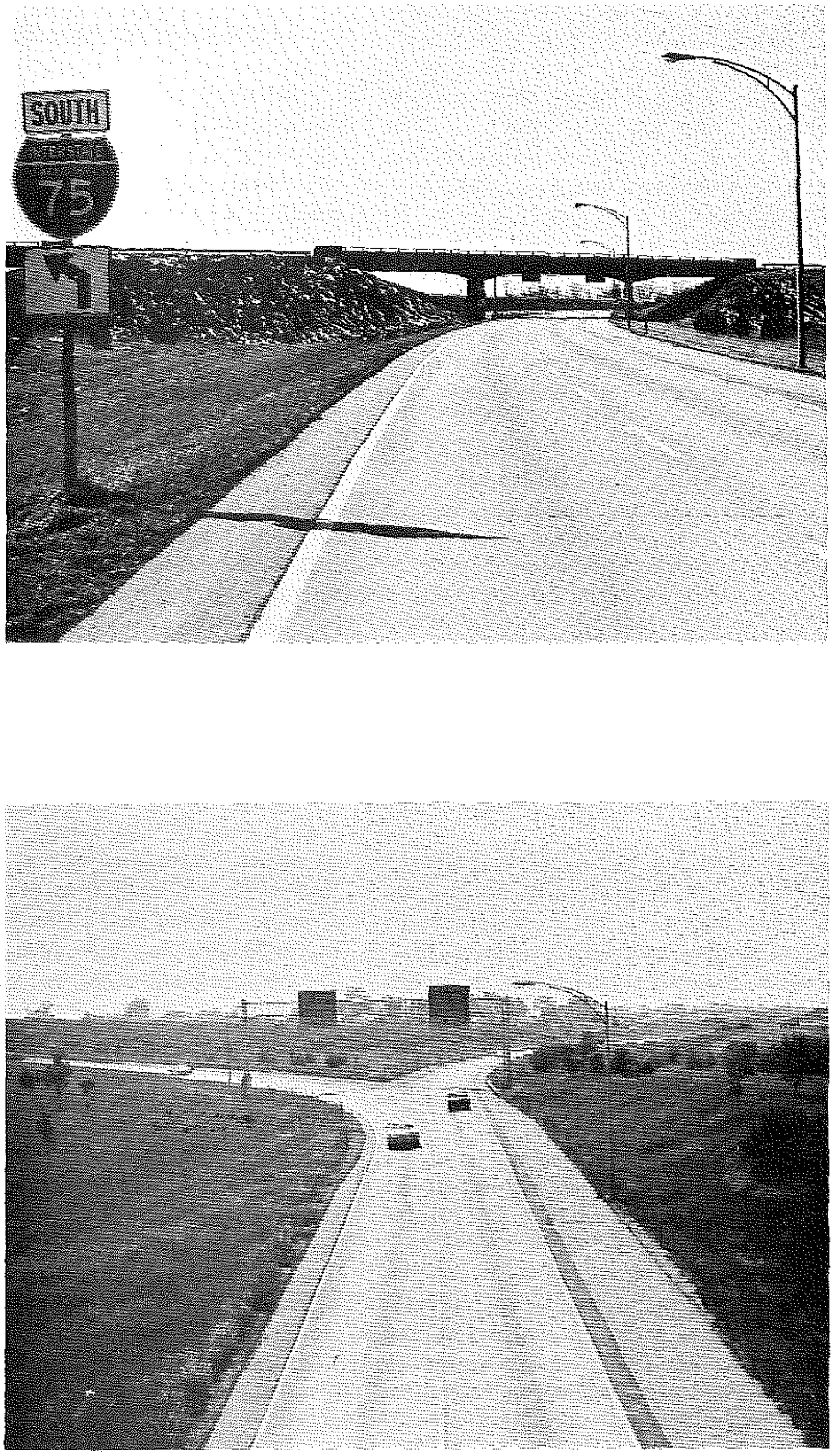


FIGURE 6. I 64 WESTBOUND LANE SPLIT

this site under nighttime conditions made it unnecessary to extend the study much beyond sunset. This schedule was abandoned because a preliminary linear multiple regression analysis failed to show any correlation between traffic volumes and erratic movement rates. The nine hours under daytime conditions were reduced; six hours were determined to be sufficient duration to obtain statistically significant results.

Traffic conflicts (erratic movements) were grouped into six categories. These six categories -- cut across gore area, crowded weave, stopped or slowed drastically, swerved, backed at gore, and multiple error -- are defined in APPENDIX A. Brakelight actuations were also recorded.

Spot-speed studies were also made at each of the three interchange approaches. These studies were made for both automobiles (minimum sample of 100) and trucks (minimum sample of 50) at four points in each two-lane approach: 1) the shoulder lane at the gore, 2) the median lane at the gore, 3) the shoulder lane a distance of 500 feet back from the gore, and 4) the median lane a distance of 500 feet back from the gore. Volume counts were made of both the median and shoulder lanes at each approach.

Only one set of observations was made at each site for each traffic-control system devised. Each set consisted of volume counts, conflicts, and spot-speed movements.

An inventory of existing traffic control devices was made. The pavement at all three lane-split locations was marked with a four-inch wide, white center line and equally wide, white edge lines. All six ramps of the I 64 - I 75 interchange, as well as approximately 750 feet of roadway leading to each split, were delineated by double amber reflectors spaced at 100- to 200-foot intervals. At greater distances from the split, white reflectors were used for delineation. The signing of the three bifurcations is shown schematically in Figures 7 through 9.

The intuitive but fundamental requirement for improving traffic flow is a fully-adequate advance warning of lane-drop situations. Advance warning is necessary in order to give drivers sufficient time for decision making and subsequent maneuvering into the proper traffic lane. Three devices used separately and in various combinations, are: 1) five-inch wide, yellow edge lining and two-foot wide, yellow gore striping, 2) double amber reflectors with decreased spacing approaching the gore area, and 3) black-on-yellow **EXIT ONLY** signs. Edge lining and reflector placement are illustrated schematically in Figure 10. A black-on-yellow **EXIT ONLY** panel is shown in Figure 5.

FINDINGS OF THE PILOT STUDIES

Although it has been argued that driving performance is largely dependent on inherent personal characteristics *(22)*, the dominance of geometrics over operational characteristics is undeniable. Exit ramps should provide good sight relationships so that there is a clear indication to the driver that he is approaching a point of departure from the through lanes *(23, 24)*. Basically, the approaches to the three lane splits provided adequate sight distances. Relatively speaking, however, it can be seen from Figure 3 that the I 75 southbound approach, with a downhill grade of 3.00 percent, offered a better sight relationship than either the I 75 northbound approach (grade of +1.90 percent) or the I 64 westbound approach (grade of +1.20 percent). Furthermore, the I 75 northbound lane split was located near the crest of a vertical curve and the I 64 westbound lane split was partially obscured by an overpass structure located approximately 400 feet from the gore. Another positive characteristic of the I 75 southbound lane-split approach was its location on a tangent, whereas the I 75 northbound and I 64 westbound approaches both have a small amount, 3°00' and 1°00' respectively, of horizontal curvature. The geometrics of the lane-split ramps, the one-lane sections of roadway in this instance, also affected the operational characteristics of these locations. Although it has been stated that a high-speed exit is best provided by a flat angle of 4° or 5° *(23)*, none of the lane-split ramps of the tri-level interchange conforms. The ramps of the I 75 southbound lane split were both downgrade, with the shoulder (right hand) lane continuing through the bifurcation on tangent and the median (left hand) lane becoming a ramp with 8°00' horizontal curvature and a radius of only 716 feet. The ramps of the I 75 northbound lane split were both upgrade, with the median-lane ramp on tangent and the shoulder-lane ramp having 6°30' horizontal curvature and an 881-foot radius. The ramps of the I 64 westbound lane split were also both upgrade, with the median-lane ramp of 6°00' horizontal curve and a 955-foot radius and the shoulder-lane ramp a 3°00' horizontal curve with a 1910-foot radius.

