

CONSTRUCTION ZONE SAFETY AND DELINEATION STUDY

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16. Abstract The Construction Zone Delineation study was conducted to find methods for improving delineation in construction zones with long term overnight closures or diversions. The need for improved delineation was established through two means: 1) a committee of traffic, construction, design, research and specifications engineers and 2) positive guidance, a technique that develops highway information system improvements from the driver's viewpoint. Once the need for improved delineation was established, delineation concepts were developed and tested in actual construction zones and evaluated for effects on traffic performance and driver visibility. The experiments showed that: 1) the use of 5" x 10" yellow high intensity reflectors as a replacement for steady burn lights did not result in any change in mean speed and speed variance or the proportions of vehicles using the lane adjacent to the reflectors ; 2) tall vertical reflectorized panels as a replacement for Type III barricades resulted in a decrease in nighttime lane encroachments while mean speeds or speed variances remained unchanged; 3) removable traffic tape was easy to install and easy to remove and proved to be problem free while down and yet was as visible as paint; 4) raised pavement markers as a paint supplement resulted in a reduction of lane changes and encroachments, both day and night; 5) raised pavement markers as a paint replacement resulted in a reduction in lane changes day and night and lane encroachments at night, though a durable marker still needs to be found; 6) the butyl adhesive with primer was still the most durable method of adhering markers to the pavement, though simpler techniques were tried.					
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SUMMARY AND CONCLUSIONS

The "Construction Zone Delineation" study was conducted to find methods improving delineation in construction zones with long term overnight closures or diversions. The need for improved delineation was established through two means: 1) a committee of traffic, construction, design, research and specifications engineers, and 2) Positive Guidance, a technique that develops highway information system improvements from the driver's viewpoint.

A survey of committee members helped determine a priority for study by construction geometry and the apparent accident contributory factors within construction work zones. Subsequent meetings helped determine delineation improvement needs and possible improvements.

Positive Guidance was implemented to evaluate construction sites of the type recommended by the committee for possible delineation improvements. Accidents before and during construction were reviewed for possible causes of construction zone accidents; on-site investigations were conducted to locate possible areas of improvement; and where warranted, driver performance pilot studies were performed.

The accident studies were not very sensitive to the need for delineation. While one site experienced increases in accidents, another site experienced decreases in accidents. Overall there was no change in accidents for the 11 sites studied.

Once the need was established, six improved delineation concepts were developed and tested in newly selected actual construction zones and eva-

luated for effects on traffic performance and driver visibility. The previously mentioned sites could not be used for the experiments since the construction was completed. The experiments showed that:

- 1 5" x 10" yellow retroreflective sheet reflectors were less expensive initially and less expensive to maintain and more dependable as delineators compared to steady burn lights during the study period. Yet vehicle mean speeds and speed variances did not change nor was there a change in the proportion of vehicles using the lane adjacent to the reflectors. Also, the reflectors could be seen from an adequate distance based on the MUTCD
2. Seven foot high vertical panels could be seen over the tops of lead vehicles while taking up less space compared to Type III barricades. The vertical panels were not accompanied with a change in vehicle mean speeds and speed variances, but there was a decrease in vehicle lane encroachments at night.
3. Removable tape was easy to install and remove and performed well under traffic. Other tests have showed the tape to be very durable under traffic. The tape was as visible as paint.
4. Raised pavement markers as a paint supplement increased diversion visibility compared to ordinary paint alone. To install the markers, a primer had to be used and vehicle pressure had to be applied. Failure to fully follow installation procedures could lead to marker failure. The markers resulted in a decrease in lane changes and lane encroachments. When not needed, the markers were easily removed.

5. Raised ceramic markers were day visible and were used to replace paint. Being raised and reflective, the markers also provided and wet pavement lane delineation superior to that provided by paint. To install the markers, a primer had to be used and vehicle pressure had to be applied. Failure to fully follow installation procedures could lead to marker failure. A large number of markers were lost while under traffic. The markers resulted in a decrease in lane changes and night lane encroachments. When no longer needed the markers were easy to remove with shovels.

6. Since the use of raised pavement markers in construction zone diversions proved favorable, an effort was made to find and test a priced temporary marker and a faster, less labor intensive method of marker installation. The markers used in current practice are expensive and are adhered to the pavement with butyl pads require a primer and vehicle pressure. The most durable marker-adhesive system proved to be the Stimsonite 911-SS with a butyl pad and primer. A lower priced marker was tested but was not durable enough for construction zone use. The ceramic markers, the only day visible markers available for testing, tended to break up or fall off the pavement when used with the butyl pad on concrete.

There is still a need to find a low priced day and night visible marker and a simple yet effective method of installation.

RECOMMENDATIONS

1. Use 5" x 10" yellow retroreflective sheet reflectors as a replacement or supplement to steady burn lights.
2. Use seven foot high panels as an alternative for Type III barricades where sight distance is critical.
3. Removable tape should be considered as an alternative to hard to remove paint where installation and removal time is critical.
4. Supplement traffic paint with raised pavement markers when there is a need for stronger night and rainy night delineation.
5. Raised day visible markers should also be further investigated as a paint replacement, especially where strong lane delineation is called for under various light and weather conditions. There is a need to find and test a durable day visible marker, however. The markers installed on concrete experienced losses and damages of 25 percent, most of the losses occurring in the vicinity of a major exit. In the same area, the installation was not closely supervised. The markers installed on another site that was mostly asphalt experienced losses of three percent, most losses occurring in the concrete transition area..
6. Marker installation with butyl tape tended to be cumbersome since a primer and vehicle pressure were required. In an attempt to use liquid adhesives as an alternative to butyl, butyl still proved to be the most durable adhesive.

INTRODUCTION

New Jersey's Construction Zone Delineation research project is part of a national federal program to research many facets of construction zone traffic and personal safety. This research was performed to improve delineation devices in safety zones where long term diversions and lane closures are created by construction.

Construction zones usually require more caution on the part of the motorist than normal highway travel. The geometric features, restricted driving conditions, changing alignments, temporary barricades and barriers, discontinuous lane lines, chaotic arrays of cones and flashing lights and undefined lanes may confuse the driver, delay his reaction time and even result in accidents.

In Illinois during 1969, nearly 7,000 motorists and workers were involved in accidents at road construction sites and it is also mentioned in a report that these figures are typical of most other states (1) losses/deaths in injuries indicate a need for broad based studies of driver problems with narrowly defined experiments with trial improvements.

BioTechnology, Inc. evaluated the effectiveness of channelization devices by conducting a literature search, controlled experimental tests, and full-scale field investigations of construction sites. Evaluations included day and night operations, illuminated and non-illuminated conditions and urban and rural environments. The conclusion was: the various channelization devices were interchangeable and equally effective(2).

A report, "Guidelines for the Application of Arrow Boards in Work Zones,"(3) developed guidelines for the application of arrow boards in highway work zones. Human factors investigations were conducted in

laboratory to determine driver information requirements, expectancy, and understanding of arrow boards. Field studies of driver responses to arrow boards were conducted in 78 construction and maintenance zones in California and Illinois. The results indicated that arrow boards were effective in lane closure work zones by promoting earlier merging into the open lane. The arrow board was more effective when it was placed on the shoulder of the roadway near the start of the lane closure taper. Arrow boards were not found to be generally effective in traffic diversions or splits or for moving shoulder closures. However, they did prove effective in reducing some specific operational problems in these types of work zones

In 1976, nine states evaluated raised pavement markers as a means of guiding traffic through construction zones. The markers were evaluated for cost, spacing, ease of application and removal, and the ability of the markers to guide traffic. In general, the markers provided excellent nighttime temporary delineation particularly when the road was wet, at a low cost with little or no maintenance (4).

The "Construction Zone Delineation" study was conducted to find methods for improving delineation in construction zones with long term overnight closures or diversions. The need for improved delineation was established through two means: 1) a committee of traffic, construction, design, research and specifications engineers, and 2) positive guidance, a technique that develops highway information system improvements from the driver's viewpoint. Once the need for improved delineation was established, delineation concepts were developed and tested in actual construction zones and evaluated for effects on traffic performance and driver visibility.

DETERMINATION OF DELINEATION NEEDS

At the beginning of the project, a committee of traffic, construction, design, research and specifications engineers was formed. Prior to first meeting, each member was interviewed to find out what type of lane closure offered the most hazard to traffic and what contributed to construction zone accidents. During the three meetings held, construction zone delineation improvement needs were presented and discussed, recommended experiments were reviewed and approved, and possible sites were discussed.

Positive guidance (5) was implemented to evaluate selected construction sites of the type recommended by the committee. Accidents were studied before and during construction, on-site investigations were conducted to locate possible areas of improvement and, where warranted, driver performance pilot studies were performed.

Committee Survey

Before the first meeting each member of the committee was interviewed to find out what type of lane closure offered the most hazard to traffic and what contributed to construction zone accidents. The interviews revealed that:

The majority of the respondents felt that the most hazardous lane closure was a left lane drop with the right shoulder used as a lane. Drivers in the left lane are not expecting a closure, the stopping distance is greater in the high speed lane. Also motorists hesitate to use the shoulder as a lane.

2. Seventy-six percent (76%) of the respondents felt that a construction zone in an unsignalized roadway was more hazardous to motorists than one in a signalized roadway. With an unsignalized roadway, the driver is not conditioned to expect any obstructions or slow speeds.

3. When the participants chose between day and night as to which offered the most hazard to traffic in construction zones, 76 percent chose night as the most hazardous. At night, visibility is lower than day and headlight glare may blind drivers. The safety setup may be knocked over during the night and not replaced.

When the respondents were asked what they experienced in construction zones they mentioned that visibility of the zone was blocked by drivers in front of motorists. A possible solution they suggested was to raise the devices higher. The participants also expressed concern over abrupt alignment changes such as reverse curves, and suggested better delineation as a solution.

From the survey, construction zones with left lane closures on high-speed, free-flowing highways were given highest priority for study. Devices not high enough and abrupt alignment changes would be watched for.

Accident Studies

Accidents were studied before and during construction for a total of 11 sites. Five of the sites were active (under construction) so that the project engineer could investigate accidents soon after they occurred, and six of the sites were completed but were used to provide a larger data base.

Completed Site Accident Study - Accidents before and during construction were studied for six completed construction projects. The procedure followed was:

1. Select project.
2. Call resident engineer. Determine if overnight lane closures had been in effect and the duration of closures, if possible. If overnight lane closures were not in effect or closures were for a very short time span, site might have to be dropped.
3. If site is "good" as determined by conversation with resident obtain construction records, plans, and straight line diagrams (during construction year and one year prior). Determine
 - a. site length (milepost to milepost)
 - b. construction duration
 - c. dates of construction
 - d. site location
 - e. construction tasks
 - f. construction operations
 - g. safety setup and operations
 - h. highway characteristics
4. Obtain traffic and accident data within site limits for construction period and one year prior. Special attention must be given to special traffic situations such as interchanges, circles, etc.

A review of all six completed sites reveals little before-during change in accidents. U.S. 46, with day and night left lane closures, experienced a significant decrease in dark-wet accidents, indicating no delineation problem. Another site (U.S. 4) had night left lane closures that may have contributed to same direction and fixed object accidents, indicating need

for more visible lane closures. Details for each site can be found in Appendix A.

Active Site Accident Study - Accidents before and during construction were studied for five active sites. The procedure followed was the same as for the past site accident study with one exception. So that the project engineer could investigate accidents soon after they occurred, the local police were instructed to inform NJDOT within 48 hours of an accident in the construction area. They provided the date, time and location of the accident and the jurisdiction reporting. It was hoped that early investigations of accidents would yield some clues as to the role delineation played. However, no such relationship could be found since eye witnesses, if any, gave conflicting reports and evidence, if any, was gone by the time the project engineer arrived.

The before construction accident summaries were adjusted to account for changes in AADT. To determine if the change in accidents was statistically significant at the 95% level of confidence, the chi square or conservative test was used (6).

As can be seen from Table 1, there was very little change in accidents from before to during construction. Perhaps accidents are not a sensitive measure of delineation needs. One site showed a significant increase in total, same direction, and night accidents indicating a need for improved delineation. Another site showed a significant decrease in same direction accidents indicating no need for delineation improvements. Details for each site can be found in Appendix B.

Table 1

SUMMARY OF ACCIDENT STUDIES

CONFIDENCE LEVEL 95%
 STATISTICAL TEST TECHNIQUE - CHI-SQUARE

DESCRIPTION

	<u>ACTIVE CONSTRUCTION</u>			<u>COMPLETED CONSTRUCTION</u>		
	<u>EASTON</u> 4/78-12/78	<u>US 1&9</u> 4/78-12/78	<u>US 46</u> 4/78-12/78	<u>I-80</u> 4/78-12/78	<u>US 1&9</u> 5/74-8/74	<u>US 46</u> 1/76-10/76
LENGTH (M.P.)	2 Miles	57.4-62.6	70.5-72.2	60.5-68.3	35.9-38.4	57.0-60.1
Evaluation Objective						
TOTAL ACCIDENTS	+S	-	+	-	-	+
FATAL ACCIDENTS	0	+	0	+	0	0
INJURY ACCIDENTS	+	-S	+			
PDO ACCIDENTS	+		+	+	-	+S
FIXED OBJECT	-	-	-	+		
SAME DIRECTION	+S	-S	+	-		+
ANGLE		+	+			+S
DARK	+S		0			+
	+					
DARK-WET	+	+	-	-	+	-S
SPRING	+S			+S		
SUMMER	+		+			
	+	-	+			
WINTER	+	0	0	0		

+ = Increase in accidents
 - = Decrease in accidents
 0 = No change in accidents
 S = Significant

Personal Observations and Photographic Documentation

The five sites mentioned in the Active Site Study were also observed and documented by the project engineer and other researchers for possible delineation improvement needs. Periodic visits to the sites were made and comments were written down and filed. To further help identify delineation needs, 8mm day and night color movies and 35mm day, black and white prints of the sites were reviewed. Once possible needs were identified, further documentation was done with 16mm day and night color movies and 35mm day night color slides, these being used primarily for presentations. Comments on each site are now presented.

Easton Avenue (FIGURE 1) - Plastic drums and Type III breakaway barricades separating the two lane undivided existing pavement and the graded shoulder area were few in number and had no ballast. Many were knocked over and were too dirty to be easily seen at night due to mud in the area.

Van Veghten Bridge (FIGURE 2) Photos show black tire marks on the edge of the barrier curb for a construction zone diversion where northbound traffic was diverted onto the southbound side of the bridge. The barrier curb closing off the original northbound lane was the only transition used and was not very visible at night. Perhaps a taper of barrels or Type III barricades would be beneficial in better leading traffic into the diversion.

U.S. 1 & 9 (FIGURE 3) The safety setups changed daily making a determination of delineation needs difficult for this four lane undivided highway.

U.S. 46 (FIGURE 4) - The three eastbound lanes of a divided highway were reduced to two lanes with 45 Type III barricades placed at 50 ft. spacing

F A TON AV NU CH MAT C

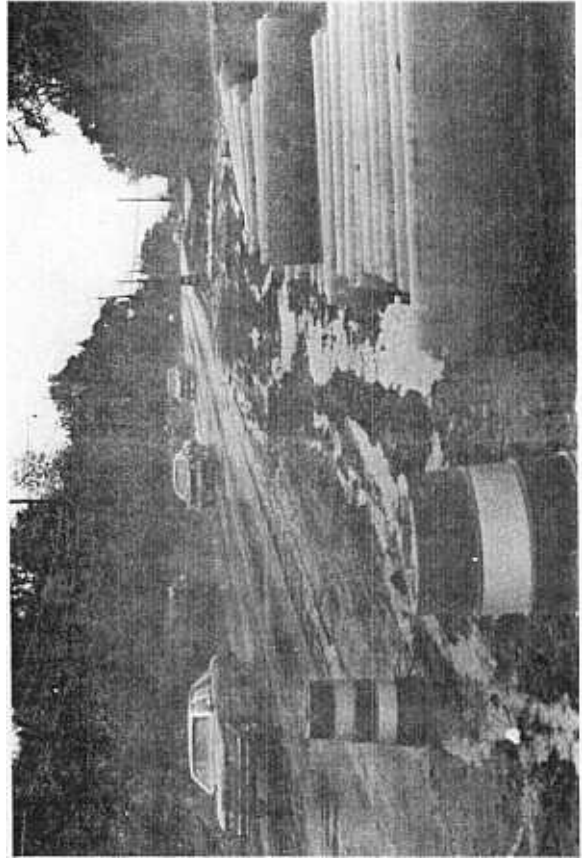
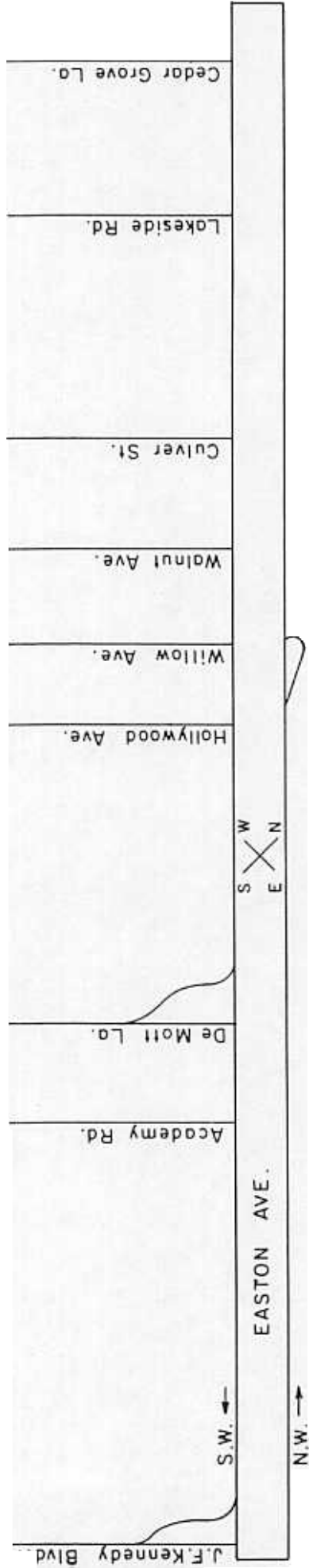
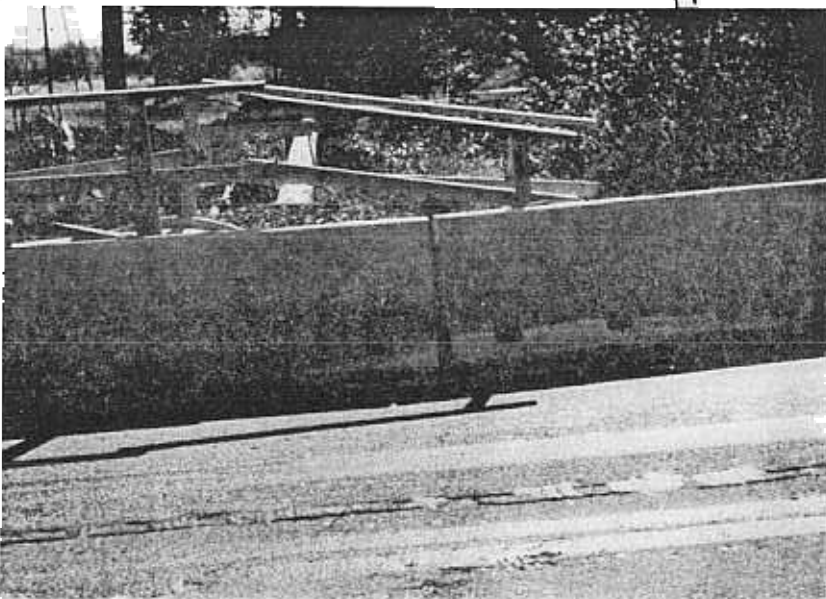
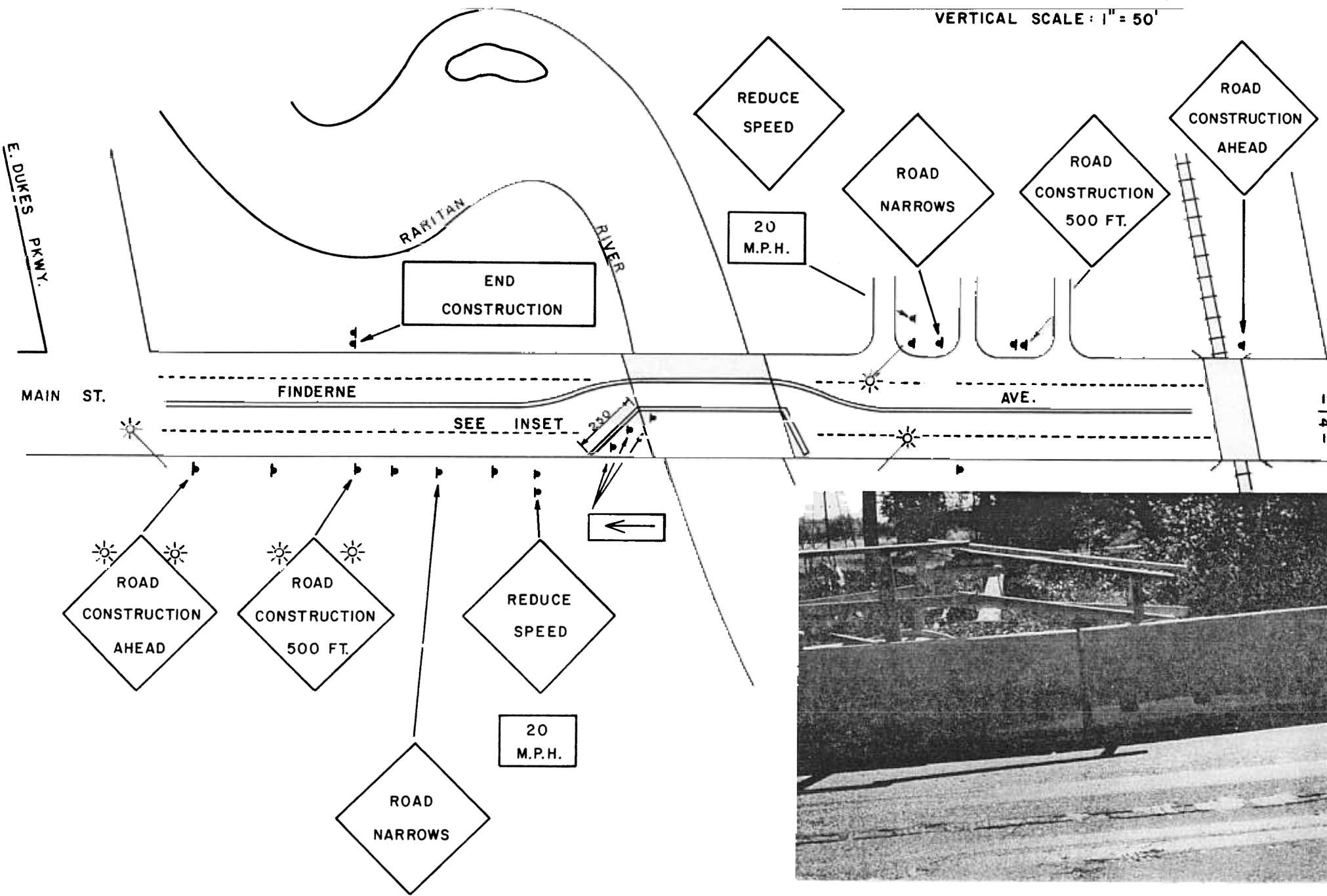


