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16. Abstract

This report presents the findings of the research conducted in the Highway Planning and Research (HPR) Project 1232-Task 5.1, Dynamic Lane Assignment Systems, sponsored by the Texas Department of Transportation. Dynamic lane assignment could be accomplished with fiberoptic technology, by electronically selecting one of the different lane use assignment displays. The research under this project was done in three phases. The first phase involved testing the sign for legibility, target value, and other human factors measures as they are affected by sign design features, and operational parameters such as sign brightness, light output, operating voltage, and sign placement relative to traffic signals.

The results of the first phase aided in developing second generation signs. These signs were used to study the operational aspects of fiberoptic signs. These studies showed that motorists do not have difficulty understanding the displays and changes in the displays and that the preferable time to change the display is approximately 2 seconds after the beginning of red in the traffic signal.

The signs were then installed at the intersection of the IH 10 frontage road and Voss/Bingle in Houston, Texas, to study the effectiveness of the system. These studies revealed that the DALAS system is capable of redistributing vehicles uniformly over different lanes. This resulted in significant reduction of delays and queue lengths. Hence, DALAS has a high potential of being an effective advanced traffic management system tool.

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SPACE MANAGEMENT : AN APPLICATION OF DYNAMIC LANE ASSIGNMENT

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Federal Highway Administration

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

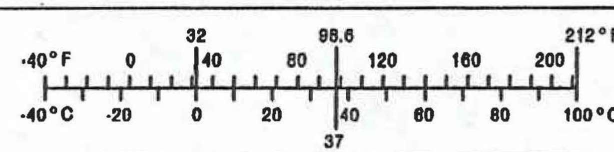
Note: Volumes greater than 1000 L shall be shown in m^3.

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



IMPLEMENTATION STATEMENT

The Dynamic Lane Assignment concept, with fiberoptic changeable message signs, is ready for implementation at a wide variety of major intersections including interchanges that involve intersections. The primary requirement is that traffic volume variations are sufficient to warrant the use of a different number of lanes at different times of the day. This change in demand may be predictable or sporadic. The concept is, in fact, implemented at the field test site in Houston where it continues to serve traffic effectively on a daily basis.

Even though the concept is fully implementable in its present state of development, additional study is needed to refine its design, installation and operation. This can be done through the incorporation of research studies within new field installations. Future installations should be made with different timing devices. There are timing devices available that permit various programming concepts to be integrated through remote computer controls. Also, some installations should utilize experimental traffic control software and hardware that will permit sign control to be accomplished through the signal controller.

Other field studies should address the location of the fiberoptic signs. To be able to locate the signs in a roadside configuration could result in a substantial savings in hardware costs.

The concept has an unfortunate stigma of being a concept applicable only at diamond interchanges. In reality, it has numerous applications at major streets in urban areas where congestion is prevalent at major intersections. By more efficiently managing turning movements through multiple turn lanes when needed, it may extend the life of the arterial for several years while reducing the queue lengths and delays through the application of Dynamic Lane Assignment.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding or permit purposes.

ACKNOWLEDGMENT

The authors wish to acknowledge the contributions of Jim Livingston and others of the National Sign and Signal Company of Battle Creek, Michigan and C. J. Hood of C. J. Hood Company of Stamford, Connecticut, for their assistance in the design and procurement of the experimental fiberoptic signs used in this study. The authors also express appreciation to various representatives of TTI and TxDOT for their advice and counsel and for their participation in the study.

The authors wish to acknowledge the great contributions of Vernon Byar of Naztec, Inc., and Curtis Herrick of Tx DOT in the development of the control logic and the hardware modifications that were necessary for operating the dynamic lane assignment signs in coordination with the existing signal controls.

A special acknowledgment is due personnel of District 12 of TxDOT for their enthusiastic participation in this research and their cooperative spirit in arranging for the installation of the signs for field studies.

EXECUTIVE SUMMARY

Introduction

A strong case is frequently made that congestion is the direct result of ever-increasing travel demands, particularly in urban areas. Also, there is merit in the claims that variability in turning movement volumes exacerbate the perennial problem of congestion. These problems prompt traffic engineers to continually search for better ways to manage traffic, particularly on urban systems. We have developed and refined "time management" methods, i.e., traffic responsive signal phasing and timing techniques, to a high level of efficiency. This research deals with a complementary concept - "space management". Space management utilizes dynamic lane assignment, i.e., changing specific lane use assignments in response to changes in the turning movement demand volumes at major intersections. This report describes the activities and results of the research conducted for the Highway Planning and Research (HPR) Project 1232-Task 5.1 Dynamic Lane Assignment Systems.

The Study

The research on the Dynamic Lane Assignment Sign (DALAS) system was performed in three phases. The first phase involved the design of the fiberoptic DALAS sign, and identifying the appropriate layout and operational features for optimal legibility, understandability, and target value. The second phase involved the development of an operating strategy for the DALAS signs, particularly the transitional phasing and timing for changing lane assignments. Finally, the third phase involved the operational assessment of the signs in actual traffic conditions.

Realizing that such a sign must be tested ultimately under actual traffic conditions, a search was begun to identify locations that would be adaptable to DALAS, and would be in reasonable proximity to TTI's research resources and facilities. Of numerous diamond interchanges and major intersections considered, the best candidate for field application was the intersection of the eastbound frontage road of IH-10 and Voss/Bingle, where there were highly significant changes in proportions of through- and left-turning traffic throughout the day.

This report presents a review of the current signing technology and a brief evaluation of the various signing technologies that can be used to design changeable message signs. The advantages of using fiberoptics technology are highlighted. Initially, a prototype fiberoptics sign was developed (Figure S1) to facilitate displays that would convey the same messages as Lane-Use Control Signs R3-5 and R3-6 as illustrated in the Manual on Uniform Traffic Control Devices, and an additional display that would provide for an exclusive through movement. This sign satisfied the "dynamic lane assignment" designation because it could be controlled electronically to select turn arrow displays for exclusive left turns, exclusive through movements, or combined left turns and through movements from the same lane. The prototype sign was evaluated at the Texas A&M Riverside Campus Sign Test Laboratory. This evaluation included studies of legibility, visibility, target value and other human factors measures affected by sign design features such as stroke width, letter height, symbol shape, pixel spacing, redundancy and others. Operational issues included in the evaluation were sign brightness, light output, operating voltage, sign placement relative to traffic signals, and the presence of fixed source lighting as they relate to the human factors measures.

The results showed that the symbols (the turn arrows) were clearly legible from a distance of 800 feet, but the supplemental text "ONLY" and "OK" were legible at 200 feet or less. An inverse relationship between legibility and target value was found. Intuitively, light output of the sign was proportional to the applied voltage; then it was observed that an increase in voltage resulted in an increase in target value but it also resulted in a corresponding decrease in legibility. The optimum voltage for acceptable levels of legibility and target value was found to be between 35 and 65 volts, where the lamps are designed for a nominal line voltage of 120 Volts. Legibility occurred when sign voltage was 35 volts, the best target value was observed at 65 volts. However, legibility and target value were found to be acceptable at all points within the range of 35 to 65 volt settings. It should be noted that the studies were performed in a field laboratory which is essentially devoid of extraneous light. For field applications, it is important that signs have features that permit voltage adjustments to compensate for the effects of ambient light conditions.

This research has demonstrated a very high potential for fiberoptics signs to effectively communicate to the driver the requirements for dynamic lane assignment. The knowledge gained in this research was used to design the second generation signs that were used at the Sign Test Laboratory at the Texas A&M Riverside Campus to develop sign/signal control strategies and were ultimately installed for field evaluation under actual traffic conditions. The second generation signs used single row pixels to form all symbols and letters. These pixels were spaced at 0.7 inches, and every other pixel in a line was connected to an alternate light source. This arrangement provides the redundancy essential for an acceptable display when one light bulb is burned out. Six-inch letters were used to improve the legibility distance for the word messages. The second generation signs are illustrated in Figure S2.

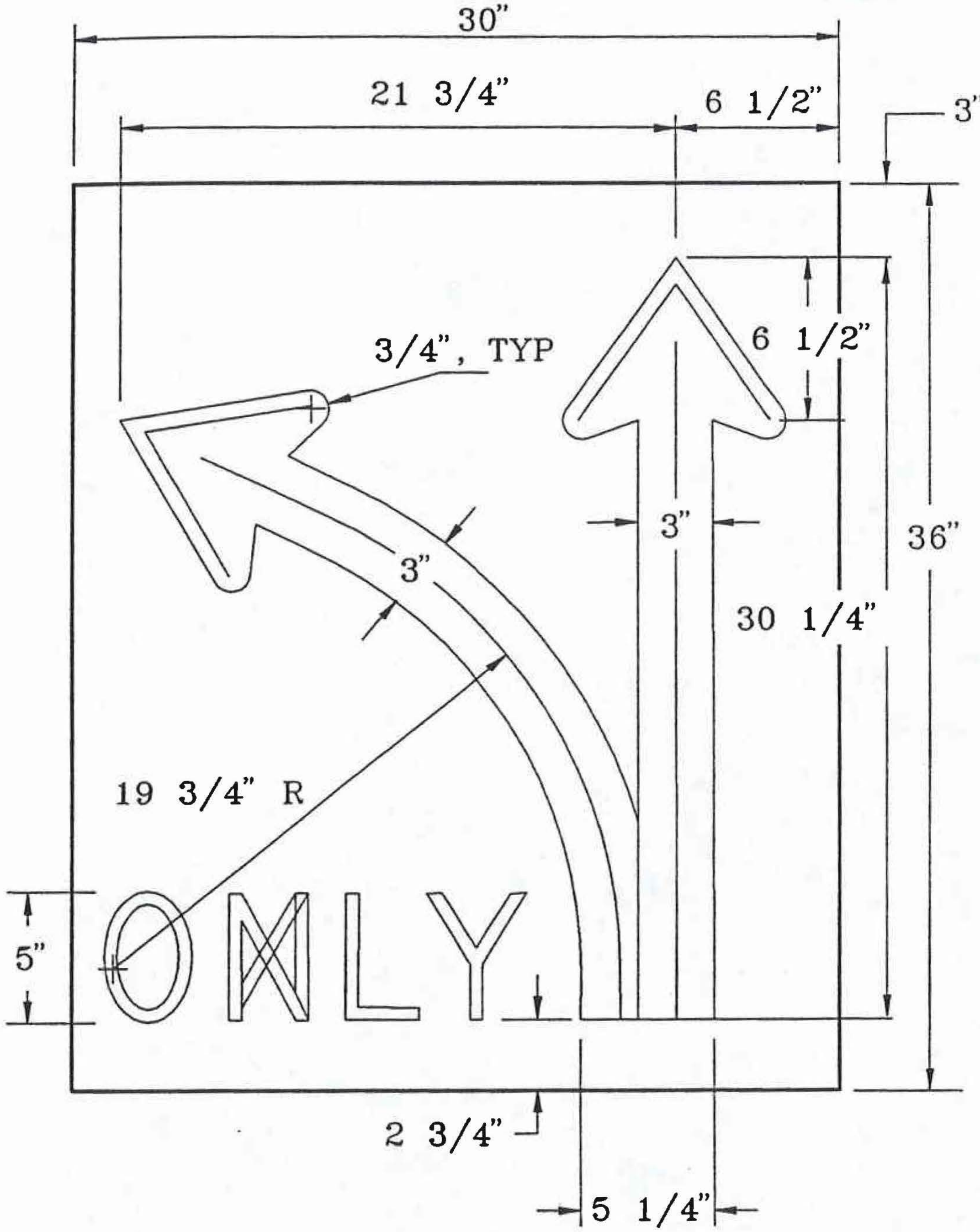
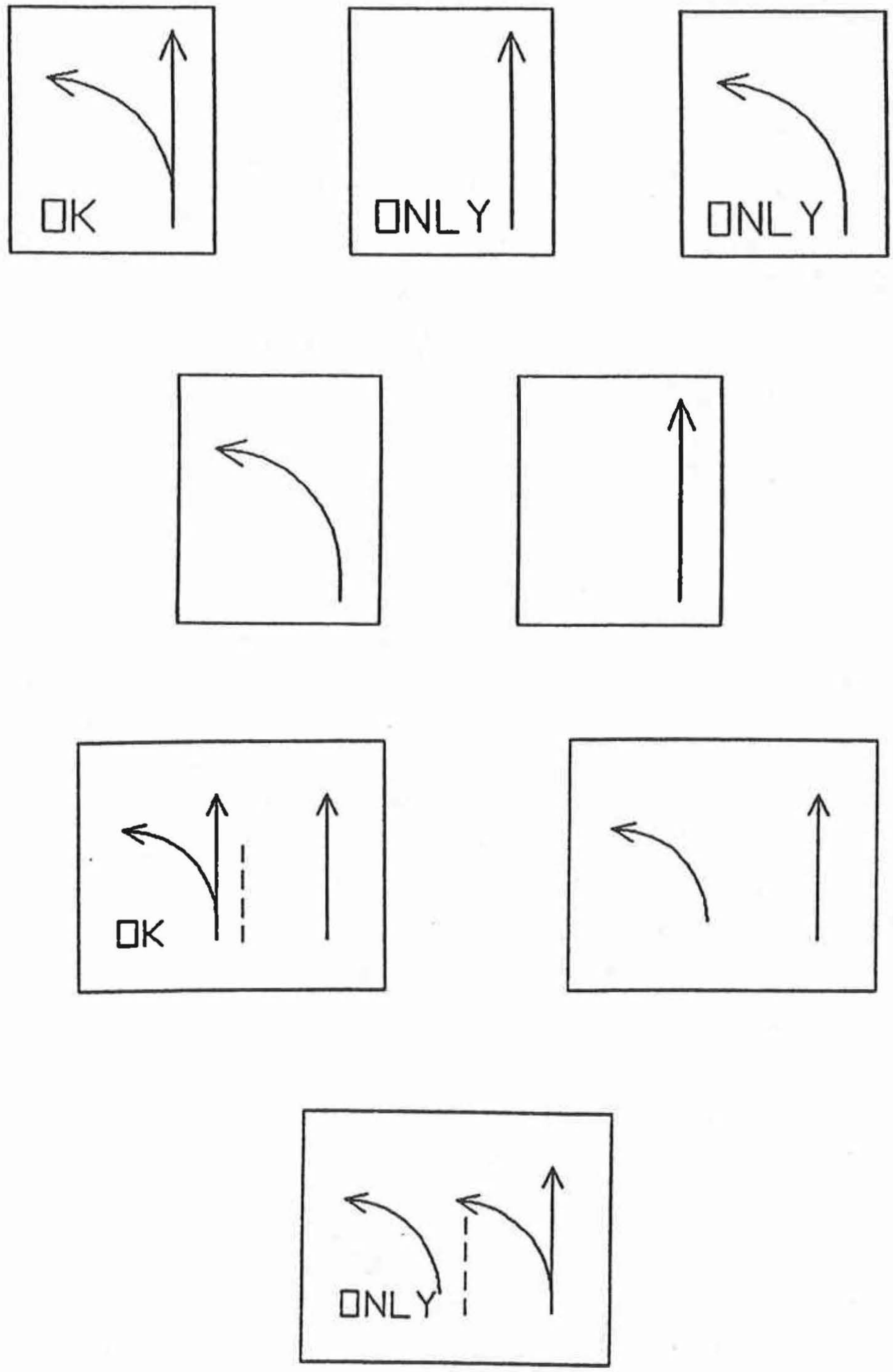


Figure S1. Detailed layout of the first generation sign.



S2. Displays generated in the second generation fiberoptic signs.

One of the principal objectives of the second phase of the research was to develop and test the transitional phasing that would permit changing lane use assignments safely and effectively. Transitional displays which change lane use assignments without creating conflicting movements are illustrated in Figure S3. It should be noted that a change from Main Display 1 to Transitional Display 1 involves only the loss of a through movement in the inner lane. Those vehicles that are already in the inner lane may proceed straight ahead without a conflict. In changing from Transition Display 1 to Main Display 2, the left-turn movement is added to the middle lane. If this display had followed Main Display 1 directly, then a conflict would exist. Finally, Transition Display 2 is used to terminate the left-turn movement from the middle lane before allowing the through movement to begin in the inner lane. In effect, the transition displays allow drivers who have committed to a particular lane for a given maneuver to complete that maneuver, even though the lane assignment has just been changed. Thus, the length of time for the transition phasing to be displayed should be sufficient to clear those vehicles that are involved in a terminated maneuver. The studies indicated that two signal cycles are a sufficient transition period.

Another objective of this second phase was to identify the control hardware and the control strategy to effectively coordinate the signal timing and the DALAS displays. Two Naztec 900 Series controllers were used to operate the signs and the signals separately. The timers for the two controllers were modified to facilitate communication between them as well as to utilize the Naztec closed loop software to control the operation of the dynamic lane assignment signs. The closed loop system permitted the monitoring of the signs as well as the signals from a computer.

The second generation signs were first installed at the sign test laboratory on the same support as the traffic signals, approximately 50 feet beyond the simulated stop line for the intersection. A roadside sign was located on the left side about 300 feet in advance of the intersection, where it was intended to provide advance information. Through preliminary studies, it was concluded that the signs and signals at the same location may create an excessive driver work load and visual clutter. Through a visual angle analysis, it was determined that the signs should be located at least 180 ft in advance of the signals. Thus, the overhead signs were located 200 feet in advance of the stop line and 250 feet in advance of the signals. The roadside sign was installed at the intersection on the far side left as a confirmation sign. The layout of the test site is shown in Figure S4.

A panel of experts in the fields of transportation and human factors evaluated the experimental layout. This evaluation confirmed the transitional phasing as the most understandable and plausible alternative. The panel concluded that the optimum nighttime legibility was achieved when the signs were operated at 50% of the nominal line voltage. Also, the panel agreed that changes in the fiberoptic displays should be made 2 to 3 seconds after the onset of red in the approach signal. This would effect the change when the queues on the approach are at their lowest point, and at a time which is not in conflict with another major event.