Operational characteristics of the lane splits at the I 64 - I 75 interchange may also be negatively affected by its non-conformance to certain rules of operational flexibility and expressway connection-system design. According to principles of operational flexibility, any change in the basic (minimum) number of lanes, in this case four, should occur at an intersection with another freeway; and then only if the exit volume is sufficiently

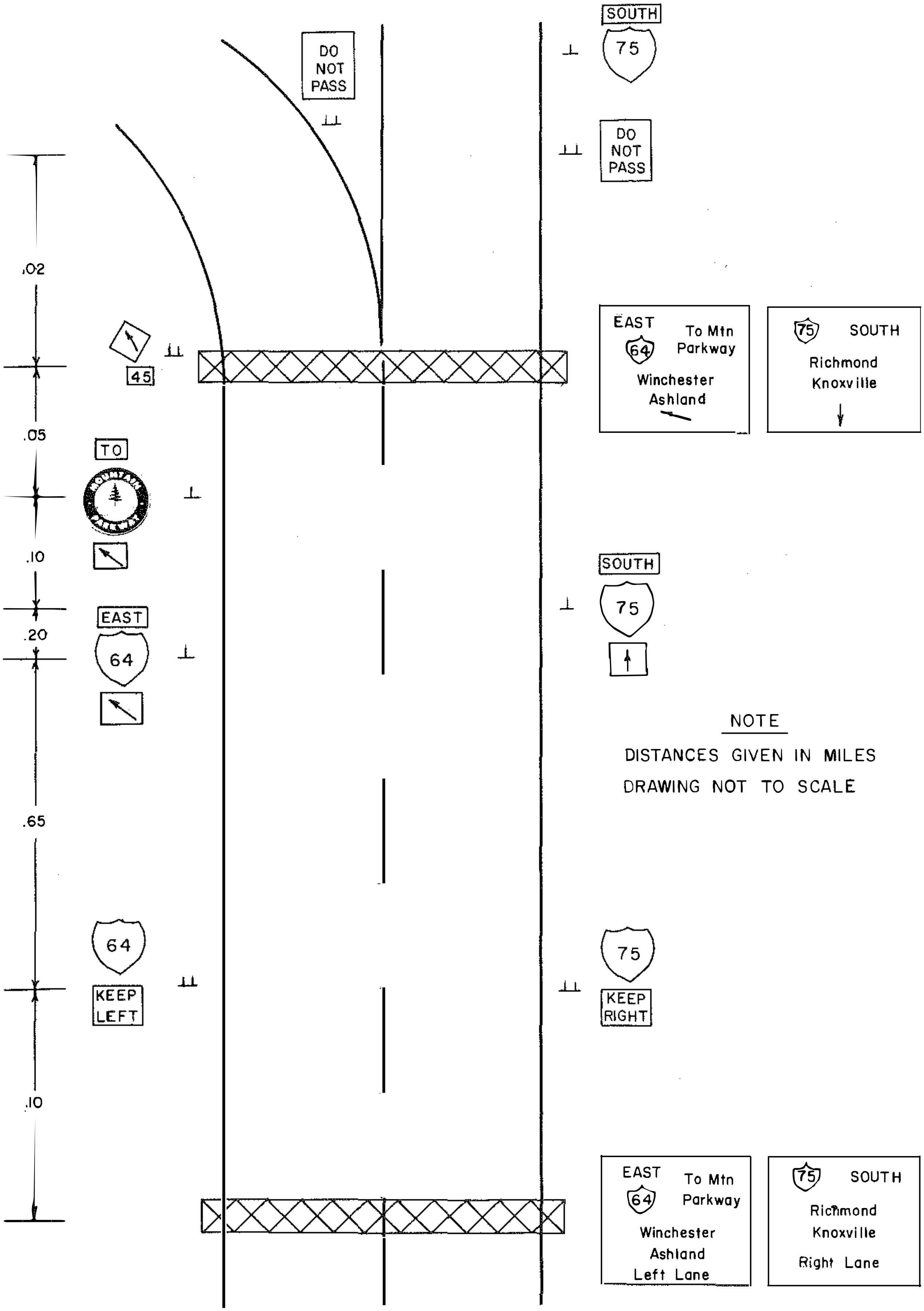


FIGURE 7. SIGNING SCHEMATIC OF THE I 75 SOUTHBOUND - I 64 EASTBOUND LANE SPLIT

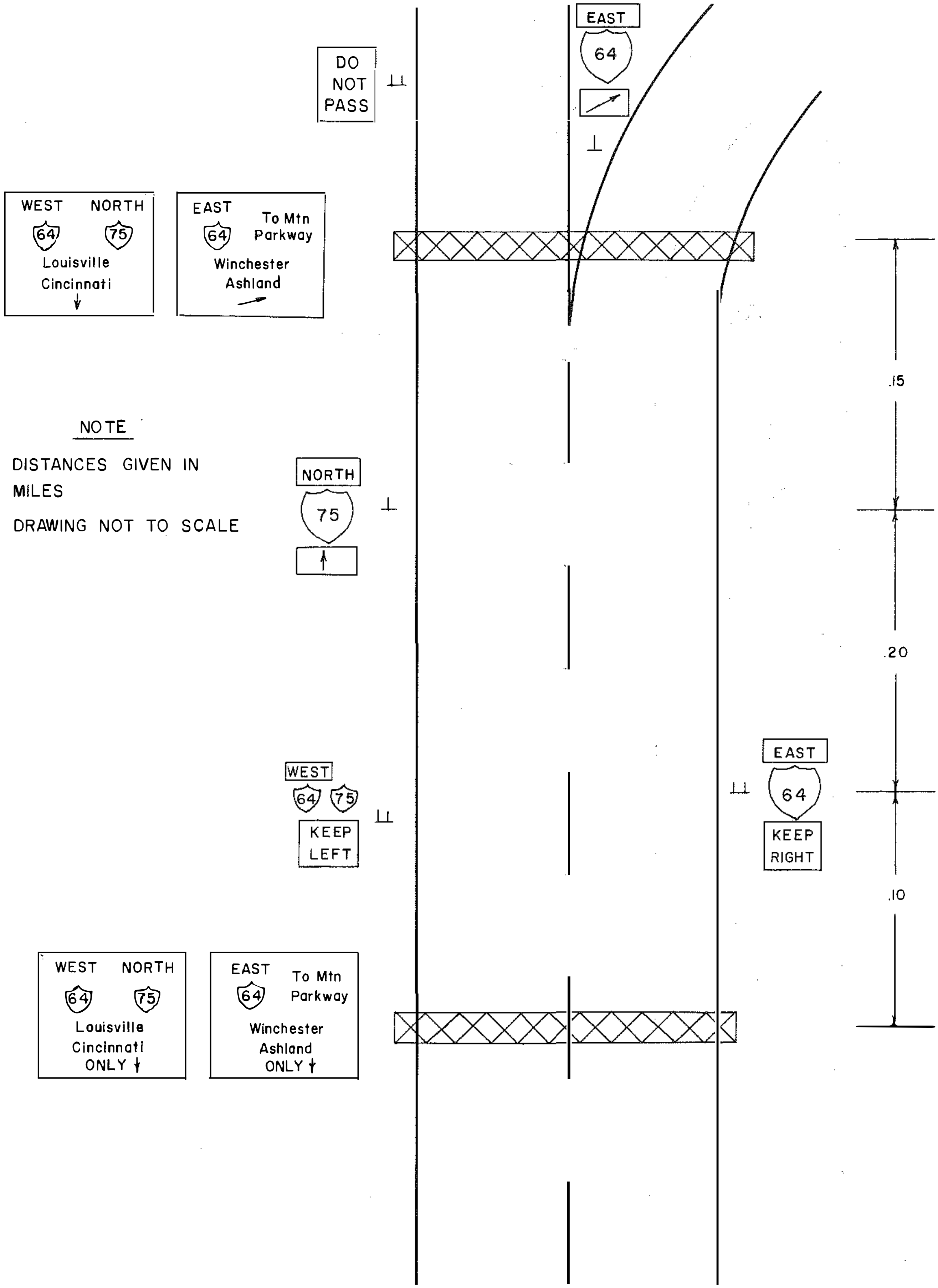


FIGURE 8. SIGNING SCHEMATIC OF THE I 75 NORTHBOUND - I 64 EASTBOUND LANE SPLIT

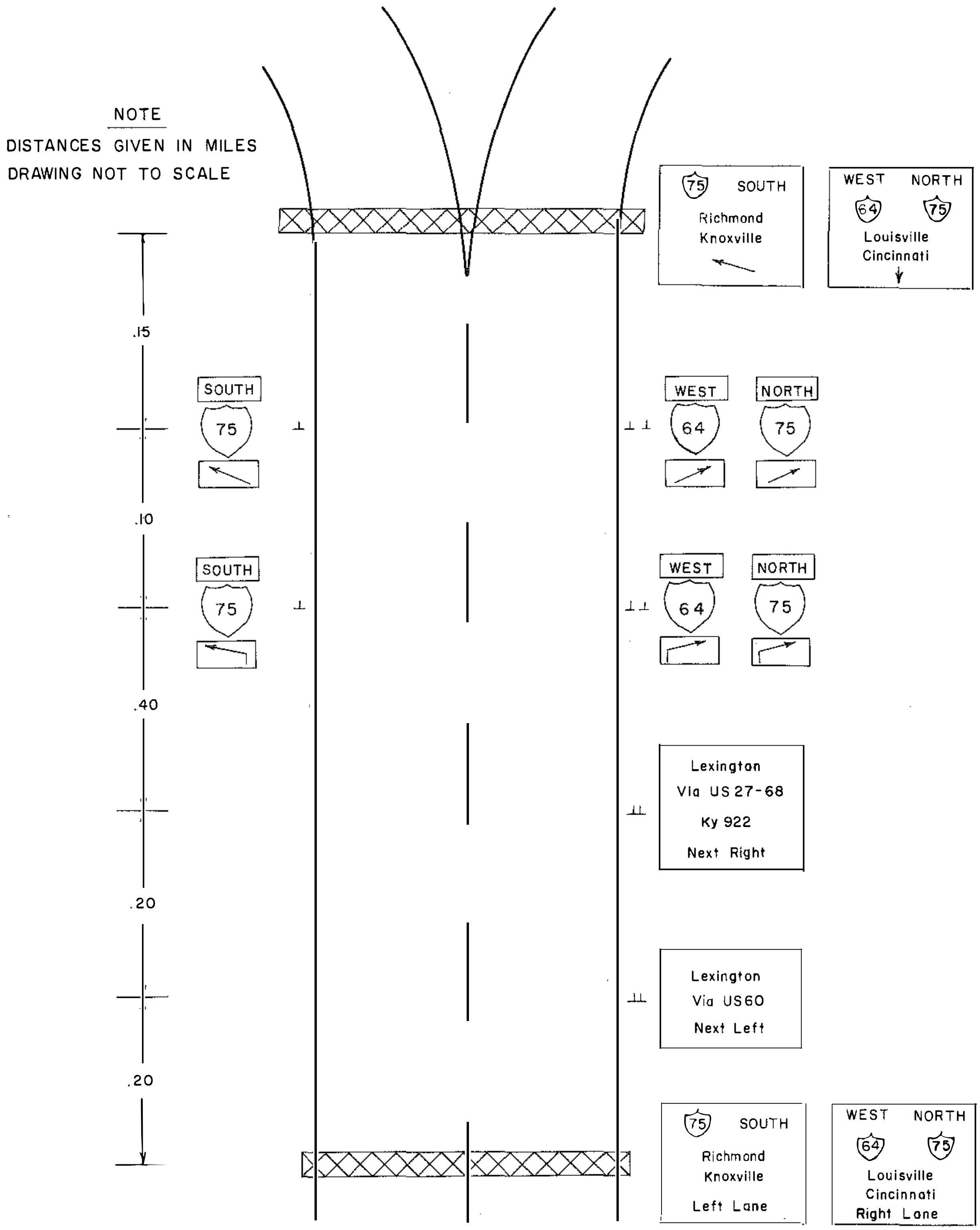


FIGURE 9. SIGNING SCHEMATIC OF THE I 64 WESTBOUND LANE SPLIT

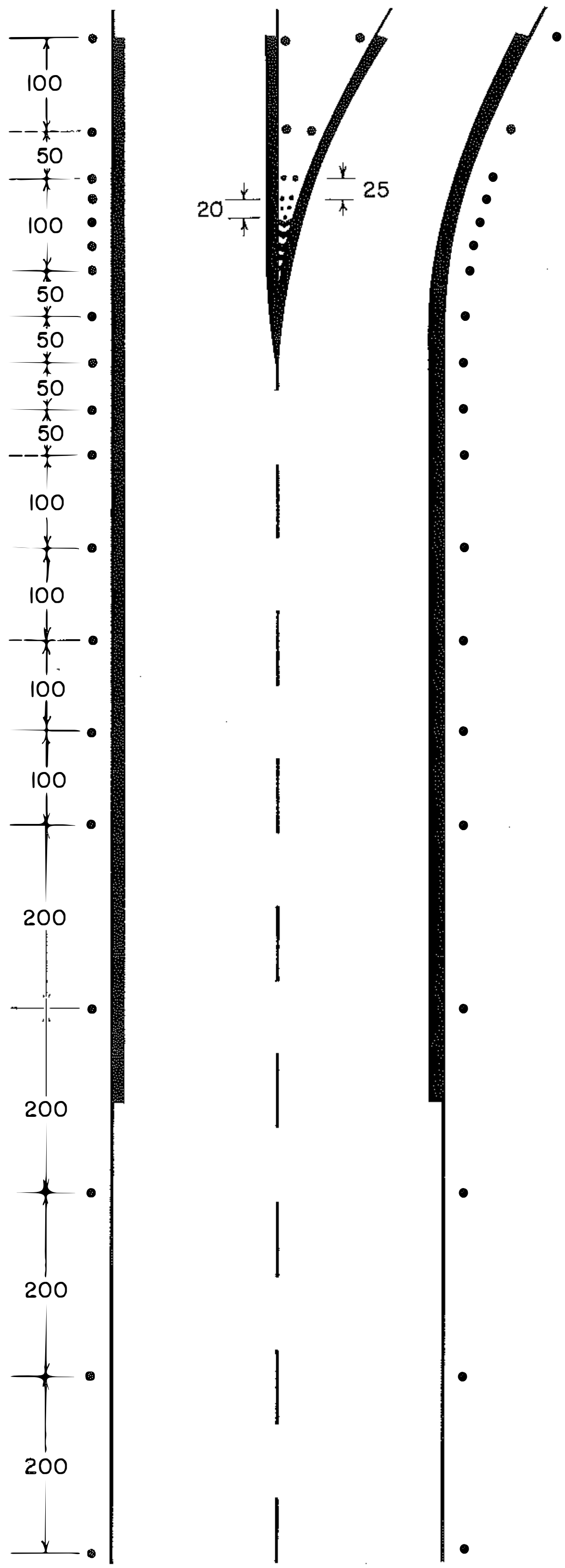


FIGURE 10. TYPICAL YELLOW EDGELINING AND AMBER DELINEATOR PLACEMENT

large to change the basic number of lanes beyond this point on the freeway route as a whole *(25)*. Two deficiencies of the I 64 - I 75 interchange may be enumerated: 1) "T" intersections between expressways should be avoided, particularly when the top of the "T" faces toward a region of higher average traffic density. 2) Two facilities should not reduce to one in areas of increasing traffic density; instead, they should branch as traffic loads become higher *(26)*.

From the preceding discussion, one might conclude that there would be a high rate of erratic movements at the I 64 - I 75 interchange. Such a conclusion would be correct. Tables 1 and 2 indicate that, as anticipated from the roadway geometrics, the I 75 southbound erratic movement rates were lower, in all cases, than those of either of the other two lane splits. The highest rates were found at the I 75 northbound lane split. This was also anticipated due to roadway geometrics and to the fact the through traffic on I 75 must go through the interchange in the left-hand lane, as the heavily traveled right lane of I 75 splits off to become the lesser traveled I 64 eastbound. (Average hourly volumes for each erratic movement count are given in Tables 1 and 2. Annual average daily traffic volumes for 1971 are shown in Figure 11.) This excessive lane-change movement is seen most easily in the high "cut across the gore" rate. It was felt by study observers that the absence of a Bluegrass Parkway directional sign at the I 64 westbound lane split was the chief source for the unusually high "stopped" rate at this location. Overall, it may be stated that these erratic movements substantiate the hypothesis that lane splits are confusing to a significant number of drivers.