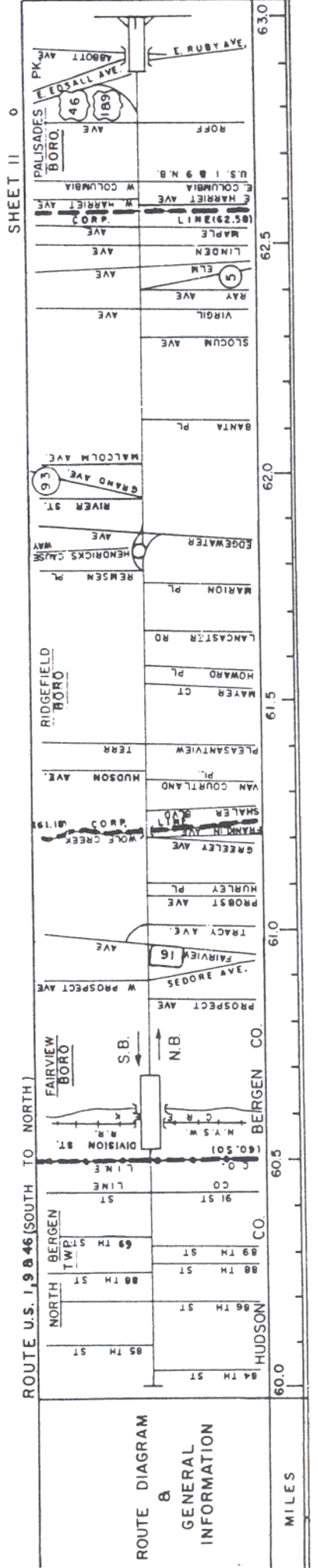
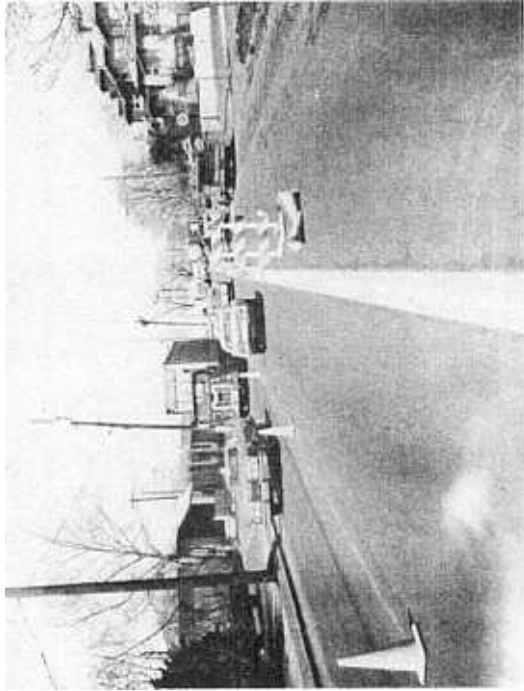
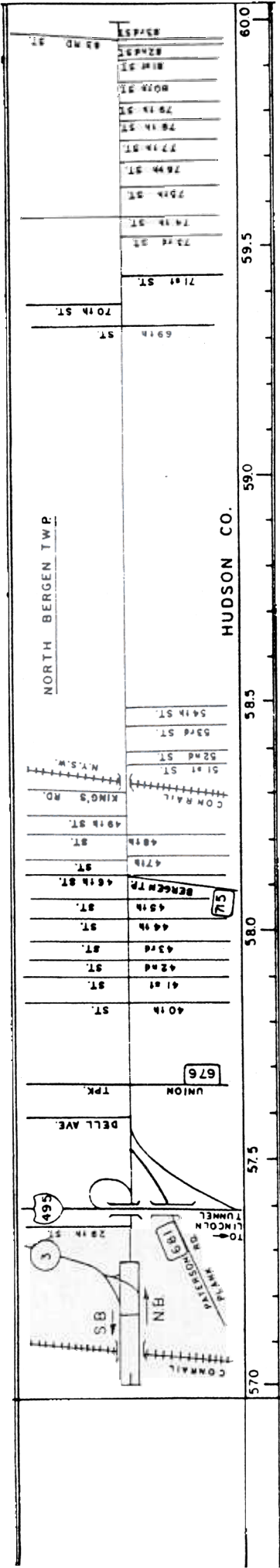
FIGURE #2 - VAN VEGHTEN BRIDGE SCHEMATIC

HORIZONTAL SCALE: 1" = 500'
VERTICAL SCALE: 1" = 50'



INSET - TIRE MARKS ON BARRIER

F U & CH MAT C



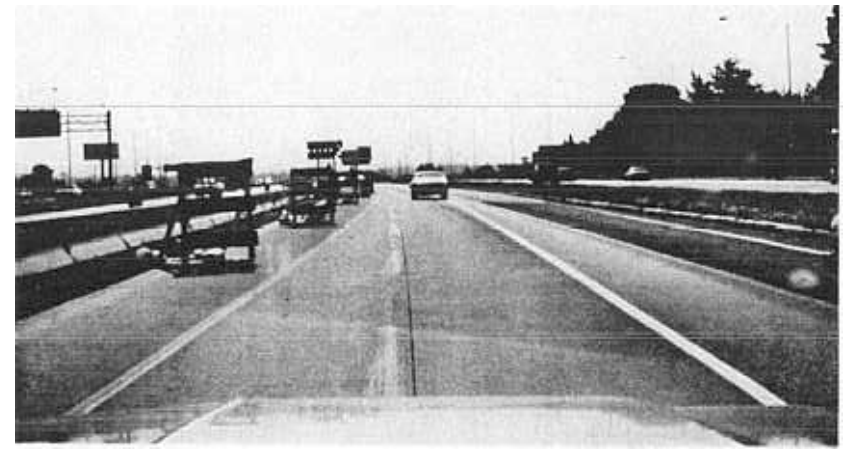
ROUTE DIAGRAM & GENERAL INFORMATION

MILES

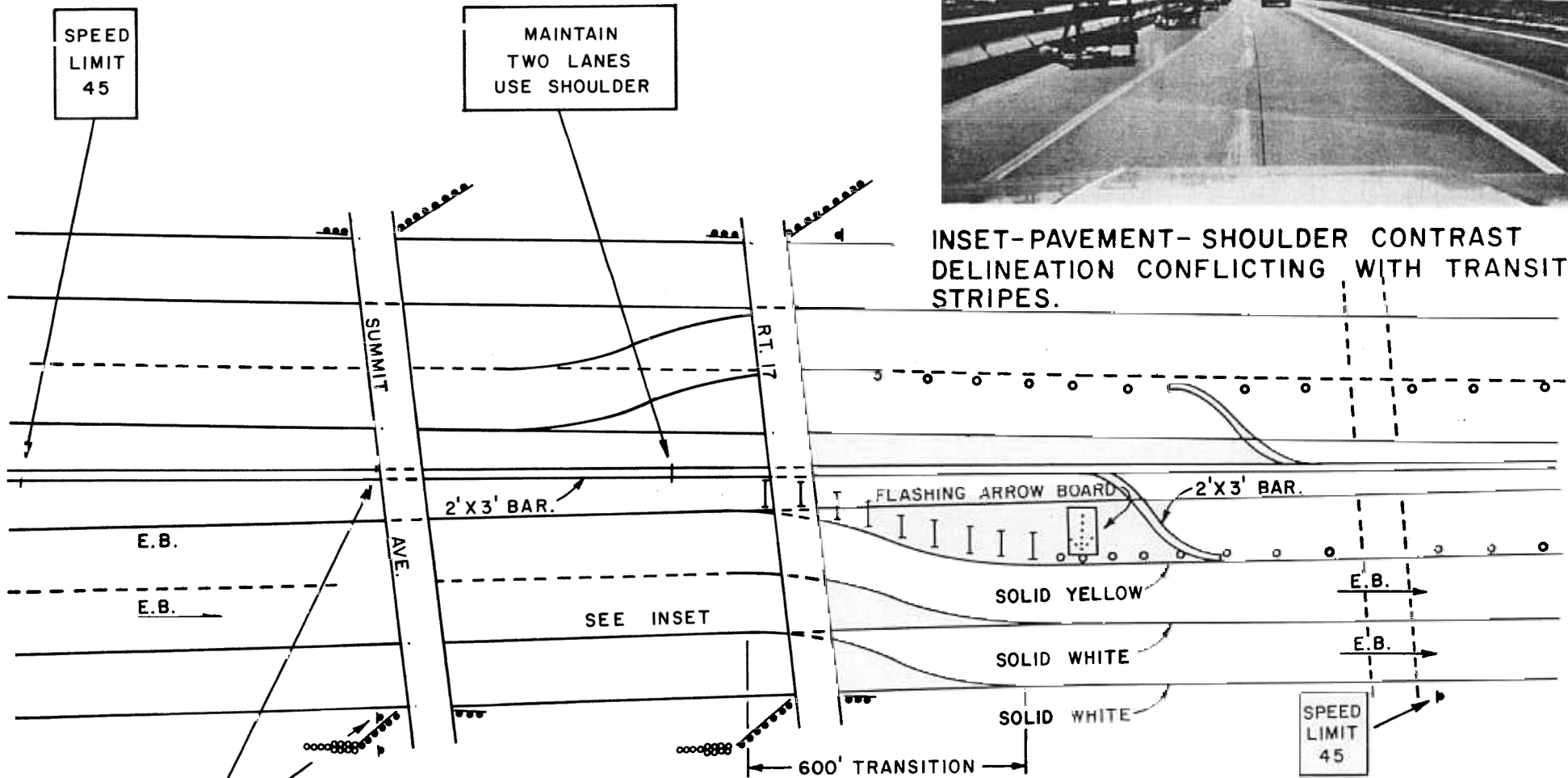
along the right lane edge line. Placed in that manner there was no deceleration area or storage for disabled vehicles. In order to enter a restaurant on the right, drivers had to decelerate in the right hand lane and pull into an entrance gore between the barricades for a turn into the parking lot. Drivers were observed stopping between the barricades with part of their vehicle still in the lane. They must stop because they have to look up an exit ramp which they have to cross to get into the restaurant's parking lot. Drivers coming down the exit ramp onto Route 46 had to look between these barricades for an appropriate place to merge into the flow of traffic. It was further observed that each barricade was only partially visible because it was blocked by the barricade in front.

I-80 (FIGURE 5) - The left lane in both directions was closed with Type III barricades mounted with steady burn lights, concrete barrier curb, and flashing arrow board. The shoulder was used as a lane to maintain two lanes of traffic. In the transition the old striping was removed and new striping applied. However, vehicles were observed still following the old alignment especially where there was a contrast between pavement and shoulder

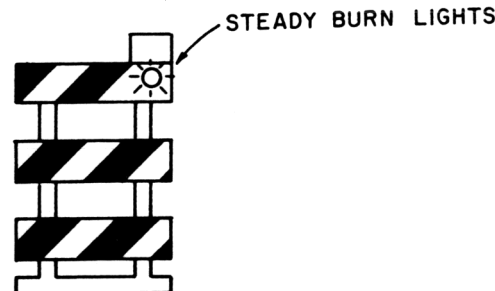
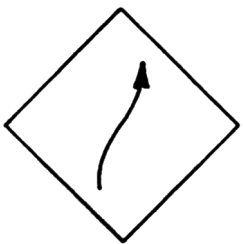
FIGURE #5 - I-80 SCHEMATIC



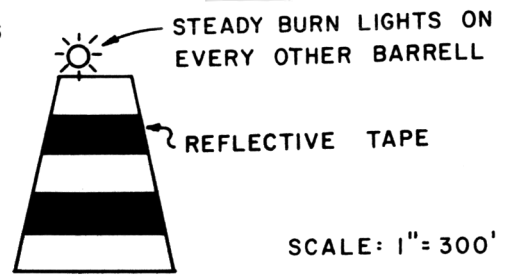
INSET-PAVEMENT-SHOULDER CONTRAST DELINEATION CONFLICTING WITH TRANSITION STRIPES.



-18-



BREAKAWAY BARRICADE (I)



PLASTIC BARREL (O)

SCALE: 1" = 300'

Driver Performance Measures

Finally, where warranted from accident and observation studies, driver performance pilot studies were conducted measuring vehicle speeds and lane distributions and motorists actions such as lane weaving and encroaching.

(Figure 5) was a 600 ft. two lane diversion with the left lane closed and the right shoulder used as a lane. In the eastbound approach the pavement was concrete with an asphalt shoulder and in the westbound the pavement was asphalt with an asphalt shoulder. The speed limit was reduced from 55 mph to 45 mph. Drivers were to maintain two lanes and use the shoulder, as directed by signs and a solid lane line. Forty-five (45) minute lane change and encroachment samples were tabulated and proportions were computed for each maneuver. For example, in 45 minutes, 26 out of 822 or 3.16 percent of the total vehicles changed lanes on the west bound asphalt pavement -- asphalt shoulder transition. Ninety-five percent (95%) confidence limits for the proportions were computed by the binomial approximation. The data can be summarized as follows:

<u>Maneuver</u>	<u>Pavement</u>	<u>Number</u>	<u>Volume</u>	<u>Percent</u>	<u>Direction</u>
Lane Change	Asphalt	26	822	3.2	WB
	Concrete	55	595	9.2*	EB
Encroachment	Asphalt	37	822	4.5	WB
	Concrete	25	595	4.2	EB

*Significant at 95% confidence level

The eastbound concrete-asphalt transition experienced a significantly higher rate of lane changes compared with the westbound asphalt-asphalt transition. Perhaps the delineation provided by the contrasting pavements and pavement joints influenced some drivers to follow the old alignment

more than the painted stripe. The painted stripe on the asphalt-asphalt transition was more obvious than on the concrete-asphalt transition.

Next the speeds were analyzed for both directions. The data can be summarized as follows:

	<u>Asphalt Pavement(WB)</u>		<u>Concrete Pavement(EB)</u>	
	<u>Approach</u>	<u>Transition</u>	<u>Approach</u>	<u>Transition</u>
Sample Size	91	100	68	50
Mean Speed (mph)	49.8	50.9	55.9	50.3*
Speed Variance (mph) ²	17.9	22.8	27.2	40.2

*Significant at the 95% confidence level.

On the concrete-asphalt transition not only were the lane changes higher, but the mean speeds dropped more compared with the asphalt-asphalt transition. Clearly a need for improved delineation was called for.

EXPERIMENTAL DELINEATION IMPROVEMENTS

The Positive Guidance procedures coupled with construction zone delineation committee involvement led to the selection of six experiments to be conducted on four upcoming construction projects. (The projects utilized during the needs study were completed by this time

1. Reflectors vs. Steady Burn Lights
2. Tall Vertical Panels vs. Type III Barricades
3. Removable Tape as a Paint Replacement
4. Raised Pavement Markers as a Paint Supplement
5. Raised Pavement Markers as a Paint Replacement
6. Marker-Adhesive Evaluation

Reflectors vs. Steady Burn Lights

The committee suggested that reflectors be evaluated to supplement or replace steady burn lights on construction barrier curbs, reflectors being:

- not dependent on batteries, therefore requiring less maintenance and being more reliable,
2. less likely to be vandalized,
3. easily checked in the day (steady burn intensity can only be checked at night), and
4. less expensive initially.

The experiment was performed on a tangent section of barrier curb along the left lane of a controlled access state highway (Garden State Parkway) with no truck traffic.

Yellow steady burn lights (12 units at 180 ft. spacing) were studied in the before condition, and 5" x 10" yellow high intensity retroreflective sheeting panels (24 units at 90 ft. spacing) were studied in the after condition (Figure 6). A control site was used to account for changes in traffic performance due to factors other than the steady burn-reflector change.

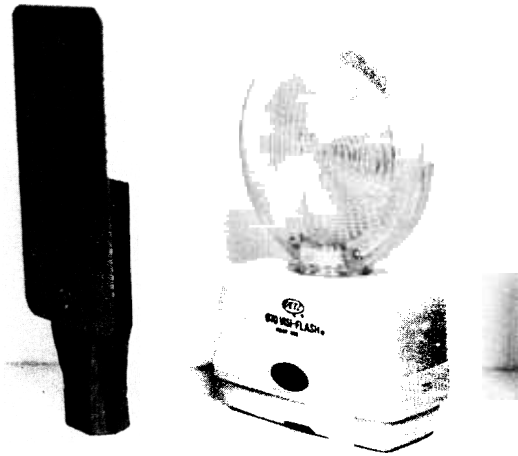
The results revealed that (at the 95% level of confidence) the reflector caused no decrease in the proportion of vehicles using the lane adjacent to the temporary construction barrier (chi-square contingency table test) and caused no change in the mean speed and speed variance (sign test). While the steady burns could be seen by a driver from a distance of 1,800 feet, the reflectors could be seen by a driver from a distance of 1,000 feet which is the minimum preferred distance according to the MUTCD, Section 6D-2. Diagrams and details are in Appendix C.

Tall Vertical Panels vs. Type III Barricades

Type III breakaway barricades appeared to be bulky (4ft. wide x 5ft high) and used up shoulder area and work area. They restricted the view of adjacent merges, and they could not always be seen over the tops of lead vehicles -- a disadvantage when drivers need advance knowledge of changing road geometry (Figure 7).

A recent study demonstrated that "for vertical panels, a tall, narrow shape is recommended over a shorter, wider device. This clear cut lab result should be tested further in the field with the device located in an

Figure#6 - STEADY LIGHT AND 5" x 10" REFLECTOR



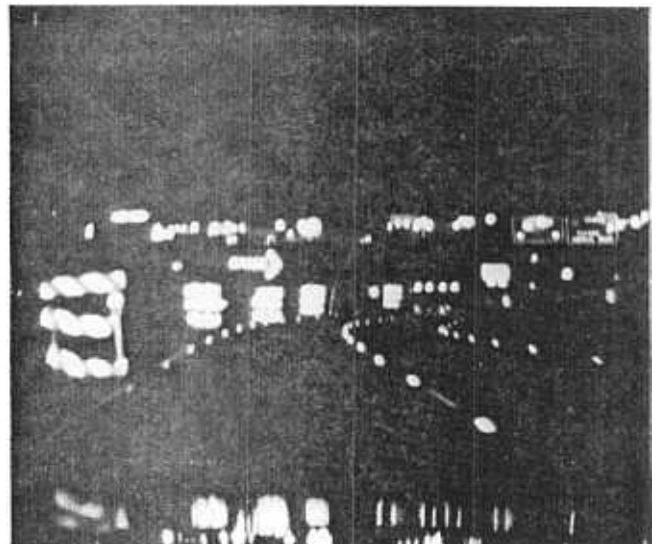
Figure#7 - FOURTH BARRICADE BLOCKED FROM VIEW



Figure#8 - FOURTH PANEL VISIBLE OVER TOP OF CAR



Figure#9 - DIVERSION VISIBILITY WITH RAISED PAVEMENT MARKERS



array and also in a visually cluttered work zone situation in the real world." (2)

A seven foot high, eight inch wide vertical panel to replace Type III barricades was developed (FIGURE 8). The panel was made up of two 4 foot long plastic glare foils bolted together and faced with microscopic vinyl corner diagonal striping. The panels were held upright in plastic barrels weighted with sandbags. A hole in the shape of the panel cross-section was cut on top of the barrel to accommodate the panel. The panels:

1. took up less space horizontally,
2. could be seen over the tops of lead vehicles (Figure 8),
3. could be used in narrow median shoulders to close off a left lane,
4. on impact offer no more hazard than Type III barricades since all components were made of plastic, and
5. were stackable after the panel was easily removed from the barrel.

To test the panels in a real-world situation, a highway diversion (U.S. 46) was selected. During the before study, barricades were installed as usual, and during the after study the barricades were replaced with panels. Mean speeds were compared using an analysis of covariance, speed variances compared with the F-test, and lane changes and encroachments were tested for a difference in proportions. The results of these experiments at the 95% level of confidence were:

1. Average speeds and speed variances did not change during day and night,
2. lane changes did not change during day or night
3. lane changes decreased from 6 percent to 3 percent in rain during

the day and from 8 percent to 3 percent in rain during the night; lane encroachments decreased from 2 percent to 1 percent at night in the rain, and

4. lane line encroachments decreased from 13 percent to 7 percent during the day and from 14 percent to 7 percent at night.

Diagrams and details are in Appendix C.

Removable Tape as a Paint Replacement

The Construction Zone Delineation Committee expressed concern over the difficulty in removing paint on construction zone diversions. To fill the need 3M Stamark removable traffic tape was installed in an interstate diversion. The tape was applied with a special tape dispensing device and pressed to the surface by another device that looked like a hand truck loaded with sandbags (Figure 10). Prior to installation, the concrete pavement was broomed. The tape was applied for 360 feet of lane line separating two lanes and installation took about three minutes. The rest of the diversion pavement markings were ordinary traffic paint. During the day and night, the tape provided delineation comparable to that of ordinary paint (Figure 11). During the 19 days the tape was in place, there were no tears, splits, cracks or bubbles, and the ends adhered firmly to the pavement. Upon removal the tape came up intact and took one laborer about 15 minutes to remove.

To test the long term performance of the tape, samples of tape were placed across the right lane of a state highway. Six thousand vehicles ran over the tape every day, and 12 percent of the vehicles were trucks. After 96 days, the tape still pulled up intact with no pavement damage.

Figure #10- REMOVABLE TAPE
INSTALLATION

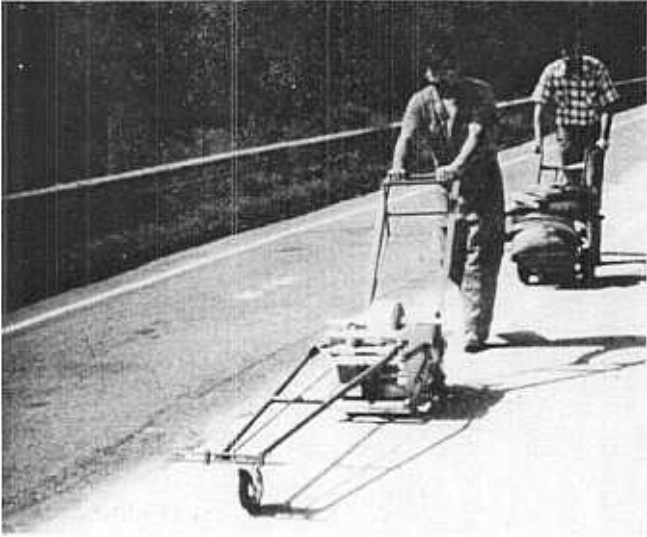


Figure #11- REMOVABLE TAPE
VISIBILITY



Figure #12- DAY VISIBILITY OF
CERAMIC MARKERS



Figure #13- NIGHT VISIBILITY OF
CERAMIC MARKERS



Raised Pavement Markers as a Paint Supplement

During the active site study, pilot studies using driver performance measures indicated that drivers had difficulty maintaining their lanes in construction zone diversions. A need for stronger lane delineation was suggested

Raised pavement markers have been used in construction zones in various states and reports indicate their use is favorable as far as cost, durability, installation, removal, and visibility. However, the markers were not evaluated using driver performance measures

Stimsonite 911-SS markers were installed on an asphalt surface prepared with a liquid primer in a two-lane (U.S. 46) diversion as a paint supplement. In addition to the primer, vehicle pressure was necessary. Failure to follow these steps could lead to marker loss. In the day, the markers were barely visible, and at night, they increased the diversion visibility (Figure 9).

Mean speeds were compared using an analysis of covariance, speed variances were compared using the F-test, encroachments and brake applications were compared by testing for a difference in proportions. The results at the 95% level of confidence were:

1. Mean speeds did not change day or night.
2. In the transition, the speed variance decreased from 19.5 mph² to 8.7 mph² in the right lane at night -- a positive result. There was no change in the left lane.
3. In the approach to the transition where markers were first encountered, the speed variance decreased from 14.3 to 9.7 mph² and from

15.1 to 10.7 mph² in the left and right lanes, respectively, during the day -- a result difficult to explain.

4. Lane changes were reduced from 8 to 6 percent during the day and from 6 to 5 percent during the night.
5. Lane encroachments (wheels cross lane line) were reduced from 2 to 1 percent during the day and from 1 to 0 percent during the night.
6. Rates of brake applications did not change.

Further, the markers were maintenance free and experienced no vandalism over a three week period. The markers were easily removed as two-thirds of were removed unintentionally by a snowplow. Analysis details are in Appendix C.

Raised Pavement Markers as a Paint Replacement

In view of the need for stronger yet removable delineation, Permark P-15 reflective ceramic road markers were installed on a concrete pavement prepared with a liquid primer to replace paint in an Interstate 78 diversion. During the before study the diversion was painted as usual. Then the paint was sandblasted off and ceramic markers were installed at six spacing on both edge and solid lane lines to simulate solid lines throughout the transition for the after study. The pavement was concrete and the shoulder was asphalt.

In the day the markers were not quite as visible as paint (Figure 12), but at night the markers increased the visibility of the transition (Figure

Mean speeds were compared using an analysis of covariance, speed variances were compared using the F-test and the lane changes, encroachments and brake applications were compared by testing for a difference in proportions. The results at the 95% level of confidence were:

Mean speeds and speed variance did not change during the day night.

2. Lane changes decreased for both day and night conditions from 11 percent to 6 percent and from 16 percent to 3 percent, respectively, indicating that vehicles better maintained their lane positions.
3. Lane line encroachments (wheels crossing line) decreased at night from 4 percent to 1 percent.
4. Brake light observations did not change during the day and night.

There were problems with the ceramic markers, the only available day visible markers. Twenty-five percent of the markers were lost or damaged, possibly due to a combination of traffic and installation technique. ceramic markers were also installed in another site that was an asphalt diversion off of an existing concrete interstate. A different contractor installed the markers, and only three percent of the markers were mostly on the concrete section. So, pavement type could also be a factor in marker losses.

Marker-Adhesive Evaluation

Since the use of raised pavement markers in construction zone diversions improved driver performance, further research was needed to find:

- 1 an alternate adhesive system for laying down temporary raised pavement markers. In the present system, a primer is necessary for good adhesion. The primer must dry for a few minutes. Then a vehicle must be driven over the marker. In practice, these steps may not be followed and the markers may fall off the pavement. During the marker-paint replacement experiment, 25 percent of the ceramic markers were lost. A non-primer adhesive that was easy to handle manually, requiring no bulky or special equipment to install, and allowed traffic to travel on it after a short time was sought
2. a low priced marker; markers now used in construction zones tend to be expensive since they are designed for permanent installation in snow free states.

Adhesives

The Ohio Department of Transportation tested several adhesives for use in adhering reflectors to snowplowable raised pavement marker castings. Two adhesives were considered satisfactory as they offered good adhesion.

1. Liquid Nail LN 601
Maco Adhesion
SCM Corporation
2. PL 400
B. F. Goodrich
Construction Materials

It was felt that these adhesives along with

3. H. B. Fuller SC-1189

Assembly Products Division

which was sent by the temporary marker manufacturer, offered the potential for easy installation and removal as well as sufficient durability.