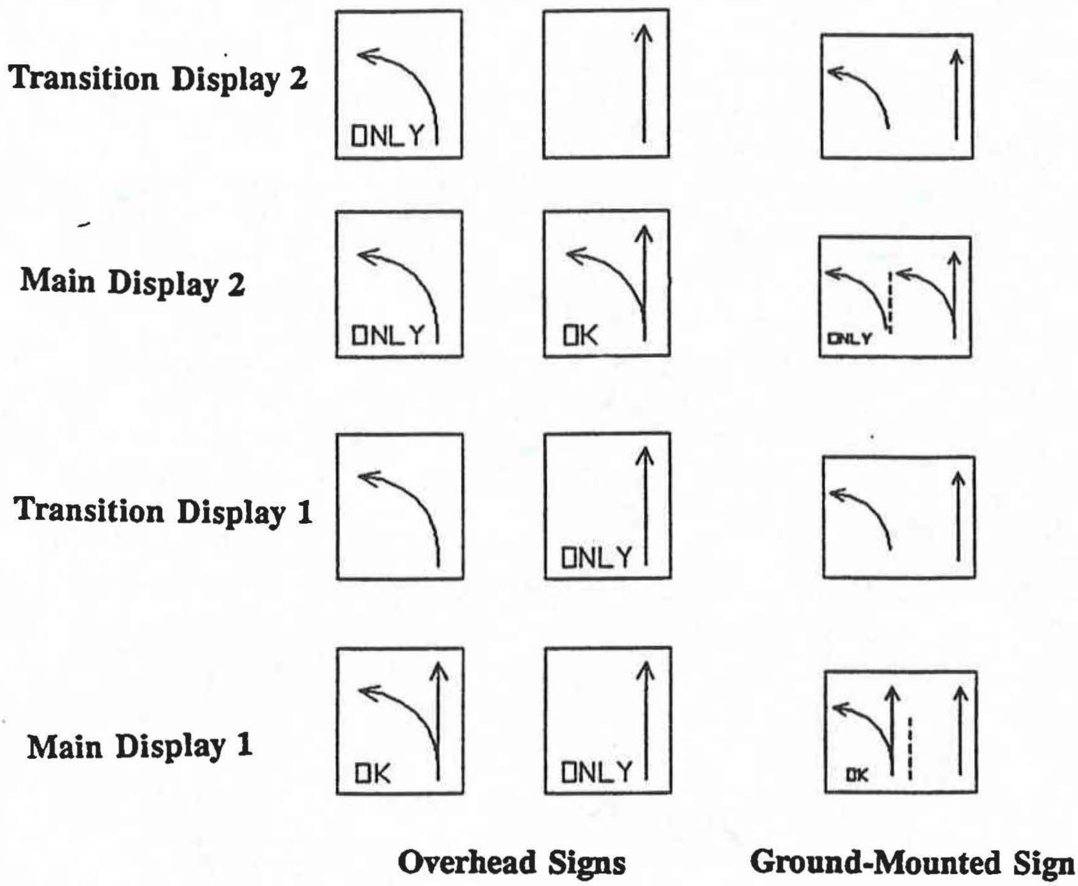


Figure S3. Sequence of the displays generated in fiberoptic signs

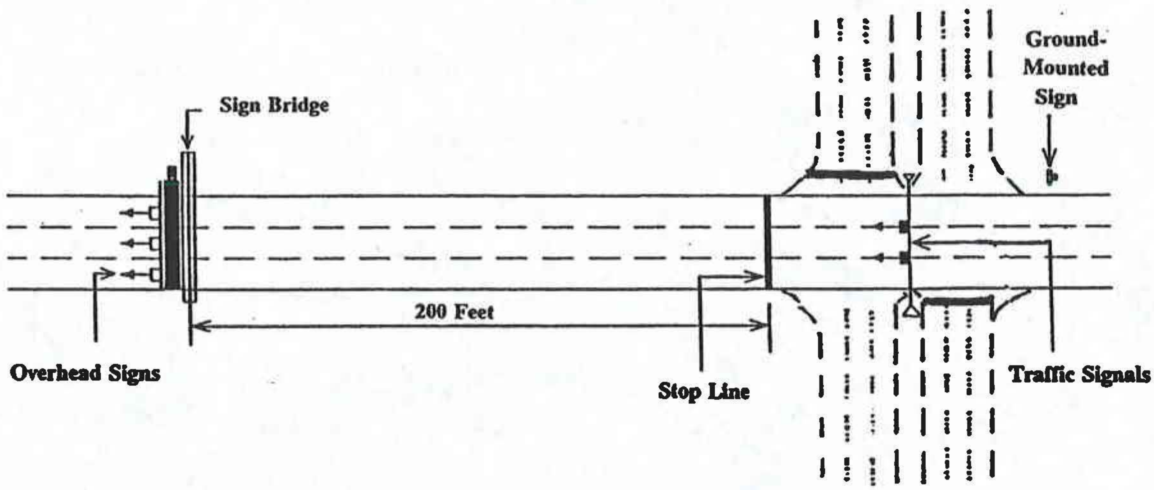


Figure S4. Experimental layout of the fiberoptic signs.

Finally, a sample of 50 driver subjects was used to evaluate the experimental layout. The results indicated that drivers had no problems interpreting the meaning of the signs. They had no difficulty in responding to display changes when a movement was added to the display. However, when the display change terminated a movement in a lane, the driver responses were distributed among the following responses:

1. Change lanes at the beginning of green;
2. Respond to the sign display even though it was not an intended maneuver; and
3. Ignore the display and continue the intended maneuver.

The reader should keep in mind that these were verbal responses rather than observed driving behavioral responses. Because there are no direct conflicts in lane assignments, the impact of any one of the responses is expected to be minimal. Further, a study of the observed traffic volumes at the proposed site in Houston indicates that a maximum of two drivers may find themselves in the wrong lane for the assigned left turn when the display change occurs.

Based on the studies conducted in the second phase, construction plans were preppared for installing signs in Houston were. The layout of dynamic lane assignment signs at IH-10 and Voss/Bingle road is shown in Figure S5. The overhead signs were installed at 200 feet upstream of the stopline. The roadside sign was installed as a confirmation sign in the far left corner of the intersection. The static signs defining the lane use before the installation of the DALAS signs were removed.

A controller for operating the signs was installed under the bridge, beside the existing signal controller. The interconnect between sign and signal controller enables the change in the sign display about 2 seconds after the onset of red for the approach. The sign controller was programmed to effect the proper displays in accordance with a pre-determined schedule. Main Display 1 was to be displayed from 6:00 a.m. to 10:00 a.m., followed by the Transition Display (Figure S3) for two signa cycles. Then, Main Display 2 was to be displayed until 6:00 a.m., when the Transition Display woud be displayed for two signal cycles, thus completing the daily sign cycle.

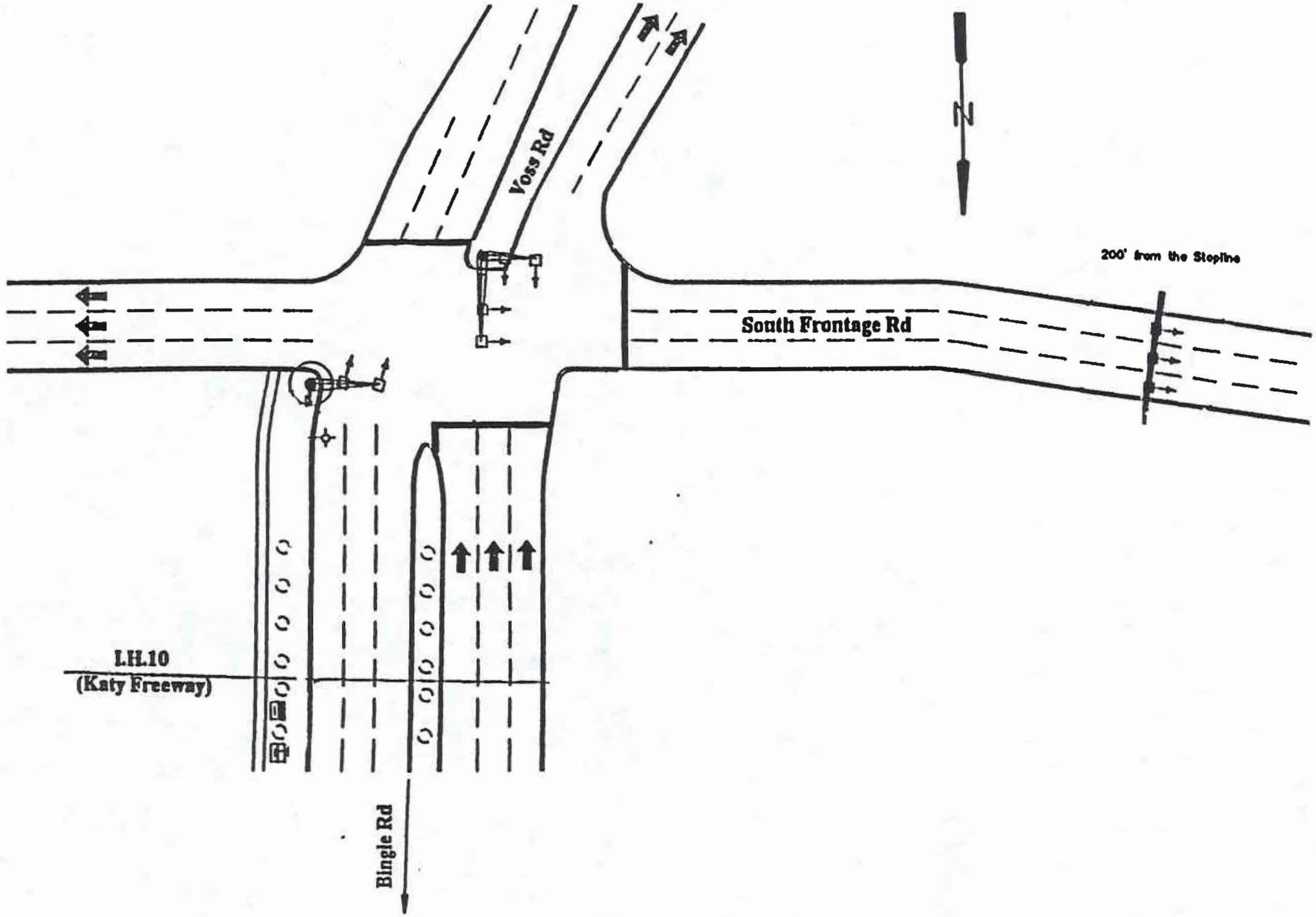


Figure S5. Layout of the signs at IH-10 and Voss/Bingle.

Before and After studies were performed to operationally assess the DALAS system under actual traffic operation conditions. Comparisons made for differences in MOEs between different lanes and different peak periods in the Before conditions revealed that:

1. In the a.m. peak period, the delays and queue lengths were uniform over different lanes, indicating that the lane assignment was appropriate for the traffic in that period; and

2. In the p.m. peak period, long delays and queue lengths were observed in the inner lane as compared to the other two lanes, indicating that the lane assignment was not serving the traffic demand effectively.

The After studies were conducted and the Before and After results compared. MOEs for the a.m. peak remained essentially the same as expected. The comparison for the p.m. peak showed substantial differences in delay and queue engths across all lanes. Figures S6a-c shows the comparison of average queue lengths and average delays relative to demand volumes for pm peak periods in the Before and After studies.

These results indicate that the DALAS sign concept is an effective traffic management tool. Its use can alleviate congestion at intersections with highly variable turning volume demand. Typical diamond interchanges in Texas, associated with frontage roads, have the problem of highly variable turning volume demand and hence, the DALAS signs were assessed at a diamond interchange. However, this problem, and the applicability of these signs is not confined to diamond interchanges.

DALAS, or Dynamic Lane Assignment, or better yet, Space Management, incorporated with Time Management provides great potential for IVHS traffic management concepts. When non-recurring freeway incidents occur, one of the primary management techniques is diverting freeway traffic to the frontage road. Under normal conditions, the frontage road control system is set up as part of the local street network. When traffic is diverted from the freeway, the efficiency of operation on the frontage road may be improved substantially by revising lane assignments and signal timing to accommodate the predominance of through traffic. As a result of this research, the space management tools are ready. What is needed at the next step is the sensory capability, the management strategy, and the communication technology for dynamically invoking space and time management techniques.

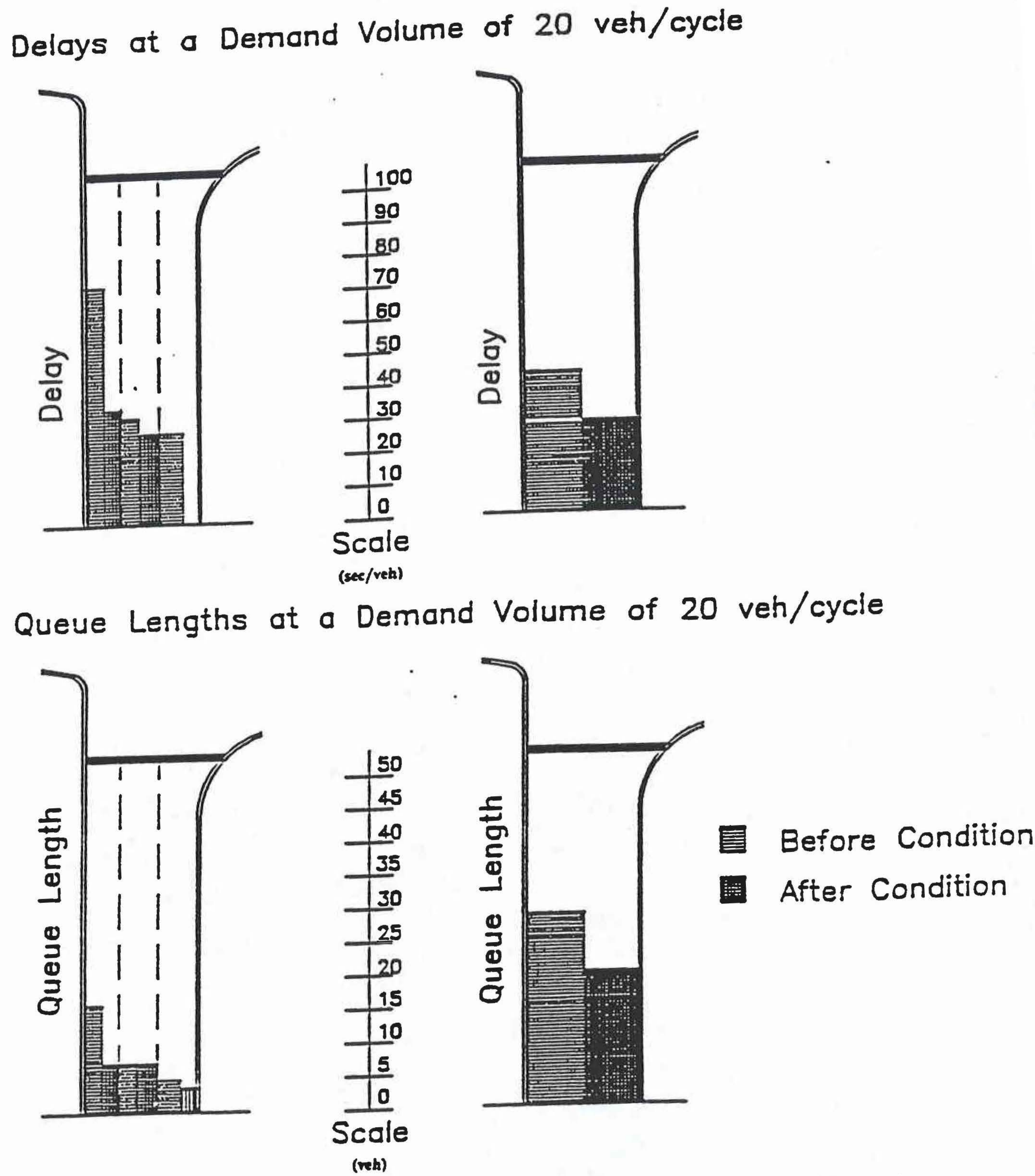
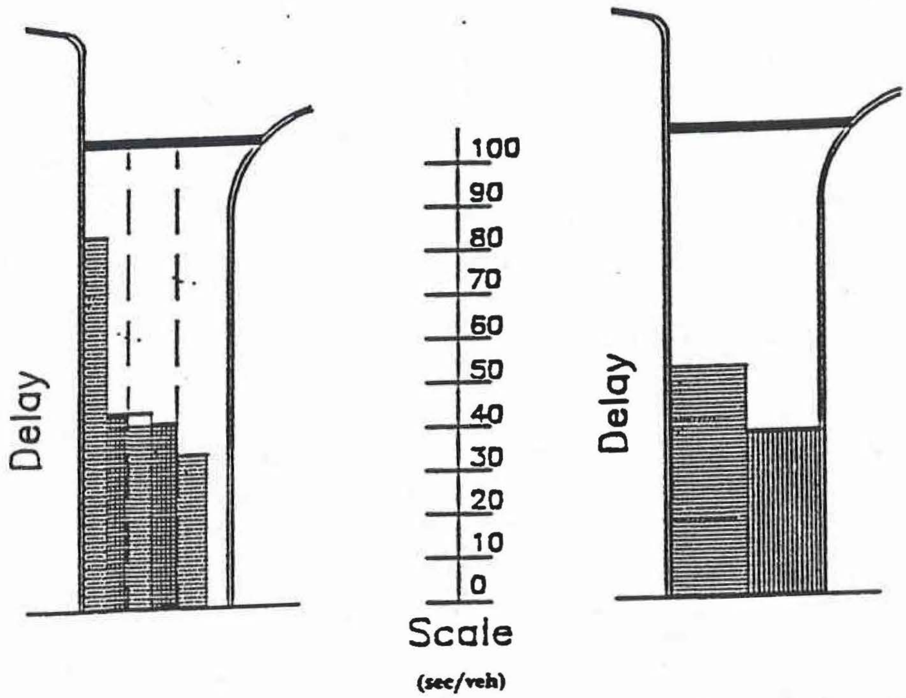


Figure S6a. Comparison between Before and After p.m. peak period conditions at a demand volume of 20 veh/cycle.