An accident analysis by Maffet *(27)* of the 7.9-mile combined route of I 64 and I 75 in Fayette County has shown that there were 313 accidents reported for the period from August 15, 1967, through December 31, 1970. The accident rate for the entire section was 143 accidents per hundred million vehicle miles of travel. The injury rate was 103 injuries per hundred million vehicle miles of travel. The accident rate for the tri-level interchange was 192 accidents per hundred million vehicle miles of travel, while the injury rate was 101 injuries per hundred million vehicle miles of travel. Fifty-six percent of the accidents on the entire combined route occurred in the southbound lanes, whereas 57 percent of the accidents in the tri-level interchange area occurred either on northbound I 75 or on the westbound ramp from I 64 to northbound I 75. The author concurs with Maffet's findings that the roadway geometrics, particularly sight distances, account for this high number of northbound accidents at the tri-level interchange. A collision diagram of the tri-level interchange is shown in Figure 12. Additional accident information is tabulated in APPENDIX B.

A statistical analysis of all erratic-movement and brakelight-rate deviations was made using the Smith-Satterthwaite test *(28)*. Significant erratic movement and brakelight rate deviations are given in Tables 3 through 7. A summary of statistical theory and tests utilized in the analysis of data is presented in APPENDIX C. A study of these deviations indicates that no type of traffic control device was significantly effective in reducing erratic movement and brakelight rates at all three lane-split locations. Rather, it appears that different devices are most effective at each of the locations, i.e., amber delineators at the I 75 southbound lane split during both day and night conditions, **EXIT ONLY** signs at the I 64 westbound lane split during day conditions, and yellow striping at the I 75 northbound lane split during day conditions. No device was particularly effective at the I 75 northbound lane split during night conditions.