The following marker was tested:

Temporary Construction Marker (TCM)

Flex-O-Lite

Division of General Steel Industries

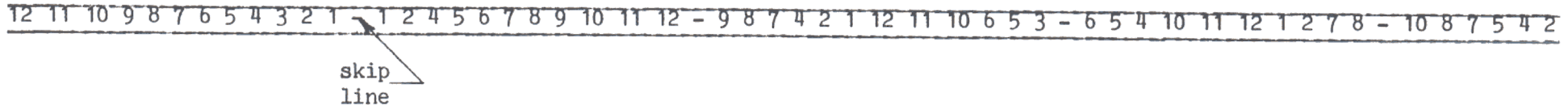
The marker was made of polystyrene plastic and had a waffle bottom construction for epoxy applications. The markers were also available with a butyl pad already in place. Currently, Stimsonite 911-SS (used in the marker with paint experiment) and Permark P-15 (used in the marker without paint experiment) are used in construction zones.

The three markers were applied with the three adhesives and with butyl adhesive. The markers were installed on asphalt and concrete sections of interstate highways and they were located where they would experience hits from weaving traffic (Figure 14). The pavement was dry and the temperature ranged from 50° F to 60° F. The adhesives came in tubes and were applied to the marker with a caulking gun. One hour was allowed for the adhesive to set before traffic was permitted to travel over the markers. The adhesives fully cured after 24 hours.

Figure 15 shows the endurance of four adhesive systems after 44 days of exposure to traffic. The following trends can be noted:

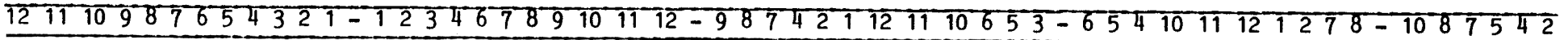
FIGURE 14

GEOMETRIC LAYOUT FOR MARKER-ADHESIVE EXPERIMENT



I-78 Westbound (AADT = 20.0)

Asphalt Pavement



I-287 Northbound (AADT = 19.1)

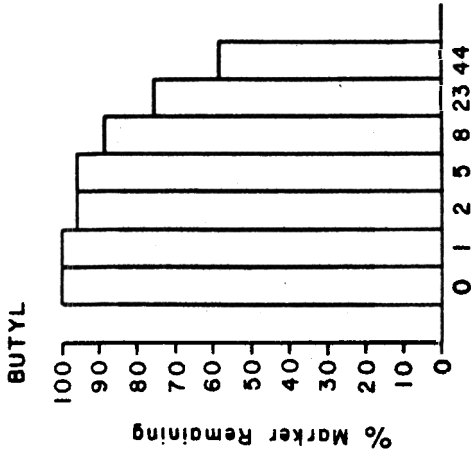
Concrete Pavement

KEY

- | | |
|---|---|
| 1. Permark P-15 with Butyl | 7. Permark P-15 with B. F. goodrich PL-400 |
| 2. Stimsonite 911-SS | 8. Stimsonite 911 with B. F. Goodrich PL-400 |
| 3. Flex-O-Lite TCM with Butyl | 9. Flex-O-Lite TCM with B. F. Goodrich PL-400 |
| 4. Permark P-15 with SCM Liquid Nail 601 | 10. Permark P-15 with H. B. Fuller SC 1189 |
| 5. Stimsonite 911 with SCM Liquid Nail 601 | 11. Stimsonite 911 with H. B. Fuller SC-1189 |
| 6. Flex-O-Lite TCM with SCM Liquid Nail 601 | 12. Flex-O-Lite TCM with H. B. Fuller SC-1189 |

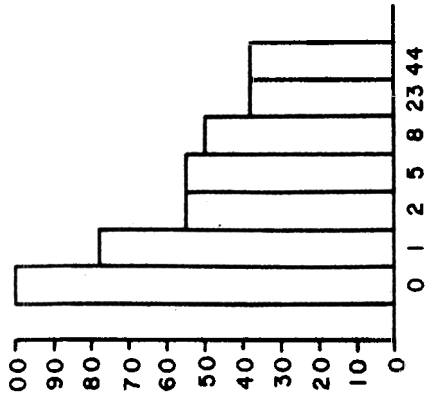
FIGURE #15 MARKER - ADHESIVE DURATION

ADHESIVE DURATION



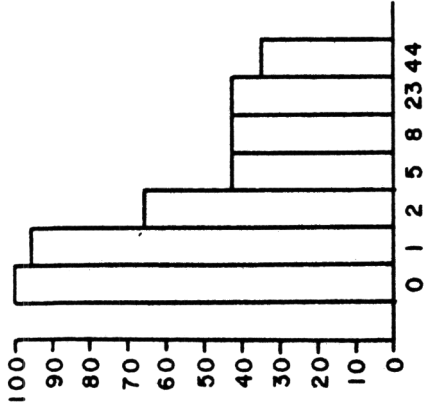
No. Days Markers in Place

FULLER



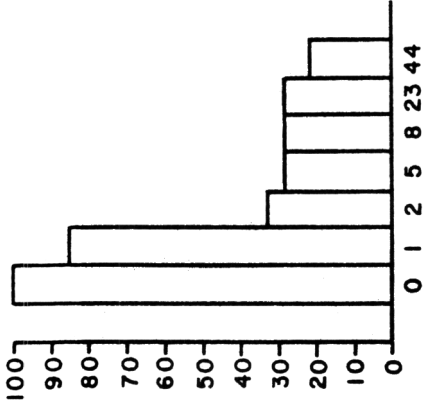
No. Days Markers in Place

PL-400



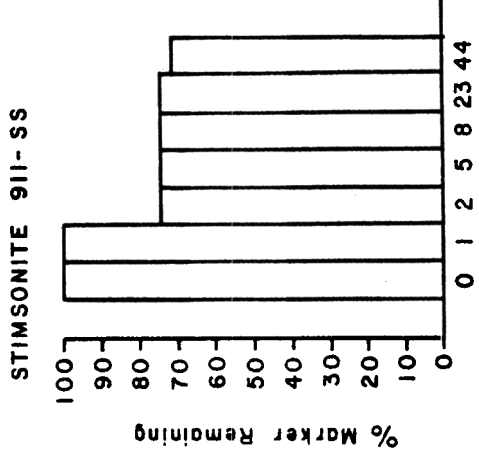
No. Days Markers in Place

LIQUID NAIL 601



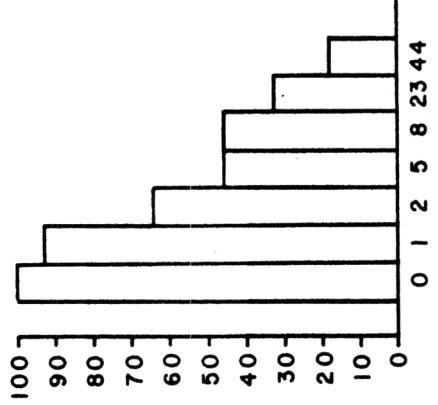
No. Days Markers in Place

MARKER DURATION



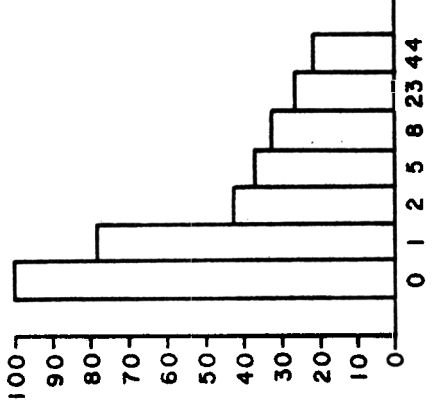
No. Days Markers in Place

FLEX-O-LITE TCM



No. Days Marker in Place

PERMARK CERAMIC



No. Days Marker in Place

1. The butyl pad proved to be the most durable adhesive with a 42 percent failure rate, though when used with the Stimsonite 911-SS butyl experienced no failures at all.
2. The H. B. Fuller adhesive had a 62 percent failure rate, though when used with the Stimsonite 911, H. B. Fuller experienced a 25 percent failure rate.
3. The PL-400 adhesive had a 65 percent failure rate
4. Liquid Nail 601 had a 79 percent failure rate.

Figure 15 also shows the endurance of the three marker types. The following trends can be noted:

- 1 The Stimsonite 911-SS proved to be the most durable marker with a 29 percent failure rate.
2. The Flex-O-Lite TCM had an 82 percent failure rate. The marker was hollow with 12 compartments, leaving 52 percent of the bottom surface available for adhesion. The adhesives tended to squeeze into the hollow compartments leaving little adhesive left for adhering the marker to the road.
3. The Ferro Permark P-15, the only day visible marker, experienced a 79 percent failure rate. However, when used in conjunction with H. B. Fuller SC-1189, the Permark had a 40 percent failure rate.

Table 2 is a summary of the results for four of the experiments.

TABLE 2

COMPARISON OF EXPERIMENT DRIVER PERFORMANCE MEASURES

MEASURES OF PERFORMANCES	REFLECTORS VS. LIGHTS	TALL PANELS VS. BARRICADES		RPMs WITH PAINTS		RPMs WITHOUT PAINT	
	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
Mean Speeds	0	0	0	0	0	0	0
Speed Variance	0	0	0	0	0	0	0
Lane Weave		0	0				
Lane Encroachment					-	0	
Brake Lights				0	0	0	0

0 = No change from base treatment

- = Decrease (better) from base treatment

= Not measured

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APPENDIX A
COMPLETED SITE ACCIDENT STUDIES

U. S. 1&9, Milepost 35.9 to 38.4 and 136.2 to 136.25

Site Description - Grass or concrete center median divided highway. Three lanes in either direction for the majority of the site, two lanes in a small section, no shoulders, and a 50 mph speed limit. AADT before construction was 51,617 and AADT during construction was 53,264.

Construction Description - Remove existing center island, construct new concrete barrier curb and resurface roadway. All construction operations were performed at night (8:00 p.m. to 6:30 a.m.).

Date of Construction May 1, 1974 to August 13, 1974

Traffic Safety Description Lane closures occurred only at night. During removal and replacement of center barrier, the center lane in either direction was closed with Type III barricades, cones, and flashing arrow boards. Two policemen were also used. Paving operations were carried out with similar safety devices and methods.

Accident Analysis The same months of accident data one year prior to construction were adjusted by AADT and were compared to the accident data period during construction (Table 3). Total accidents decreased 18 percent from 76 to 62. This was not significant at the 95% level of confidence. Overall, this construction zone was not hazardous. Perhaps the presence of police officers as traffic directors had a positive effect on lane shifting maneuvers. More vehicles travelled through the highway segment during construction than a year prior, yet accidents decreased in many categories. The safety setup apparently succeeded in making drivers exert more caution.

TABLE 3

U.S. 1 & 9 ACCIDENT SUMMARY

CONFIDENCE LEVEL - 95%
 STATISTICAL TEST TECHNIQUE · CHI-SQUARE

Evaluation Objective	During	Before	Percent Change		Significant (Yes or No)*
			Observed	Required	
TOTAL ACCIDENTS	62	76	-18	28	No
FATAL ACCIDENTS	0	0	0	*	*
INJURY ACCIDENTS	29	31	- 6	45	No
POD ACCIDENTS	33	45	-27	37	No
FIXED OBJECT	9	12	-25	65	No
SAME DIRECTION	37	48	-23	37	
ANGLE	6	8	-25	*	*
DARK	16	21	-24	54	No
DARK-WET	6	4	50	*	*

*Too small to test

Route 46, Milepost 57.0 to 60.1

Site Description - This was a divided highway with three lanes in both directions, a relatively straight alignment, no signals, and a 55 mph speed limit. AADT before construction was 101,000 and AADT during construction was 107,400.

Construction Description Day - The existing grass median was replaced with a concrete barrier curb and existing beam guide rail was replaced.

Night - Resurfacing.

Date of Construction - January 1, 1976 to October 29, 1976

Traffic Safety Description During the day the express (median) lane was closed while at night two lanes were closed and traffic was maintained in one lane with flashing arrow boards, type III barricades, cones, and uni-formed traffic directors.

Accident Analysis - The same months of accidents one year prior to construction were adjusted by AADT and compared with the same months of accidents during construction (Table 4). Total accidents increased 9 percent from 505 to 548. There were significant changes at the 95% level of confidence as follows:

1. Property damage only accidents increased 24 percent from 293 to 364.
2. Right angle accidents increased 56 percent from 32 to 50.
3. Dark-wet accidents decreased 64 percent from 87 to 31.

TABLE 4

U.S. 46 ACCIDENT SUMMARY

CONFIDENCE LEVEL - 95%
 STATISTICAL TEST TECHNIQUE · CHI-SQUARE

Evaluation Objective	During	Before	Percent Observed	Change Required	Significant (Yes or NO)*
TOTAL ACCIDENTS	548	505	9	18	No
FATAL ACCIDENTS	0	0	0	*	*
INJURY ACCIDENTS	170	199	-15	18	No
PDO ACCIDENTS	364	293	24	18	Yes
FIXED OBJECT	59	81	-27	27	No
SAME DIRECTION	392	366	7	18	No
ANGLE	50	32	56	44	Yes
DARK	152	150	1	22	No
DARK-WET	31	87	-64	26	Yes

* Too small to test

Although there were no dark-wet problems, there was an increase in right angle accidents.

Accident Case Studies

Accident case studies taken from the resident engineers diary were not detailed enough to implicate any need for delineation improvements. In two cases, Type III barricades were hit by drivers, one driver being drunk. In another case, a worker was hospitalized with leg injuries due to being hit by a cone that was struck by a vehicle.

After completing two past sites, it became apparent that there were problems regarding accidents relating to delineation in construction zones. Accident summaries were not sensitive enough to reveal a reliable relationship regarding the effect of delineation or the lack of it. For the next four sites, only construction related accidents were analyzed.

Route 4, Milepost 2.2 to 10.3

Site Description - This was a divided highway with from two to three lanes in each direction. There were two major interchanges and full business access.

Construction Description - Day - none.

Night - Removal of existing median curb and building of a new median curb.

Date of Construction - September 29, 1975 to October 8,

Traffic Safety Description - Type III barricades were set up first as the transition and the Type III's were then set up in the tangent. A truck mounted flashing arrow board was utilized. One lane was maintained when the contractor worked.

Accident Analysis - The accidents studied (four rear-end, two fixed object, one sideswipe) all occurred at night. The accidents indicated that the drivers were caught by surprise by the closure of the left lane with Type III barricades.

Route 31, Milepost 39.5 to 39.9

Site Description An undivided highway with one lane in each direction.
The terrain was hilly and rural.

Construction Description - Day work - bridge removal and reconstruction
Night work - none

Date of Construction October 3, 1977 to May 25, 1979

Traffic Safety Description One lane in each direction was to be maintained. Traffic was channelized with Type II barricades and concrete temporary barriers. The speed limit was dropped from 50 to 35 mph. Old traffic stripe was to be removed and new stripes applied. Barricades were lit with steady burn lights.

Accident Analysis The case studies did not yield any connection between accidents and construction zone delineation.

I-287, Milepost 6.0 to 10.5

Site Description - Divided interstate with a grass median and three lanes in each direction. Lanes were 12 ft. wide and shoulders 10 ft. wide. alignment was straight and there was no access to business driveways.

Construction Description - Day - removal of pavement before and after bridge approaches, repaving entire roadway, replacing existing low center barrier curb with new standard 32 inch high barrier curb, and improving existing beam guide rail.

Night - none

Date of Construction - April 28, 1976 to December 31, 1976

Traffic Safety Description - During construction two lanes of traffic were maintained in each direction, and traffic was maintained with cones, barricades, and uniformed traffic directors. The contractor used flashing arrows on back of work trucks and high intensity lights on barricades.

Accident Analysis - There were seven construction related accidents, none of which could be tied in with a need for delineation improvement. There were three cases of vehicles stopping for construction and being hit behind, one vehicle lost control and ran off the road, and three sideswiped other vehicles.

Route 40 and 322, Milepost 62.0 to 63.5

Site Description A straight run of divided highway with two lanes in each direction separated by a dual face guide rail. Lanes were 12 ft. wide and shoulders were 10 ft. wide. There was access to business driveways.

Construction Description - Day - opening up bridge deck and replacing timber and piling

Night - None

Date of Construction September 16, 1976 to February 18, 1977

Traffic Safety Description One lane in each direction was closed at a time. The closure was maintained with Type III barricades in the transition. Steady burn lights were mounted on the barricades. High intensity lights were used on all advance warning signs and the first barricade. Additionally, three arrows were placed on the transition barricades.

Accident Analysis The case studies did not yield any connection between accidents and construction zone delineation. In one case, a drunken driver hit six barricades destroying three or four. In another case, a driver stopped in the transition although there was no obstruction to traffic and the car behind skidded into the barricades. In yet three other cases, vehicles stopped for construction were hit from behind by other vehicles.

APPENDIX B
ACTIVE SITE ACCIDENT STUDIES

Easton Avenue from Kennedy Boulevard to Cedar Grove Lane

Site Description - This site was a two-lane, undivided roadway with shoulders, ten at-grade intersections, full commercial or residential access and a 30 mph speed limit. AADT prior to construction was 24,400 and AADT during construction was 23,900.

Construction Description - The work consisted of widening, drainage and resurfacing and all work was done during the day. The construction zone was two miles long and was studied for nine months. Traffic was maintained with traffic directors, cones around equipment working in shoulders, plastic barrels along graded areas.

Accident Analysis - Before accidents from April 1, 1977 to December 31, 1977 were adjusted by AADT and compared with during accidents from April 1, 1978 to December 31, 1978 (Table 5). Total accidents increased significantly 40 percent from 83 to 116 and 23 out of 116 or 20 percent of the during accidents were judged to have been related to construction based on driver and police comments. There were also significant increases as follows:

1. Same direction accidents increased 50 percent from 42 to 63.
2. Dark accidents increased 75 percent from 20 to 35
3. Spring accidents increased 80 percent from 20 to 36.

Case Study On August 22, 1978 at 1:50 a.m., two people were injured when their car struck a bridge abutment. The driver said the road narrowed and he did not see the bridge abutment. The driver said the road narrowed and he did not see the bridge. According to police, the roadway was under construction and there were no reflectors on the bridge. Perhaps the edge

TABLE 5

EASTON AVENUE ACCIDENT SUMMARY

CONFIDENCE LEVEL - 95%
 STATISTICAL TEST TECHNIQUE . CHI-SQUARE

Evaluation Objective	During	Before	Percent Observed	Change Required	Significant (Yes or No)*
TOTAL ACCIDENTS	116	83	40	27	Yes
FATAL ACCIDENTS	0	0	0	*	*
INJURY ACCIDENTS	45	31	45	45	No
PDO ACCIDENTS	71	53	34	35	No
FIXED OBJECT	10	14	-29	60	No
SAME DIRECTION	63	42	50	39	
RIGHT ANGLE	16	26	-38	48	No
DARK	35	20	75	55	
WET	29	25	16	48	No
DARK-WET	11	8	38	*	*
SPRING	36	20	80	55	
SUMMER	31	26	19	48	No
FALL	44	33	33	43	No
WINTER	5	4	25	50	No

*Too small to test

of the road could have been better delineated with reflective devices, drums, or barricades. Some barrels were used in the zone but usually they were dirty or knocked over.

Other Studies - The before-during collision diagrams and day of week-time of day tables were made up but they showed no changes.

Conclusions - There appeared to be a need for delineation improvements in view of the increased night and same direction accidents and the case study. Also the construction zone may have generated an element of surprise in view of the increase in spring time accidents, though the increase was evenly spread through the season.

VanVeghten Bridge from East Dukes Parkway to Main Street

Site Description This site was a four lane undivided roadway with a 45 mph speed limit and two lanes in each direction narrowed to one lane in direction to cross a bridge. There was no shoulder, two traffic signals, and full industrial access. Prior to construction, AADT was 18,900 and during construction, the AADT was 18,140.

Construction Description - The construction was done mostly during the with some night work and consisted of bridge deck replacement and widening. Northbound and southbound traffic shared the original southbound side of the bridge and traffic was maintained with a concrete barrier curb between traffic and work area mounted with steady burn lights. The original yellow center line was blacked out and a new double yellow center line was put down. There was an advisory speed limit of 20 mph posted. The transition was 250 ft. long.

Accident Analysis Before accidents from April 17, 1977 to December 31, 1977 were adjusted by AADT and compared with during accidents from April 17, 1978 to December 31, 1978 (Table 6). However, there were not enough accidents to run any statistical tests since there were only seven accidents before and five accidents during construction.

TABLE 6

VAN VEGHTEN BRIDGE ACCIDENT SUMMARY

CONFIDENCE LEVEL - 95%
 STATISTICAL TEST TECHNIQUE - CHI-SQUARE

Evaluation Objective	During	Before	Percent Observed	Change Required	Significant (Yes or No)*
TOTAL ACCIDENTS	5	7	-29	*	*
FATAL ACCIDENTS	0	0	0	*	*
INJURY ACCIDENTS	2	2	0	*	*
PDO ACCIDENTS	3	5	-40	*	*
FIXED OBJECT	1	1	0	*	*
SAME DIRECTION	3	5	-40	*	*
ANGLE	0	1	-100	*	*
DARK	3	3	0	*	*
WET	2	3	-33	*	*
DARK-WET	2	2	0	*	*
SPRING	1	1	0	*	*
SUMMER	1	5	-80	*	*
FALL	3	1	200	*	*
WINTER	0	0	0	*	*

*Too small to test

U.S. 1 & 9 from Milepost 57.36 to Milepost 62.58

Site Description This was a straight and level section of a four lane undivided highway with two lanes in each direction, no shoulders, 67 at-grade intersections, 20 of which were signalized, full commercial access and a speed limit of 35 mph. AADT before was 25,200 and AADT during was 28,940.

Construction Description - The construction zone was five miles long and was studied for nine months. During the day, up to two lanes were closed for drainage work, and at night up to two lanes were closed for resurfacing. Traffic was maintained with cones, Type III barricades, and flashing arrow boards.

Accident Analysis - Before accidents from April 1, 1977 to December 31, 1977 were adjusted by AADT and compared with during accidents from April 1, 1978 to December 31, 1978 (Table 7). Total accidents decreased 15 percent from 494 to 420, and 35 out of 420 or 8 percent of the during accidents were judged to have been construction related based on driver and police comments. There were also significant decreases as follows:

1. Injury accidents decreased 32 percent from 220 to 150.
2. Same direction accidents decreased 26 percent from 258 to 191.

Case Studies - Eleven drivers reported to have run into metal plates over excavations and six drivers ran into arrow boards at night.

Other Studies Before-during collision diagrams and day of week-time of day tables did not show any differences.

TABLE 7

U.S. 1 & 9 ACCIDENT SUMMARY

CONFIDENCE LEVEL . 95%
 STATISTICAL TEST TECHNIQUE - CHI-SQUARE

Evaluation Objective	During	Before	Percent Observed	Change Required	Significant (Yes or No)*
TOTAL ACCIDENTS	420	494	-15	18	No
FATAL ACCIDENTS	4	3	33	*	*
INJURY ACCIDENTS	150	220	-32	18	Yes
PDO ACCIDENTS	266	271	- 1	18	No
FIXED OBJECT	47	55	-15	34	No
SAME DIRECTION	191	258	-26	18	Yes
RIGHT ANGLE	135	130	4	23	No
DARK	151	173	-13	20	No
WET	80	98	-18	25	No
DARK-WET	39	31	26	45	No
SPRING	104	129	-19	23	No
SUMMER	123	152	-19	22	No
FALL	173	193	-10	19	No
WINTER	20	20	0	55	No

*Too small to test

Conclusions The decreases in injury and same direction accidents could have been due to a more cautious attitude on the part of drivers. Overall construction constraints seemed to improve the accident picture. The detailed police reports did not yield any clues as to why drivers were hitting arrow boards at night.

U.S. 46 from Milepost 70.50 to Milepost 72.15

Site Description This was a divided highway with three eastbound lanes four westbound lanes, shoulders, no traffic signals, full commercial access, and a 50 mph speed limit. The construction zone was one mile long and lasted for nine months. AADT before was 56,700 VPD and AADT during was 62,500 VPD

Construction Description - The work consisted of replacing the eastbound bridge deck. Eastbound traffic was diverted over to the westbound half of the bridge and two lanes in each direction were maintained across the bridge. During the month it took to install the temporary barrier curb, the left lanes were closed to traffic with Type III barricades and plastic barrels. Once the curb was installed, Type III barricades and flashing arrow boards in the right lanes were used to reduce traffic to two lanes in each direction across the bridge. The transition was 2250ft. long. A regulatory 35 mph speed limit was posted.

Accident Analysis - Before accidents from April 14, 1977 to December 21, 1977 were adjusted by AADT and compared with during accidents from April 1978 to December 21, 1978 (Table 8). Total accidents increased 11 percent from 75 to 83 , and 16 out of 83 or 19 percent of the during accidents were judged to have been related to construction. There were no significant before-during changes in accidents.