Delays at a Demand Volume of 35 veh/cycle



Queue Lengths at a Demand Volume of 35 veh/cycle

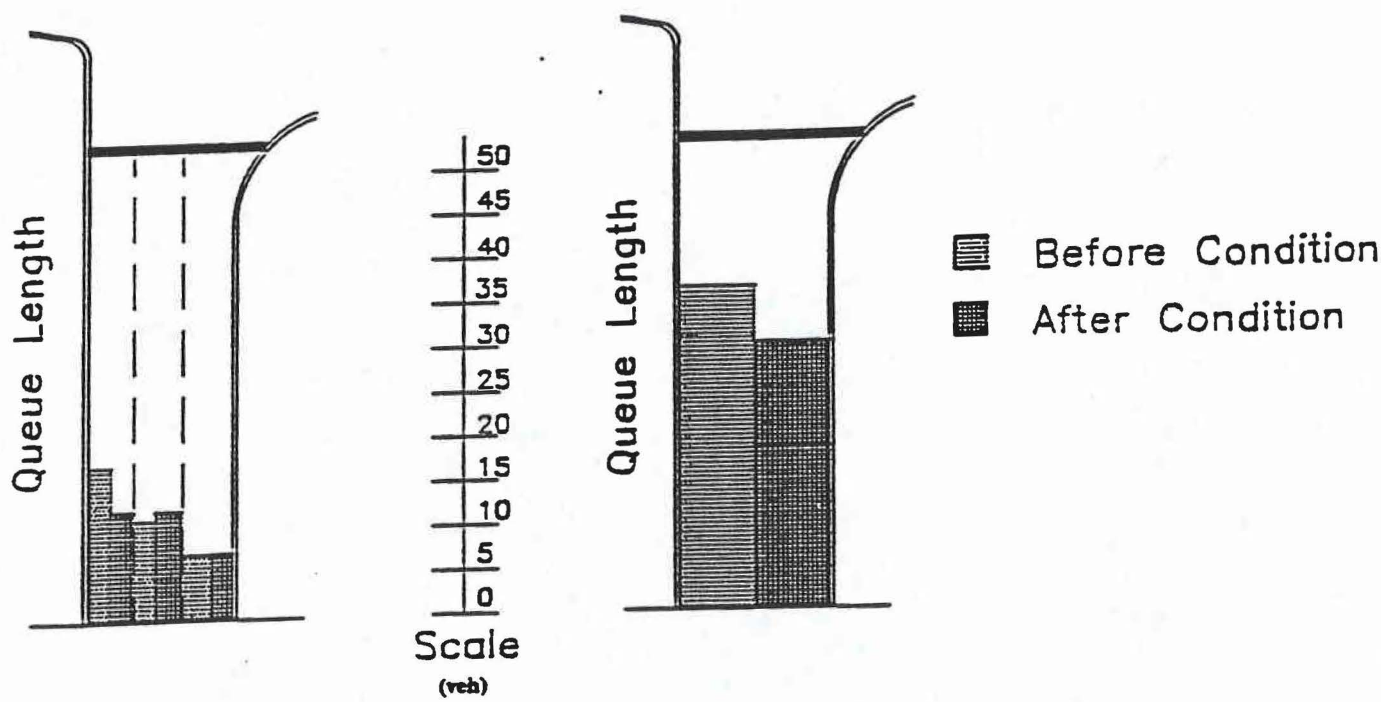
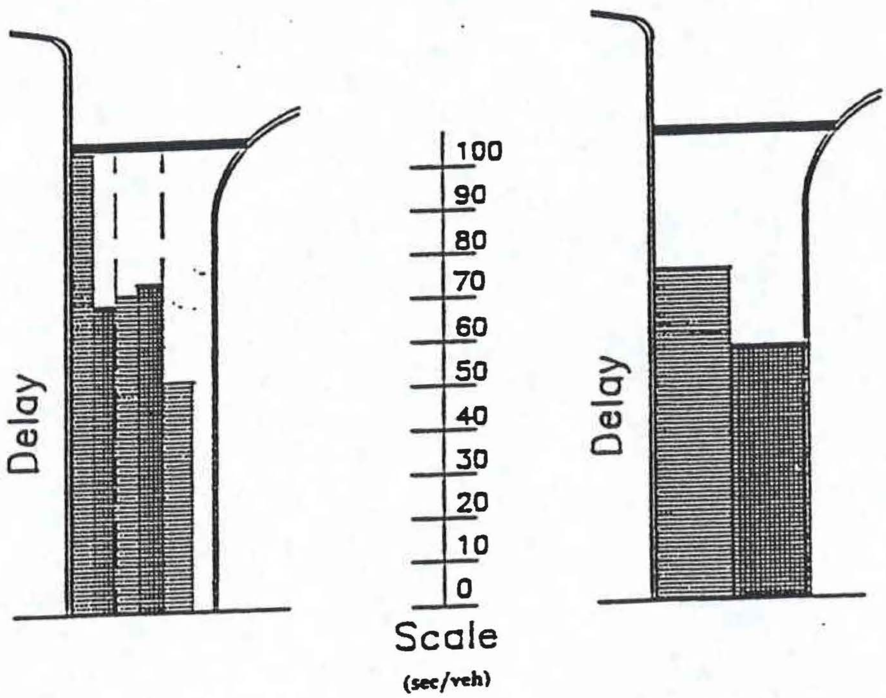


Figure S6b. Comparison between Before and After p.m. peak period conditions at a demand volume of 35 veh/cycle.

Delays at a Demand Volume of 50 veh/cycle



Queue Lengths at a Demand Volume of 50 veh/cycle

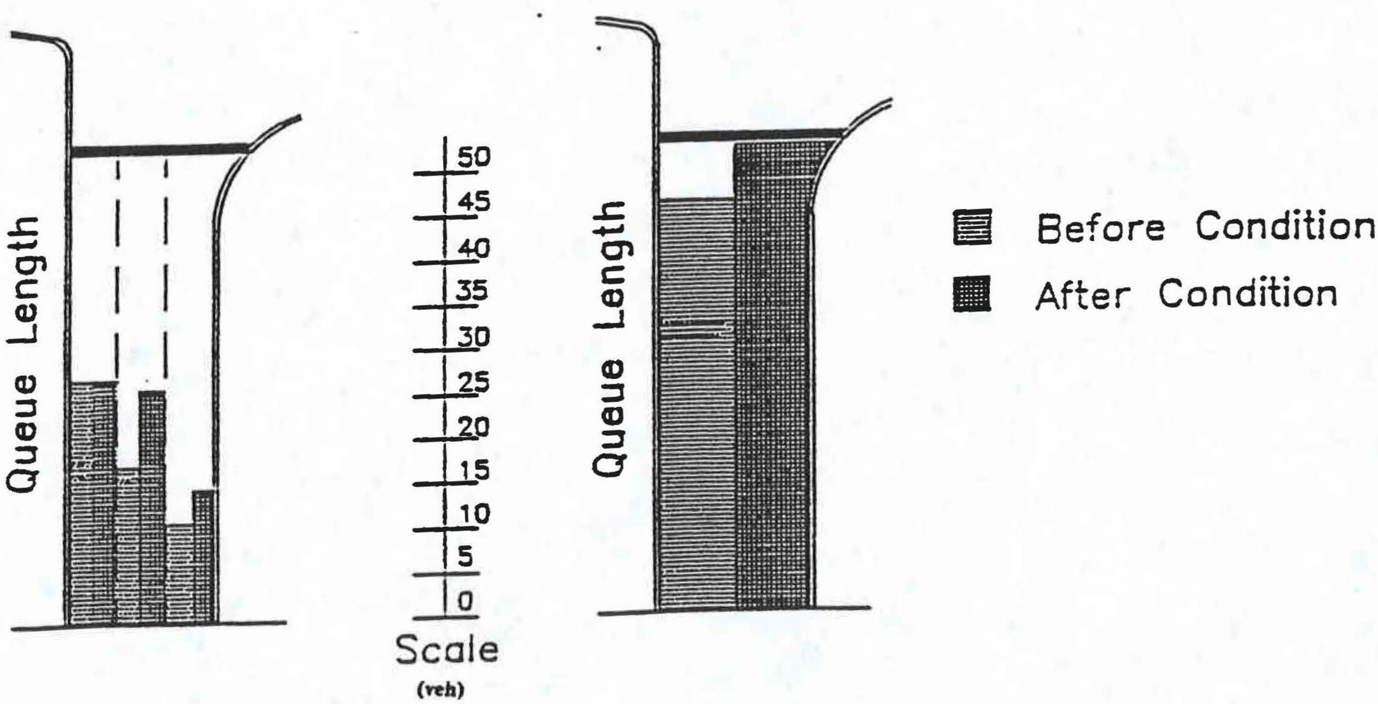


Figure S6c. Comparison between Before and After p.m. peak period conditions at a demand volume of 50 veh/cycle.

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GLOSSARY

Acceptability - a subjective measure of the ease with which a motorist comprehends the message being conveyed by a traffic control device.

Arm - group of fiberoptic strands one end of which is grouped to form an individual pixel while the other end is grouped with other arms into which light can be projected.

Attention Value - a subjective measure of the sign's ability to attract the attention of a driver. Attention value can be broken down into terms of target value and priority value.

Brightness - a measure of luminous energy being reflected or emitted from an reflective object or a light source.

Changeable message sign - a sign which has the capability to generate a finite number of pre-determined displays.

Contrast - (1) the ratio of the difference between the object being viewed and the background surroundings or (2) the ratio of the difference between the legend of a sign and the sign background.

Driver work load - a measure of the effort expended by a human operator while performing a task, independently of the performance of the task itself.

Element - a group of pixels forming a part of a display.

Glance Legibility - a measure of a person's ability to discern a legend in a very limited amount of time.

Glare - sensation caused when light intensity within the visual field is sufficiently greater than that to which the eye is adapted; this causes annoyance, discomfort, or loss of visual performance and visibility.

Internally-lighted Signing - signing that produces its own light to form displays.

Irradiation - the point at which the disability glare occurs in a fiberoptic sign due to high voltage across the display.

Legibility - a measure of a person's ability to read and/or discern the actual appearance of an object under good viewing conditions.

Legibility distance - the distance from the sign providing satisfactory legibility.

GLOSSARY (Contd.)

Luminance - the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction. It is typically expressed in foot-lamberts or candelas per unit area.

Pixel - an aperture on the face of a fiberoptic sign. One end of the line of fibers from the light source emits light through the pixel. A number of pixels placed in particular order form, an element of a sign display. The size of the pixel determines the quality and the resolution of symbols.

Reflective Signing - signing that utilizes reflective materials to redirect light produced by external sources, e.g., headlights, street lighting, sunlight, etc., to provide sign visibility under low levels of illumination.

Sign-signal coordination - an issue about the status of the traffic signal at the instant of a display change in the fiberoptic sign.

Target Value - a subjective value that corresponds to a signs ability to compete with its surroundings for the driver's attention. Target value is dependent on contrast, relative size, placement, and the type of signing.

Space-management technique - the concept of utilizing the available right-of-way in a more efficient manner by dynamically assigning space (lanes) to satisfy the dynamic demands of traffic.

Time-management technique - the traditional means to improve the operations at signalized intersections by assigning time to each movement in a more efficient manner (i.e., improved signal timing).

Traffic sign - a device mounted on a fixed or a portable support whereby a specific message is conveyed by means of words or symbols.

Traffic control devices - all signs, signals, markings, and devices placed on, over, or adjacent to a street or highway by authority of a public body or official having jurisdiction to regulate warn or guide traffic.

Variable message signs - a sign capable of generating any number of displays or messages.

Conversion Factors

1 Foot-lambert	=	452 Candelas/in^2
1 Foot-lambert	=	3.142 Candelas/ft^2
1 Lumen	=	12.57 Candelas
1 Foot-candle	=	3.14 Foot-lamberts
1 Foot-candle	=	1 Lumen/ft^2
1 Foot-candle	=	12.57 Candelas/ft^2

INTRODUCTION

The research reported herein was conducted as Task 5.1, TRAFFIC CONTROL SYSTEMS of the HP&R Project 1232. This research was conducted in three phases.

The initial definition of Task 5.1 (1) was stated as follows:

> **Task 5.1 (1): Dynamic Lane Assignment.** Turning movements at diamond interchanges vary by time of day, yet traditional *traffic signing* for lane use is static. The result is inefficient use of available capacity, particularly along one-way frontage roads which must serve not only temporal surges of traffic but also traffic diversion from the freeway due to incidents and pavement maintenance activities. This task will consist of several related steps. Preliminary functional specifications will be developed initially for DynAmic Lane Assignment Signs (DALAS) operating within a SC&C system together with preliminary real-time operations strategies and control logic. Human factors issues will be identified including visibility, understandability, signal transitions, and driver response. These human factors issues will be examined and addressed through a carefully designed series of laboratory experiments based on high-resolution VCR color video techniques. Plans for field testing the signs will be formulated.

It was decided that the human factors laboratory experiment could be effectively integrated into full-scale field laboratory experiments at the TTI Sign Laboratory located at the Texas A&M Riverside Campus. To facilitate these full-scale field laboratory experiments, a fiberoptic sign providing dynamic lane assignment capability was designed, procured and installed at the TTI sign laboratory. Traffic signals and roadway illumination devices were installed to create a realistic sign test environment.

The principal objective of the first phase of the research was to identify the design requirements for a second generation of fiberoptic DALAS signs which would be installed at a selected diamond interchange for evaluation under real-world traffic conditions. Thus, the first generation sign was designed in such a manner that it would completely encompass the probable range of design and performance requirements for the real-world application. In other words, the flexibility designed into the sign allowed the selection of displays that were far more than adequate for visual performances on one extreme and then less than adequate, on the other extreme, of performance levels. This flexibility was achieved by providing for variation of stroke width, *pixel* spacing, and voltage/light output of the sign.

Realizing that such a sign must be tested ultimately under actual traffic conditions, a search was begun to identify locations that would be adaptable to DALAS, and would be in reasonable proximity to TTI's research resources and facilities. Of numerous diamond interchanges considered, the best candidate for field application was the intersection of the eastbound frontage road of IH-10 and Voss/Bingle.

The results of this phase of the research have been reported in a thesis by Wayne Gisler, a graduate student in the Transportation and Public Works Area of Civil Engineering at Texas A&M University. The thesis is entitled "Dynamic Lane Assignment Using Fiberoptic Signing."

The primary objective of the second phase of the research was to develop alternative strategies for operating fiberoptic signs displaying a changeable message for lane assignment. Since no standards exist about the installation of such signs, emphasis was placed on providing information to facilitate the development of standards or guidelines for the installation and operation of fiberoptic signs.

The results of this phase of the research have been reported in a thesis by Srinivasa Sunkari, a graduate student in the Civil Engineering Department at Texas A&M University. The thesis is entitled "Factors Involved in the Operation of Fiberoptic Dynamic Lane Assignment Signs."

The overall goal of the third phase of this research was to evaluate the effectiveness of the dynamic lane assignment system as a transportation system space management tool under actual field conditions. The results of this phase of the research were reported in a thesis by Rohini Kumar Jella, a graduate student in the Civil Engineering Department at Texas A&M University. The thesis is entitled "An Operational Assessment of Dynamic Lane Assignment Signs in Houston."

PROBLEM STATEMENT

Maintaining uncongested traffic conditions at intersections that exhibit wide variations in turning movement volumes is a challenging problem for transportation agencies in many Texas metropolitan areas. Lane use information at intersections is presently conveyed to drivers via pavement markings and overhead *reflective signing*[1]. Problems occur at intersections that use these *traffic control devices* for lane use assignments when wide variations in turning movement volumes exist. The static nature of these devices does not allow lane usage to be optimized. The use of changeable message signing would provide a more efficient means of responding to cyclical variations in turning movement volumes.

Static signs and changeable message signs have basically the same performance requirements: they must first attract the attention of the driver, then provide a display that is easily discernable. Furthermore, to allow a reasonable and prudent driver to act accordingly, a display must be discerned and understood sufficiently in advance of the point where the information is needed (1). The ability of a sign to function in this manner depends on the *legibility* and *target value* of the sign. Legibility and target value of signs vary with the contrast between the sign legend and background as well as the contrast between the sign and its surroundings. The characteristics that contribute to a sign's effectiveness are external illumination, whether the sign reflects or emits light, and the size of the sign and its legend (2). While design procedures for reflective signs have been documented throughout transportation and human factors engineering journals, the design and operation of *internally lighted* displays depend on basic "rules-of-thumb" and experience. Design procedures for changeable message signs are not yet well established, due largely to the rapid development of changeable message signs (1). Design procedures and requirements must be developed that take into account the limitations of driver visibility in both daytime and nighttime driving conditions. Liability issues further mandate that changeable message signing conform as closely as possible to the requirements of the Manual on Uniform Traffic Control Devices (MUTCD) for signing (1).

Fiberoptic technology provides a viable alternative to many other types of changeable message signing. Fiberoptic displays are typically associated with providing higher levels of resolution, very uniform light output between individual pixels, and lower costs than are associated with other types of internally illuminated signing (3). A large amount of work has been done by European companies to quantify the light output of this type of signing and to develop design procedures that limit the number of pixels used to form a display based on the average pixel output (3). Procedures must be developed that provide engineers with the ability to design displays such that they can be discerned at specific distances. The development of national standards for the design of fiberoptic displays is essential to ensure that future transportation systems continue to provide information to drivers in a safe, effective, and uniform manner.

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[1]Italicized words denote Glossary terms.

OBJECTIVES

The primary objective of the first phase of this research was to evaluate target value and legibility distance of a changeable message sign developed by the Texas Transportation Institute and the National Sign and Signal Company. This sign is capable of producing several different displays (see Figure 1). To accomplish this research objective, specific procedures were adopted to:

- Conduct a survey of professionals in the Transportation and Industrial Engineering fields to evaluate sign characteristics for:
  - Various illumination conditions,
  - Various pixel spacings, and
  - Different distances from the sign.

- Conduct a pilot study to refine testing procedures

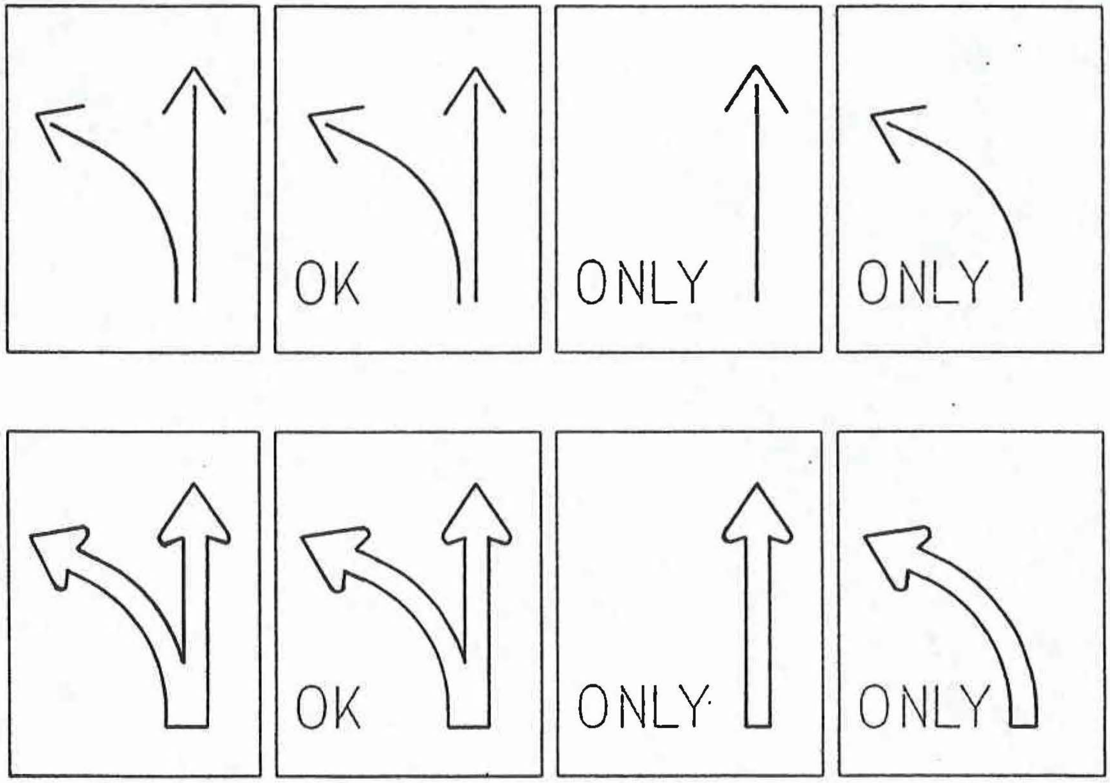


Figure 1. Displays tested in the first phase.