Spot speeds were analyzed to determine significant mean speed differences before and after each different traffic control device installation. The statistical method used may be found in APPENDIX C *(29)*. Mean speeds for each of the three study locations are given in Figures 13 through 15. Although these speeds appear low upon initial inspection, it should be recognized that horizontal alignment is the principal roadway feature related to spot-speed characteristics *(30)*. Thus, from the geometric data given in Figure 3, subnormal speeds would be expected at each of the four ramps possessing relatively high (by interstate standards) degrees of horizontal curvature. Furthermore, it has been stated that, on the average, operating speeds through weaving sections for a given level of service will fall from 5 to 10 miles per hour below those for the same level on adjacent roadway sections *(31)*.

At the beginning of this study, it was hypothesized that an effective traffic control device at a lane-split location would result in higher spot speeds in the immediate vicinity of the gore and in slightly lower or unchanged spot speeds at a distance of approximately 500 feet back from the gore. It was felt that a driver recognizing the lane-split situation ahead would either slow down slightly or keep a constant speed during the final few seconds of approach. This final decision making was estimated to occur at a distance of 500 feet from the lane split. At the gore, the driver becomes more certain of his path of travel and recovers speed. Basically, this trend was observed for all auxiliary traffic control devices installed during the pilot study. Particular adherence to this trend was associated with the amber delineators at the I 75 southbound lane split

TABLE I

ERRATIC MOVEMENT AND BRAKELIGHT RATES*
DAYTIME CONDITIONS

LOCATION	STUDY NUMBER	TRAFFIC CONTROL DEVICE(S) EMPLOYED	ERRATIC MOVEMENT RATES							BRAKELIGHT RATES			AVERAGE HOURLY TRAFFIC VOLUMES		
			CUT ACROSS GORE	CROWDED WEAVE	STOPPED	SWERVED	BACKED AT GORE	MULTIPLE ERRORS	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL
I64 WB	1	ORIGINAL	1.38	.40	1.92	.34	.05	.33	4.40	27.86	24.60	25.10	137	219	356
	2	YELLOW STRIPING	1.37	.24	1.74	.66	.26	.36	4.51	26.57	18.01	20.69	157	274	431
	3	"↑ ONLY" SIGNS YELLOW STRIPING	.74	.02	.07	.75	.02	.17	1.80	22.83	14.38	17.83	151	207	358
	4	"↑ ONLY SIGNS YELLOW STRIPING AMBER DELINEATORS	.71	1.0	1.30	.60	.06	.40	3.18	35.62	18.59	25.30	167	246	413
I75 NB	1	ORIGINAL	2.69	.81	.55	.92	.04	1.23	6.11	8.91	34.97	14.12	832	202	1034
	2	YELLOW STRIPING	1.62	.81	.73	.30	.04	.73	4.10	6.90	29.32	12.61	666	220	886
	3	"↑ ONLY" SIGNS YELLOW STRIPING	2.32	1.19	.10	.16	.00	.91	4.69	6.68	29.27	11.80	848	253	1101
	4	"↑ ONLY" SIGNS YELLOW STRIPING AMBER DELINEATORS	2.27	.66	.39	.91	.20	.79	5.19	3.60	37.70	15.12	319	172	491
I75 SB	1	ORIGINAL	.70	.55	.25	.42	.01	.43	2.38	56.93	7.92	27.11	179	295	474
	2	YELLOW STRIPING	.57	.46	.45	.22	.02	.29	2.19	64.00	8.40	28.95	392	689	1081
	3	YELLOW STRIPING AMBER DELINEATORS	.40	.25	.08	.03	.00	.14	.81	53.56	5.50	23.19	234	390	624
	4	"↑ ONLY" SIGNS YELLOW STRIPING AMBER DELINEATORS	.17	.09	.08	.14	.15	.16	.60	60.45	5.13	24.25	292	535	827
	5	"↑ ONLY" SIGNS YELLOW STRIPING	.25	.22	.19	.21	.00	.29	1.21	67.81	3.35	29.05	226	324	550

* RATES WERE OBTAINED BY DIVIDING THE NUMBER OF ERRATIC MOVEMENTS OR BRAKELIGHT APPLICATIONS BY THE APPLICABLE TRAFFIC VOLUMES AND EXPRESSING THIS QUOTIENT AS A PERCENTAGE.

TABLE 2

ERRATIC MOVEMENT AND BRAKELIGHT RATES*
NIGHTTIME CONDITIONS

LOCATION	STUDY NUMBER	TRAFFIC CONTROL DEVICE(S) EMPLOYED	ERRATIC MOVEMENT RATES							BRAKELIGHT RATES			AVERAGE HOURLY TRAFFIC VOLUMES		
			CUT ACROSS GORE	CROWDED WEAVE	STOPPED	SWERVED	BACKED AT GORE	MULTIPLE ERRORS	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL
I75 NB	1	ORIGINAL	4.21	.45	.59	.73	.00	1.33	7.38	11.80	48.13	18.53	378	84	462
	2	YELLOW STRIPING	3.28	1.10	.41	.68	.00	1.42	7.90	6.48	39.65	15.70	256	134	390
	3	"↑ ONLY" SIGNS YELLOW STRIPING	4.17	1.86	.22	.38	.08	1.83	8.52	13.67	34.40	17.03	649	134	783
	4	"↑ ONLY SIGNS YELLOW STRIPING AMBER DELINEATORS	3.70	.68	1.21	1.14	.12	1.30	8.10	3.27	50.80	15.59	176	59	235
I75 SB	1	ORIGINAL	.97	.18	.31	.56	.05	.26	2.33	78.13	16.27	36.10	126	263	389
	2	YELLOW STRIPING	1.12	.23	.32	.06	.00	.64	2.50	75.[illegible]8	12.17	31.07	297	719	1016
	3	YELLOW STRIPING AMBER DELINEATORS	.36	.00	.00	.13	.00	.00	.62	74.88	2.60	30.77	97	163	260
	4	"↑ ONLY" SIGNS YELLOW STRIPING AMBER DELINEATORS	.47	.15	.18	.09	.00	.00	1.21	68.77	3.90	27.10	172	300	472
	5	"↑ ONLY" SIGNS YELLOW STRIPING	.41	.22	.31	.26	.15	.41	1.81	77.20	3.23	29.31	90	160	250

* RATES WERE OBTAINED BY DIVIDING THE NUMBER OF ERRATIC MOVEMENTS OR BRAKELIGHT APPLICATIONS BY THE APPLICABLE TRAFFIC VOLUMES AND EXPRESSING THIS QUOTIENT AS A PERCENTAGE.