Accident Case Studies - At the eastbound bridge abutment, there were no rear-end or fixed object accidents during construction. Before construction there were four cases of vehicles hitting the guard rail at the bridge entrance and four rear-end collisions in the same area. This 100 percent

TABLE 8

U.S. 46 ACCIDENT SUMMARY

CONFIDENCE LEVEL . 95%
 STATISTICAL TEST TECHNIQUE - CHI-SQUARE

Evaluation Objective	During	Before	Percent Change		Significant (Yes or No)*
			Observed	Required	
TOTAL ACCIDENTS	83	75	11	28	No
FATAL ACCIDENTS	0	0	0	*	*
INJURY ACCIDENTS	33	31	6	45	No
PDO ACCIDENTS	50	44	14	37	No
FIXED OBJECT	11	18	-39	55	No
SAME DIRECTION	43	42	2	40	No
	17	8	113	*	*
	32	32	0	45	No
	16	26	-38	49	No
DARK-WET	9	20	-55	55	No
SPRING	13	19	-32	55	No
SUMMER	34	24	42	51	No
FALL	36	32	13	45	No
WINTER	0	0	0	*	*

*Too small to test

decrease in accidents was significant at the 95% level of confidence. During construction, the bridge abutment and approach was better delineated than it was before construction. Also, vehicle speeds averaged 33 mph during construction and the posted speed limit was lowered from 50 to 35 mph. All of the before accidents at the bridge abutment occurred at night mostly on wet pavement.

Other Studies Before-during day of week-time of day tables did not show any difference.

Conclusions - Construction activity at this site appeared to reduce many accident categories.

I-80 from Milepost 60.53 to Milepost 68.30

Site Description This was a divided interstate with four to five lanes in each direction. AADT before construction was 103,930 VPD and during construction was 103,640 VPD.

Construction Description The work zone was 7.5 miles long and consisted of overhead sign post protection, guide rail replacement, and new light standard installment. Most of the work was done off the road and during the day and traffic was maintained with Type III barricades and drums about a month, there was a one-mile long traffic diversion for sign post work. The median lane in each direction was closed using Type III barricades with steady burn lights, concrete barrier curbs, and flashing arrow boards in the transition, and plastic barrels with steady burn lights in the tangent. To maintain two lanes the shoulder was used as a lane. Also a regulatory speed limit of 45 mph was posted. Transition length was 600 ft.

Accident Analysis Before accidents from April 1, 1977 to December 31, 1977 were adjusted by AADT and compared with during accidents from April 1 1978 to December 31, 1978 (Table 9). Total accidents decreased one percent from 564 to 560 and six out of 560 or one percent of the during accidents were judged to have been related to construction. There were also significant changes as follows:

- 1 Spring accidents increased 38 percent from 124 to 171.

Other Studies Before-during day of week and time of day tables showed no changes

TABLE 9

I-80 ACCIDENT SUMMARY

CONFIDENCE LEVEL . 95%
 STATISTICAL TEST TECHNIQUE - CHI-SQUARE

Evaluation Objective	During	Before	Percent Observed	Change Required	Significant (Yes or No)*
TOTAL ACCIDENTS	560	564	- 1	18	No
FATAL ACCIDENTS	4	0	*	*	*
INJURY ACCIDENTS	193	223	-13	18	No
PDO ACCIDENTS	363	341	6	18	No
FIXED OBJECT	134	128	5	23	No
SAME DIRECTION	329	335	- 2	18	No
ANGLE	51	56	- 9	34	No
DARK	206	208	- 1	18	No
WET	148	179	-17	20	No
DARK-WET	60	80	-25	28	No
SPRING	171	124	38	23	Yes
SUMMER	176	193	- 9	20	No
FALL	192	226	-15	18	No
WINTER	21	21	0	55	No

*Too small to test

Conclusions - The original installation of construction zones may have generated an element of surprise in view of the increase in spring time accidents. Overall there was very little change in the accident picture.

APPENDIX C
EXPERIMENTS

REFLECTORS VS. STEADY BURN LIGHTS

Introduction

To determine how the switch from steady burn lights to reflectors for delineating a concrete barrier affected traffic flow through the zone, several measures of effectiveness were used: lane distribution, speed, and visibility. The lane distribution data was collected to show how well the vehicles maintained positions in the lane next to the barrier curb, the speed data was to show how smooth traffic flow was, and the visibility data was to show how far away each device could be detected. During the before study, steady burn lights were mounted on the barrier curb and during the after study, reflectors were mounted on the barrier curb. A control was utilized to check for changes in traffic due to factors other than the reflector treatment.

Description

Components - The "before" tests utilized 12 standard size steady lights spaced every 180' on top of the center barrier. They were in good condition and had new batteries and they were maintained throughout the experiment.

The "after" tests used a standard yellow high intensity encapsulated reflective sheeting mounted on an aluminum plate. The units were new and measured 5" by 10", which area was equivalent to the area of the steady burns. One screw held the reflector to an 8" long piece of 2 x 3 wood support, and the 2 x 3 was in turn taped into a special slot built into the top of the barrier. A total of 24 reflectors were used, spaced at intervals. A cluster of three steady burns was left at the beginning of the barrier for both the before and after tests.

Site Description - The evaluation was conducted on the Garden State Parkway, a controlled access highway with three lanes (Figure 16) in each direction separated by a median under construction. Trucks are not allowed on the Garden State Parkway.

Test Site - 2,000 ft. of barrier curb located along the edge of the median. Drivers entered the site after coming downhill.

Control Site - 3,700 ft. of barrier curb located along the edge of median, 4,000 ft. upstream of the test site. Drivers leave the site going uphill.

Data Collection

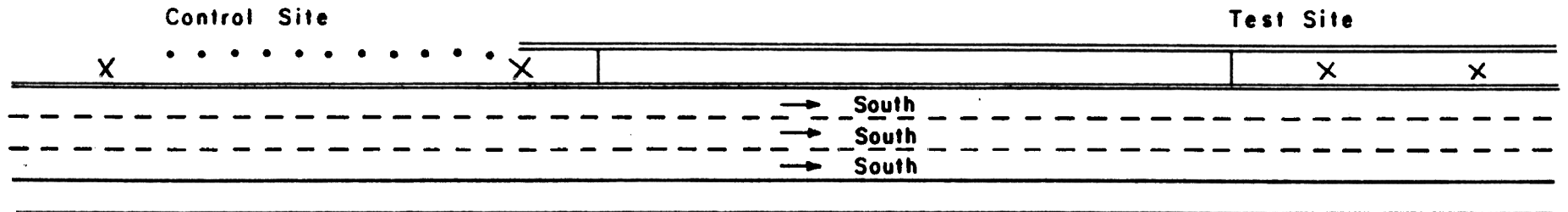
Data was collected at the four locations by two hidden observers. counted all vehicles in each of the three southbound lanes. The other observer took speed data from a radar unit positioned behind the barrier to pick up only the barrier lane speeds (see Figure 16).

Observation of traffic was conducted between the hours of 9 p.m. to 11 p.m. in increments of 15 minutes per observation location. One hour of data was recorded per day. Monday through Thursday.

Data Analysis

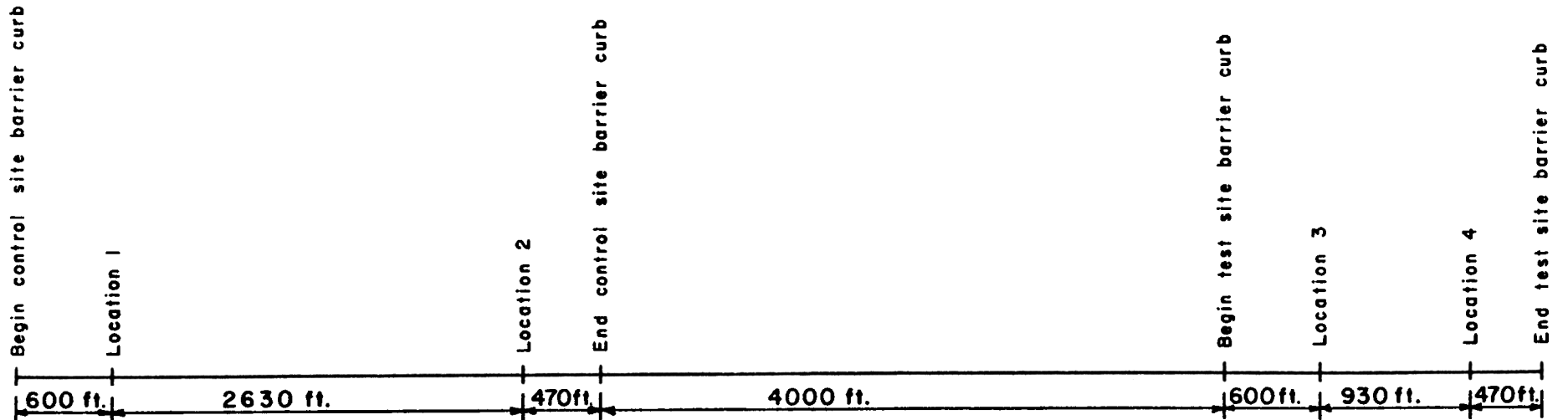
Lane Distribution - Comparisons were made using chi-square (x^2) contingency tables (7) to test if the results under different sets of conditions (test. control, before, after, particular lane) are independent of one another. If they are not, it might be inferred that the change from a control to a test section was the cause of the difference, etc.

FIGURE #16 REFLECTOR - STEADY BURN SITE SCHEMATIC



Legend

- Plastic barrel
- Concrete barrier curb
- X Observation location



Although it is possible to construct a three-way contingency table, this test will be sensitive to all factors such as the difference between middle and shoulder lanes and, therefore, not as useful. A simpler and more meaningful approach was to use the control data to confirm that basic test conditions are essentially the same both before and after reflectors were installed. Provided this is true, the test data can then be analyzed directly.

The data from the two test locations and the control locations are so nearly identical in regard to the proportion of vehicles in each lane that this data has been combined to yield one set of data for the test and control sections both before and after the reflectors were installed. data can be summarized as follows:

	<u>Test</u>	<u>Control</u>
Before	R: 764 (30.9%)	R: 780 (25.9%)
	M: 1034 (41.8%)	M: 1358 (45.1%)
	L: 677 (27.3%)	L: 874 (29.0%)
After	R: 1148 (29.1%)	R: 1027 (27.1%)
	M: 1685 (42.8%)	M: 1701 (44.9%)
	L: 1107 (28.1%)	L: 1057 (27.9%)
Where	R = right lane	
	M = middle lane	
	L = left lane	

and numbers represent vehicle counts

It is apparent from the percentage in the above table that there is very little difference in the lane-to-lane distribution of vehicles under before-after and test control conditions. Statistical tests were run to check this, however

First, the control site lane distribution was compared before and after the installation of reflectors.

	<u>Left Lane</u>	<u>Other Lanes</u>	<u>Total</u>
Before	874(a)	2138(b)	
After	<u>1057(c)</u>	<u>2728(d)</u>	
	1931	4866	6797

$$\chi^2 = \frac{(\sum ad - bc)^2 - N/2)^2 N}{(a+b)(a+c)(b+d)(c+d)} = 0.93$$

$$df = 1(2 \times 2 \text{ table})$$

$$\chi^2_{1, @ 0.95} = 3.84 \quad \text{Not Significant}$$

The results from the control site (before and after installation of the reflectors) do not come close to achieving statistical significance in regard to the proportion of vehicles using the barrier lane. Thus, it seems satisfactory to assume that the basic conditions are essentially identical so that a comparison of the test site (before and after) can be made.

Next, the test site was compared by the same method.

	<u>Left Lane</u>	<u>Other Lanes</u>	<u>Total</u>
Before	677	1798	2475
After	<u>1107</u> <u>1784</u>	<u>2833</u> <u>4631</u>	<u>3940</u> <u>6415</u>

$$\chi^2 = 0.38$$

$$df = 1$$

$$\chi^2_{1, @ 0.95} = 3.84 \quad \text{Not Significant}$$

This indicates that the slight difference in the proportion of vehicles

in the barrier lane is not great enough to be attributed to anything other than chance effect.

Speeds

Comparisons were made using a sign test for two independent samples(7). First the sign test was applied to the control data to confirm that the basic test conditions were essentially the same both before and after the reflectors were installed. Provided this is true, the test data can then be analyzed directly.

The control data can be summarized as follows:

Light	44.9	55.3	55.4	45.9	53.3	54.7		
<hr/>								
Reflector	45.5	56.0	46.8	58.2	52.6	49.1	57.3	49.9

The median is 52.95 and the resulting signs are as follows:

Light		+	+		+	+		
Reflector		+	-	+	-			+
		<u>+</u>	<u>—</u>	<u>Total</u>				
Light		4	2	6				
Reflector		<u>3</u>	<u>5</u>	<u>8</u>				
		7	7	14				

$$x^2 = 0.29$$

$$d.f. = 1$$

$$x^2 @ 95\% = 3.85 \quad \text{Not Significant}$$

The results from the control site (before and after installation of the reflectors) do not come close to achieving statistical significance in regard to the mean speed of vehicles using the barrier lane. Thus, it

seems satisfactory to assume that the basic conditions are essentially identical so that a comparison of the test site (before and after) can be made.

Next, the test site was compared by the same method.

Lights	55.4	55.6	52.6	55.8	55.4			
Reflectors	54.9	48.9	56.6	58.2	53.4	47.0	55.2	47.5

Median = 55.2

Lights + + - + +

Reflectors + +

Lights	$\frac{+}{4}$	$\frac{-}{1}$	Total 5
--------	---------------	---------------	------------

Reflectors	$\frac{2}{6}$	$\frac{6}{7}$	$\frac{8}{13}$
------------	---------------	---------------	----------------

$$x^2 = 1.86$$

d.f. = 1

$$x^2 @ 95\% = 3.85 \quad \text{Not Significant}$$

This indicates that the slight difference in the mean speed in the barrier lane is not great enough to be attributed to anything other than chance effects

The speed variances were handled in the same manner. First, the control site.

Lights	35.3	18.6	14.1	28.9	29.2	17.7		
Reflectors	21.2	14.7	17.6	11.4	6.4	18.7	14.0	21.9

Median = 18.15

Lights + + + +

Reflectors + - - + +

	<u>+</u>	<u>-</u>	<u>Total</u>
Lights	4	2	6
Reflectors	$\frac{3}{7}$	$\frac{5}{7}$	$\frac{8}{14}$

$$\chi^2 = 0.29$$

d.f. = 1

$$\chi^2 @ 95\% = 3.84 \text{ Not Significant}$$

Then, the test site.

Lights 20.2 10.6 19.3 18.3 18.8

Reflectors 9.5 23.5 6.3 25.2 12.8 20.2 9.9 39.1

Median = 18.8

Lights + - +

Reflectors - + + + - +

	<u>+</u>	<u>-</u>	<u>Total</u>
Lights	2	3	5
Reflectors	$\frac{4}{6}$	$\frac{4}{7}$	$\frac{8}{13}$

$$\chi^2 = 0.05$$

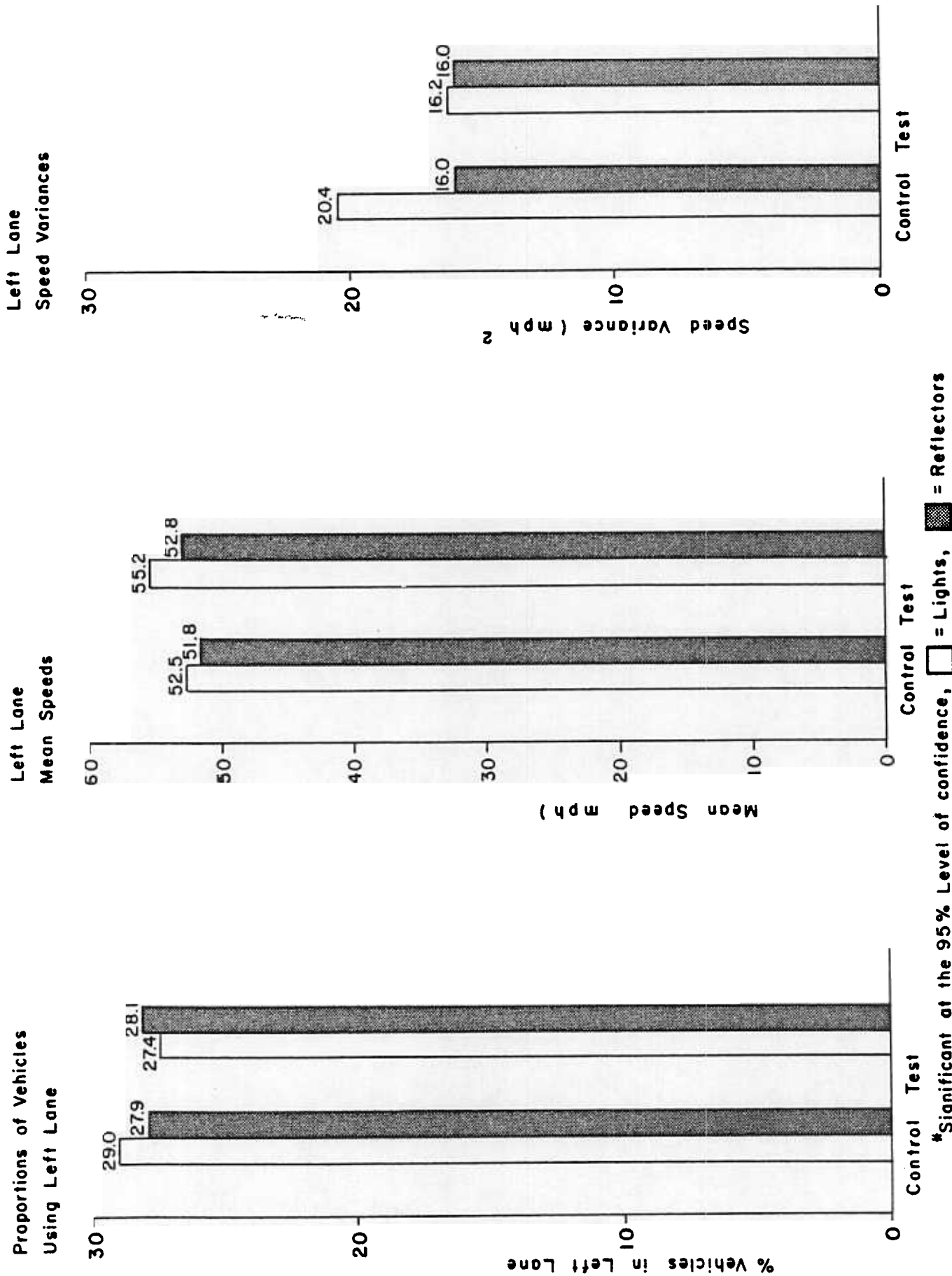
d.f. = 1

$$\chi^2 @ 95\% = 3.84 \text{ Not Significant}$$

Conclusions

Figure 17 indicates the small changes in vehicle proportions, mean speeds and speed variances of vehicles using the barrier lane in the control and test sites. The chi-square tests showed no significant statistical differences.

FIGURE #17 REFLECTOR - STEADY BURN BEFORE - AFTER COMPARISONS.



TALL VERTICAL PANELS VS. TYPE III BARRICADES

Description

Experiment Site Our aim was to choose a site that exposed the tall vertical panels to heavy, fast traffic in a commonly encountered, yet critical geometric situation. The site selected was one direction of a U.S. 46 diversion. The surrounding area was commercial and the AADT was 19,300 vehicles. Prior to construction, there were two lanes and a shoulder. During construction, the left lane was closed to traffic as shown in Figure 19 and the shoulder was utilized as an additional lane. Access control was restricted at this interchange type site.

Field Installation - In the before study, five Type III breakaway barricades were placed every 50 ft. In the after study, Type III's were replaced with the vertical panels spaced every 50 ft. (Figure 18). The barrels were turned so that the flat side faced traffic.

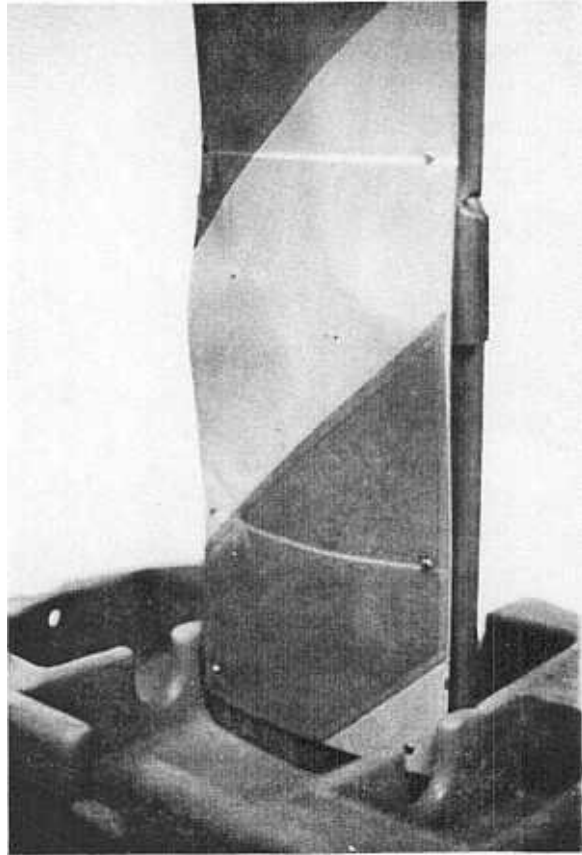
During the first attempt to install the panels there was a heavy rain driven by winds gusting to 60 mph. One panel was installed with two 20 pound sand bags placed in the barrel. The panel remained upright for a half hour before a gust brought it down and it fell parallel to the road even though the wind was blowing perpendicular to the road. The same wind also relocated or toppled Type III's used throughout the construction zone

In the next attempt, the panels were installed successfully with four 20 pound sand bags placed in the barrels.

The panels remained in place for 15 days with no major difficulties. The second panel in the array was struck by an auto and the barrel holding it broke away from its base. The panel, however, remained intact and was reused.

FIGURE 18

DETAILS



Evaluation Plan




Measures of Effectiveness When traffic is moved from its normal path without reducing the number of lanes, drivers should maintain their own lane and follow the lane diversion without encroaching on adjacent lanes or severely changing speeds. Therefore, three performance measures were used, namely:

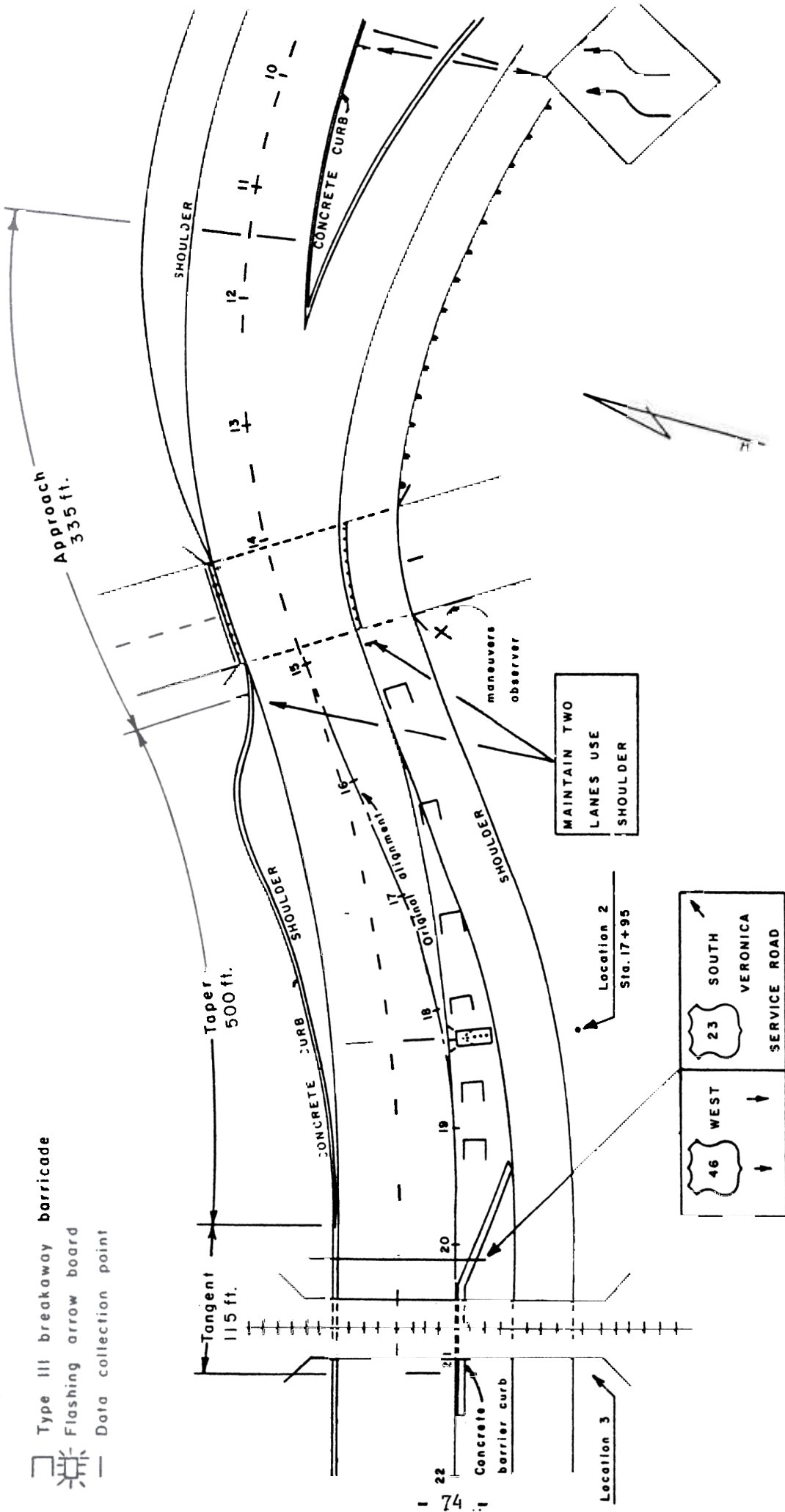
1. lane distribution
2. lane changes and encroachments on other lanes, and
3. speed

An encroachment occurred when the wheels of a vehicle went across the lane line.