- Utilize the results from the pilot study to:
  - Identify limitations of the study design, and
  - Identify the range of study variables needed to obtain a manageable study size.

- Conduct a second subjective survey to:
  - Evaluate the final laboratory design,
  - Establish ranges to be used for study variables, and
  - Evaluate target value, legibility, and the interaction of the sign with the traffic signals.

- Develop and conduct a driver study to evaluate legibility distance of various fiberoptic displays.

Secondary objectives of this research were to evaluate various characteristics of the fiberoptic sign and to identify areas for future fiberoptic sign research. Characteristics that were examined included:

- Differences in pixel spacings,
- The minimum visual angle of the light output for the study settings, and
- The effect that light *intensity* produced by the sign has on the legibility of different displays.

The primary objective of the second phase of the research was to develop alternative operating strategies for the DALAS system. Studies for this phase of the research were performed using two overhead signs and a ground-mounted sign, which were developed by Texas Transportation Institute and National Sign and Signal Company, based on the results of the first phase of the research. The specific tasks performed for attaining this objective were:

- A survey of professionals in the Transportation and Industrial Engineering fields to evaluate the sign system for:
  - Various illumination conditions of signs and signals,
  - Understandability of the displays shown in Figure 2,
  - Understandability of a change in the displays,
  - Coordination between the signs and signals.

- A pilot study to refine testing procedures

- Use of results from the pilot study to:
  - Identify limitations of the study design, and
  - Identify the range of study variables needed to obtain a manageable study size.

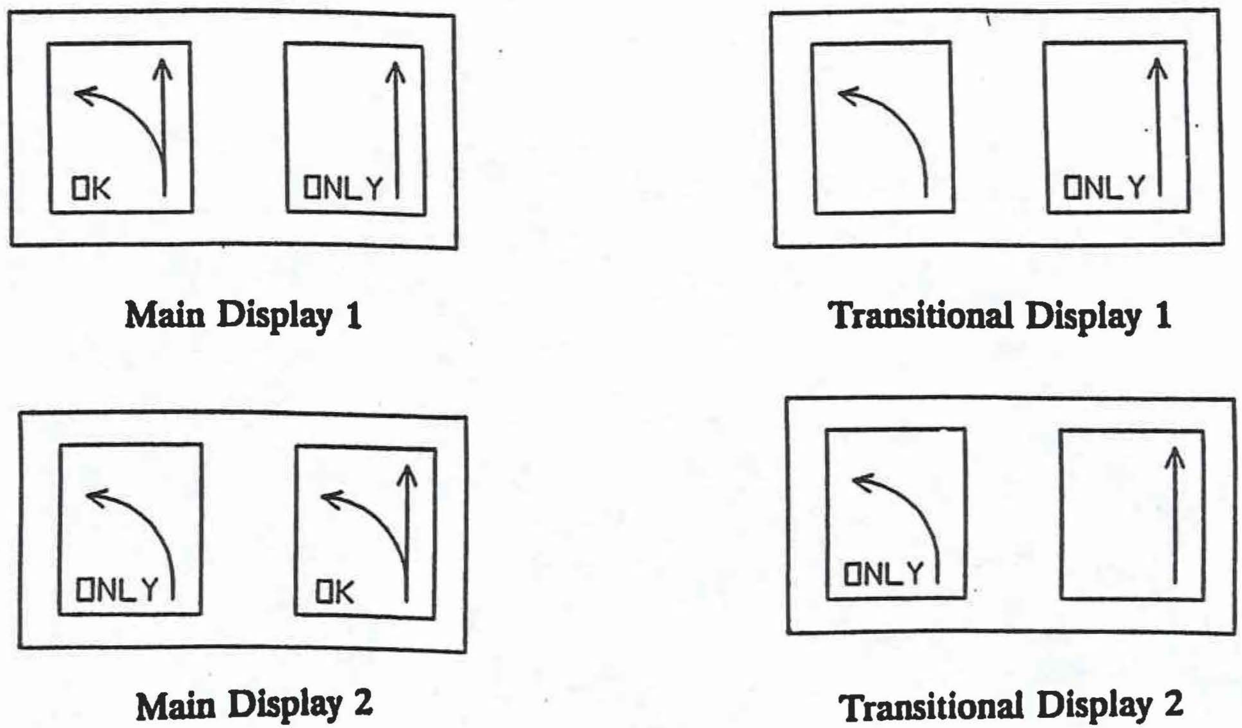


Figure 2. Displays tested in the second generation fiberoptic signs.

- A driver study to evaluate the DALAS system for coordination between signs and signals and understandability of displays and changes in displays.

Since no standards exist about the installation of such signs, emphasis was placed on providing information to facilitate the development of standards or guidelines for the installation and operation of fiberoptic signs. The concept of dynamic lane assignment at intersections is a novel concept. Driver reactions to the display changes in the fiberoptic signs were to be studied. The limitations of the design and operation of the fiberoptic signs were to be identified. The operating strategy for the signs was developed.

The principal objective of the third phase was to evaluate the effectiveness of the DALAS system as a transportation system management tool. This goal could be achieved through the following objectives:

1. Identifying the criteria by which to evaluate the traffic conditions before and after the installation of the signs.

2. Evaluating the traffic conditions before and after the installation of the signs according to the identified preset criteria.

3. Comparing the Before and After traffic conditions and evaluating the effectiveness of the implementation of the DALAS system.

The tasks involved in accomplishing the above objectives were:

1. Collecting data for the Before conditions and checking the data for internal validity. For example, due to an incident on the freeway on a particular day, the volumes on the frontage road might be significantly higher than on a typical day. Consideration of such data sets might significantly affect the traffic performance variables. Hence, the validity of a data set must be checked before an analysis could be undertaken.

2. Collecting the data after the implementation of DALAS. Also, checking the data for internal validity.

3. Identifying the statistical means to compare the pre- and post- implementation traffic conditions and comparing the traffic flow during the two analysis periods.

A minimum sample of 50 drivers was specified for the driver studies that evaluated the fiberoptic sign in the first two phases. This number was expected to provide a statistically balanced study for evaluating the legibility of the displays at different levels of light output.

The selection of participants used in these studies was based solely on the age distribution for Texas drivers (see Table 1).

Table 1. Age distribution of Texas drivers

AGE GROUP	1988 ESTIMATES OF TEXAS DRIVER POPULATION BY AGE[1]	MINIMUM NUMBER OF DRIVERS FOR EACH AGE GROUP[2]
< 25	21.7%	11
25 - 54	53.8%	27
55+	24.5%	12

[1]Obtained from the Texas State Data Center, Department of Rural Sociology, Texas A&M University.
[2]The number of study subjects required in the specified age groups.

BACKGROUND

Types of Signing

The process for selecting or designing a sign display for dynamic lane assignment narrowed the field of candidates to changeable message sign technology. Actually, many different technologies are used in the design of changeable message signs. These include rotating drum displays, lamp matrix displays, blank-out displays, and fiberoptic displays. Rotating drum signs use reflective sheeting placed on each side of a multi-sided drum. Each drum that makes up a display rotates about its centroid to exhibit different patterns, depending on the desired display. A variety of symbols and displays can be produced using this type of signing. It is limited, however, because of its size and the number of displays that can be presented with a single sign. The large number of mechanical parts results in high maintenance costs. It is, however, an effective means of utilizing reflective sheeting for changeable message signs.

Lamp matrix displays have also been used in the design of changeable message displays. These displays utilize light bulbs arranged in a series of columns and rows. This type of signing is capable of producing a wide variety of displays and/or symbols. The size of the bulbs used, however, requires a large sign face in order to obtain an acceptable level of resolution. The intensity of the light typically does not provide a uniform appearance because of variances in the length of life for individual bulbs.

The blank-out or shutter display utilizes a mechanical shutter system to "black out" parts of the sign face that are not needed to form a display. Blank-out displays have many of the same advantages and disadvantages that bulb matrix signs have. The physical makeup of this type of signing limits the size and complexity of the symbols which can be produced.

Fiberoptic Technology

The use of fiberoptic technology for providing information to drivers has gained popularity in recent years. Fiberoptic signing provides advantages over other types of internally lighted signing. Words and symbols are formed using individual bundles of fiberoptics known as *arms*. One end of each arm is clamped together with other arms to form a larger bundle of fibers. The end of this large bundle is then polished and clamped to a fixture that holds a lamp aimed directly at this end. On the other end of this arm, the fibers are divided into individual pixels which are strategically placed to form a desired display. Thus, when the lamp is energized, the light is transmitted to the pixels and the display is formed.

Table 2 shows the range of pixel sizes that are typically used as well as the purpose for which they are used. The largest pixels shown in Table 2 are typically smaller than the lighting elements used in other types of internally lighted signing. Smaller pixel sizes allow symbols and words to be formed with greater resolution so that a more continuous appearance is obtained. The application of a single light source to the common end of a bundle of arms produces highly uniform light output for individual pixels. The high light output and intensity associated with these pixels eliminates the "phantom effect" sometimes exhibited by other types of internally illuminated signing.

Several tradeoffs must be identified and addressed when considering the use of internally lighted fiberoptic signing versus conventional reflective signing. The ability of fiberoptic signing to produce light can be both an advantage and a disadvantage. While fiberoptic signs provide more target value than do reflective signs, the amount of light produced by fiberoptic signs must be adjusted to insure that the sign is legible sufficiently in advance of the point where the information is needed. A variety of information can be presented using fiberoptic displays, whereas conventional reflective signing provides only one message.

Several disadvantages associated with internally illuminated signing also exist. These disadvantages make the decision to utilize this type of signing highly dependent on the benefits that can be gained at the facility. These include higher capital, maintenance, and operating costs for the sign itself. Backup systems that provide redundancy must be designed to assure that, in the event of a mechanical breakdown or bulb failure, the sign will still be capable of providing a message. Internally lighted signs are also heavier than conventional reflective signs and require the development of special, more substantial supports and mast arms to accommodate the increased weight.

Table 2. Typical fiberoptic pixel sizes

PIXEL DIAMETER[1]	TYPICAL USE/APPLICATION
0.055"	Pedestrian Signals
0.068"	Lane Assignment/Regulatory Signing
0.090"	
0.125"	Lane Control Signing
0.177"	Word Message Signing
0.238"	Used for turn angles that need wide angle of dispersion

[1]Obtained from the National Sign and Signal Company, Battle Creek, Michigan.

PHASE I - HUMAN FACTOR ISSUES RELATED TO FIBEROPTIC SIGNING STUDY DESIGN

The first task of this study was to design and procure a prototype sign that would facilitate an evaluation of the various aspects of the dynamic lane assignment concept. After considering the various changeable message signs previously discussed, it was decided that a fiberoptic sign was the best choice. This decision was based on the characteristics of color choice, contrast, flexibility in design, and compatibility in control techniques with accompanying signalization. The prototype sign design was a joint effort of the project staff and representatives of the National Sign and Signal Company. The project staff prepared the preliminary functional layout and specifications. The manufacturer provided valuable assistance in the physical design and layout of the sign.

Design Characteristics of the Fiberoptic Sign

The sign used in this research was procured for the purpose of evaluating (1) the light output characteristics of fiberoptics, (2) the legibility distance associated with the sign displays, (3) the target value associated with each display, and (4) the general applicability of DALAS to predictable variations in traffic movement volumes at intersections. Also, consideration of DALAS applications in the overall Traffic Operations Management is important. Figure 3 shows a dimensioned layout of three different views of the sign box used to house the circuitry and fiberoptics. The face of the sign is hinged on the left side of the box and functions as a door to allow access to the circuitry and lamps which power the sign. A numerical aperture monofilament glass face plate protects the pixels from adverse weather conditions. A hood eliminates problems associated with glare and adverse weather conditions. With the exception of the glass face plate, the entire exterior of the sign was painted black so that contrast and target value were maximized. The sign was used to produce the eight different displays shown previously in Figure 1. Figure 4 shows a detailed layout of the face of the fiberoptic sign. Each pixel is part of a group of fiberoptic pixels that make up a single element of a sign display. A total of 14 lamps and transformers were used to power the individual lines used to form various displays. Lines were grouped as necessary to form specific displays. Two overlapping lines were used to form an arrow shaft. Pixels were arranged such that pixels from each line that formed a shaft alternated on 1/2 inch centers. This allowed both 1/2- and 1-inch pixel spacings to be evaluated. Actual field applications will utilize a similar arrangement to provide redundancy in displays as a backup measure to protect against mechanical and lamp failure. This concept was not used in the design of word messages for this sign. Each word message was made up of two lines arranged such that different stroke-widths could be evaluated.

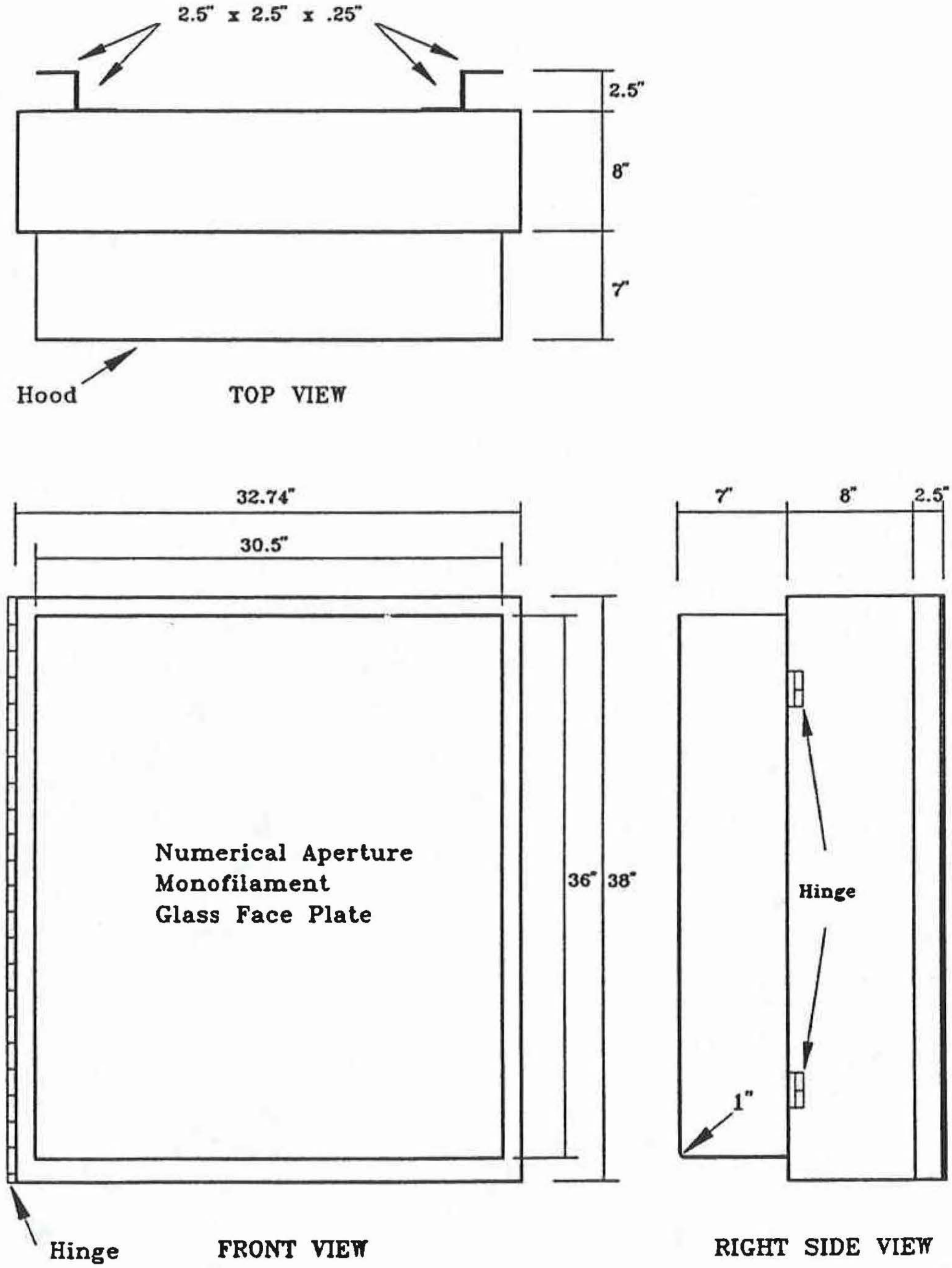


Figure 3. Dimensioned layout of the fiberoptic sign box.

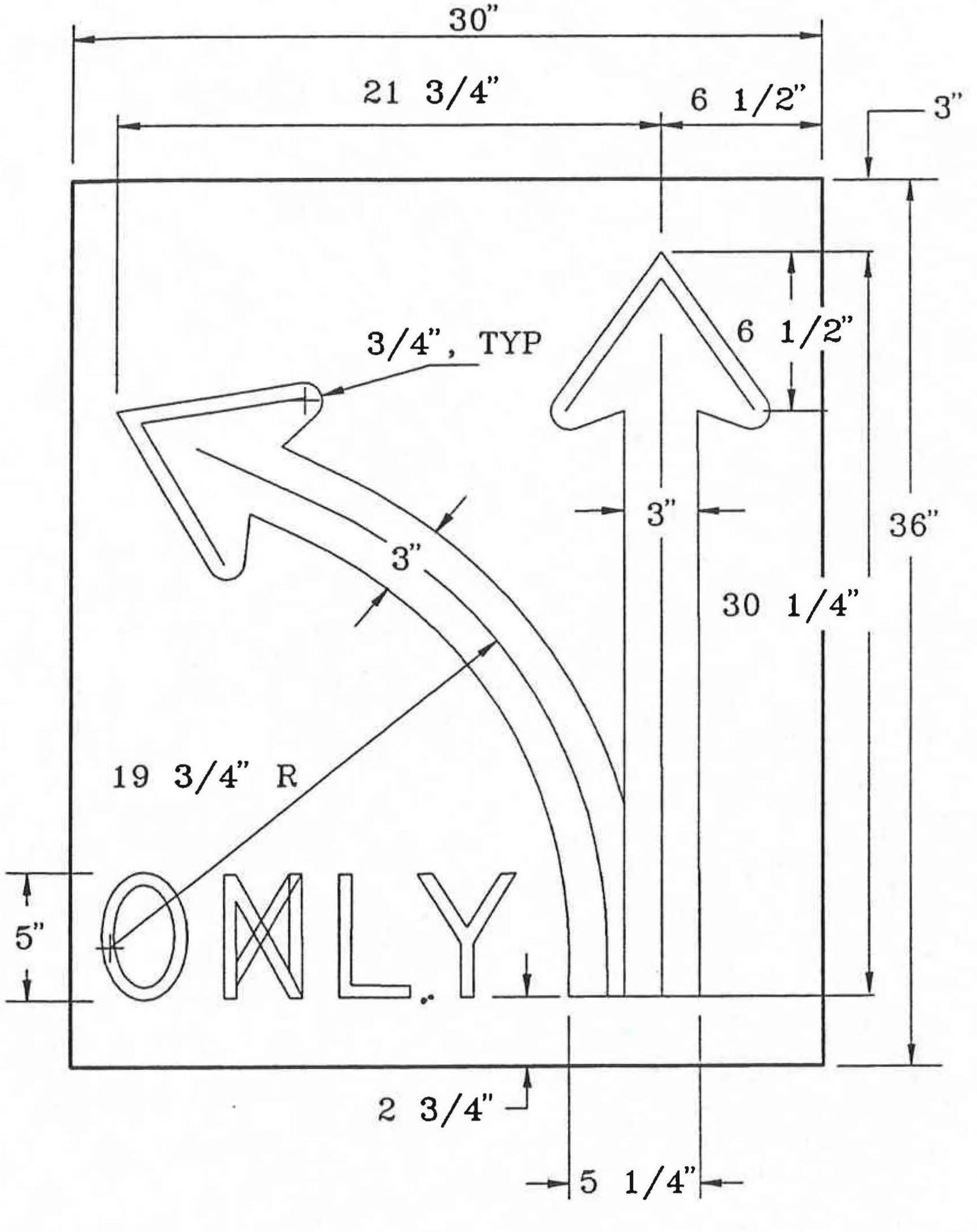


Figure 4. Detailed layout of the fiberoptic sign face.