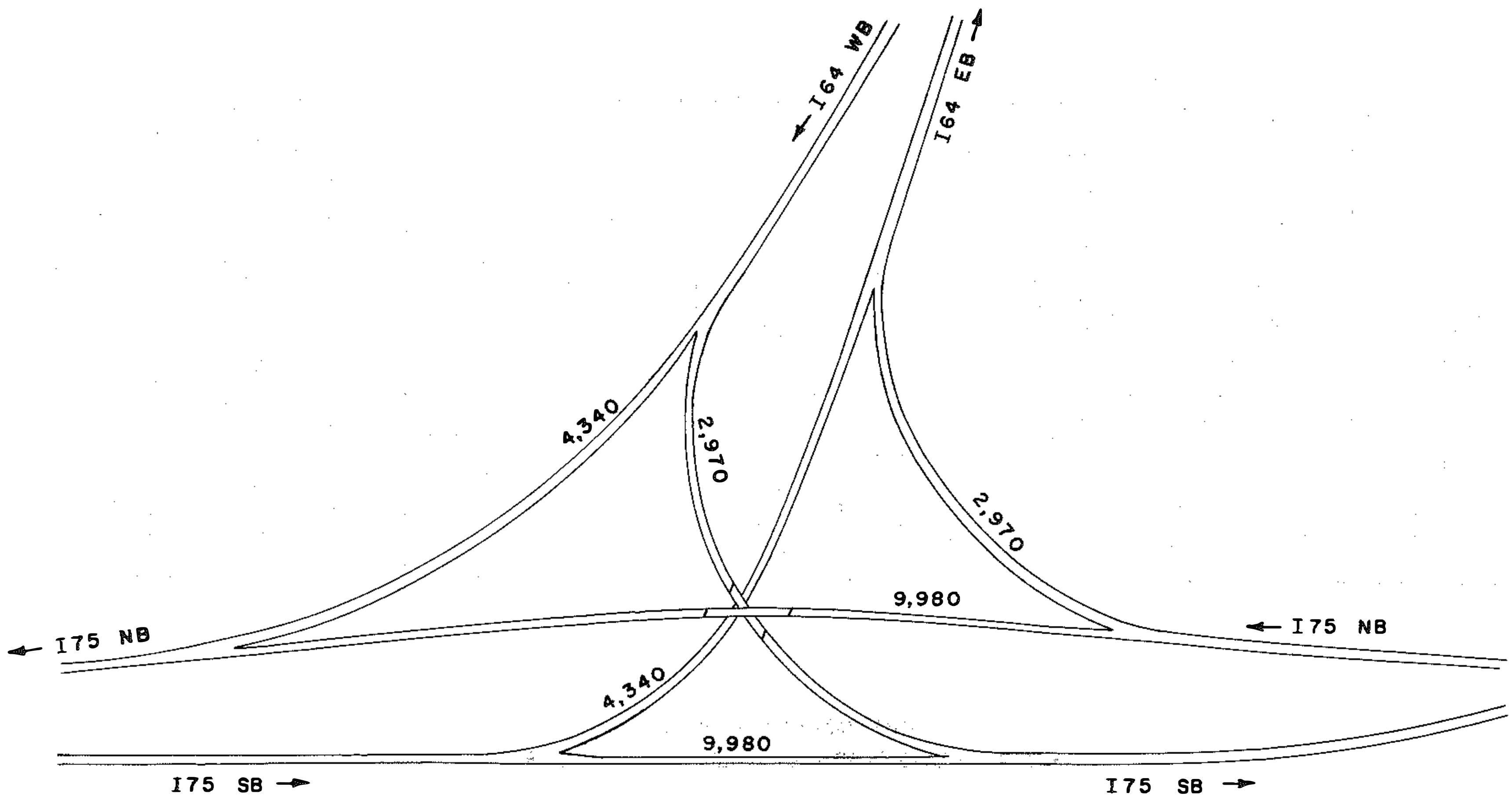


FIGURE 11. 1971 ADJUSTED AVERAGE DAILY TRAFFIC VOLUMES FOR THE I 64 - I 75 TRI-LEVEL INTERCHANGE

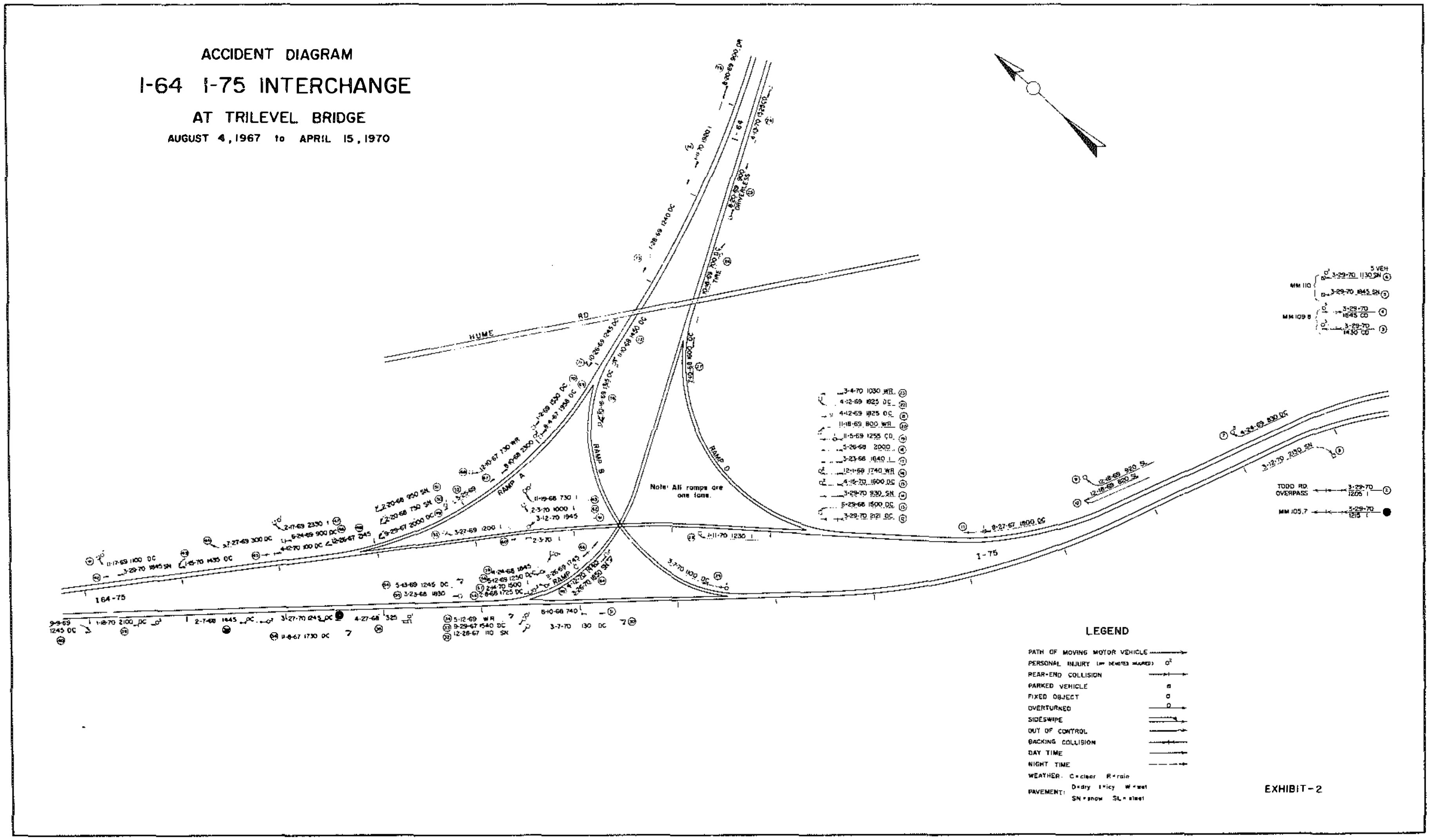


FIGURE 12. COLLISION DIAGRAM OF THE I 64 I 75 TRI-LEVEL INTERCHANGE

TABLE 3

I 75 SB - I 64 EB LANE SPLIT (DAYTIME)
SIGNIFICANT ERRATIC MOVEMENT AND BRAKELIGHT RATE DEVIATIONS*

STUDY NUMBER	TRAFFIC CONTROL DEVICE(S) EMPLOYED
1	ORIGINAL
2	YELLOW STRIPING
3	YELLOW STRIPING & AMBER DELINEATORS
4	"↑ ONLY" SIGNS, YELLOW STRIPING, & AMBER DELINEATORS
5	"↑ ONLY" SIGNS & YELLOW STRIPING

COMPARISON		TYPE OF ERRATIC MOVEMENT RATE							TYPE OF BRAKELIGHT RATE		
FROM STUDY #	TO STUDY #	CUT ACROSS GORE	CROWDED WEAVE	STOPPED	SWERVED	BACKED AT GORE	MULTIPLE ERRORS	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL
1	2	—	—	—	DECREASE	—	—	—	INCREASE	—	—
1	3	—	DECREASE	DECREASE	DECREASE	—	DECREASE	DECREASE	—	—	DECREASE
1	4	DECREASE	DECREASE	DECREASE	DECREASE	INCREASE	DECREASE	DECREASE	—	—	—
1	5	DECREASE	DECREASE	—	—	—	—	DECREASE	INCREASE	DECREASE	—
2	3	—	DECREASE	DECREASE	DECREASE	—	DECREASE	DECREASE	DECREASE	DECREASE	DECREASE
2	4	DECREASE	DECREASE	DECREASE	—	INCREASE	—	DECREASE	—	DECREASE	DECREASE
2	5	DECREASE	DECREASE	DECREASE	—	—	—	DECREASE	—	DECREASE	—
3	4	—	DECREASE	—	INCREASE	INCREASE	INCREASE	—	INCREASE	—	—
3	5	—	—	—	—	—	INCREASE	INCREASE	INCREASE	DECREASE	INCREASE
4	5	—	—	INCREASE	—	DECREASE	INCREASE	INCREASE	INCREASE	DECREASE	INCREASE

* The words "INCREASE" & "DECREASE" refer to certain erratic movement or brakelight rate deviations that were found to be statistically significant at the 95% confidence level.