Figure #19 PANEL - BARRICADE SITE SCHEMATIC

Legend

-  Type III breakaway barricade
-  Flashing arrow board
-  Data collection point



Experimental Design A before-after design was selected. Before data (barricades) was taken Tuesday through Thursday from 3:45 p.m. to 8:15 p.m. Following a six day acclimation period, after data (panels) was taken on the same days and times by the same data collectors under the same climatic conditions as in the before study. Data was collected at three locations:

- Location 1 - in the approach
- Location 2 - in the transition (500 ft.), and
- Location 3 - in the tangent.

For each data collection location, 45 minutes of daytime data collected from 3:45 p.m. to 5:30 p.m. and 45 minutes of nighttime data was collected from 6:30 p.m. to 8:15 p.m. After the data was reduced, tistical tests were run to determined if the markers produced significant changes in vehicle performance.

Data Collection On a typical day, three observers would collect data -- one to collect maneuver and brake light data, two to collect speed and volume data. Data was collected in 15 minute increments followed by 30 minute periods to allow the observers to travel and set up at the next location.

The volume observer used a manual counter to count the number of vehicles in each lane as they passed a given point. The maneuvers observer recorded his data on a manual counter. Finally, the speed observer used a radar unit to record the speeds of vehicles in each lane as they passed a given point to ensure uniformity in readings. The radar antenna was set up on the same spot (i.e., the beginning of the barrier curb) each time aimed at a given landmark such as a street light. Only single vehicle or vehicles leading a platoon were documented.

At Location 1, the vehicles were 335 ft. upstream from the devices and hence assumed to be unaffected by the devices since they were not visible

At Location 2, the vehicles were most affected by the devices. And at Location 3, the vehicles were 115 ft. downstream of the devices and hence, assumed to be no longer affected by the devices.

The observers as well as their vehicles were carefully concealed behind trees or construction barricades and were not visible to passing motorists.

Data Reduction

Lane Distribution Each crew of observers was given a form on which to record volume, lane changing, and encroachment data. Then the lane volumes for each day were recorded on a single table to facilitate further analy-

Next, for each observation location, the counts for each lane were totalled and a proportion of left lane vehicles to total volume at each location was developed. For example, at Location 1, in the day, in the lane, during the before condition 862 out of 1,598 vehicles or 53.9 percent used the left lane. Finally, a set of 95% confidence limits (C.L.) were computed by the binominal approximation (7) as follows:

$$C.L. = P \pm 1.96 \frac{\sqrt{pq}}{\sqrt{n}}$$

where p = proportion of vehicles using left lane

$$q = 1 - p$$

n = total of left and right counts.

The proportions and confidence limits are presented in Table 10.

TABLE 10

PANEL - BARRICADE LANE DISTRIBUTIONS

	<u>Location</u>	<u>Time</u>	<u>Left Lane Volume</u>	<u>Right Lane Volume</u>	<u>Total Volume</u>	<u>95% Confi- dence Limits</u>	
						<u>P</u>	<u>+/-</u>
D	1	Before	862	736	1598	0.539	0.024
		After	918	652	1570	0.585	0.024
A	2	Before	596	950	1546	0.386	0.024
		After	601	889	1490	0.403	0.025
Y	3	Before	601	910	1511	0.398	0.025
		After	678	914	1592	0.426	0.024
N		Before	621	821	1442	0.431	0.026
I		After	779*	769	1548	0.503	0.025
G	2	Before	481	945	1426	0.337	0.025
		After	475	969	1444	0.329	0.024
T	3	Before	509	952	1461	0.348	0.024
		After	495	984	1479	0.335	0.024

*Significant

The confidence limits are plotted in Figure 20, the upper plot for day and the lower plot for night. If the treatment envelope (panels) falls outside the base treatment envelope (barricades), then the difference is statistically significant.

Before-after rain data matched by day and hour was obtained from the experiment. The confidence limits are presented in Table 11.

The confidence limits are plotted in Figure 21, the upper plot for day and the lower plot for night. If the treatment envelope (panels) falls outside the base treatment envelope (barricades), then the difference is statistically significant. There were no significant differences.

FIGURE#20 PANEL -BARRICADE LANE DISTRIBUTIONS

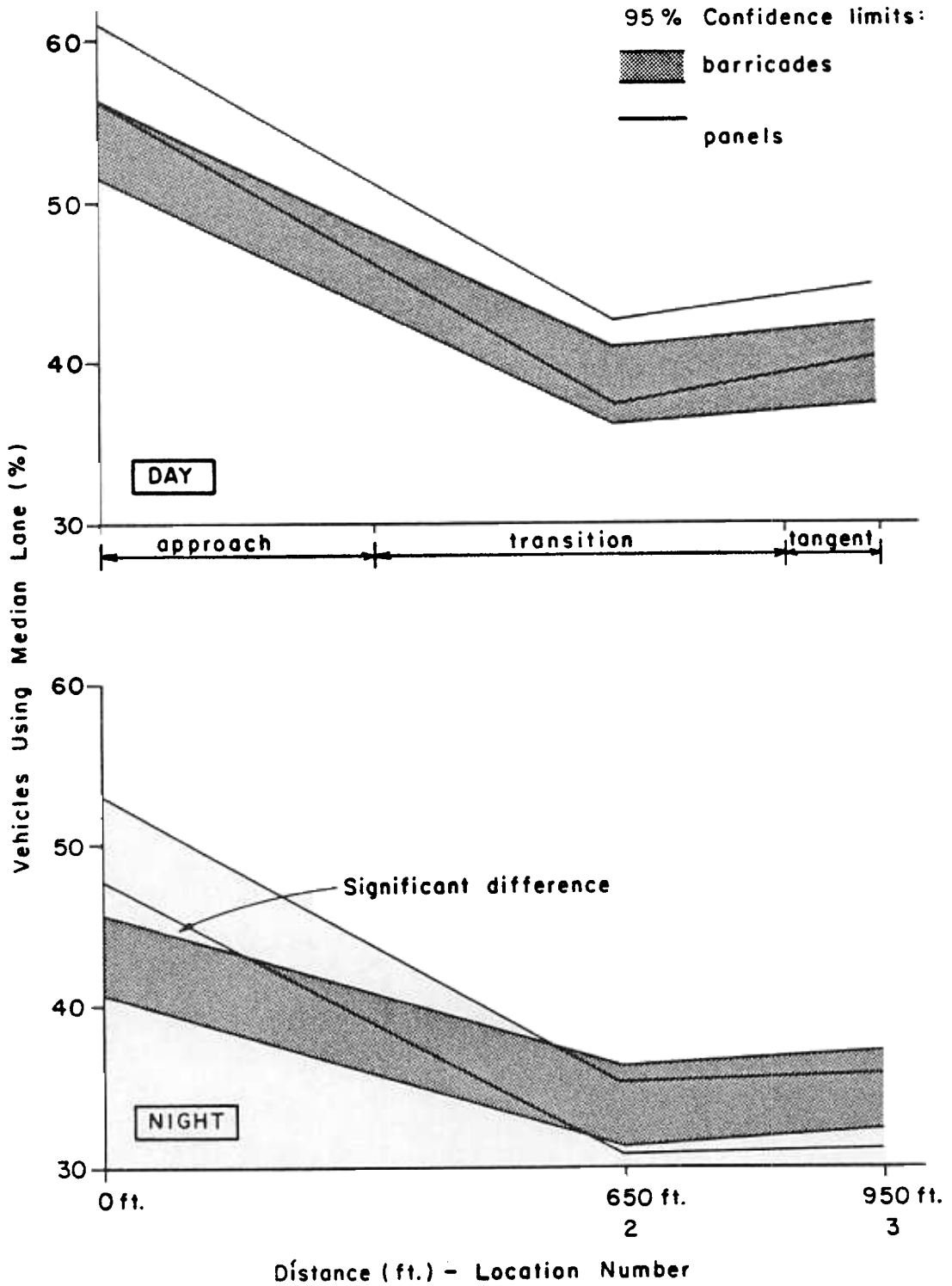


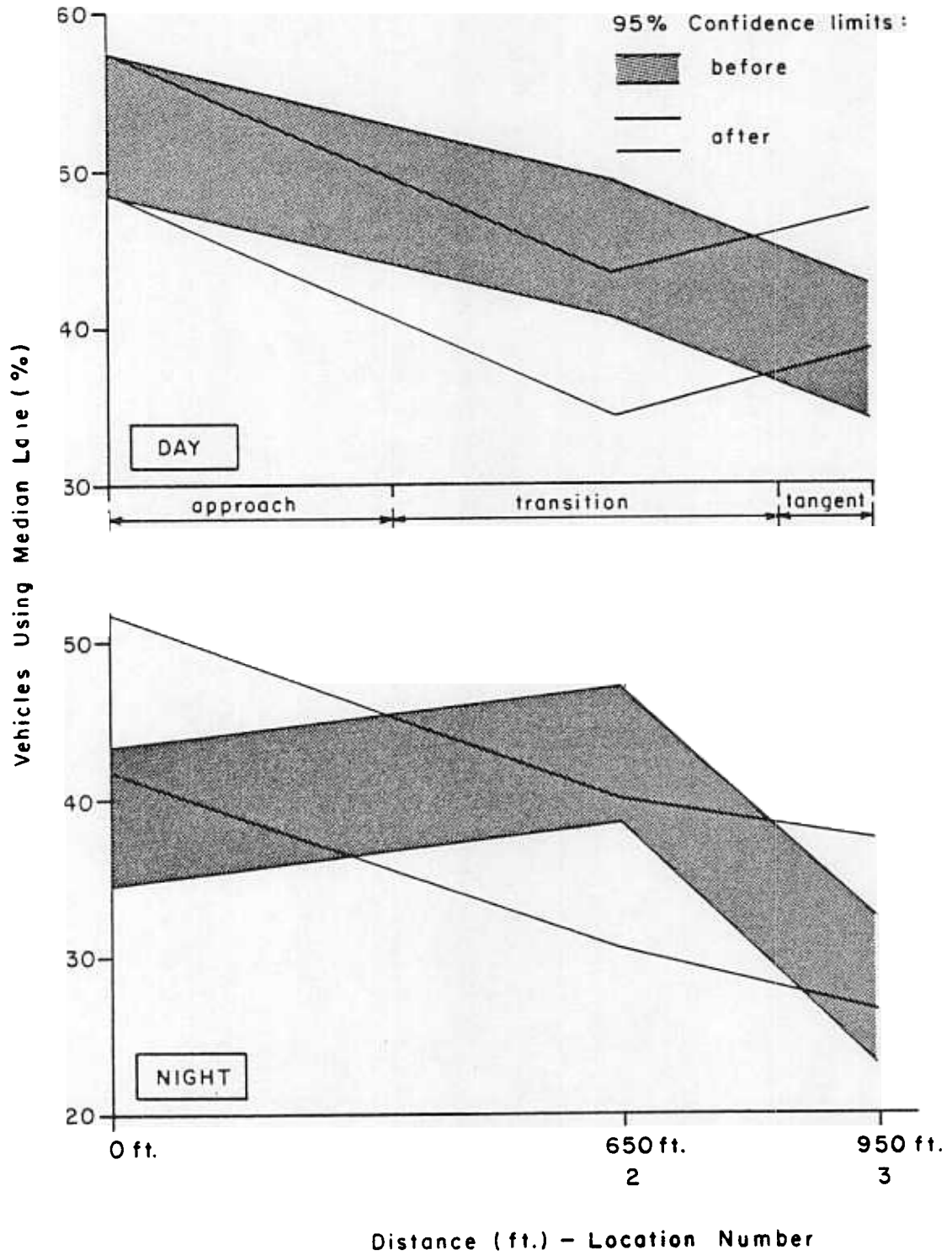
TABLE 11

PANEL - BARRICADE RAIN LANE DISTRIBUTIONS

	<u>Location Time</u>	<u>Left Lane Volume</u>	<u>Right Lane Volume</u>	<u>Total Volume</u>	<u>95% Confidence P</u>	<u>Limits +/-</u>
D	1 Before	260	233	493	0.527	0.044
	1 After	247	218	465	0.531	0.045
A	2 Before	236	290	526	0.449	0.043
	2 After	167	261	428	0.390	0.046
Y	3 Before	206	327	533	0.386	0.041
	3 After	205	269	474	0.432	0.045
N	1 Before	172	270	442	0.389	0.045
I	1 After	175	200	375	0.467	0.050
G	2 Before	223	297	520	0.429	0.043
	2 After	137	252	389	0.352	0.047
T	3 Before	101	261	362	0.279	0.046
	3 After	91	193	284	0.320	0.054

*Significant

FIGURE #21 PANEL - BARRICADE RAINY NIGHT LANE DISTRIBUTIONS



Lane Changes and Encroachments Next, two hour and 15 minute lane change and encroachment samples were tabulated and proportions were computed for each maneuver. For example, 254 out of 4,464 or 5.69 percent of the total vehicles switched from the left lane to the right lane during the before study. Ninety-five percent confidence limits for the proportions were computed by the binominal approximation and are presented in Table 12.

Speeds - Forty-five minutes of speed data was collected in 15 minute increments under various conditions -- left and right lanes, day and night, barricades and panels, and three locations. An analysis of variance performed to determine how much variability in traffic speeds could be attributed to each of the various conditions. If a factor accounts little or no variability, then one is led to the conclusion that the true average traffic speed is constant over the different levels of that factor. If a factor accounts for a significant amount of the total variability, then one concludes that there are at least two different average traffic speeds associated with that factor's levels.

At the 95% confidence level both counting sites and traffic lanes had significantly different traffic speeds for both day and night counts. Barricade types, however, did not significantly influence the traffic speeds. With at least 95% confidence, therefore, it is concluded that traffic speeds in the construction zone studied are independent of the types of barricades studied.

Changes in the variances were checked for significance with an F-test. The statistics are summarized in Table 14, and plotted in Figures 22 & 23.

TABLE 12

PANEL - BARRICADE MANEUVERS

	<u>Maneuver</u>	<u>Time</u>	<u>No. of Maneuvers</u>	<u>Total Volume</u>	<u>95% Confidence</u>	
					P	+/-
D	Lane Change	Before	254	4464	0.0569	0.0068
	Left-Right	After	281	4652	0.0604	0.0068
A	Encroachment	Before	60	4664	0.0129	0.0032
		Left-Right	After	33*	4652	0.0071
N	Lane Change	Before	276	4329	0.0638	0.0073
	Left-Right	After	292	4471	0.0653	0.0072
I	Encroachment	Before	66	4329	0.0152	0.0037
		Left-Right	After	33*	4471	0.0074

*Significant

Rain data can be reduced similarly:

TABLE 13

PANEL-BARRICADE RAIN MANEUVERS

D	Lane Change	Before	68	1059	0.064	0.015
	Left-Right	After	44*	1367	0.032	0.009
A	Encroachment	Before	5	1059	0.005	0.004
		Left-Right	After	5	1367	0.004
N	Lane Change	Before	106	1324	0.080	0.015
	Left-Right	After	30*	1048	0.029	0.010
I	Encroachment	Before	26	1324	0.020	0.008
		Left-Right	After	5*	1048	0.005

*Significant

TABLE 14

PANEL-BARRICADE SPEEDS

		LEFT LANE			RIGHT LANE		
		LOCATION 1	LOCATION 2	LOCATION 3	LOCATION 1	LOCATION 2	LOCATION 3
		TYPE III PANEL	TYPE III PANEL	TYPE III PANEL	TYPE III PANEL	TYPE III PANEL	TYPE III PANEL
n		124	80	98	113	105	78
\bar{x}		37.0	42.8	43.7	34.4	40.5	39.4
s ²		7.0	9.9	11.5	7.8	12.3	15.3
F		1.14	1.11	1.17	1.16	1.24	1.24
n		84	50	84	89	78	83
\bar{x}		36.4	39.3	42.1	33.3	36.3	35.8
s ²		9.5	12.6	12.5	5.5	8.1	19.5
F		1.16	1.06	1.01	1.54*	1.27	1.72*

n = Sample Size

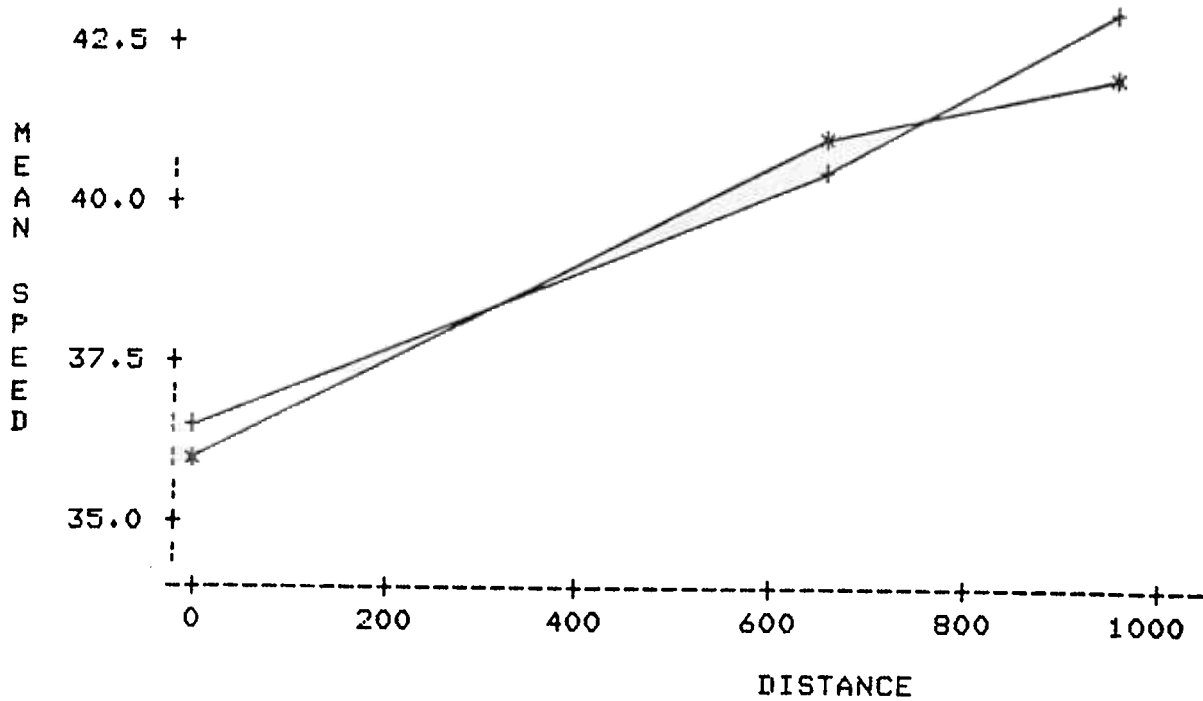
\bar{x} = Mean Speed

s² = Variance

* = Significance at the 95% level of confidence

FIGURE 22 BARRICADE (BEFORE) - PANEL (AFTER)
LEFT LANE MEAN SPEEDS

PLOT OF BEFORE*DISTANCE SYMBOL USED IS *
PLOT OF AFTER*DISTANCE SYMBOL USED IS +



RIGHT LANE MEAN SPEEDS

PLOT OF BEFORE*DISTANCE SYMBOL USED IS *
PLOT OF AFTER*DISTANCE SYMBOL USED IS +

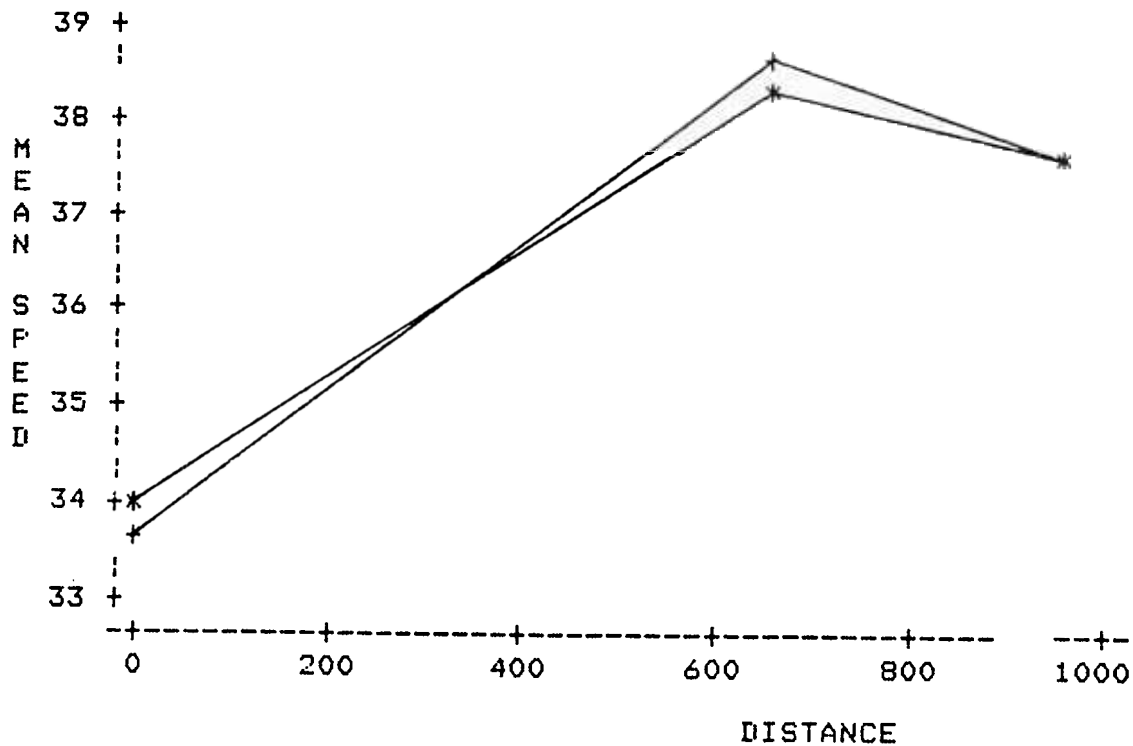
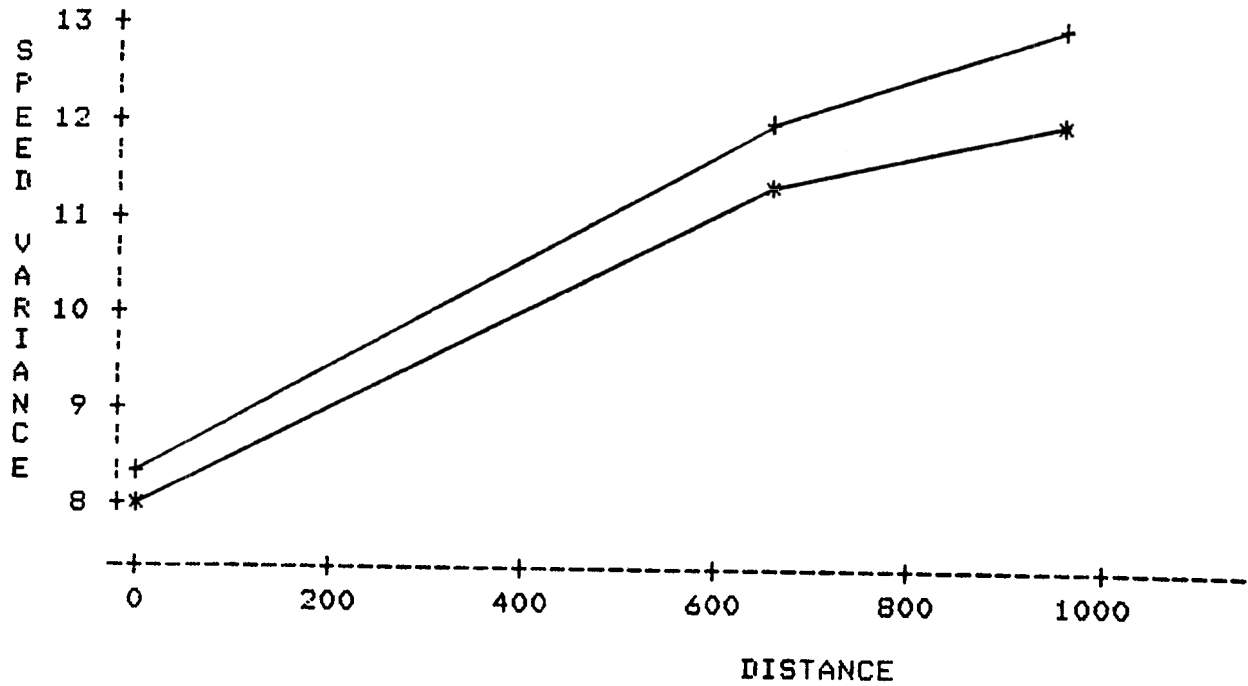


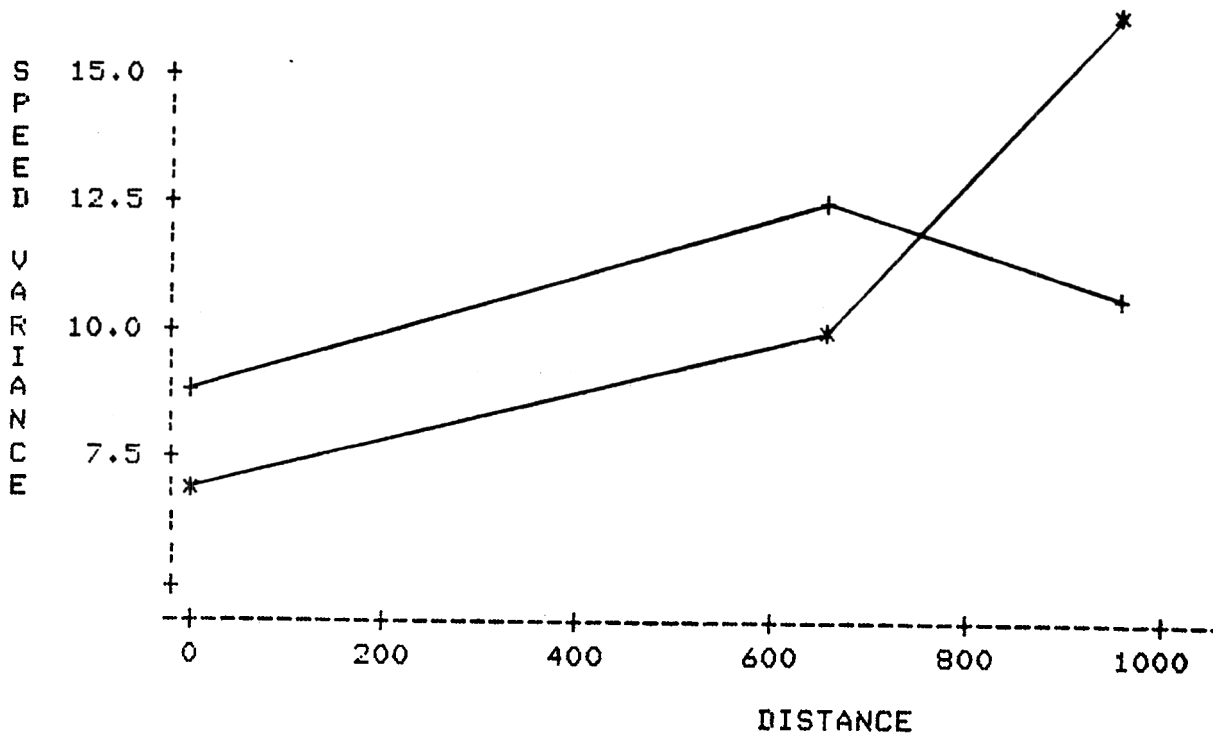
FIGURE 23 BARRICADE (BEFORE) - PANEL (AFTER)
LEFT LANE SPEED VARIANCES

PLOT OF BEFORE*DISTANCE SYMBOL USED IS *
PLOT OF AFTER*DISTANCE SYMBOL USED IS +



RIGHT LANE SPEED VARIANCE

PLOT OF BEFORE*DISTANCE SYMBOL USED IS *
PLOT OF AFTER*DISTANCE SYMBOL USED IS +



RAISED PAVEMENT MARKERS AS A PAINT SUPPLEMENT

Description

Components The markers used were Stimsonite 911-SS self-adhesive markers (Figure 24). Clear markers supplemented lane lines and right edge lines, and amber markers supplemented the left edge line. Stimsonite also supplied a liquid primer for use on the pavement to provide a better surface for the marker to adhere to.