The pixel layout allows both a single-row and a bold or outline arrow shaft to be produced. The height and stroke-width associated with bold arrow displays were designed to parallel that of arrow shaft designs used in reflective signing. The radius of the left-turn arrow is slightly larger than that of a standard R3-6L retroreflective sign. This radius was increased so that the light output would be spread over a wider expanse of the sign. This reduced the concentration of light across the sign face and provided a more legible display with higher target value than would have otherwise been obtained.

Two different stroke-widths for word messages were evaluated. The letters were 5 inches tall and conformed to letter design and spacing for standard Series-E lettering (4). The height of the lettering was selected after the design of the arrow shafts had been determined. The major concern with the design of the lettering was that the word messages not interfere with arrow shafts as they were intended to supplement the information conveyed by the arrow shafts.

Initial Design of Laboratory

The major objective of the initial laboratory design was to provide realistic conditions for the study of legibility and target value of the sign. The initial laboratory design was evaluated through a series of subjective observations. A number of changes were made to this setup as a result of these observations.

The laboratory layout shown in Figure 5 illustrates the laboratory design used for evaluating legibility and target value for the fiberoptic sign. The sign tower was used to support two 3-lens traffic signal heads with 12-inch lenses, two overhead high-intensity grade retroreflective signs, and the overhead fiberoptic changeable message sign. The distance between the right edge of the signals and the sign to the left of the signals is 3 feet. Longitudinal pavement joints simulated three traffic lanes. The fiberoptic sign and its associated signal were centered over the middle lane of the installation. External illumination was provided by placing Type II, 250 watt high pressure sodium luminaires 120 feet in front of and behind the sign tower. A 120 volt portable generator was used to power the fiberoptic sign and the luminaires.

First Subjective Analysis

A group of professionals from the fields of Transportation and Industrial Engineering evaluated the preliminary layout of the laboratory. Several informal reviews were held to provide input to the design of laboratory conditions and parameters. In this manner, conditions that are considered more characteristic of signalized intersections were established at the laboratory. Subjective evaluations of the attention value and legibility of the fiberoptic sign were obtained. Individuals were asked to compare the fiberoptic and reflective signing with respect to legibility and target value.

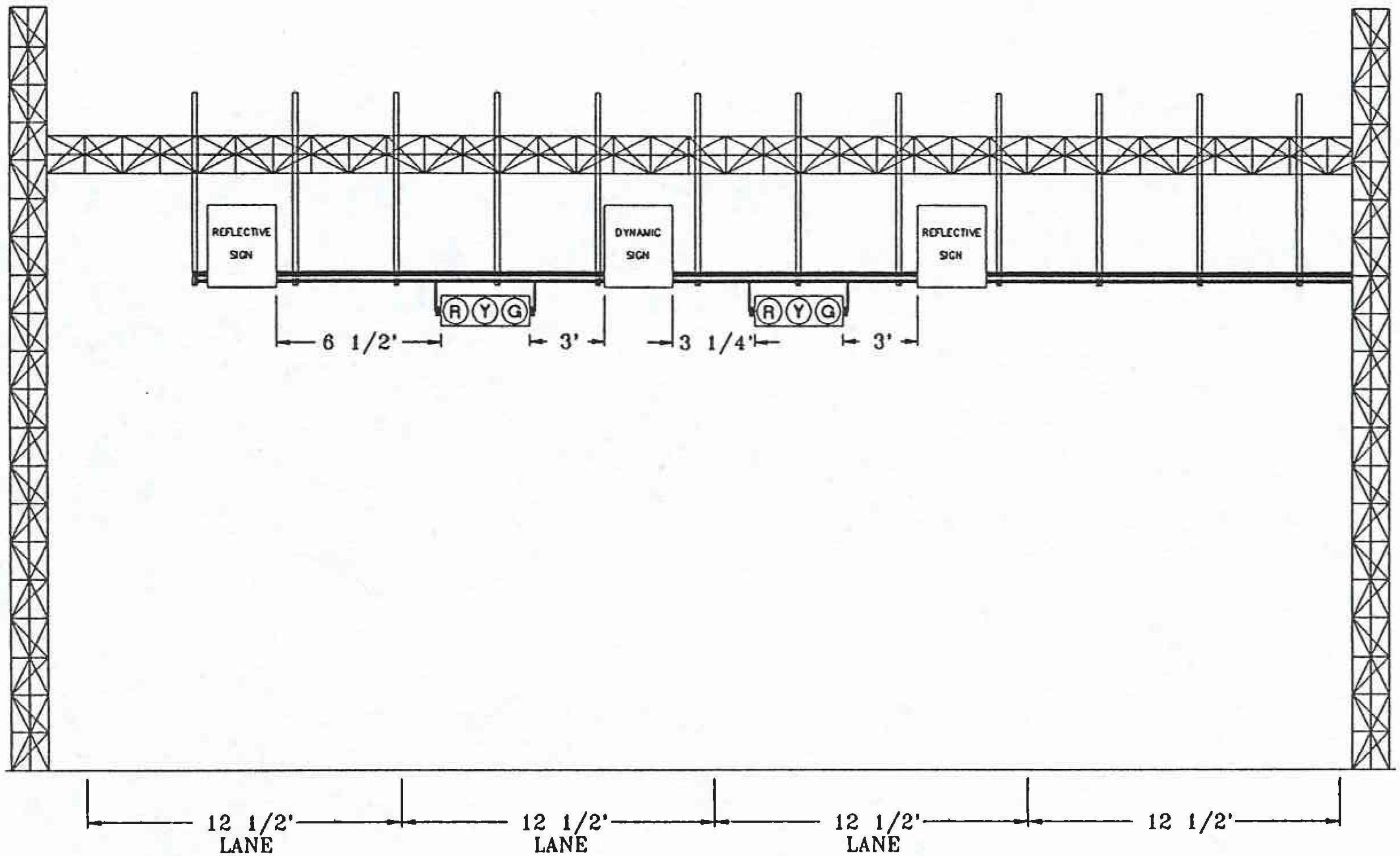


Figure 5. Laboratory layout used for legibility studies.

Participants in the first group of professionals were asked to fill out the questionnaire presented in Appendix A. This questionnaire evaluated the layout of the laboratory and provided information concerning a number of variables that affected the safe and efficient operation of the traffic control devices that made up the facility. The variables identified prior to this survey were evaluated by posing specific questions to the group concerning their effect on legibility and target value. These variables included:

- The effects of pixel spacing,
- Differences in the formation of arrow shafts,
- The effectiveness of the sign at different levels of light output,
- The effectiveness of the word messages, and
- The effectiveness of the fiberoptic changeable message sign as compared to the retroreflective signing.

Pilot Study

The pilot study was designed to relate the limitations of the human eye to light output levels for the light-emitting components at the laboratory. The effect of glare from the traffic signals and the point at which *irradiation* occurred in the fiberoptic displays was analyzed with respect to the overall quality of target value and legibility of the signing. The two-part study required each participant to view various displays produced by the sign from distances of 800, 600, 400, and 200 feet. The first part of the study involved evaluating threshold intensity for the traffic signals and the point of irradiation for the fiberoptic displays. Threshold intensity corresponds to the light output of the signals that caused disability glare with respect to a person's ability to view the fiberoptic display. The point of irradiation for fiberoptic displays corresponded to the initial voltage level that produced irradiation for a given display.

The process used to evaluate these two parameters was termed "focussing". This process involved displaying the traffic signals at their maximum light output, and lowering the light output until an observer indicated that the disability glare no longer prevented reading or discerning the fiberoptic sign. Next, the light output was turned down completely, and then increased gradually until the observer began to experience disability glare to the extent that it influenced discernment of the fiberoptic sign. The median of these two values was then identified as the threshold value of light intensity that produced disability glare with respect to discernment of the fiberoptics sign. The corresponding voltage across the sign lamps was recorded as the measure related to threshold intensity.

This same focussing procedure was used to determine the threshold value for irradiation in the fiberoptic sign. These analyses provided information for operational purposes to produce voltage settings for the traffic signals and signs such that the light output of the total installation was below the glare threshold.

Four additional displays were then presented in a random order to the participants at each distance. Each person was asked to draw the displays presented to them exactly as the sign appeared. The data obtained from this portion of the study was analyzed to determine the usefulness of the test procedure in evaluating legibility distance of the fiberoptic displays. Restructuring of the instructions was completed as necessary to eliminate unclear statements and instructions.

Second Subjective Analysis

A second group of professionals was utilized in evaluating laboratory conditions selected for analysis of legibility of the fiberoptic displays. The purpose of these observations was to evaluate the pixel spacing, arrow design, and the light output associated with various voltage settings. These parameters were evaluated in order to limit the number of variables so that the results of the *glance legibility* study would provide statistically significant results.

Comparisons between the fiberoptic displays and the reflective signing at the installation were also evaluated. Comparisons of legibility and target value were made between the two types of signing by means of specific questions posed in the questionnaire and through general comments provided by the participants. Information was also obtained concerning problems associated with mixing sign types for an approach to an intersection.

Quantitative Evaluation of Glance Legibility

The purpose of this portion of the study was to evaluate the legibility associated with different elements of the fiberoptic sign. Glance legibility was evaluated in an attempt to provide results that would more closely represent actual driving conditions (5). The displays shown in Figure 1 were presented to study participants at distances from the sign of 800, 600, 400, and 200 feet. Specific settings for the displays during the legibility studies were selected based on results from subjective observations. These settings included:

- One-half inch pixel spacings,
- No adverse weather conditions,
- Fifty volts across the traffic signals, and
- A constant level of external illumination.

Each participant was provided with a walkie-talkie, a data form, and a pencil. They were then instructed to travel to a distance of 800 feet from the face of the sign and park the test vehicle in the lane which lined up with the fiberoptic sign. Each participant was then informed that eight different displays would be presented on the sign and remain visible for a total of three seconds. Each participant was instructed to view the sign long enough to identify the visual image, then look away and begin drawing the display exactly as it appeared to them. The remaining displays were presented to the subject in the same manner. The participant was then instructed to proceed to 600 feet where this procedure was repeated. Displays were presented in a random order to insure that each display was given proper consideration by each participant.

Analysis of the data involved grading the drawings from each study participant to determine the glance legibility distance associated with specific elements that make up the different displays. An evaluation of when drivers perceived the difference between single row and bold shaft arrows was made to evaluate the effects of light output on the visual acuity of the study participants. Data from the pilot study provided additional questions pertaining to how participants, at specific distances from the sign, perceive different elements.

RESULTS OF PHASE I

Results from First Subjective Observations

Evaluation of the Fiberoptic Sign

Several factors associated with the design of the fiberoptic sign were subjectively evaluated during this part of the study. These factors were evaluated using a questionnaire survey. Information obtained from these evaluations was used to prioritize the variables so as to limit the scope of the driver studies. The factors that were evaluated included:

A. The effect of luminous output on legibility and target value,
B. The type of arrow design, and
C. The design of word messages.

Evaluation of the sign's legibility and target value at different voltage levels revealed the relationship of these variables to light output. Legibility of the displays decreased as the light output increased. Target value, however, increased with increasing light output. The relationships between legibility, target value and voltage indicate the existence of an inverse relationship between target value and legibility. This relationship should be considered in selecting operational settings for fiberoptic displays.

Subjective evaluations were made by professional observers from a viewing distance of 300 feet. The consensus of these observers indicated a preference of the single-row arrow design over the bold arrow design. Discussions indicated that the single-row displays were easier to discern than the bold arrow displays. The difference in target value for the two types of arrow shaft designs did not provide a significant advantage for the bold arrow indications over the more legible single-row alternative.

Two different word messages ("ONLY" and "OK") were also viewed by the study participants. Each word message was displayed using two different stroke-widths. Different stroke-widths were formed using one row (single-stroke) and two rows (double-stroke) of pixels. Double-stroke word messages could not be discerned by the group. Some letters of the single-stroke word messages were partially legible at the 300 foot viewing distance. The group did not, however, feel that they would be discernible if the effects of dynamic visual acuity were taken into account. The consensus of the group was that the word messages should be enlarged and possibly repositioned to improve their legibility. The group preferred the single-stroke letters to the double-stroke letters. The double-stroke letters were subsequently eliminated from further observations.

Laboratory Improvements

One purpose of the first subjective observations was to identify needed improvements to the laboratory so that conditions would more closely simulate those of a typical signalized urban intersection. Analysis of the information obtained from this portion of the study identified the need for the following improvements:

D. The provision of external illumination in the form of standard roadway lighting,

E. The rearrangement of the initial sign and signal layout,

F. The need to vary the light output of the signals and the fiberoptic sign independently, and

G. The need to design the study to simulate dynamic visual acuity.

Pilot Study Results

The purpose of the pilot study was to identify the relationship between the capabilities of the human eye and the voltage and light output of the traffic signals and the fiberoptic sign. These relationships were utilized to determine voltage settings for the signals and fiberoptic signs, such that:

H. The voltage settings minimized disability glare and still provided adequate target value to allow the signals to compete with the fiberoptic display for the attention of the driver, and

I. The relationship between legibility and target value for the fiberoptic displays was optimized.

A total of 19 individuals participated in this portion of the study. Analysis of data obtained from the first six participants, however, revealed a need to modify the study design. A total of 42 observations from the remaining thirteen subjects were utilized in identifying the desired voltage distribution for the traffic signals. A total of 52 observations were made by the last 13 subjects to establish the desired voltage distribution for the fiberoptic displays.

Voltage Distribution for the Traffic Signals

The traffic signal voltages were evaluated in an attempt to identify voltage settings below which glare did not interfere with a specific percentage of the participants' ability to view the fiberoptic displays. The distribution of these voltages was expected to be normal, but observations showed it to be modal. One possible reason for the non-normal distribution is the small sample size used in this portion of the pilot study. The inability to identify a normal distribution of voltages at the threshold intensity for glare warranted a subjective evaluation of a range of voltages for the traffic signals prior to the evaluation of glance legibility for the fiberoptic displays.

Voltage Distribution for Fiberoptic Signing

The focussing process described previously was used to evaluate the voltage distribution associated with the point of irradiation for each display. The average voltage obtained from each participant corresponded to the point at which the light output from the sign caused irradiation to occur. These average voltages were statistically analyzed to determine whether or not they could be grouped to obtain a single voltage distribution that represented the point of irradiation for all displays. Initial groupings compared all single-row displays with 1-inch pixel spacings to single-row displays with 1/2-inch pixel spacings. Bold-arrow displays were grouped in the same manner. F-tests compared the variance of these groups using a 95% confidence level. Based on these results, pooled estimates of the standard deviation for the combined group permitted statistical t-tests to evaluate whether or not the means were statistically equal.

The results of this analysis showed that the mean and standard deviation for the average voltages for each subgroup were the same. All single-row displays and bold displays were then grouped together and compared. Similar analyses indicated that the means and variances of these groups were also the same. This finding enabled all voltage measurements obtained from the pilot study to be grouped together to provide a single voltage distribution that could represent all displays that were tested. This finding was unexpected. Prior to the evaluation of the pilot study results, it was felt that the difference in the number of pixels used to form a display would cause individuals to select lower voltages for signs made up of greater numbers of pixels. The voltages obtained, however, were relatively consistent for each individual regardless of the display viewed or the viewing distance. Two possible reasons are:

(1) A significant difference in the point of irradiation was not caused by the difference between 1/2- and 1-inch pixel spacings. All but two of the voltages identified by the pilot study participants during the focussing process for the traffic signals were below 80 volts. Furthermore, 85% of the average voltages were below 65 volts. Results from the first subjective analysis indicated that virtually no practical difference in light output existed for 1/2- and 1-inch pixel spacings below approximately 60 volts.

(2) The displays associated with higher numbers of pixels utilized more of the sign face. Although the number of pixels increased, it is possible that the distribution of these pixels over a larger area of the sign face offset the effects of the increased light output.

A Chi-Square analysis performed for this data indicated that the distribution of the data was normal at a 95% confidence level with 52 degrees of freedom. Also, this analysis indicated that the 15th, 50th, and 85th percentile values for the voltage distribution were 38.7, 51.0, and 63.2 volts, respectively. These voltages were presented to a second group of professional observers to be evaluated subjectively with respect to target value and legibility.

Intensity Distribution for Fiberoptic Signing

Figure 6 shows a plot of the distribution of observations for intensity which corresponded to the voltages selected by study participants. Luminous output of the displays was obtained for the range of voltages. Radiation physics and geometry were utilized to convert *luminance* values to estimates of the light output for the sign.

A Chi-Square goodness of fit analysis performed at a 95% confidence level with 52 degrees of freedom indicated that the data fit a normal distribution. Figure 6, however, shows that the actual distribution of the data is skewed to the left. The distribution of voltages selected during the study was shown to be normal. According to statistical theory, the square of values that define a standard normal curve should produce a skewed distribution (6). The development of design criteria for fiberoptic displays should examine the relationship between intensity and voltage. This would provide an efficient means of setting light output levels in the field.