TABLE 4

I 75 NB - I 64 EB LANE SPLIT - DAYTIME
SIGNIFICANT ERRATIC MOVEMENT & BRAKELIGHT RATE DEVIATIONS*

STUDY NUMBER	TRAFFIC CONTROL DEVICE(S) EMPLOYED
1	ORIGINAL
2	YELLOW STRIPING
3	"↑ ONLY" SIGNS & YELLOW STRIPING
4	"↑ ONLY" SIGNS, YELLOW STRIPING, & AMBER DELINEATIONS

COMPARISON		TYPE OF ERRATIC MOVEMENT RATE							TYPE OF BRAKELIGHT RATE		
FROM STUDY #	TO STUDY #	CUT ACROSS GORE	CROWDED WEAVE	STOPPED	SWERVED	BACKED AT GORE	MULTIPLE ERRORS	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL
1	2	DECREASE	—	—	DECREASE	—	DECREASE	DECREASE	—	DECREASE	—
1	3	—	—	DECREASE	DECREASE	—	—	—	—	—	—
1	4	—	—	—	—	—	—	—	DECREASE	—	—
2	3	INCREASE	—	DECREASE	—	—	—	—	—	—	—
2	4	INCREASE	—	DECREASE	INCREASE	—	—	—	DECREASE	INCREASE	—
3	4	—	—	INCREASE	INCREASE	INCREASE	—	—	—	INCREASE	—

*The words "INCREASE" & "DECREASE" refer to certain erratic movement or brakelight rate deviations that were found to be statistically significant at the 95% confidence level.

TABLE 5

I 64 WB LANE SPLIT (DAYTIME)
SIGNIFICANT ERRATIC MOVEMENT AND BRAKELIGHT RATE DEVIATIONS*

STUDY NUMBER	TRAFFIC CONTROL DEVICE (S) EMPLOYED
1	ORIGINAL
2	YELLOW STRIPING
3	"↑ ONLY" SIGNS & YELLOW STRIPING
4	"↑ ONLY" SIGNS, YELLOW STRIPING, & AMBER DELINEATIONS

COMPARISON		TYPE OF ERRATIC MOVEMENT RATE							TYPE OF BRAKELIGHT RATE		
FROM STUDY #	TO STUDY #	CUT ACROSS GORE	CROWDED WEAVE	STOPPED	SWERVED	BACKED AT GORE	MULTIPLE ERRORS	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL
1	2	———	———	———	———	INCREASE	———	———	———	DECREASE	DECREASE
1	3	DECREASE	DECREASE	DECREASE	———	———	———	DECREASE	———	DECREASE	DECREASE
1	4	DECREASE	———	DECREASE	———	———		DECREASE	———	DECREASE	———
2	3	DECREASE	———	DECREASE	———	DECREASE	———	DECREASE	———	DECREASE	———
2	4	DECREASE	———	———	———	DECREASE	———	DECREASE	———	———	———
3	4	———	———	INCREASE	———	———	———	INCREASE	INCREASE	———	INCREASE

*The words "INCREASE" & "DECREASE" refer to certain erratic movement or brakelight rate deviations that were found to be statistically significant at the 95% confidence level.

TABLE 6

I 75 SB - I 64 EB LANE SPLIT (NIGHTTIME)
SIGNIFICANT ERRATIC MOVEMENT AND BRAKELIGHT RATE DEVIATIONS*

STUDY NUMBER	TRAFFIC CONTROL DEVICE(S) EMPLOYED
1	ORIGINAL
2	YELLOW STRIPING
3	YELLOW STRIPING & AMBER DELINEATORS
4	"↑ ONLY" SIGNS, YELLOW STRIPING, & AMBER DELINEATORS
5	"↑ ONLY" SIGNS & YELLOW STRIPING

COMPARISON		TYPE OF ERRATIC MOVEMENT RATE							TYPE OF BRAKELIGHT RATE		
FROM STUDY #	TO STUDY #	CUT ACROSS GORE	CROWDED WEAVE	STOPPED	SWERVED	BACKED AT GORE	MULTIPLE ERRORS	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL
1	2	—	—	—	—	—	—	—	—	—	—
1	3	—	—	—	—	—	—	—	—	—	—
1	4	—	—	—	—	—	—	—	—	—	—
1	5	—	—	—	—	—	—	—	—	—	—
2	3	DECREASE	—	DECREASE	—	—	—	DECREASE	—	DECREASE	—
2	4	DECREASE	—	—	—	—	DECREASE	DECREASE	—	DECREASE	DECREASE
2	5	DECREASE	—	—	—	—	DECREASE	—	—	DECREASE	—
3	4	—	—	—	—	—	—	—	—	—	—
3	5	—	—	—	—	—	INCREASE	INCREASE	—	—	—
4	5	—	—	—	—	—	INCREASE	—	—	—	—

*The words "INCREASE" & "DECREASE" refer to certain erratic movement or brakelight rate deviations that were found to be statistically significant at the 95% confidence level.

TABLE 7

I 75 NB - I 64 EB LANE SPLIT (NIGHTTIME)
SIGNIFICANT ERRATIC MOVEMENT AND BRAKELIGHT RATE DEVIATIONS*

STUDY NUMBER	TRAFFIC CONTROL DEVICE (S) EMPLOYED
1	ORIGINAL
2	YELLOW STRIPING
3	"↑ ONLY" SIGNS & YELLOW STRIPING
4	"↑ ONLY" SIGNS YELLOW STRIPING, & AMBER DELINEATIONS

COMPARISON		TYPE OF ERRATIC MOVEMENT RATE							TYPE OF BRAKELIGHT RATE		
FROM STUDY #	TO STUDY #	CUT ACROSS GORE	CROWDED WEAVE	STOPPED	SWERVED	BACKED AT GORE	MULTIPLE ERRORS	TOTAL	MEDIAN LANE	SHOULDER LANE	TOTAL
1	2	—	INCREASE	—	—	—	—	—	DECREASE	—	—
1	3	—	—	—	—	—	—	—	—	DECREASE	—
1	4	—	—	—	—	—	—	—	DECREASE	—	—
2	3	—	—	—	—	—	—	—	—	—	—
2	4	—	—	—	—	—	—	—	DECREASE	—	—
3	4	—	—	INCREASE	—	—	—	—	DECREASE	—	—

*The words "INCREASE" & "DECREASE" refer to certain erratic movement or brakelight rate deviations that were found to be statistically significant at the 95% confidence level.