Experimental Site Our desire was to locate a site that would expose the markers to a high volume of auto and truck traffic on a high speed construction zone diversion. The site selected was the westbound diversion of Route 46 (Figure 25). The surrounding area was commercial and the AADT was 19,300 vehicles. Since the left lane was closed for median barrier curb and drainage work, the original two lanes of traffic were diverted to the right. Traffic was to maintain two lanes and use the shoulder.

Installation On November 27, 1979, a total of 273 markers were installed on the entire westbound side of the construction zone. Figure 26 shows in detail the marker layout for the zone diversion. The approach consisted of markers installed between skip lines or every 40 feet, the transition consisted of a marker spacing of 20 feet, and the tangent consisted of markers installed every 40 feet.

The markers were installed on a clear day with a minimum temperature of 50° F and a 20 mph wind. The amber left edge line markers and the clear skip line markers were placed using one safety setup.

To determine the marker location, two workers stretched a cord between two skip lines and a third worker measured the proper distance and made a

crayon + on the pavement. Next, a fourth worker cleaned a four inch square area of pavement with a wire brush to remove loose material and applied a primer. The primer was used to provide a smooth surface for the marker to adhere to, and about 6 minutes were required for the primer to dry. A fifth worker peeled the paper backing off the marker and placed the marker on the pavement and stepped on it. Finally, a truck was used to run over the marker. The truck rested on top of the marker for about one minute. A sixth worker guided the truck over the marker. Since the contractor had no previous experience with markers, the project engineer provided training, instruction, and advice during the installation.

No markers were lost during the 23 days of the study even though traffic was heavy and there was lane changing through the transition. On December 19, 1979, two-thirds of the markers were removed in snowplow operations. The remaining one-third were either missed or damaged by the plow blade.

FIGURE 24
Stimsonite 911-SS

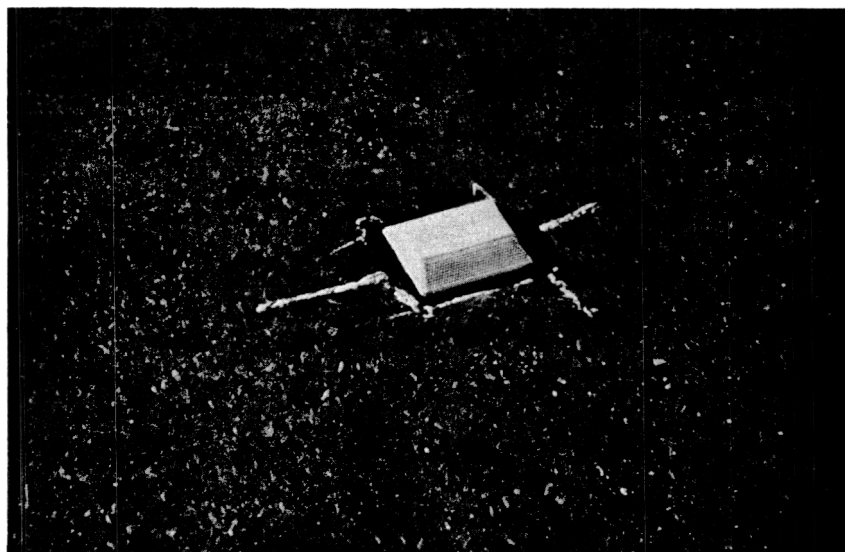



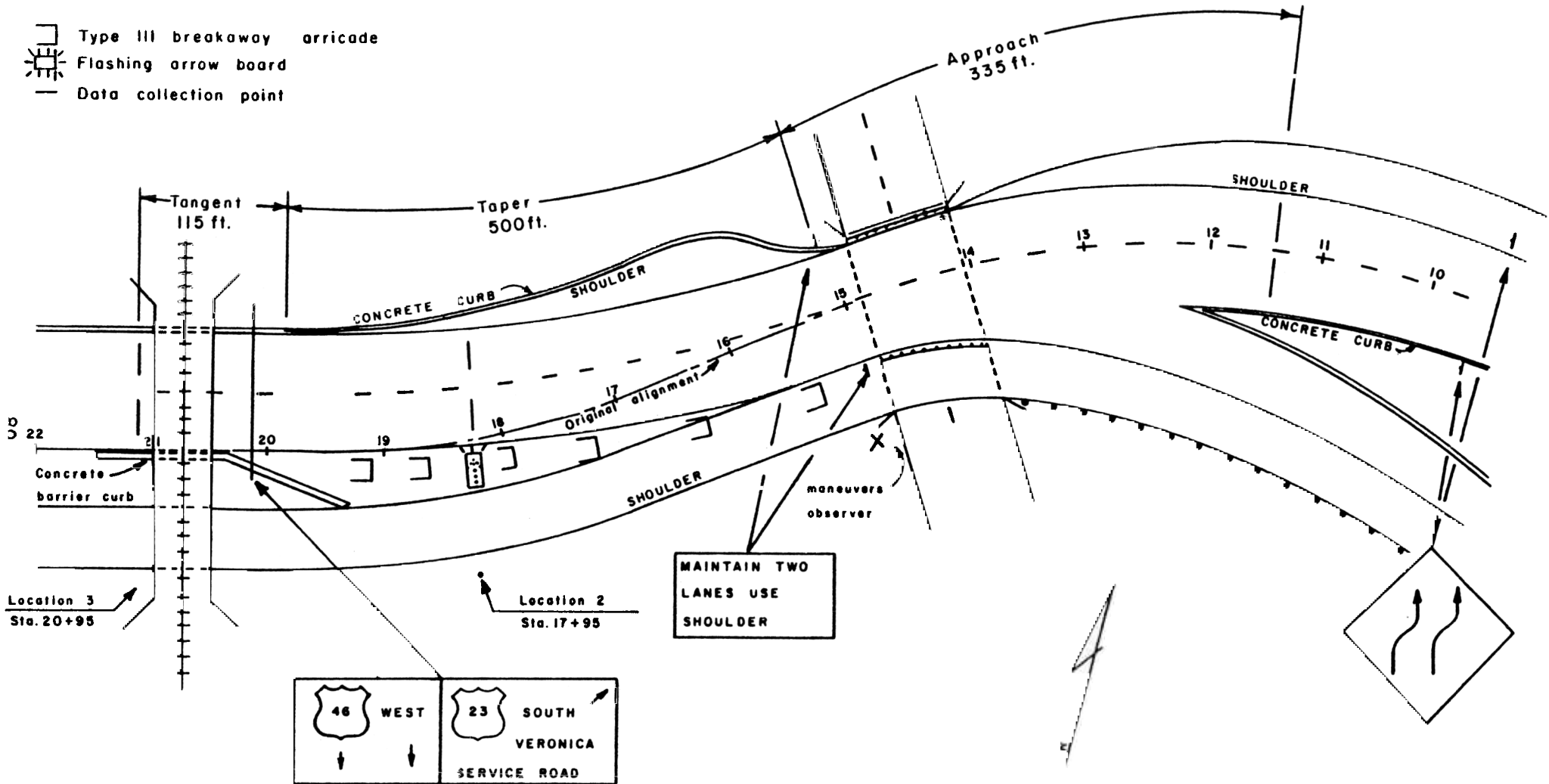


Figure #25 MARKER - PAINT SUPPLEMENT SITE SCHEMATIC

egend

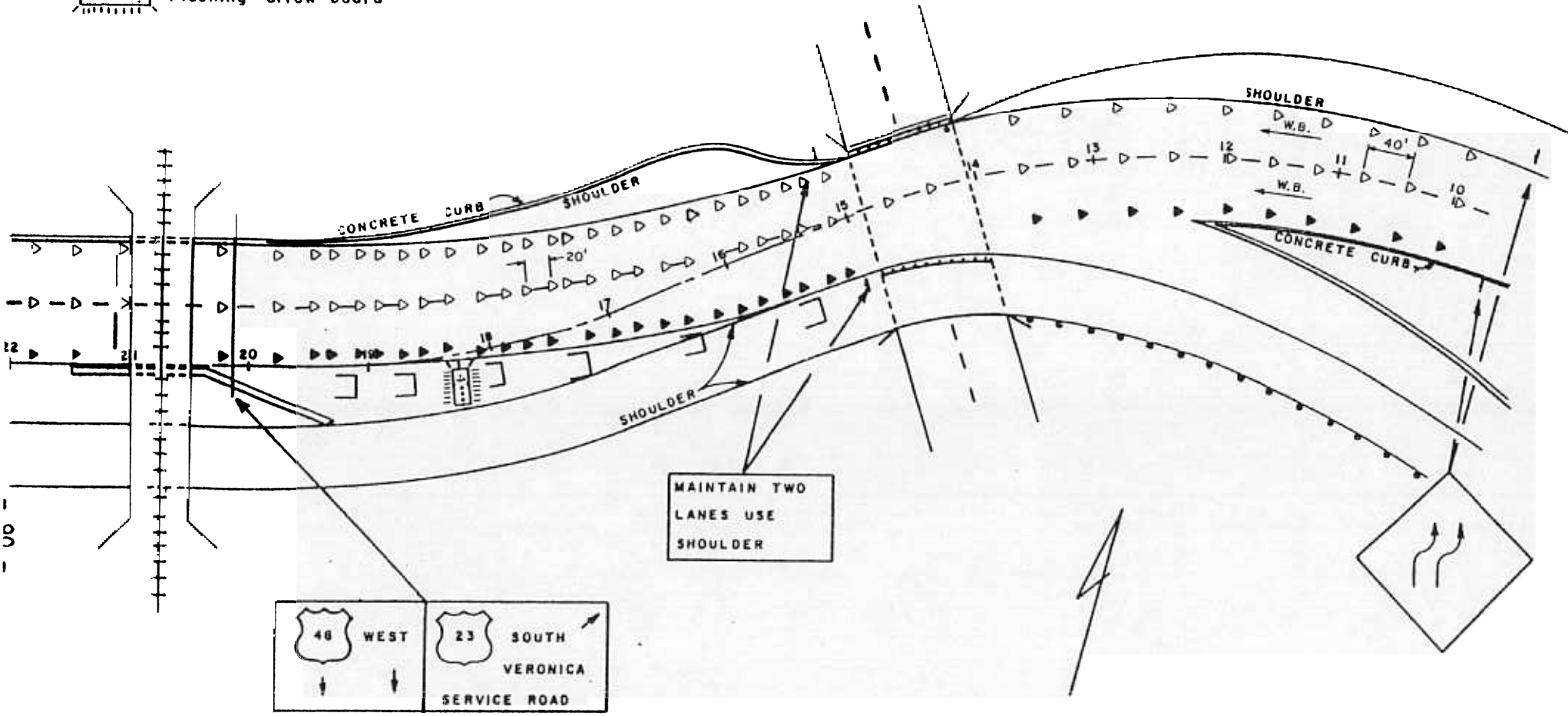
-  Type III breakaway arricade
-  Flashing arrow board
-  Data collection point



Figure# 26 MARKER - PAINT SUPPLEMENT MARKER LAYOUT

Legend

- ▷ Crystal reflective marker
- ▶ Amber reflective marker
- Type III breakaway barricade
- ▨ Flashing arrow board



The approximate cost to lay out, install, and remove the markers was about \$10 per marker. The work was done as a change order and the contractor had no previous experience with markers.

Visual Characteristics - Under dry night conditions, only three skip lines could be seen at one time at this site. And at night with a wet pavement, skip lines could hardly be seen at all. However, with the markers, night visibility was limited only by road geometry, and rain had little effect on visibility.

Evaluation Plan

Measures of Effectiveness The measures of effectiveness used were:

1. lane distribution
2. lane changes and encroachments
3. brake applications
4. speeds

Our objective was to use markers to reduce lane changes, encroachments, and speed variance, and improve the speed profile.

An encroachment occurred when the wheels of an encroaching vehicle went across the lane line

Experimental Design - A before-after design was selected. Before data was taken Monday through Thursday. Following a six day acclimation period, after data was taken on the same days and times by the same data collectors under the same climatic conditions as in the before study. Data was collected at three locations (Figure 25):

1. Location 1 - in the approach
2. Location 2 - in the transition, and
3. Location 3 - in the tangent

For each data collection location, one hour of daytime data collected from 2:15 p.m. to 4:00 p.m. and one hour of nighttime data was collected from 5:00 p.m. to 6:45 p.m.

After the data was reduced, statistical tests were run to determine if the markers produced significant changes in vehicle performance.

Data Collection - On a typical day, three observers would collect data one to collect maneuver and brake light data, two to collect speed volume data. Data was collected in 15 minute increments followed by 30 minute periods to allow the observers to travel and set up at the next location.

The volume observer used a manual counter to count the number of vehicles in each lane as they passed a given point. The maneuvers observer called his data into a portable tape recorder. Finally, the speed observer used a radar unit to record the speeds of vehicles in each lane as they passed a given point. To ensure uniformity in readings, the antenna of radar was set up on the same spot (i.e., the beginning of the barrier curb) each time and aimed at a given landmark such as a street light. Only single vehicles or vehicles leading a platoon were documented.

The observers as well as their vehicles were carefully concealed behind trees or construction barricades and were not visible to passing motorists

Data Reduction

Lane Distribution - From one hour volume samples, day and night proportions were developed. For example, at Location 1 during the day, a total of 988 vehicles out of 1,985 vehicles or 52.1 percent used the left lane in

the before study. A set of 95% confidence limits (C.L. for both the before and after conditions were computed by the binomial approximation as follows:

$$C.L. = P \pm 1.96 \sqrt{\frac{pq}{n}}$$

where

p = proportion of vehicles using left lane

q = 1 - p

n = total of left and right lane counts

The proportions and confidence limits are presented in Table 15.

Figure 27 is a plot of the confidence limits, the upper plot for and the lower plot for night. If the treatment envelope (reflectors) falls outside the base treatment envelope (no reflectors) then the difference is statistically significant.

Lane Weaves and Encroachments - Next, four hour lane weave, encroachment and braking samples were tabulated and proportions were computed for maneuver. For example, in four hours 431 out of 5,392 or 8 percent of the total vehicles weaved during the before period. Ninety-five percent confidence limits for the proportions were computed by the binomial approximation and are presented as in Table 16.

Although one would be tempted to attribute the above maneuver changes to the markers themselves, this may not necessarily be correct. The after counts taken during the day showed a consistent decrease in lane changes and encroachments, yet the reflectors are less visible during the day than during the night. One or more unidentified factors could also be at work.

Speeds One hour of speed data was collected in 15 minute increments

TABLE 15

MARKER-PAINT SUPPLEMENT LANE DISTRIBUTIONS

<u>Location</u>	<u>Time</u>	<u>Left Lane Volume</u>	<u>Right Lane Volume</u>	<u>Total Volume</u>	<u>95% Confidence Limits P</u>	<u>Limits +/-</u>
D	1 Before	988	907	1895	.521	.022
	After	1073	1006	2079	.516	.022
A	2 Before	590	957	1547	.381	.024
	After	834	1239	2073	.402	.021
Y	3 Before	822	1128	1950	.422	.022
	After	833*	1379	2212	.377	.020
N I G H T	1 Before	1253	993	2246	.558	.021
	After	1328	1118	2446	.543	.020
	2 Before	947	1419	2366	.400	.020
	After	1160	1536	2696	.430	.019
	3 Before	807	1426	2233	.361	.020
	After	1070*	1557	2627	.407	.019

*Significant

FIGURE # 27 MARKER - PAINT SUPPLEMENT LANE DISTRIBUTIONS

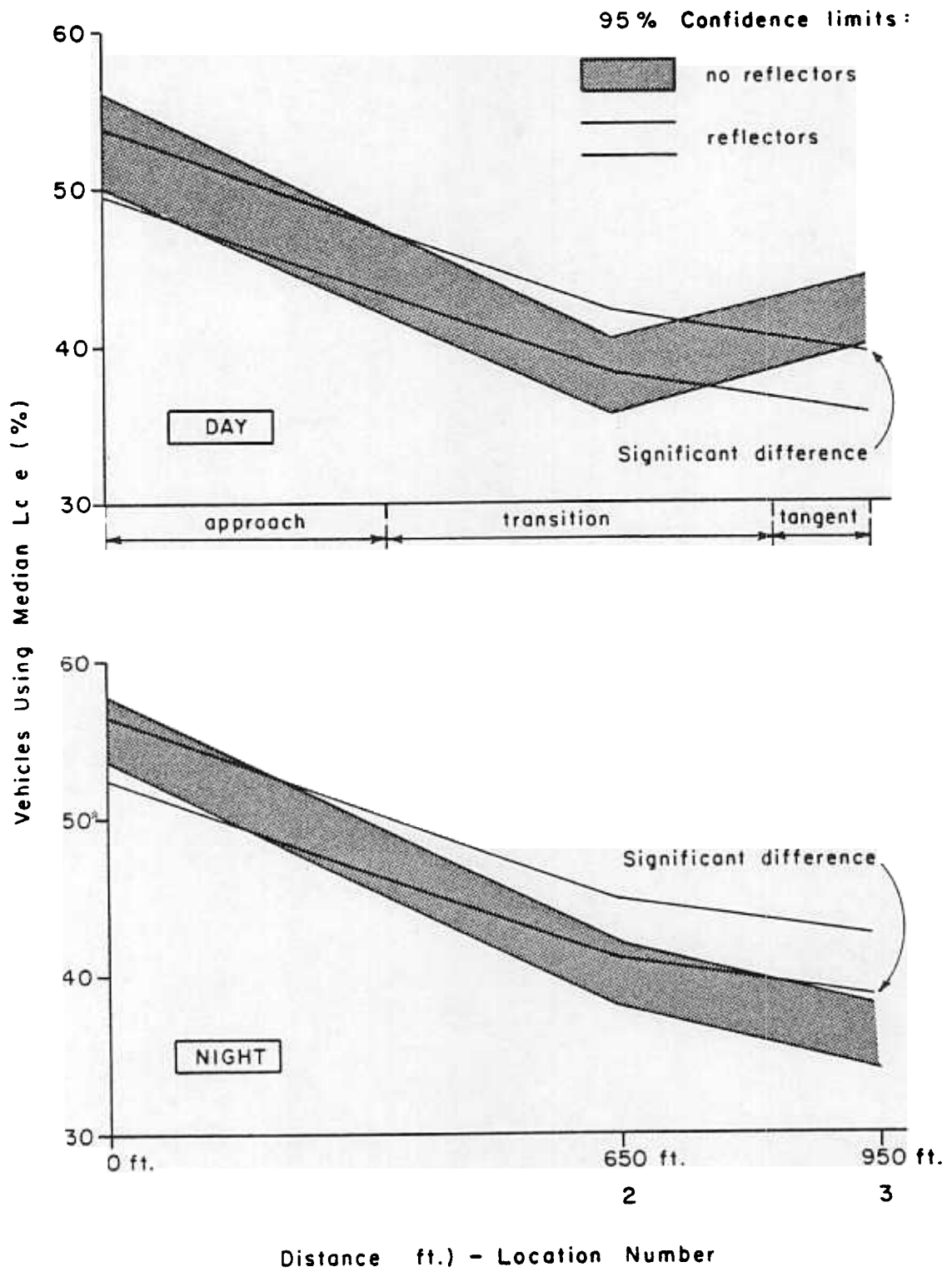


TABLE 16

MARKER-PAINT SUPPLEMENT MANEUVERS

	<u>Maneuver</u>	<u>Time</u>	<u>Number</u>	<u>Volume</u>	<u>95% Confidence Limits</u>	
					<u>P</u>	<u>+/-</u>
D	Weave	Before	431	5392	0.080	0.007
		After	343*	5899	0.058	0.006
A	Encroachment	Before	121	5392	0.022	0.004
		After	36*	5899	0.006	0.002
Y	Brake	Before	1928	5392	0.358	0.013
		After	2047	5899	0.347	0.012
N	Weave	Before	352	6220	0.057	0.006
		After	320*	7179	0.045	0.005
I	Encroachment	Before	84	6220	0.014	0.003
		After	17*	7179	0.002	0.001
H	Brake	Before	2082	6220	0.335	0.012
		After	2367	7179	0.330	0.011

*Significant

under various conditions: left and right lanes, day and night, reflectors and no reflectors, and three locations. An analysis of covariance was performed to determine whether the traffic speeds were significantly different after each of the above factors had been considered. Essentially analysis of covariances uses a regression technique to adjust an experimental observation (speed) for an uncontrolled covariate (volume). This analytical procedure was required because of the dependency of speed upon volume analysis of traffic speeds without regard for volumes may produce misleading results. All speed observations were reduced by a linear function to a common basis of comparison.

The SAS computer package was used to construct the appropriate regression models, confirming the linear relationship between volume and speed at the 98% confidence level. Reflective markers did not affect vehicle speeds at the 95% confidence level.

Changes in the variances were checked for significance with an F-test. The speed statistics are summarized in Table 17 and plotted in Figures 28, 29.