Results from Second Subjective Analysis

This portion of the study was used to evaluate the legibility and target value of the fiberoptic sign as well as the target value and glare associated with the traffic signals at the voltage levels identified by the pilot study results. The format used to obtain data during this portion of the study was similar to that used in the first subjective analysis. A questionnaire survey provided specific information concerning:

J. The magnitude of the glare produced by the traffic signals at two different voltage settings,
K. The target value associated with each voltage setting for the traffic signals,
L. The legibility and target value for single-row and bold displays at the 15th, 50th, and 85th percentile voltage settings (35, 50, and 65 volts) determined from the pilot study, and
M. The use of different pixel spacings at the 15th, 50th, and 85th percentile voltages (35, 50, and 65 volts) determined for the fiberoptic display.

Participants were allowed to inspect the installation from various distances prior to group discussions and completion of the survey. Following these preliminary observations, the group was assembled at a viewing distance of 300 feet from the sign to evaluate the signal and sign voltage settings.

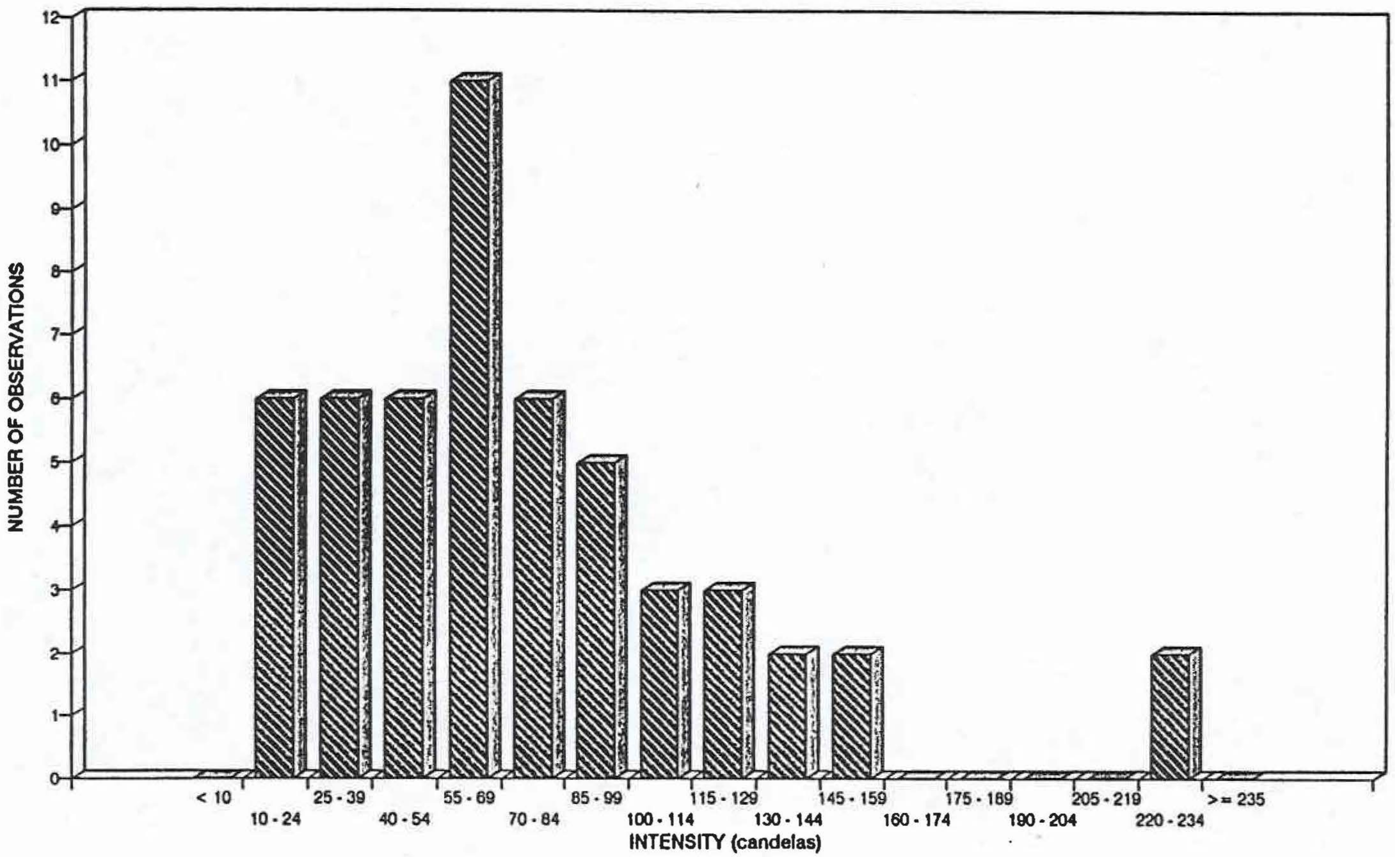


Figure 6. Frequency distribution for fiberoptic display intensities.

Evaluation of Traffic Signal Settings

The magnitude of the glare caused by the traffic signals was evaluated for voltage levels of 50 and 65 volts. Glare was rated on a five-point rating system (see Appendix B). The green indication was used for the evaluation of glare since, as has been previously stated, it provides the limiting condition under low levels of illumination.

The glare caused by the signals at the 50 volt setting was less than discomfort glare. Glare associated with 65 volts across the signal was greater than the threshold level for discomfort glare. None of the participants, however, felt that either of these settings produced disability glare. The target value associated with both voltage settings was found to be acceptable for the conditions at the laboratory.

Evaluation of Fiberoptic Sign Voltage Settings

The single-row and bold through-and-left arrow indications were selected for an evaluation of the different voltage settings for the fiberoptic sign. These settings were selected to maximize light output for each type of arrow shaft design. These displays were presented to the participants at voltage levels of 35, 50, and 65 volts. The selection of these voltages corresponded approximately to estimates of the 15th, 50th, and 85th percentile voltages as determined in the pilot study. Evaluation of the displays at these voltage levels showed that the legibility and target value for the displays were, at worst, acceptable. Analysis of the surveys further supported an inverse relationship between target value and legibility.

The group was asked to rank order the reflective signing and the bold and single-row indications with respect to target value and legibility. Evaluation of this data indicated a preference for the single-row arrow indications over the bold arrow indications and the reflective signing. Discussion indicated that the majority of the group felt that the difference in target value between the single-row and bold fiberoptic indications was not sufficient to offset the more readable legend associated with the single-row indications. The group also indicated that mixing the reflective and fiberoptic signing was not desirable because of the difference in contrast and light intensity of the two types of signing. The group further indicated that if these types are mixed, then external illumination should be provided above the reflective signing so that differences in target value could be reduced as much as possible.

Selection of Voltage Settings for Legibility Studies

Analysis of the information obtained from this portion of the study was utilized to select the voltage settings for the traffic signals and fiberoptic displays. These settings were used in the evaluation of legibility distance of the fiberoptic displays. The voltage selected for the traffic signals was 50 volts. Glare at this setting provided a more comfortable viewing condition without significantly reducing the target value as compared to the 65 volt setting. Legibility for the fiberoptic displays was evaluated at 35 and 50 volts. Two settings were selected so that (1) an estimate of the glance legibility for the displays at each setting could be obtained and (2) the significance of the difference in light output at these voltages could be evaluated.

Analysis of Glance Legibility Studies

Studies were conducted to evaluate the glance legibility distance associated with specific elements which make up individual fiberoptic displays. These studies required participants to view eight displays at 800, 600, 400, and 200 feet. After viewing these displays, participants were to draw the display exactly as it had appeared to them. These drawings were evaluated to determine when the participants were able to distinguish:

N. The distance at which the general format of the sign was identified,
O. The distance at which the word messages were discerned, and
P. The distance at which the difference between single-row and bold arrow shafts could be detected.

This information provided an estimate of the overall effectiveness of the sign with respect to glance legibility, and of individual elements.

Results from Legibility Studies

Drivers were asked to view the sign at 200 foot intervals between distances of 200 and 800 feet, inclusive. Prior to this study, the participants would be divided into two groups. One group viewed the sign at a 35 volt setting, while the other group viewed it at a 50 volt setting. The use of 200-foot intervals was to insure that the distribution of the driver observations was large enough to make an inference about the glance legibility of specific elements.

Glance legibility distance for the general format of the fiberoptic displays was evaluated. The "ability to discern the general format of the sign" refers to when word messages and arrows could be identified as separate elements. Prior to this point, the majority of the study participants, at both voltage levels tested, typically perceived word messages as second or third arrows.

Approximately 85% of the participants who viewed the displays were able to discern the separation between the word message and the arrow shaft(s) at a distance of 400 feet from the face of the sign for both voltage levels. The use of smaller distance intervals would have provided a more uniform distribution for the observations. It is believed that voltage setting had very little effect on the ability of the participants to discern this separation.

Glance legibility distance was also evaluated for the "OK" and "ONLY" word messages. The size and spacing of the word messages corresponds to standard Series E lettering used for reflective signing. The arrows are considered the primary information element while the word messages are supplemental information. The glance legibility observations for the "OK" showed that approximately 10% of the participants were able to discern this message at distances greater than 200 feet. However, approximately 50% of the participants were able to read the "ONLY" at a greater distance than 200 feet. No difference in legibility is believed to have existed at the two different voltages for the "OK". The 35 volt setting appeared to provide slightly more legibility for the "ONLY" word message than did the 50 volt setting.

The difference in legibility between the "OK" and "ONLY" is believed to be due to the length of the words and the legibility of the "O" and the "Y" letters in "ONLY". The legibility of the "O" in both word messages and the "Y" was much better than that of the "K", "N", and "L". They had better legibility because of their width, outside position in the message, and because of their simple shape, especially at the 35 volt setting. Once participants were able to distinguish the "O" and "Y" in the "ONLY" indication, it is believed that they inferred the remaining letters within this message based on prior experience. Because the "OK" word message was only two letters long and because of the complexity of the design of the letter "K", participants had more difficulty in making these inferences. Several participants identified the word messages as saying "ON" and "OFF" at greater distances than where they were actually able to discern their identity. These findings indicate that the spacing of word messages is very important in the design of fiberoptic displays.

The distance at which participants were able to detect the difference between single-row and bold arrow shaft design was also analyzed. The ability to discern this difference was originally intended for evaluating the minimum visual acuity of the participants. Figure 7 indicates that the ability of the participants to discern this level of detail was not consistent for either voltage. While no single distance could be identified as the point at which this detail became evident, virtually all participants identified a difference in shaft design at or before 200 feet. These results indicate, therefore, that the ability to identify fine details in symbol designs is highly dependent on the capabilities of an individual's eye to deal with the light emitted by the sign.

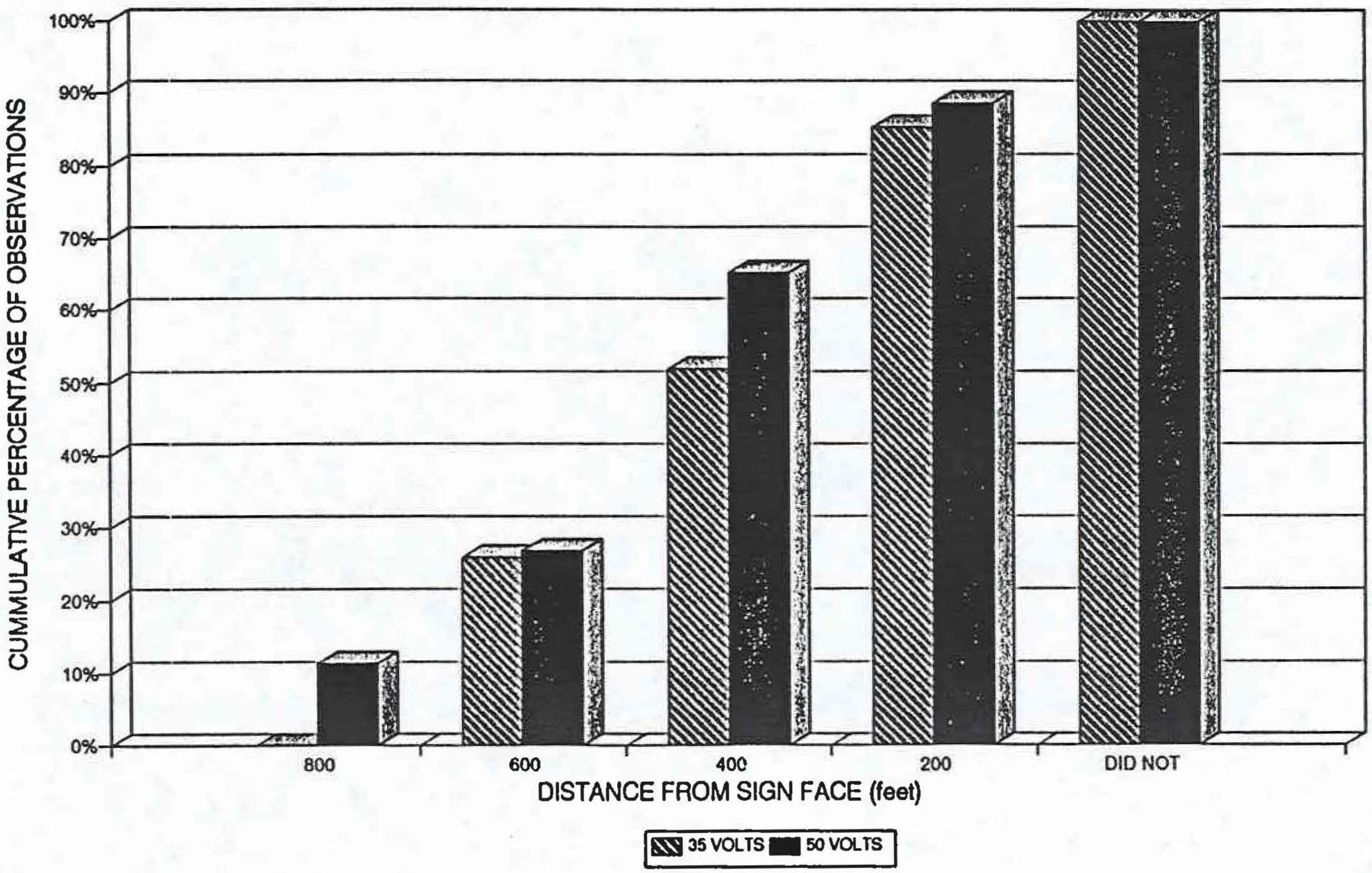


Figure 7. Glance legibility distance for shaft design.

PHASE II - OPERATIONAL STRATEGY FOR FIBEROPTIC SIGNS
STUDY DESIGN

Overview of Study Design

This research evaluated the installation and operation of the second generation fiberoptic signs developed by the Texas Transportation Institute in cooperation with National Sign and Signal Company, Battle Creek, Michigan. Two identical overhead signs and one roadside sign were developed. A Naztec 900 Series traffic signal controller was used to operate the fiberoptic signs. The fiberoptic signs were initially tested in the laboratory at the Texas Transportation Institute. Once the desired displays were obtained, the signs were installed at the sign test facility at the Riverside Campus of Texas A&M University.

A schematic of the studies conducted is indicated in Figure 8. Experts from the fields of transportation engineering, human factors and safety were invited to survey the experimental layout. The experts also evaluated the legibility, target value, and the ability to understand the sign displays. They were also asked to comment on and determine the appropriate *sign-signal coordination.* The experts also gave their opinion regarding the possible reactions of a motorist when confronted by changes in the display of the fiberoptic signs. The study was conducted during daytime and night-time conditions. Some changes suggested in the first half of the investigation were incorporated into the second half of the study to determine their appropriateness. The refinement of the various variables in the operation of the fiberoptic signs provided the basis for the driver study.

Based on the recommendations of the expert study, a strategy to operate the fiberoptic signs for the driver study was developed. This study was conducted during daytime only. The objective was to estimate the *acceptability* of the dynamic nature of the lane assignment signs by a motorist.

Design of the Fiberoptic Signs

The design of the second generation fiberoptic signs was based on findings of the studies conducted on the first generation fiberoptic sign in an earlier study. As stated earlier, the main characteristics of the second generation signs are:

1. A uniform pixel spacing,
2. A single row of pixels to form arrows, and
3. A single row of pixels to form the legend.

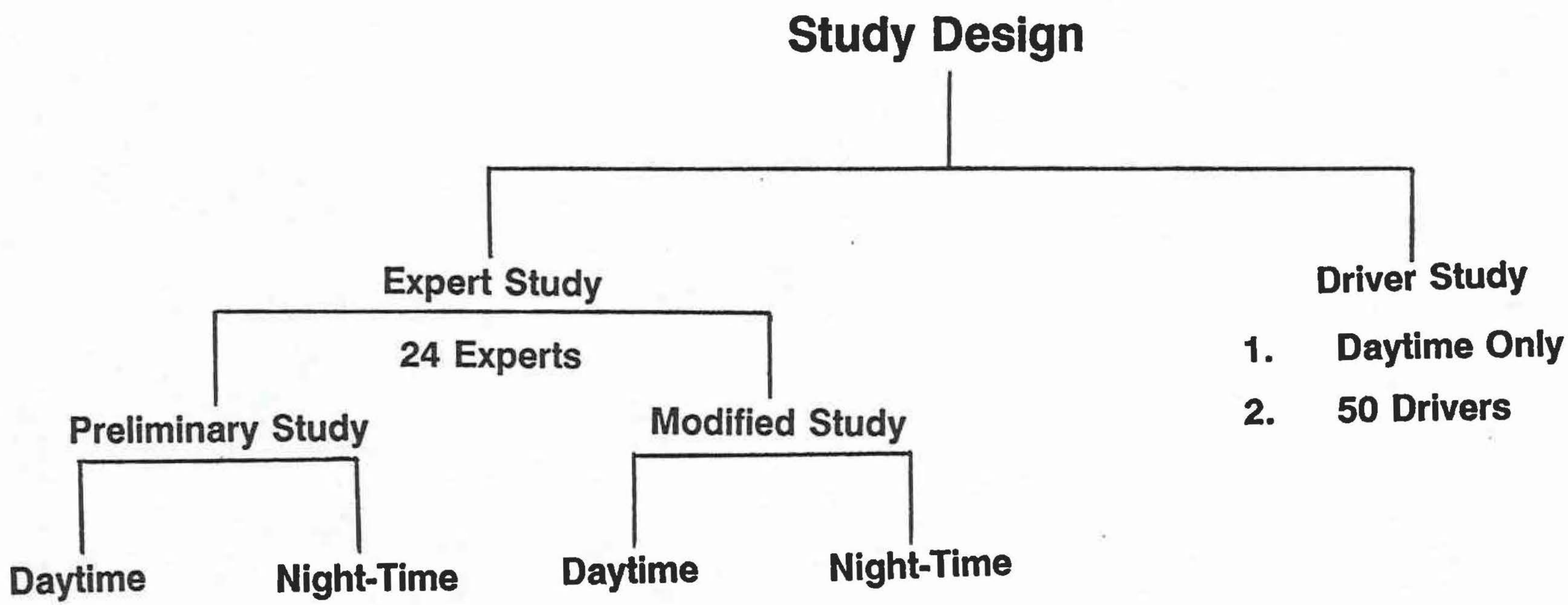


Figure 8. Schematic of the studies conducted during the second phase.