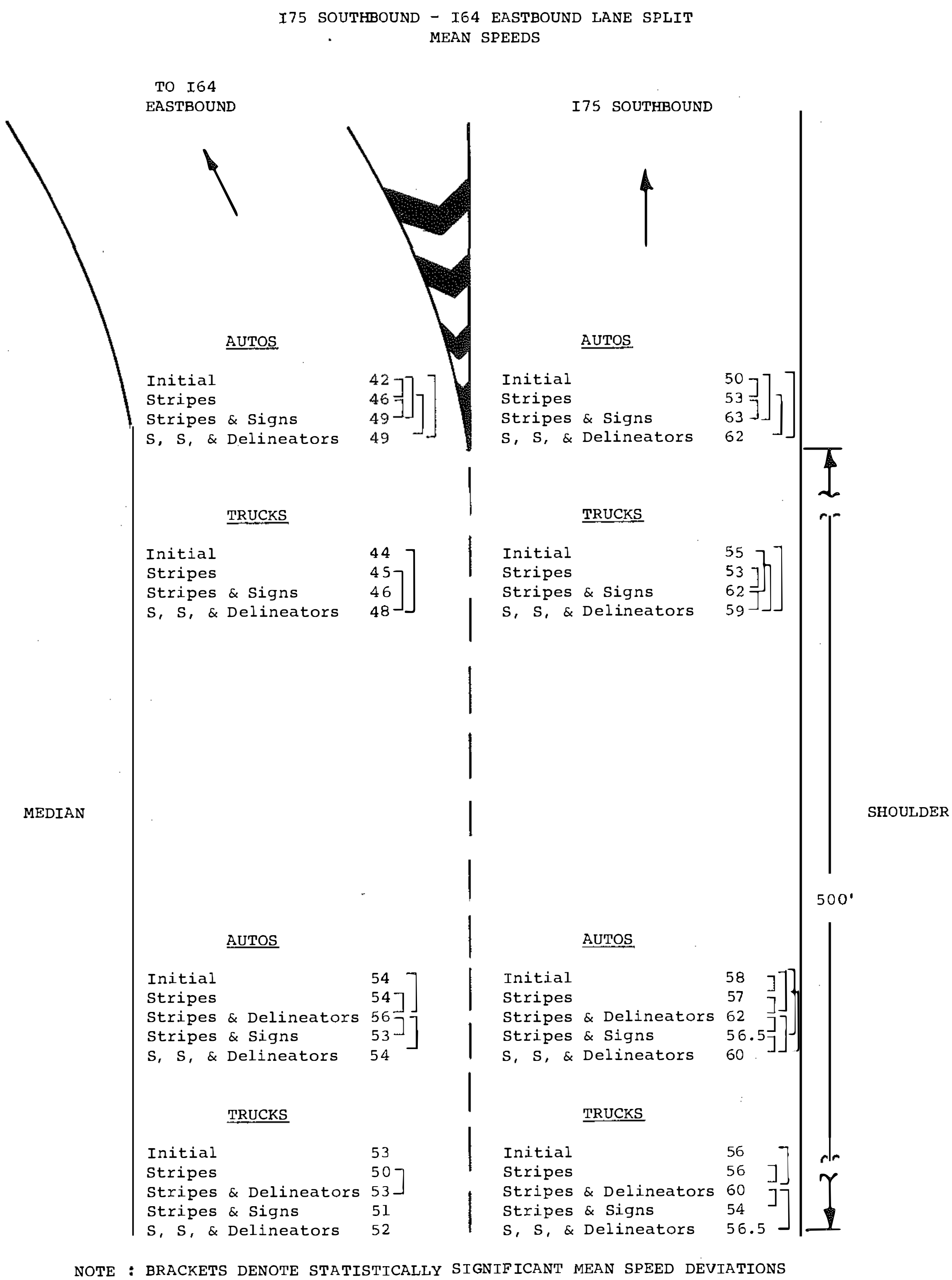
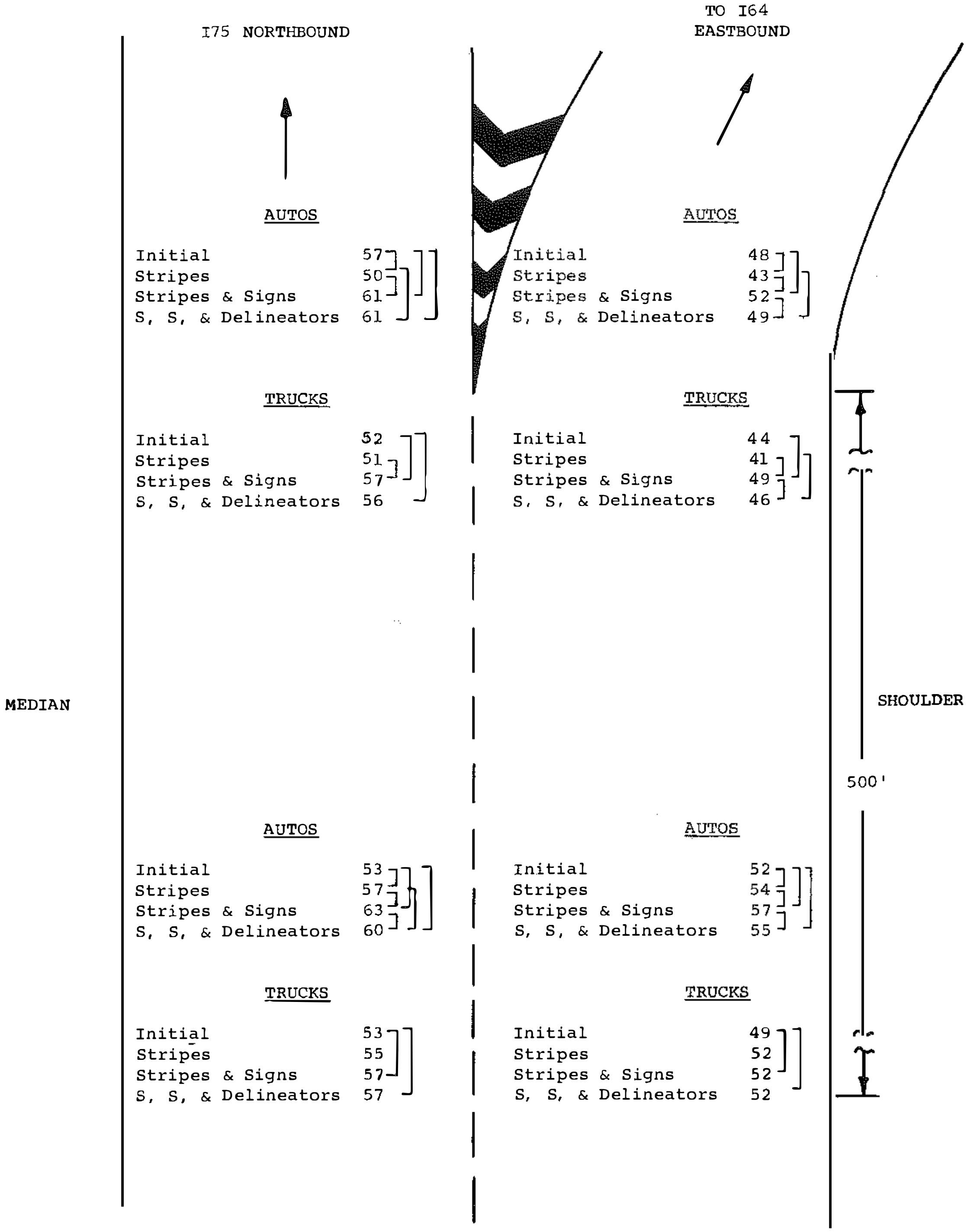


FIGURE 13. MEAN SPEEDS AT THE I 75 SOUTHBOUND - I 64 EASTBOUND LANE SPLIT

I75 NORTHBOUND - I64 EASTBOUND LANE SPLIT
MEAN SPEEDS



NOTE : BRACKETS DENOTE STATISTICALLY SIGNIFICANT MEAN SPEED DEVIATIONS

FIGURE 14. MEAN SPEEDS AT THE I 75 NORTHBOUND - I 64 EASTBOUND LANE SPLIT

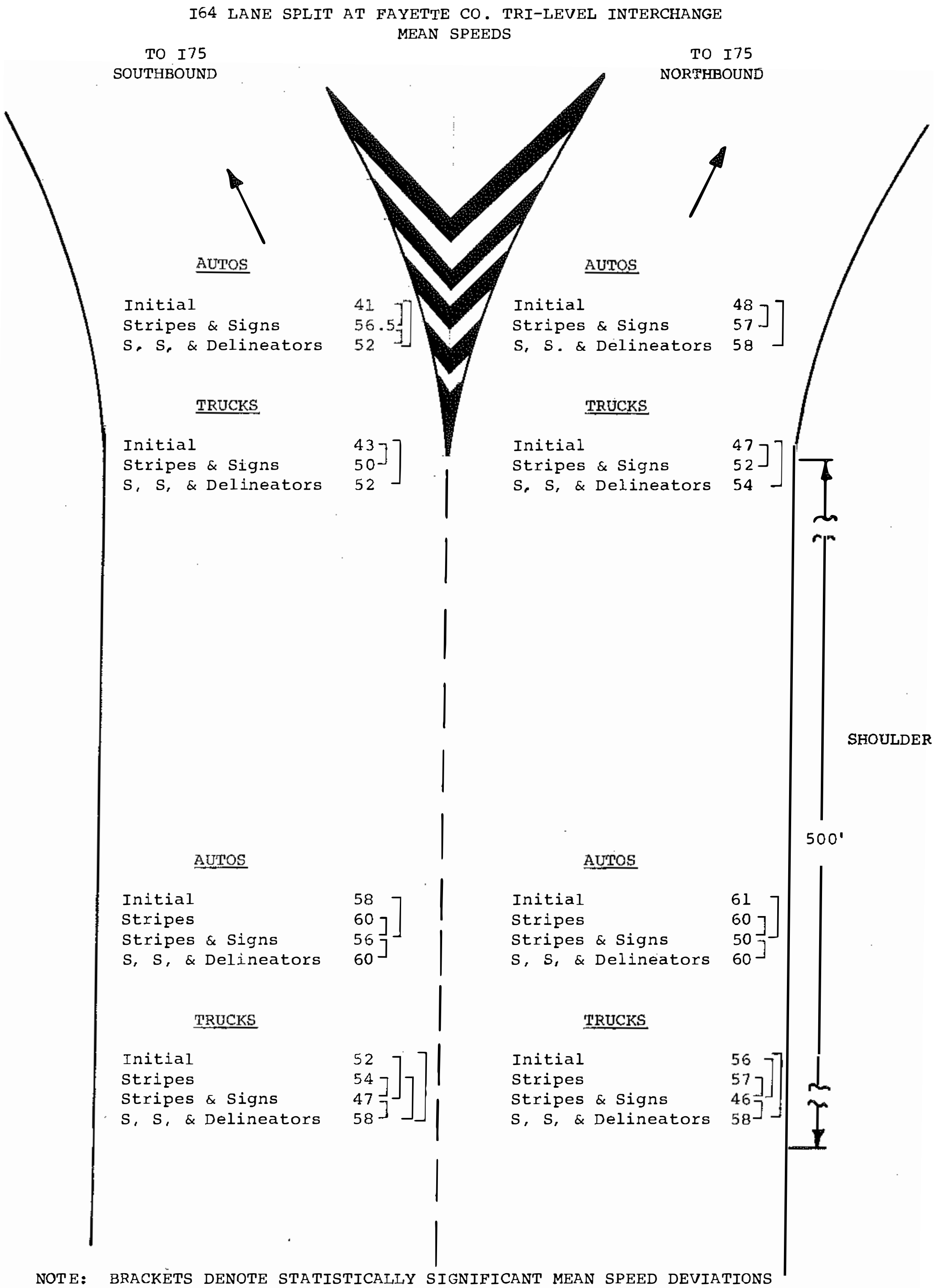


FIGURE 15. MEAN SPEEDS AT THE I 64 WESTBOUND LANE SPLIT

and by the **EXIT ONLY** signs at the I 64 westbound lane split. However, the application of yellow striping at the I 75 northbound lane split unexpectedly showed a reverse trend, i.e., vehicles increased speed slightly 500 feet back from the gore but slowed down at the gore. The steepness of the vertical curve, the poor sight relationships, and the necessary lane change by through vehicles are believed to have some connection with this irregularity.