TABLE 17

MARKER-PAINT SUPPLEMENT SPEEDS

		LEFT LANE						RIGHT LANE					
		LOCATION 1		LOCATION 2		LOCATION 3		LOCATION 1		LOCATION 2		LOCATION 3	
		No Markers	Markers	No Markers	Markers	No Markers	Markers	No Markers	Markers	No Markers	Markers	No Markers	Markers
D A Y	n	172	166	134	143	135	137	165	153	242	147	199	120
	\bar{x}	33.2	37.3	38.5	38.2	40.4	38.4	30.9	35.9	38.9	37.5	37.2	36.9
	s ²	14.3	9.7	18.4	19.0	21.6	20.8	15.1	10.7	11.6	13.9	20.2	16.8
	F	1.5*		1.0		1.0		1.4*		1.2		1.2	
N I G H T	n	162	122	68	113	190	114	106	88	90	102	256	100
	\bar{x}	33.6	34.7	39.5	37.1	39.2	39.5	33.2	33.2	37.3	33.8	36.0	34.2
	s ²	12.2	10.9	11.9	13.2	12.5	11.6	19.5	8.7	12.1	7.5	12.7	11.0
	F	1.1		1.1		1.1		2.2*		1.6*		1.2	

n Sample Size

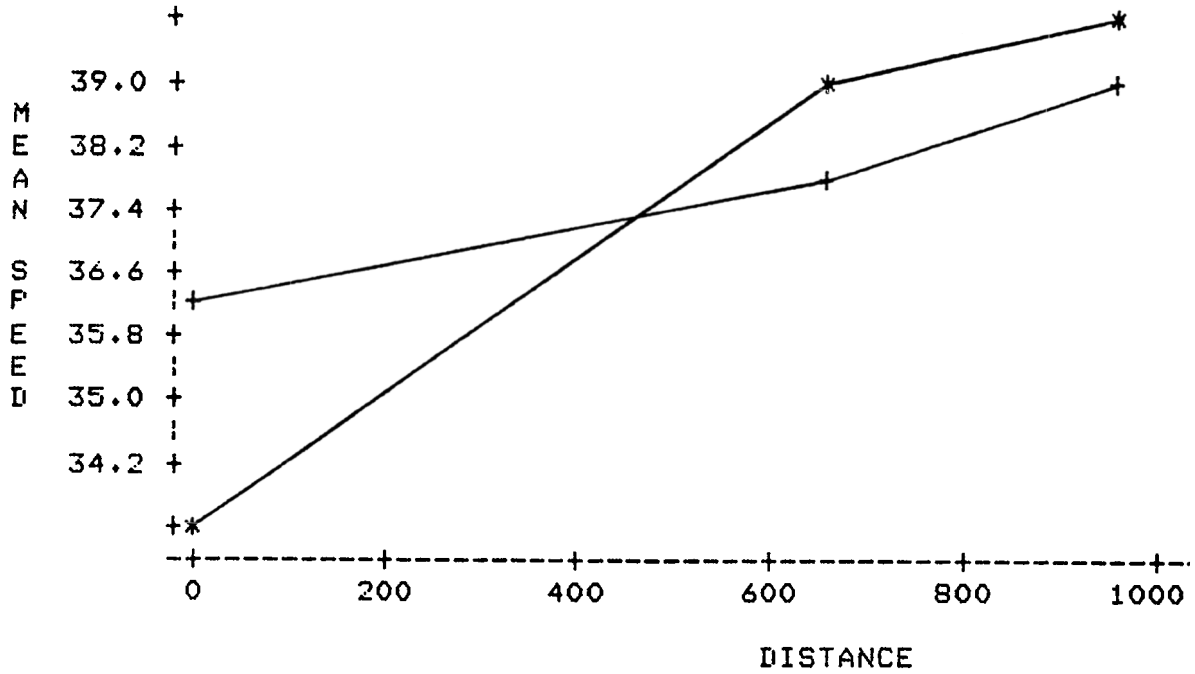
\bar{x} Mean Speed

s² = Variance

* Significance at the 95% level of confidence

FIGURE 28 MARKER - PAINT SUPPLEMENT MEAN SPEEDS
LEFT LANE MEAN SPEEDS

PLOT OF PAINT*DISTANCE SYMBOL USED IS *
PLOT OF MARKERS*DISTANCE SYMBOL USED IS +



RIGHT LANE MEAN SPEEDS

PLOT OF PAINT*DISTANCE SYMBOL USED IS *
PLOT OF MARKERS*DISTANCE SYMBOL USED IS +

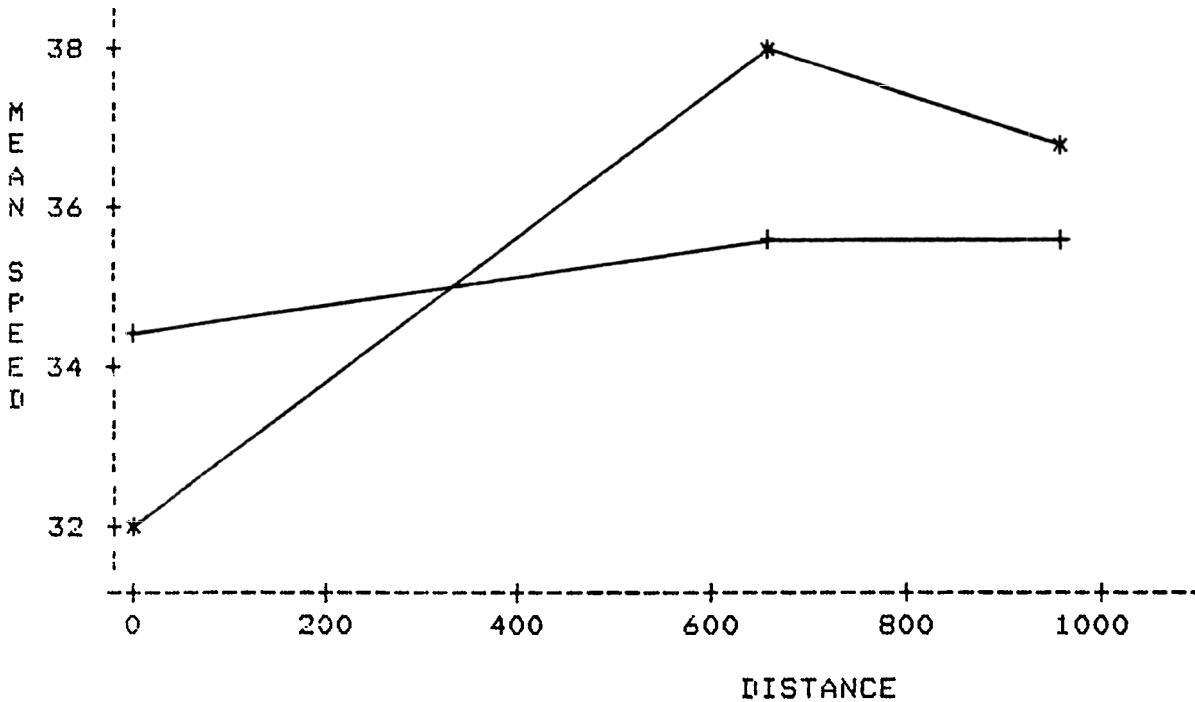
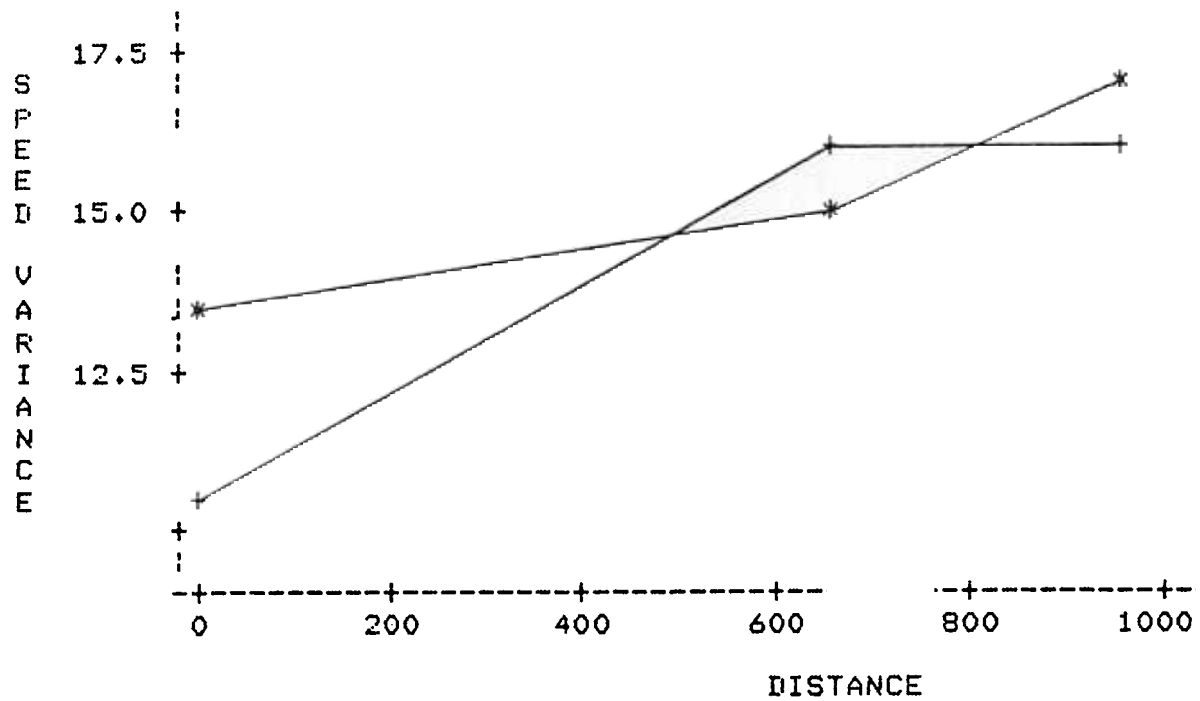


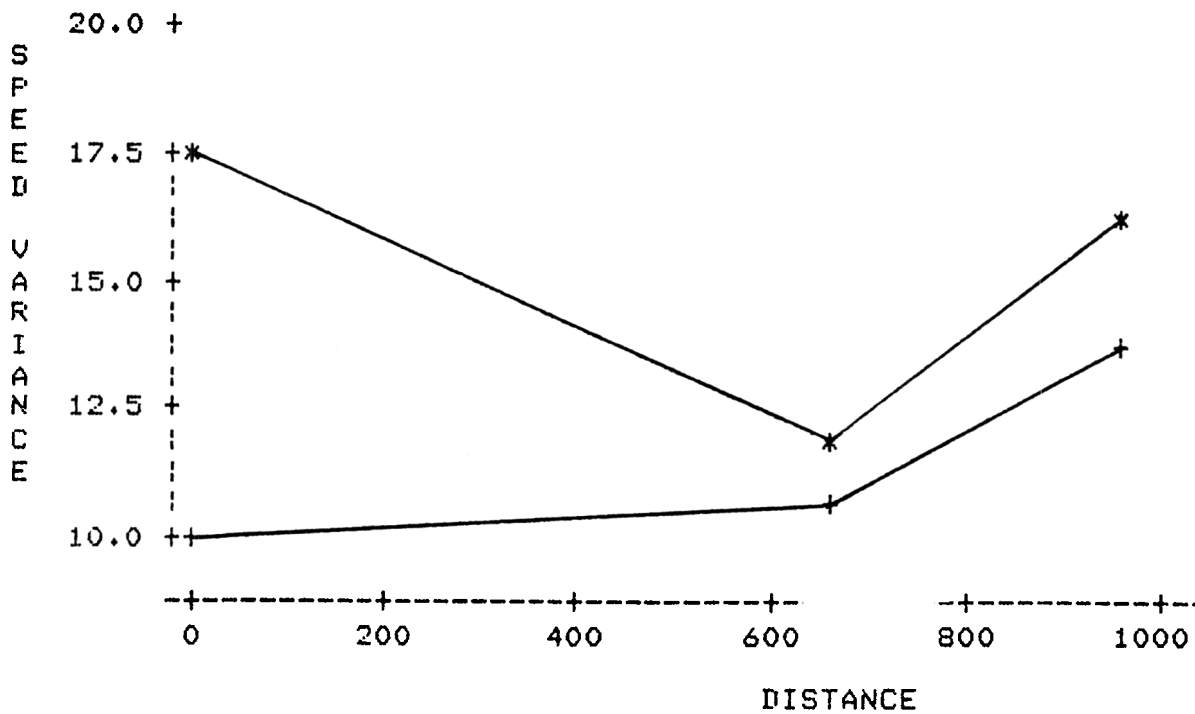
FIGURE 29 MARKER - PAINT SUPPLEMENT SPEED VARIANCES
LEFT LANE SPEED VARIANCE

PLOT OF PAINT*DISTANCE SYMBOL USED IS *
PLOT OF MARKERS*DISTANCE SYMBOL USED IS +



RIGHT LANE SPEED VARIANCE

PLOT OF PAINT*DISTANCE SYMBOL USED IS *
PLOT OF MARKERS*DISTANCE SYMBOL USED IS +



RAISED PAVEMENT MARKERS AS A PAINT REPLACEMENT

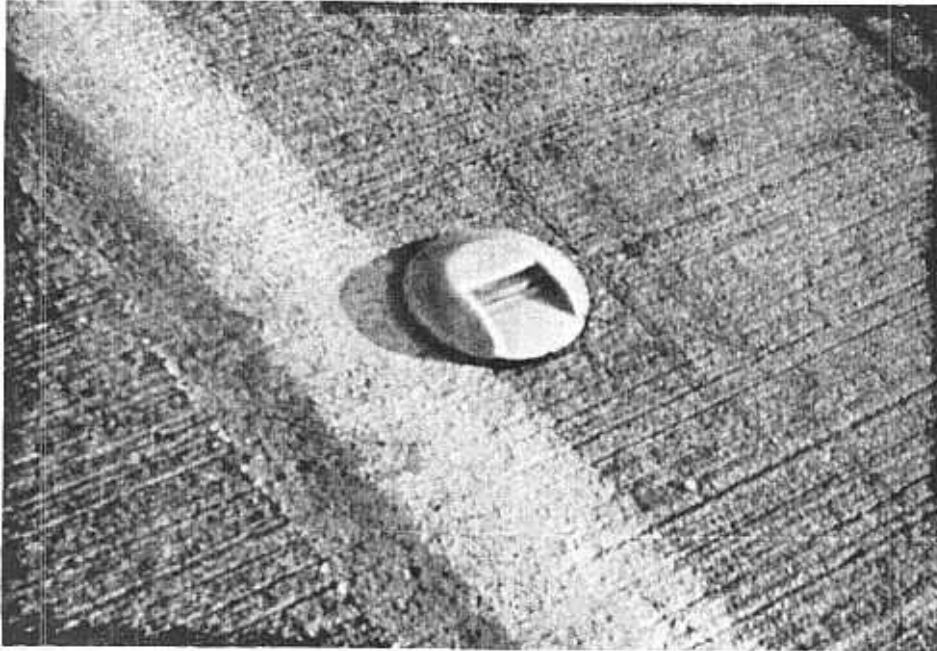
Description

Components The markers used were Permark P-15 reflective ceramic road markers (Figure 30). White markers were used to replace white paint and yellow markers were used to replace yellow paint. A pressure sensitive butyl pad was attached to each marker. A liquid primer was used to provide a smooth surface for the marker to adhere to.

Experimental Site Our desire was to locate a site that would expose the markers to a high volume of auto and truck traffic on a high speed construction zone diversion. The site selected was one direction of Interstate 78 in the vicinity of the Garden State Parkway in an industrial setting. The left lane was closed to traffic. However, two lanes were maintained and vehicles were to stay in their lane and use the shoulder as a lane. Figure 31 shows the maintenance of traffic plan. The site level and straight throughout.

Installation and Removal On October 17 and 20, 1980, a total of 1,236 markers were installed as shown in Figure 32. The approach consisted of markers supplementing paint at a spacing that went from 40 feet to 10 feet. Markers in the approach were felt to be necessary since at night the driver would be faced with an abrupt change from paint to reflective markers. markers were spaced at 6 feet in the transition where they replaced paint.

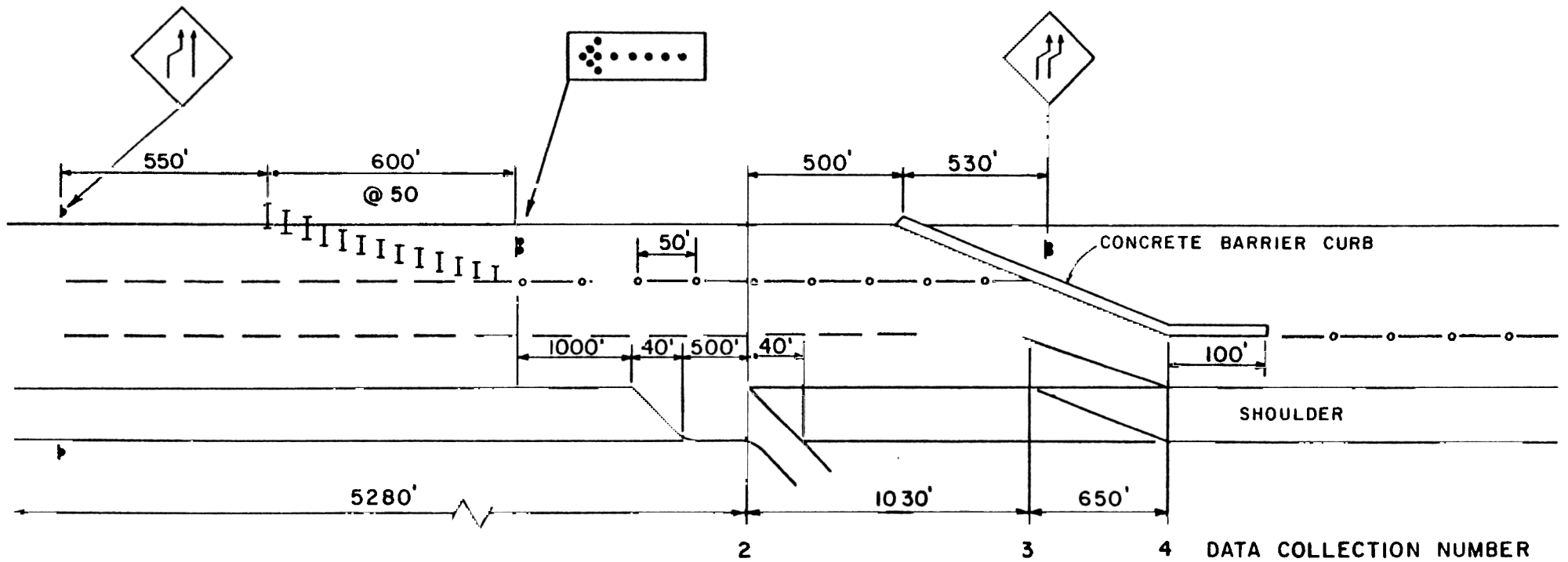
FIGURE 30
CERAMIC MARKER



The markers were installed on a clear day with a minimum temperature of (75° F). The marker spacing was layed out with a yard stick. The surface prepared with a liquid primer to provide a smooth surface for the marker to adhere to. Since the butyl pad was pressure sensitive a truck ran over each marker, resting on the marker for one minute. The project engineer provided training, instruction, and advice during the installa-
since the contractor had no experience with markers. The markers were a contract item and the contractor charged \$2.90/marker to cover the cost of the markers, installation, and removal

During the six days the diversion was in effect virtually no markers were damaged or lost in the transition. However, 310 out of 1,236 or 25 percent of the total markers were lost or damaged, the majority of the losses occurring in the approach. These losses could have been due to heavy traffic weaving in the vicinity of a major exit and less supervision of the workers during installation of the markers in this area.

Figure # 31 MARKER - PAINT REPLACEMENT SITE SCHEMATIC



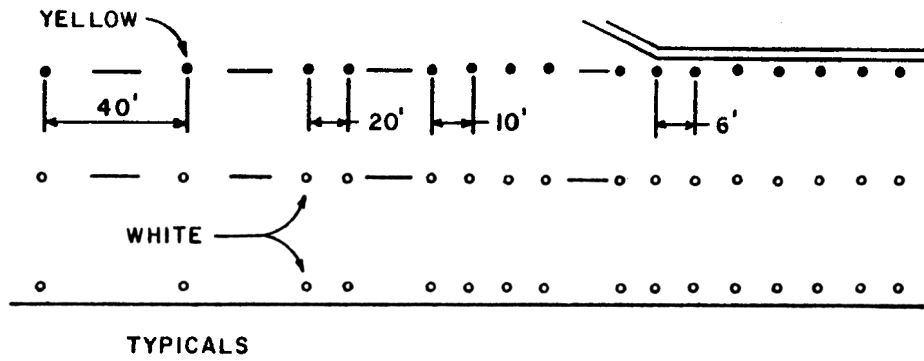
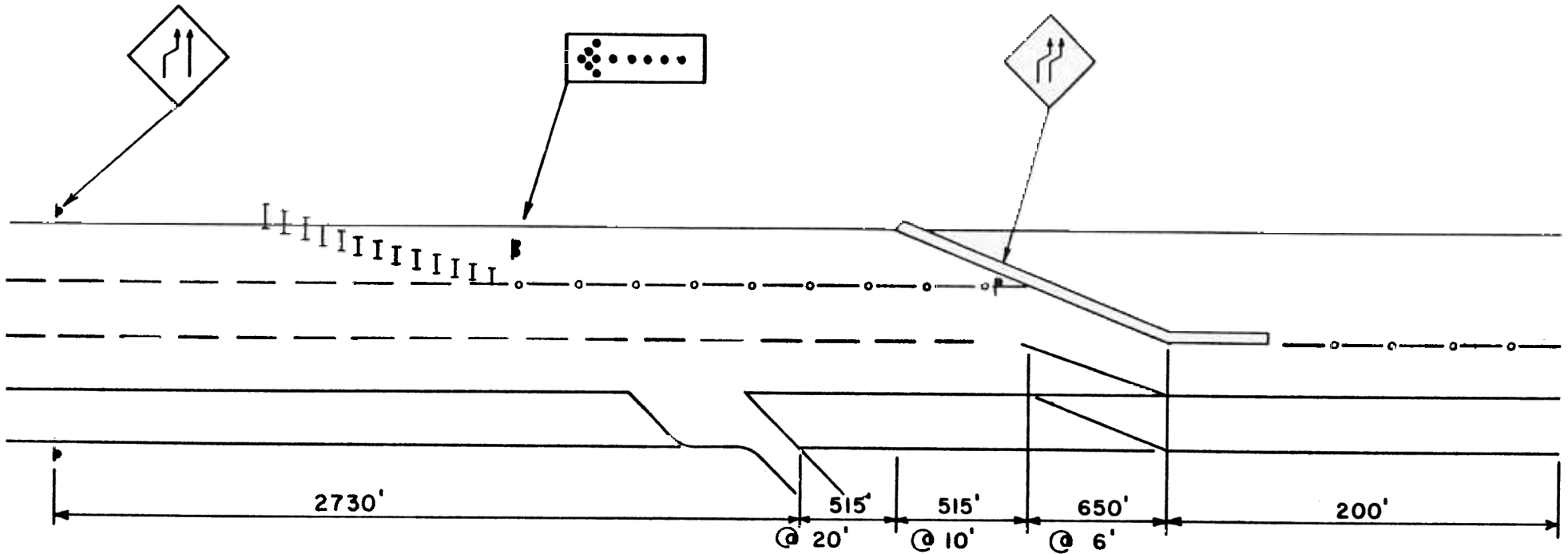
Legend:

I Type III breakaway barricade

O Plastic drum

Figure # 32 MARKER - PAINT REPLACEMENT MARKER LAYOUT

104 -



Once construction was completed, the markers were removed from the pavement by laborers using shovels. Most of the markers left some butyl on the pavement, but this was not visible from a car.

Evaluation Plan

Measures of Effectiveness - The measures of effectiveness used were:

1. lane distribution
2. lane changes and encroachments
3. brake applications, and
4. speeds.

The objective was to use the markers to not only replace paint, but also reduce lane changes, encroachments, speed variances, and brake applications. An encroachment occurred when the wheels of an encroaching vehicle went across the lane line.

Experimental Design A before after design was selected. Data was taken on Tuesdays and Wednesdays. An acclimation period of four days was allowed to give drivers a chance to get used to the markers.

Data was collected from four locations:

- Location 1 - before the drivers were influenced by markers
- Location 2 - in the approach to the transition
- Location 3 - at the beginning of the transition, and
- Location 4 - at the end of the transition.

At each data collection location, from 30 minutes to one hour and 20 minutes of day data were collected from 4:45 p.m. to 6:05 p.m. The variation in the amount of day data was due to construction activity influencing data. At night, an hour and a half of data was collected for each location from 6:45 p.m. to 8:35 p.m.

After the data was reduced, statistical tests were run to determine if the markers produced significant changes in vehicle performance.

Data Collection On Tuesdays, five observers collected data at Locations 2 and 4 -- two to collect speeds and volumes at each location and one to collect weaves, encroachments, and brake lights. On Wednesdays, six observers collected data at Locations 1 and 3 two to collect speeds and volumes at each location, one to collect the maneuvers, and one to collect volumes at Location 2 as a control on the variability of the data. Data was collected in 10 minute increments and one 10 minute break was allowed for each data collection period

The volume observer used a manual counter to count the number of vehicles in each lane as they passed a given point. The maneuvers observer called his data into a portable tape recorder. Finally, the speed observer used a radar unit to record the speeds of vehicles in each lane as they passed a given point. To ensure uniformity in readings, the radar antenna was set up on the same spot each time and aimed at a given landmark. To distinguish which lane vehicles were in when the meter registered, only single vehicles or vehicles leading a platoon were documented.

The speed and volume observers were carefully hidden behind barrier curbs and were not visible to passing motorists, and the maneuvers observer was stationed on an overpass.