Design of the Displays

After extensive trials in the laboratory, a sequence of the displays to be generated by the fiberoptic signs was designed as shown in Figure 9. The sequence consists of two main displays and two transition displays. The two main displays cater to varying turning movements at different times of the day. Main Display 1 will be used during periods having a high proportion of through traffic, and Main Display 2 will be used during periods of having a high proportion of left turning traffic.

The transition displays were designed to provide a safe period while changing from one main display to the other main display. Transition Display 1 acts as a transition phase between Main Display 1 and Main Display 2. This transition display is intended to clear the vehicles going straight in the left lane before allowing the vehicles to turn left from the middle lane. Transition Display 2 acts as a transition phase between Main Display 2 and Main Display 1. This transition display is intended to clear any vehicles turning left from the middle lane before allowing vehicles to go straight from the left lane. Both these transition displays would last for approximately two to four minutes.

Equipment for Operating the Fiberoptic Signs

A Naztec 848 series traffic signal controller was programmed to generate the displays in the fiberoptic signs. The displays were initially generated on a cycle-by-cycle basis. Subsequently, two Naztec 900 series traffic signal controllers were obtained from TxDOT. One controller was programmed to generate the displays in the fiberoptic signs according to the time of day. The signal timings in the traffic signal controller at the intersection of IH 10 and Voss/Bingle were obtained and the second traffic signal controller was programmed accordingly. Representatives of Naztec Inc. assisted in programming the controllers. A communication link between the two controllers provided sign-signal coordination.

Experimental Setup

The layout of the test facility was selected to simulate the geometric layout of the intersection of the east-bound frontage road of IH 10 and Voss/Bingle. The layout is as shown in Figure 10 and Figure 11. The expansion joints of the pavements, spaced 12.5 feet apart, served as the lane lines. It is seen in Figure 10 that the overhead fiberoptic signs were positioned over the center of the left lane and the middle lane. A standard reflectorized sign was placed over the center of the right lane.

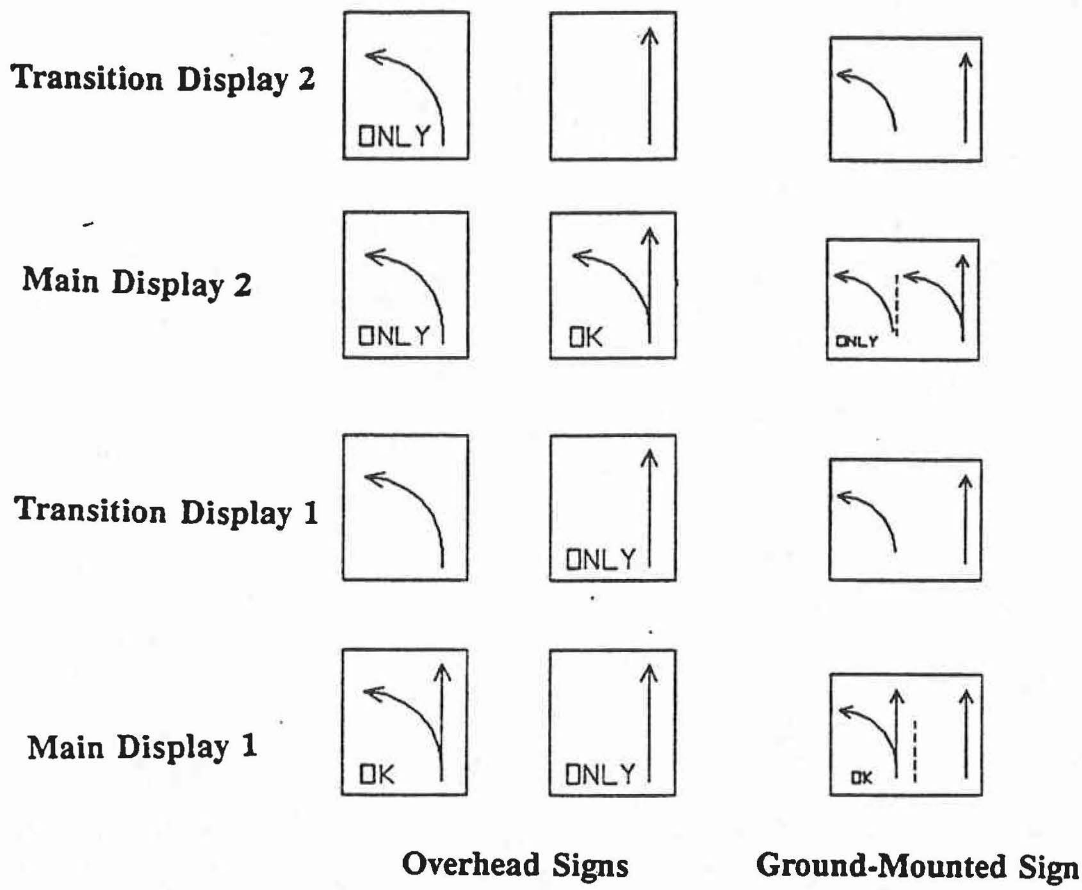


Figure 9. Sequence of the displays generated in the fiberoptic signs.

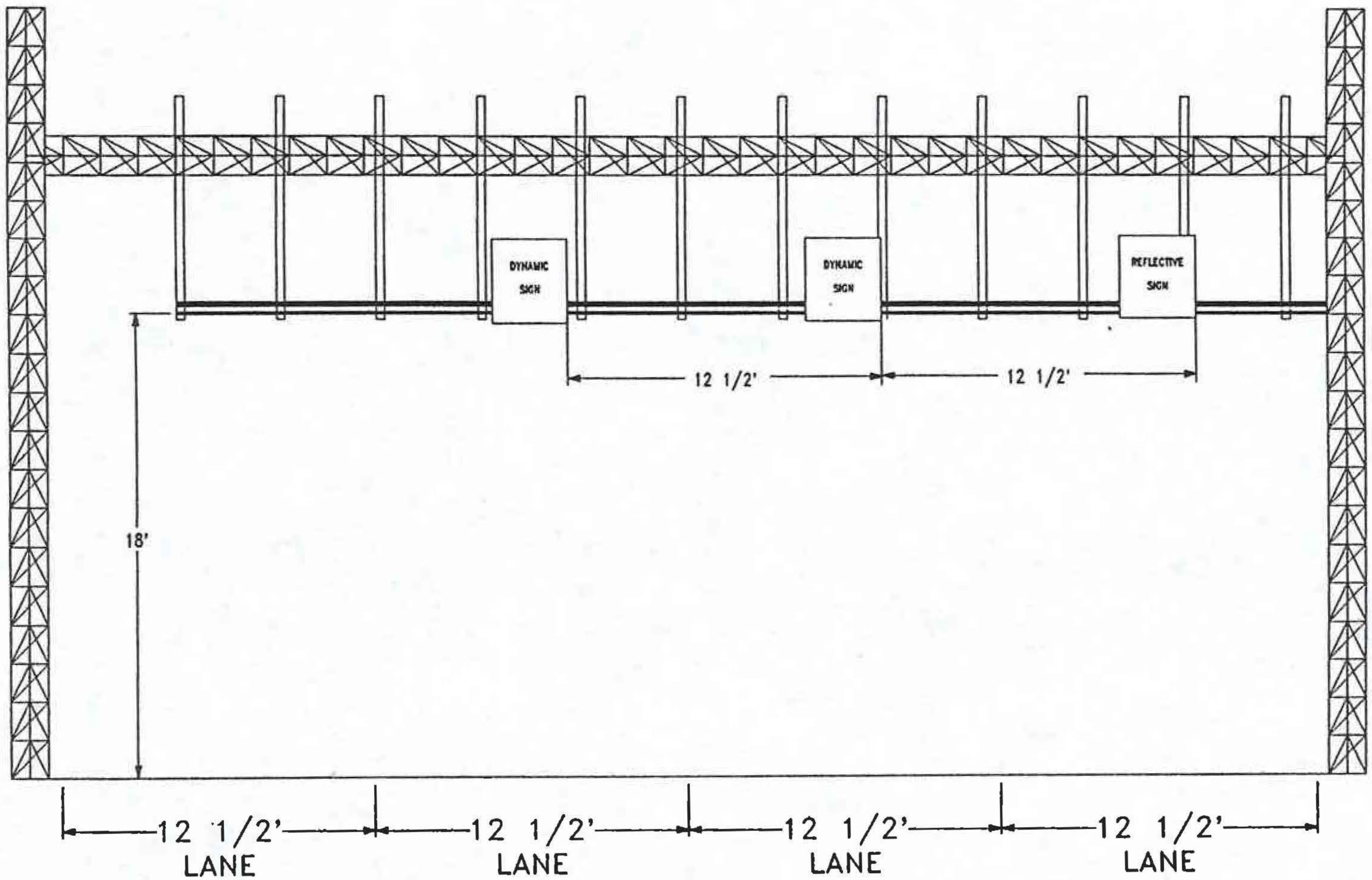


Figure 10. Experimental layout of the fiberoptic signs (elevation).

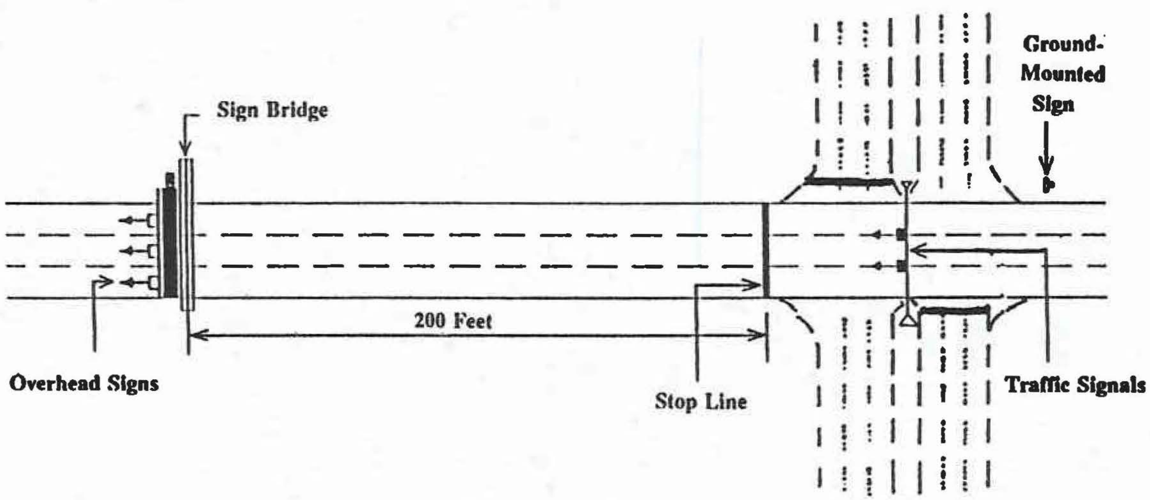


Figure 11. Experimental layout of the fiberoptic signs (plan).

At the intersection, a pair of three-section signal heads with twelve-inch lenses were installed on a cable at a height of seventeen feet. Figure 11 shows the details of the experimental layout. An eighteen-inch wide stop line was painted at the intersection a distance of 200 feet from the overhead fiberoptic sign. The signal heads were installed at a distance of 50 feet from the stop line. The roadside-mounted sign was placed about 100 feet downstream of the stop line and about eight feet to the left of the left lane. The intersection shown in dashed lines is only simulated and not found at the test site. Two Type II High Pressure Sodium (HPS) luminaires were placed about 120 feet upstream and downstream of the overhead sign structure to provide illumination for the night-time studies.

Expert Study

Description

Experts from the fields of transportation engineering, human factors, and safety were invited to participate in the expert study. The experts completed a questionnaire which is illustrated in Appendix B. They were positioned at a distance of 250 feet upstream of the overhead signs for their observations.

The voltage across the traffic signals and the fiberoptic signs were varied independently to arrive at an optimum voltage level. The experts were asked to select the voltage setting across the traffic signal and the fiberoptic signs, that provided the optimum legibility and target value for the signs.

The displays generated in the overhead fiberoptic signs were then presented. The experts were asked to give their opinion about motorist's perception of the displays. This question was to determine the ability to understand the displays in the fiberoptic signs.

The indication in the traffic signal at the instant of a display change in the fiberoptic sign has a marked influence on the reactions of the drivers. The sign-signal coordination scenario selected should ensure that the driver notices, understands, and reacts in a safe manner on observing a display change in the sign. Different scenarios of the sign-signal coordination were presented to the experts. The experts were asked to select and suggest an appropriate scenario.

The experts' opinions of the drivers' reactions to a display change in the overhead fiberoptic sign were then obtained. The experts were asked to give their opinion about the reactions of the drivers in the left and the middle lanes for two display changes. These display changes involved the onset of the transition displays from the main displays. Experts were asked similar questions about the reactions of a motorist on observing the display changes in the roadside-mounted sign at the intersection. The experts were positioned at the stop line and were introduced to all four changes in the display of the roadside-mounted sign. The opinions of the experts about the probable driver reactions were expected to give a estimate of the acceptability of the dynamic nature of the lane assignment signs.

Driver Study

The objective of the driver study was to determine the acceptability of the dynamic nature of the lane assignment signs. It was conducted in daytime only. The voltage across the traffic signals and the fiberoptic signs was kept constant at full intensity of 110 volts during the driver study. A sign-signal coordination to change the display in the fiberoptic signs at 2 seconds after the onset of red in the traffic signal was selected.

Based on the experts' comments, two critical changes in the display of the fiberoptic signs were identified for the driver study. These display changes result in a lane movement being dropped from the approach (from a main display to a transition display in Figure 9). The driver reaction for a particular change is influenced by the driver position with respect to the intersection. The driver reaction on observing a display change in the overhead sign is different from observing the same in the roadside-mounted sign. On observing a display change in the overhead sign, the driver has adequate distance to make a lane change maneuver if desired. However, on observing a display change in the roadside-mounted sign at the stop line, the driver has no room to change lanes if desired. Similarly, the driver reaction on observing a display change from the left lane is different than observing the same from the right lane.

Procedure Adopted for the Driver Study

The two critical changes in the fiberoptic sign display as explained earlier were presented to the subjects in the driver study. The subjects were asked to drive through different scenarios of changes in the display of the fiberoptic signs. These scenarios were based on, (1) the changes in the display of the fiberoptic sign, (2) the lane the subject occupied, and (3) the position with respect to the overhead sign (i.e., upstream or downstream of the overhead signs) at the instant of the display change in the sign. There were eight test runs, in which a change in the display of the fiberoptic signs occurred. The eight runs are illustrated in Figure 12 (a)-(h).

Fifty subjects were used in the driver study. Each driver participated in about nine to ten test runs. However, in only four of the nine to ten runs was a change made in the display of the fiberoptic sign. The rest of the runs had either a change in the traffic signal indication or no change at all. In order to introduce an element of surprise to the subject, runs with changes in the display of the fiberoptic signs were randomly mixed with runs having no changes.

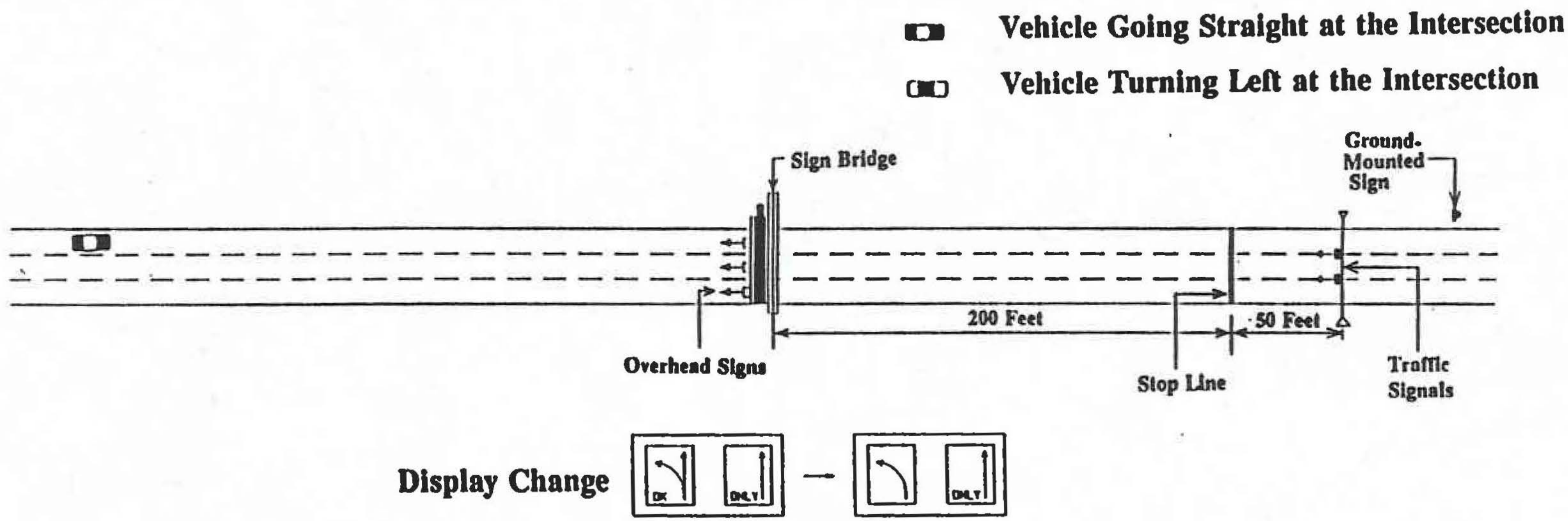


Figure 12a. Scenario 1.

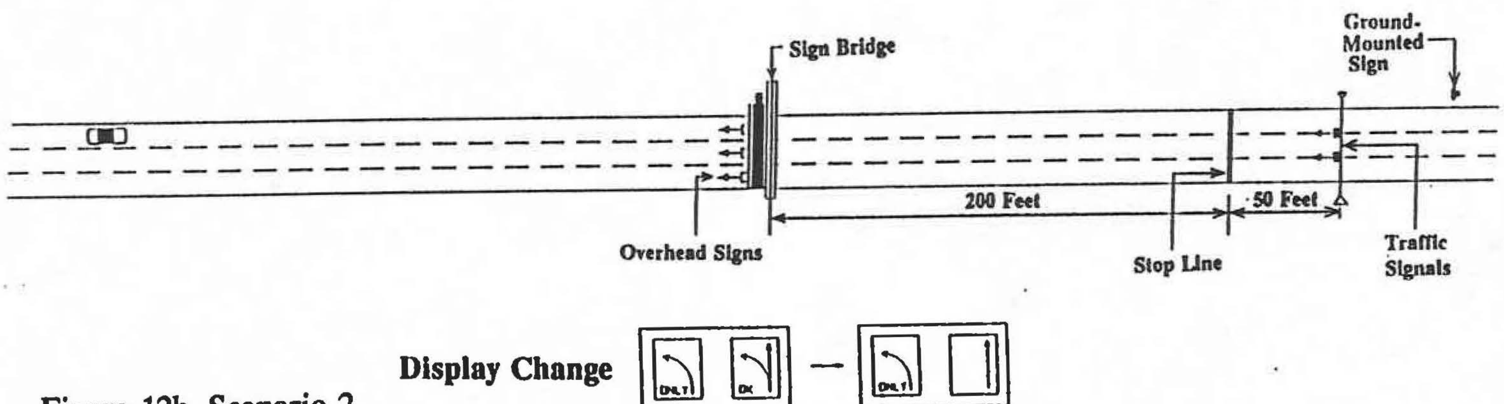


Figure 12b. Scenario 2.