FURTHER STUDIES

Four lane-drop situations, shown in Figures 16 through 19, will be observed using refined data collection techniques. An attempt will be made to use motion picture photography in collecting some of the data.

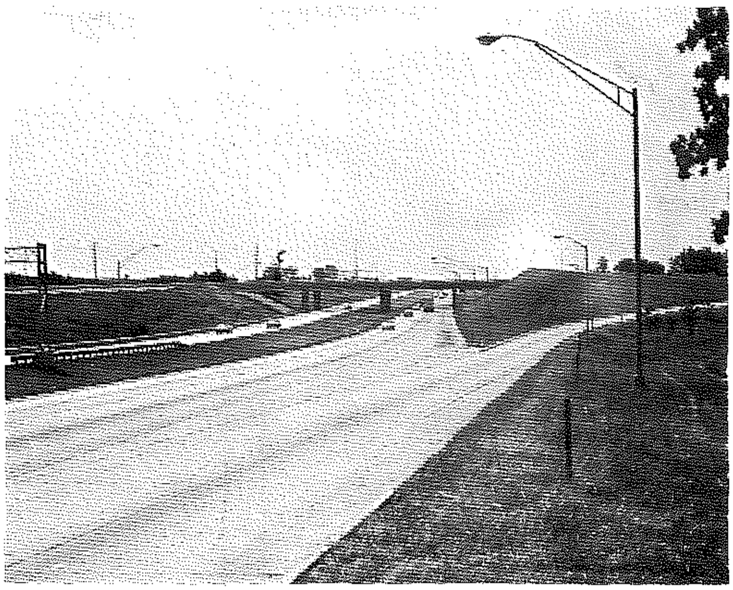


FIGURE 16. SINGLE-LANE EXIT WITH TAPER (I 75 SOUTHBOUND - I 71 SOUTHBOUND)

FIGURE 17. SINGLE-LANE EXIT WITHOUT TAPER (I 75 NORTHBOUND AT THE 5TH STREET EXIT IN COVINGTON)

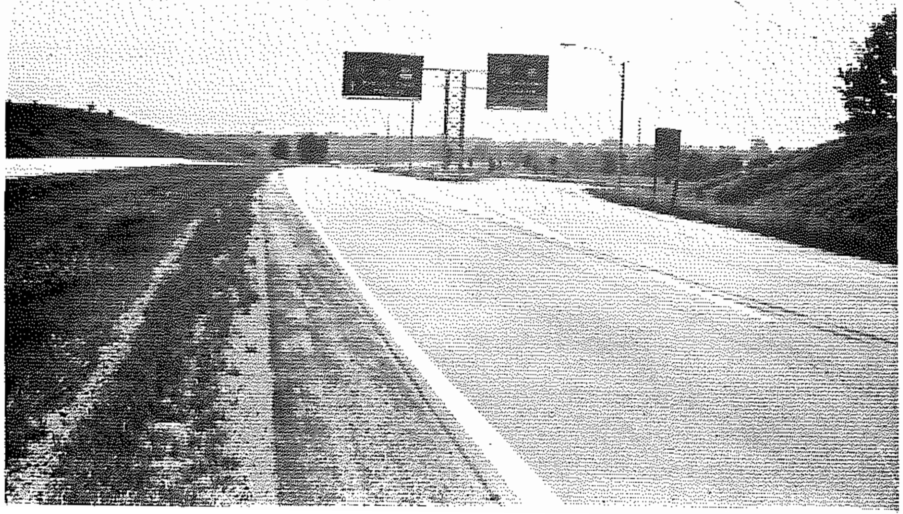


FIGURE 18. SINGLE LANE SPLIT (WESTERN TERMINUS OF THE BLUEGRASS PARKWAY)

FIGURE 19. LANE END (US 27 - 68 (PARIS PIKE) NORTHBOUND, JUST NORTH OF NEW CIRCLE ROAD, FAYETTE COUNTY)

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APPENDIX A

ERRATIC MOVEMENT DEFINITIONS

ERRATIC MOVEMENT DEFINITIONS

CUT ACROSS GORE AREA - Vehicle *crosses over* the *pavement markings* used to delineate the gore area.

CROWDED WEAVE - Vehicle changes lanes *directly in front of* a following vehicle, causing the *following vehicle to apply its brakes.* This type of erratic movement *always directly involves* at least *two* vehicles.

STOPPED or SLOWED DRASTICALLY - Vehicle either comes to a complete stop or undergoes a *very rapid* deceleration, causing *"dipping"* of the front end or *tire squealing.*

SWERVE - Vehicle *abruptly veers* from its *straight ahead course.* A swerve *may* or *may not* consist of a change of lanes for the erratic vehicle. This type of erratic movement *always involves* only *one* vehicle.

BACKED AT GORE - Vehicle *backs up* either in a traffic lane, on the shoulder, or in the gore area.

MULTIPLE ERROR - Occurs when a vehicle commits a combination of two or more of the above errors.

APPENDIX B

ACCIDENT ANALYSIS

I 64 - I 75 TRI-LEVEL INTERCHANGE

ACCIDENT ANALYSIS

I 64 - I 75 TRI-LEVEL INTERCHANGE

STUDY PERIOD -- August 15, 1967, through December 31, 1970

ACCIDENT RATE -- 192 accidents per hundred million vehicle miles

INJURY RATE -- 101 accidents per hundred million vehicle miles

	NORTHBOUND	SOUTHBOUND	TOTAL	PERCENT
NUMBER OF ACCIDENTS	65	49	114	100
MULTIPLE VEHICLE ACCIDENTS	28	30	58	51
Sideswipe	10	12	22	
Rear-End	18	18	36	
SINGLE VEHICLE ACCIDENTS	37	19	56	49
Mechanical Failure	2	0	2	
Loss of Control*	35	19	54	
ACCIDENTS INVOLVING INJURY	17	17	34	30
TOTAL NUMBER INJURED	29	31	60	
TOTAL FATALITIES	0	0	0	
LIGHT CONDITION				
Daylight	49	27	76	67
Dark	16	22	38	33
PAVEMENT CONDITION				
Wet	27	12	39	34
Dry	38	37	75	66

*Loss of control includes falling asleep, adverse roadway conditions (wet, ice, snow, etc.), inattention, drinking, object in roadway, etc.

APPENDIX C

STATISTICAL THEORY

STATISTICAL THEORY

INFERENCES CONCERNING MEANS

The following Smith Satterthwaite test can be used to test for equality of means when concerned with two independent random samples with normal populations whose variances are not necessarily equal:

$$H_0 : x = y \qquad\qquad H_1 : x \neq y$$

$$t = (x - y) \Big/ \left[\frac{s_x^2}{n_1} + \frac{s_y^2}{n_2} \right]^{1/2}$$

$$\upsilon = \left[\frac{s_x^2}{n_1} + \frac{s_y^2}{n_1} \right]^2 \Big/ \left[\frac{(s_x^2 / n_1)^2}{n_1 - 1} + \frac{(s_y^2 / n_1)^2}{n_2 - 1} \right]$$

"BEFORE AND AFTER" SPOT-SPEED STUDIES

In order to determine significant differences between the mean speeds of "before and after" studies, it is necessary to estimate the standard deviation of the difference in means by use of the equation:

$$\hat{s} = \sqrt{s_{\bar{x}_b}^2 + s_{\bar{x}_a}^2}$$

where $\hat{s}$ = standard deviation of the difference in means

$$s_{\bar{x}_b}^2 = \frac{\Sigma f_{b_i} (x_{b_i})^2 - \frac{1}{n_b} (\Sigma f_{b_i} x_{b_i})^2}{n_b (n_b - 1)}$$ = mean variance of "before" study,

$$s_{\bar{x}_a}^2 = \frac{\Sigma f_{a_i} (x_{a_i})^2 - \frac{1}{n_a} (\Sigma f_{a_i} x_{a_i})^2}{n_a (n_a - 1)}$$ = mean variance of "after" study.

If the difference in mean speeds is greater than twice the standard deviation of the difference in means, i.e.

$$\bar{x}_b - \bar{x}_a > 2\hat{s},$$

it can be said with 95 percent confidence that the observed difference in mean speeds is significant (the change in conditions has significantly affected the mean speed).