Data Reduction

Lane Proportions Volume samples were summarized and day and night portions were developed. For examples at Location 1 during the day, a total of 998 vehicles out of 2,118 vehicles or 47.1 percent used the right lane in the before study. A set of 95% confidence limits for both the before and after conditions were computed by the binomial approximation as follows:

$$C.L. = p \pm 1.96 \sqrt{\frac{pq}{n}}$$

where

p = proportions of vehicles using right lane

q = 1 - p

n = total of left and right lane counts

The proportions and confidence limits are presented in Table 18.

Figure 33 is a plot of the confidence limits, the upper plot for day and the lower plot for night. If the treatment envelope (markers) is outside the basic treatments envelope (paint) then the difference is statistically significant.

Maneuvers Next, lane weave, encroachment, and braking samples were tabulated and proportions were computed for each maneuver. For example, 113 out of 1,071 or 10.6 percent of the total vehicles weaved from right to the left lane during the before period in the day. Ninety-five percent confidence limits for the proportions were computed by the binomial approximation and are presented in Table 19.

Speeds Samples were collected under various conditions: left and right lanes, day and night, paint and markers, and four locations. A regression analysis showed no before-after change in the mean speeds at the 95% confidence level and the F-test showed no before-after changes in the variances at the 95% confidence level. The speed statistics are summarized in Table 20 and plotted in Figures 34 and 35.

TABLE 18

MARKER-PAINT REPLACEMENT LANE DISTRIBUTIONS

<u>Location</u>	<u>Time</u>	<u>Left Lane Volume</u>	<u>Right Lane Volume</u>	<u>Total Volume</u>	<u>95% Confidence Limits</u>	
					<u>P</u>	<u>+/-</u>
D	Before	1120	998	2118	.471	.021
	After	1244	1080	2324	.465	.020
A	2 Before	346	528	874	.604	.032
	After	309	509	818	.622	.033
Y	3 Before	644	455	1099	.414	.029
	After	727	453	1180	.384	.028
N	4 Before	330	205	535	.383	.041
	After	271	221	492	.449	.044
I	1 Before	573	663	1236	.536	.028
	After	535	669	1204	.556	.028
G	2 Before	362	1002	1364	.735	.023
	After	358	891	1249	.713	.025
H	3 Before	329	420	749	.561	.036
	After	394	426	820	.520	.034
T	4 Before	374	377	751	.502	.036
	After	333	349	682	.512	.038

FIGURE #33 MARKER-PAINT REPLACEMENT LANE DISTRIBUTIONS

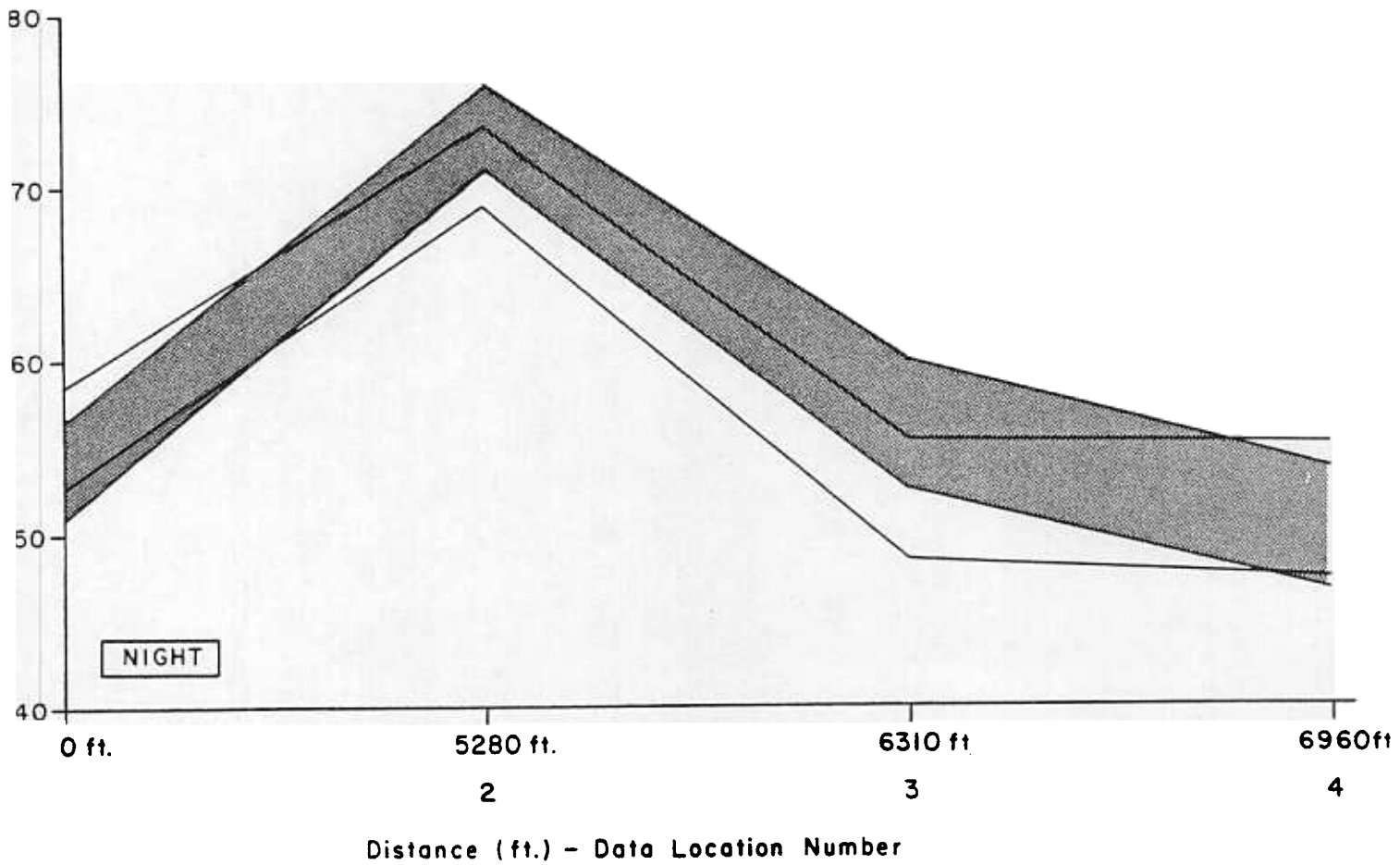
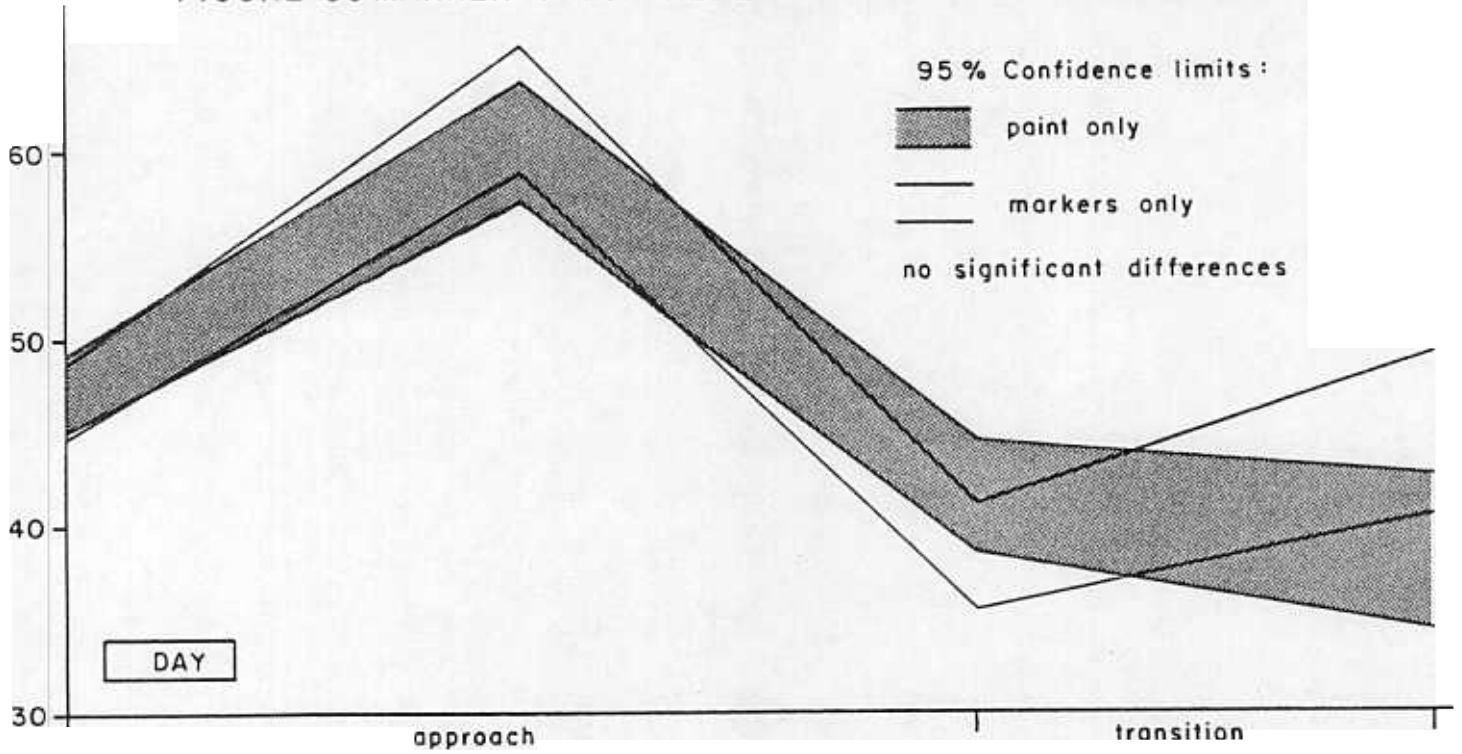


TABLE 19

MARKER-PAINT REPLACEMENT MANEUVERS

	<u>Maneuver</u>	<u>Time</u>	<u>Number</u>	<u>Volume</u>	<u>95% Confidence Limits</u>	
					<u>P</u>	<u>+/-</u>
	Weave	Before	113	1071	0.106	0.018
	Right to Left	After	60*	1017	0.059	0.014
D	Weave	Before	25	1071	0.023	0.009
	Left to Right	After	20	1017	0.020	0.009
A	Encroachment	Before	18	1071	0.017	0.008
	Right to Left	After	29	1017	0.029	0.010
Y	Encroachment	Before	25	1071	0.023	0.009
	Left to Right	After	16	1017	0.016	0.008
	Brake	Before	96	1071	0.090	0.017
	Application	After	90	1017	0.088	0.017
	Weave	Before	185	1184	0.156	0.021
N	Right to Left	After	40*	1160	0.034	0.011
	Weave	Before	17	1184	0.014	0.007
I	Left to Right	After	25	1160	0.022	0.008
	Encroachment	Before	50	1184	0.042	0.011
G	Right to Left	After	16*	1160	0.014	0.007
	Encroachment	Before	39	1184	0.033	0.010
H	Left to Right	After	8*	1160	0.007	0.005
T	Brake	Before	85	1184	0.072	0.015
	Application	After	56	1160	0.048	0.012

*Significant

TABLE 14

PANEL-BARRICADE SPEEDS

		LEFT LANE			RIGHT LANE		
		LOCATION 1	LOCATION 2	LOCATION 3	LOCATION 1	LOCATION 2	LOCATION 3
		TYPE III PANEL	TYPE III PANEL	TYPE III PANEL	TYPE III PANEL	TYPE III PANEL	TYPE III PANEL
n		124	80	98	113	105	78
\bar{x}		37.0	42.8	43.7	34.4	40.5	39.4
s ²		7.0	9.9	11.5	7.8	12.3	15.3
F		1.14	1.11	1.17	1.16	1.24	1.24
n		84	50	84	89	78	83
\bar{x}		36.4	39.3	42.1	33.3	36.3	35.8
s ²		9.5	12.6	12.5	5.5	8.1	19.5
F		1.16	1.06	1.01	1.54*	1.27	1.72*

n = Sample Size

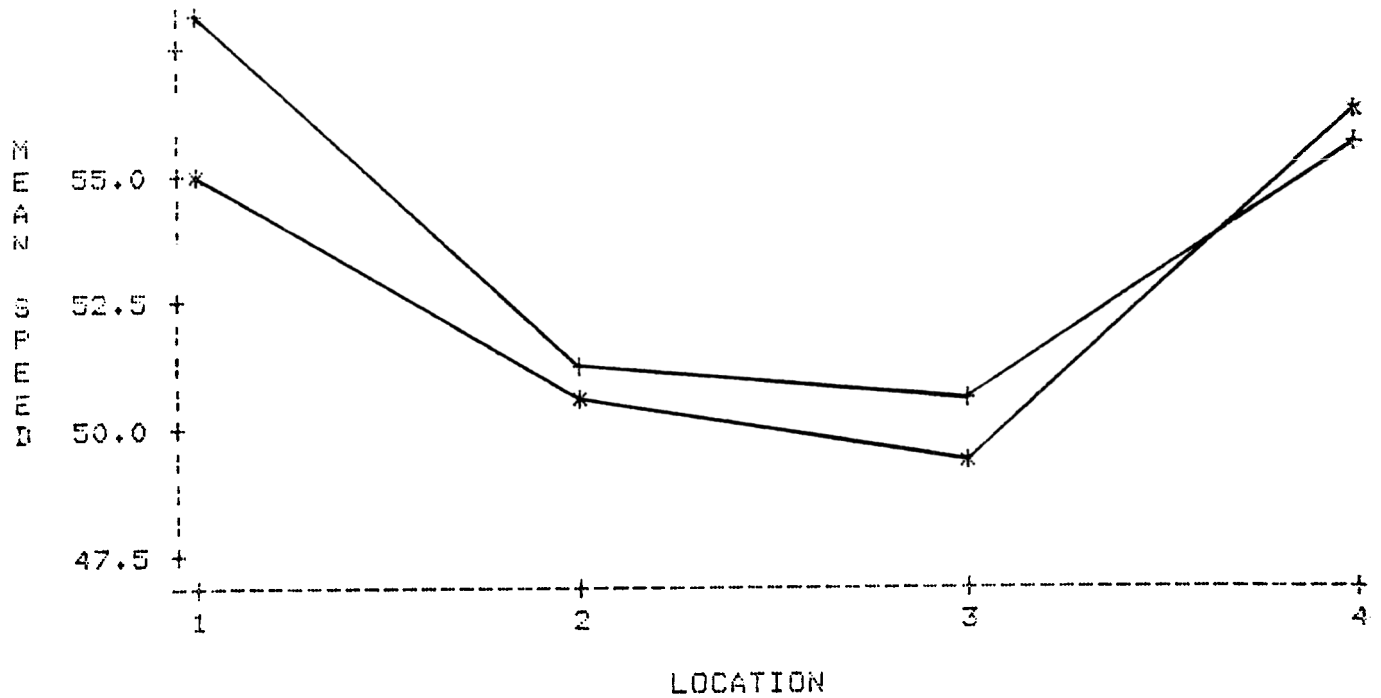
\bar{x} = Mean Speed

s² = Variance

* = Significance at the 95% level of confidence

FIGURE 34 MARKER - PAINT REPLACEMENT MEAN SPEEDS
LEFT LANE MEAN SPEEDS

PLOT OF PAINT*LOCATION SYMBOL USED IS *
PLOT OF MARKERS*LOCATION SYMBOL USED IS +



RIGHT LANE MEAN SPEEDS

PLOT OF PAINT*LOCATION SYMBOL USED IS *
PLOT OF MARKERS*LOCATION SYMBOL USED IS +

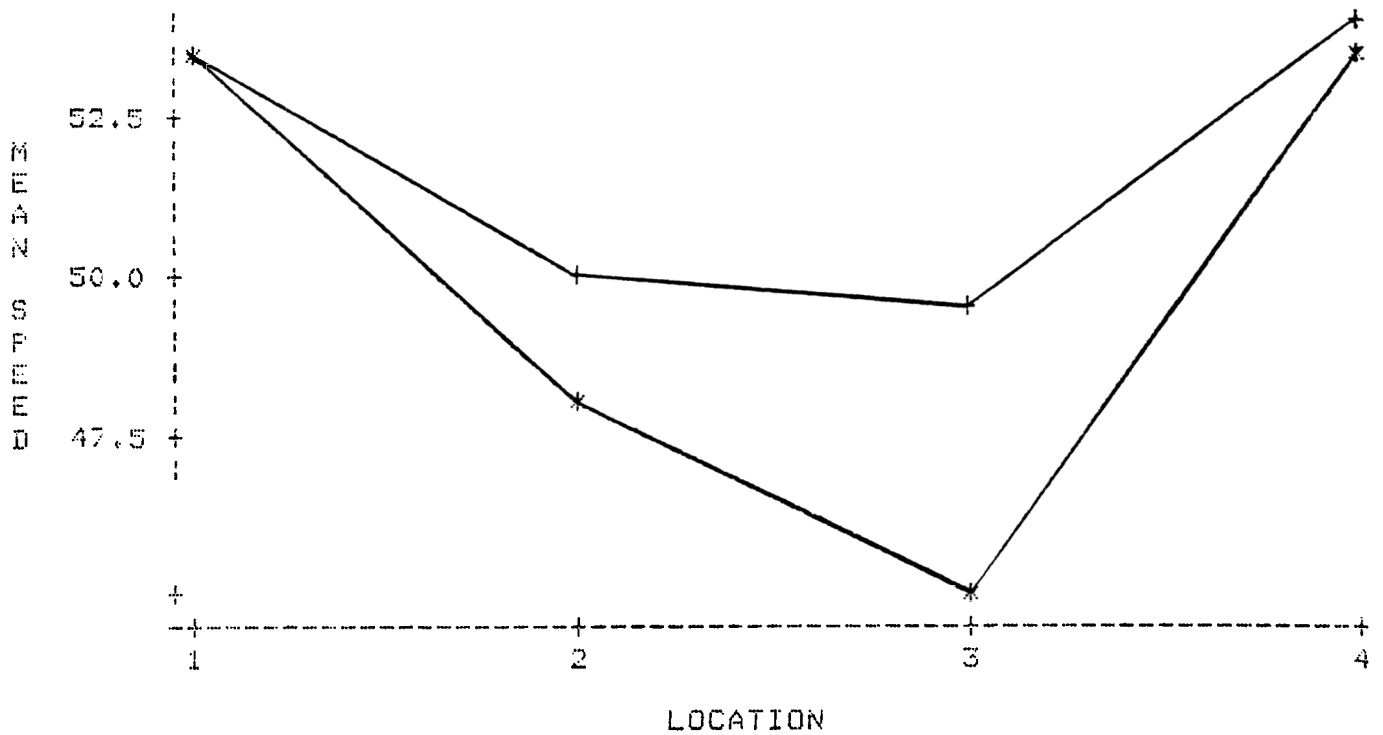
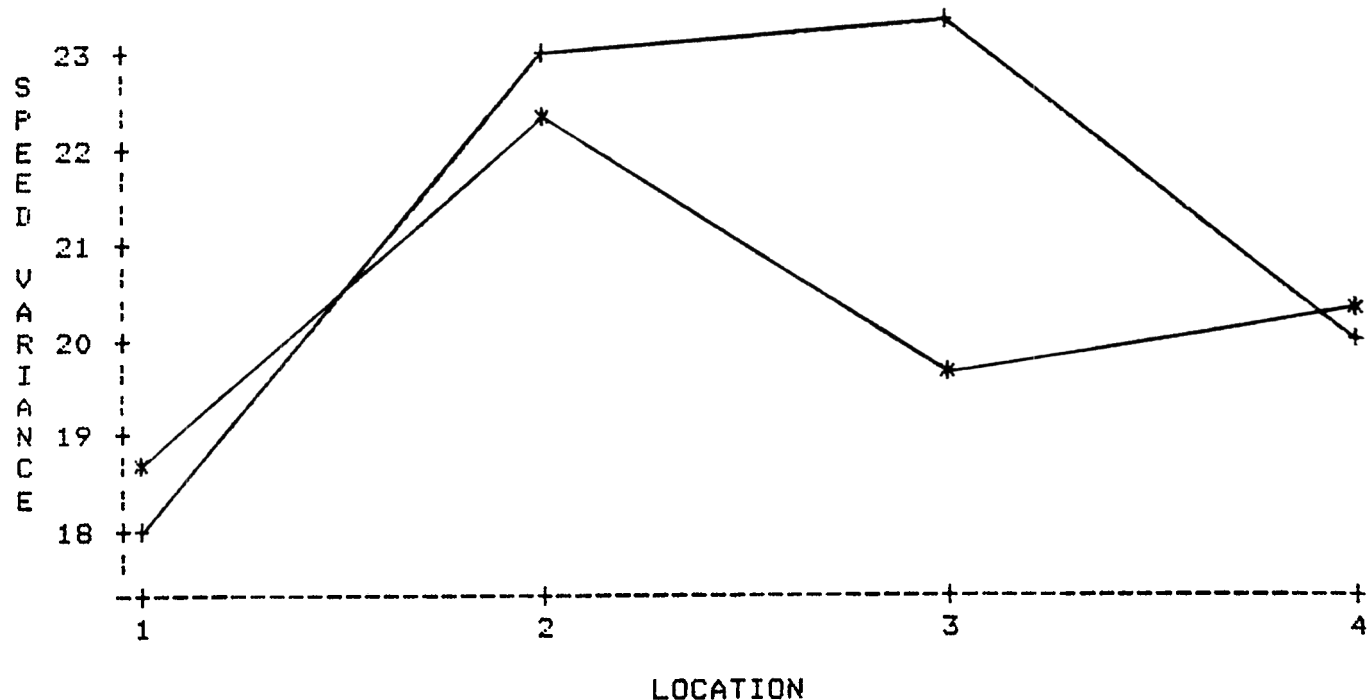


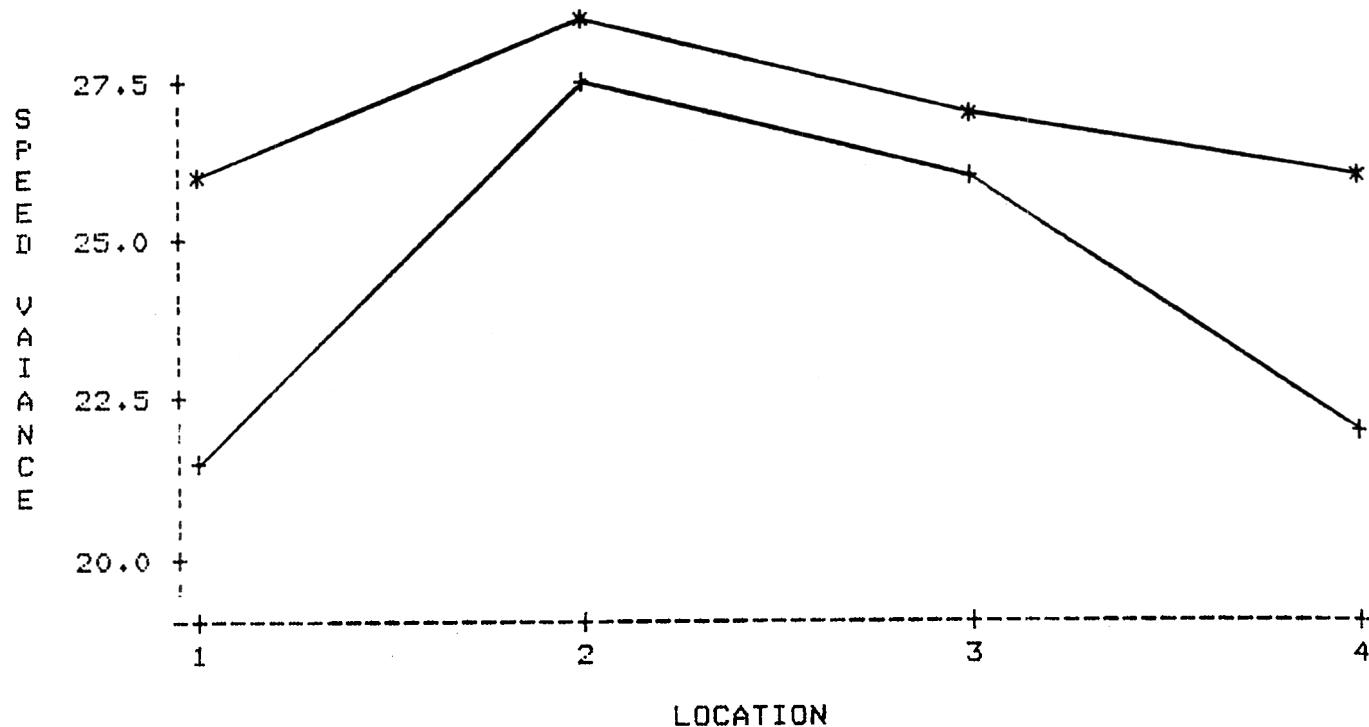
FIGURE 35 MARKER - PAINT REPLACEMENT SPEED VARIANCES
LEFT LANE SPEED VARIANCE

PLOT OF PAINT*LOCATION SYMBOL USED IS *
PLOT OF MARKERS*LOCATION SYMBOL USED IS +



RIGHT LANE SPEED VARIANCE

PLOT OF PAINT*LOCATION SYMBOL USED IS *
PLOT OF MARKERS*LOCATION SYMBOL USED IS +



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