Figure 12. Scenarios of the driver runs.

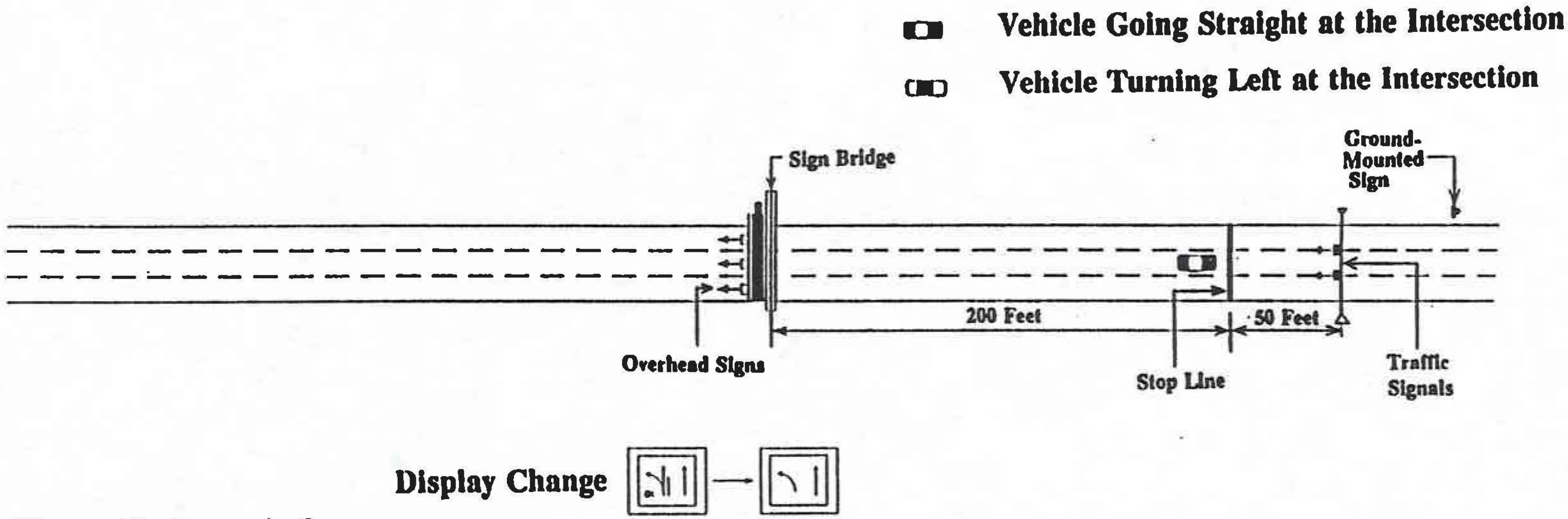


Figure 12c Scenario 3.

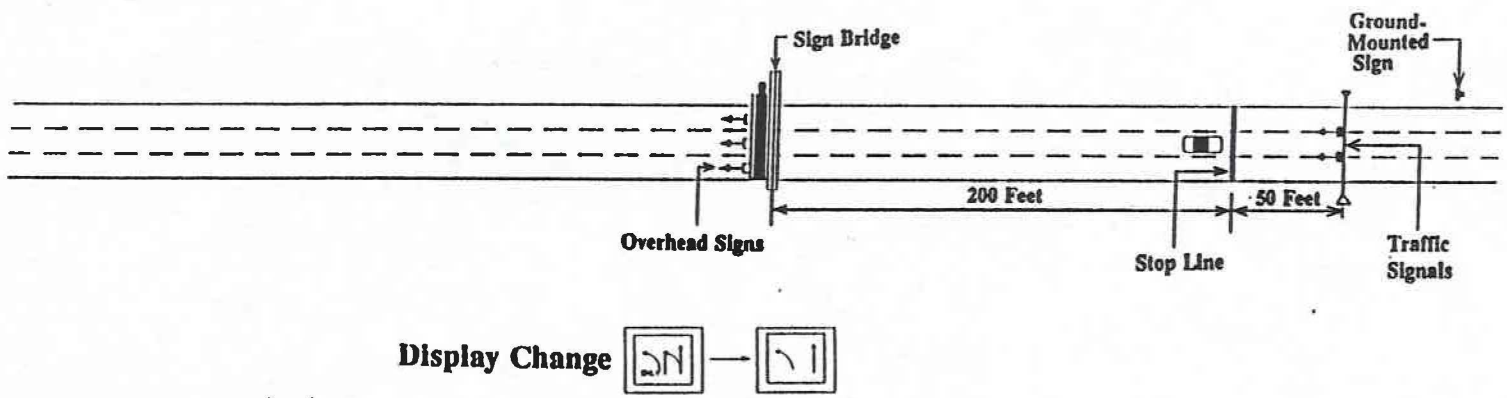


Figure 12d. Scenario 4.

Figure 12. Scenarios of the driver runs (contd.).

Vehicle Going Straight at the Intersection

Vehicle Turning Left at the Intersection

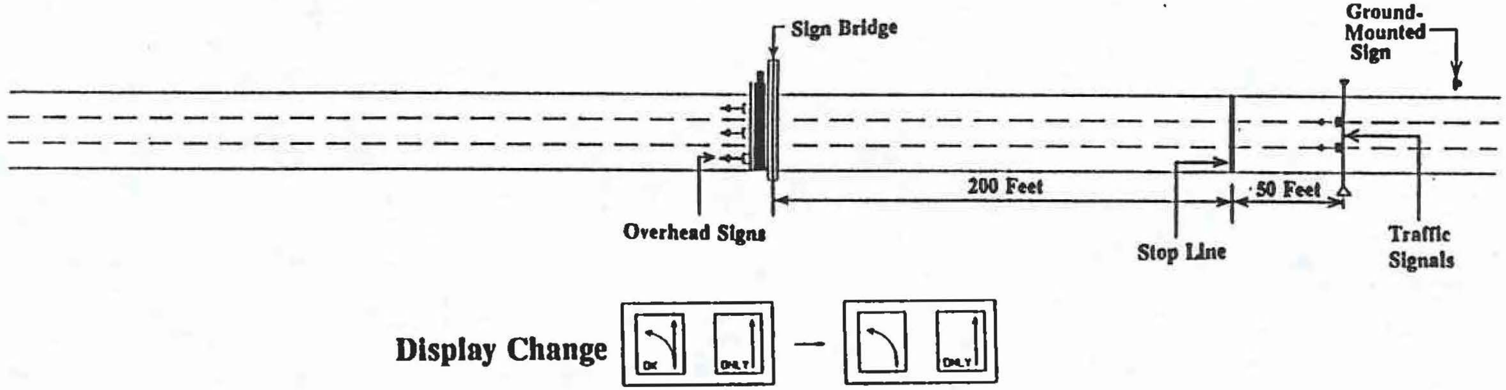


Figure 12e. Scenario 5.

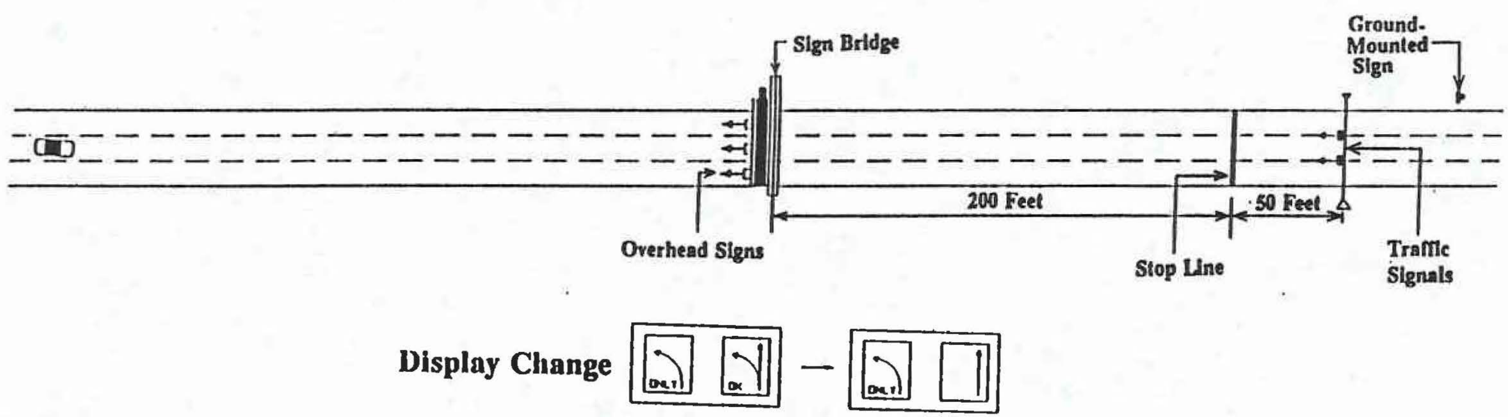


Figure 12f. Scenario 6.

Figure 12. Scenarios of the driver runs (contd.).

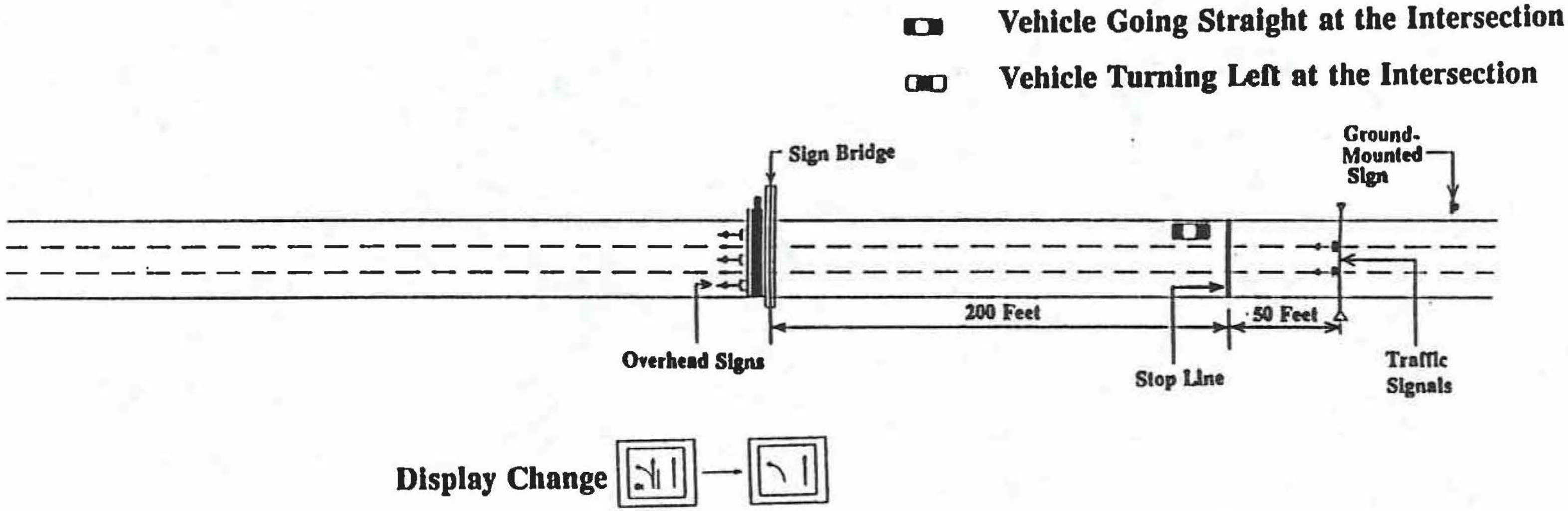


Figure 12g. Scenario 7.

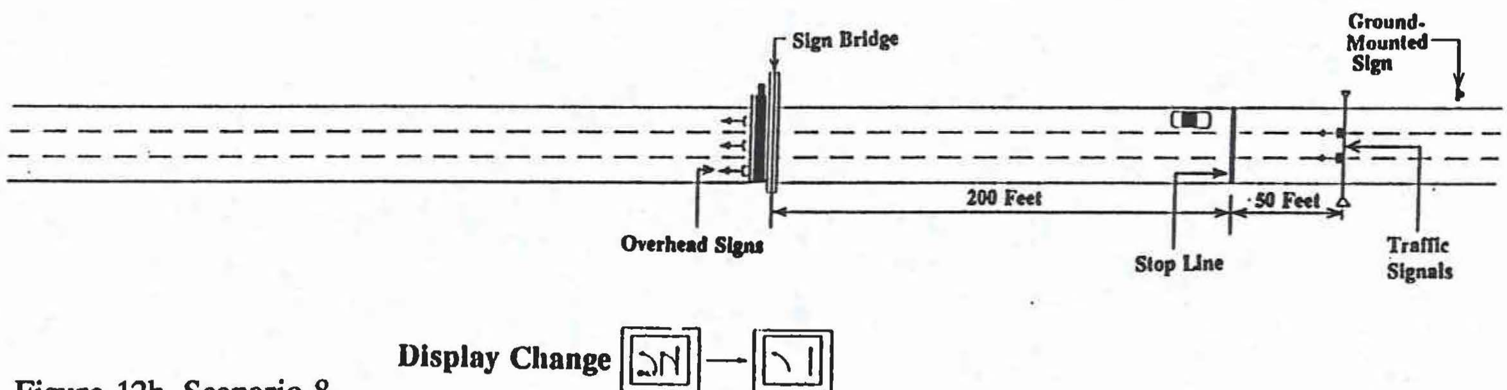


Figure 12h. Scenario 8.

Figure 12. Scenarios of the driver runs (contd.).

RESULTS OF PHASE II

Expert Study

The objective of the expert study was to refine the variables involved in the operation of the fiberoptic dynamic lane assignment signs, and develop a strategy to operate the fiberoptic signs during daytime and night-time. Twenty four experts from the fields of Transportation Engineering, Safety, and Human Factors were invited to evaluate the layout and recommend the appropriate strategy to operate the fiberoptic signs.

Results from the Expert Study

The following variables were tested in the expert study.

1. The voltage settings across the traffic signals and the fiberoptic signs were examined to confirm the results of the earlier study by Gisler. The relationships between voltage, brightness, legibility and target value in the fiberoptic signs were obtained.
2. The ability to understand the various displays in the fiberoptic signs was confirmed.
3. The appropriate sign-signal coordination was tested.
4. The likely reactions of a motorist to changes in the display of the overhead and roadside-mounted fiberoptic signs were obtained.

The expert study indicated that increasing the voltage across the fiberoptic signs has a direct relationship on the brightness of the displays. As brightness increased, there was an increase in the target value of the fiberoptic sign. This was however accompanied by a decrease in the legibility of the displays. A voltage range of 45 to 110 volts was studied. The traffic signal controller used to operate the fiberoptic signs cannot operate under a lower voltage.

All of the experts indicated that 100 percent of the maximum voltage (110 volts) was needed for daytime operation. However, for night-time operation over 50 percent of the experts did not find any difference between the three voltage settings of 50, 55, and 60 percent. While about a third of the experts preferred 55 percent of the voltage, about 15 percent of the experts preferred 50 percent of the voltage to obtain optimum legibility and target value in the fiberoptic signs.

The ability to understand the sign displays was considered next. The experts had no difficulty in understanding the four displays generated in the fiberoptic signs. While the absence of the word messages in some displays in the transition phases was noted, it was not considered to be a critical factor in the comprehension of the displays.

The sign-signal coordination study indicated that about two-thirds of the subjects preferred a display change in the fiberoptic sign 2 seconds after the onset of red in the traffic signal. The remaining experts were equally divided in the other two scenarios. As stated earlier, a simultaneous change in the fiberoptic sign and the traffic signal imposes a high workload on the driver. Due to the higher attention value of the traffic signal, the driver may fail to notice the display change in the fiberoptic sign. However, a lag time longer than 5 seconds may result in the attention of the driver being diverted away, resulting in the driver not noticing the change in the fiberoptic sign.

The experts were asked to render their opinion about the probable driver reactions to display changes in the fiberoptic signs. The experts' opinions of the driver reactions were classified into two categories based on whether the driver observes a display change in the overhead sign or the roadside-mounted sign. Seventy percent of the experts felt that the drivers who observed a display change in the overhead sign involving a loss of movement and were directly affected by it, would switch lanes. Twelve percent of the experts opined that the drivers would do whatever the sign displayed regardless of their initial intentions, and about 17 percent said that the drivers would do what they wanted to do regardless of the display.

These reactions changed dramatically when the drivers saw a display change in the roadside-mounted sign at the intersection. Only 10 percent of the experts said that the drivers would try to switch lanes. This seemed reasonable considering the lack of space to switch lanes when a vehicle is at the stop line. The proportion of the experts stating that the drivers would perform their intended maneuver regardless of the display change was about 46 percent. The proportion of the experts stating that the drivers will do whatever the sign indicates regardless of their initial intentions was 27 percent. A few experts felt that the drivers would be confused. It should, however, be noted that the restricted maneuvers being performed by the drivers are safe. The transition phases have been designed to clear the vehicles through the intersection, belonging to a lane movement which has been dropped in the display change.

Driver Study

The results of the driver study estimated the acceptability of the dynamic nature of the lane assignment signs. The driver reactions/verbal responses to a display change in the fiberoptic signs were observed. This gave an indication of the ability to understand the changes in the display of the fiberoptic sign. These observations were compared with the opinions of the experts regarding the expected reactions of the motorist to a change in the sign display.

The driver reactions/responses were categorized according to the age of the drivers. The effect of the driver age on the driver reactions to a display change in the fiberoptic signs was also investigated.

The results of the driver study were analyzed statistically. The r x c contingency method using the chi-square test was adopted for testing the independence of one variable with the other. The method involved the calculation of the expected values of the observed data.

Display Change 1 involved the loss of the through movement from the left lane when the left lane was a shared lane and Display Change 3 involved the loss of the left turn movement from the middle lane when the middle lane was shared lane. Four indicated driver responses were recorded to observe display changes in the fiberoptic signs. They are:

1. Switch Lane:

   Display Change # 1 produces a driver response to switch lane from the left lane to the middle lane.
   Display Change # 3 produces a driver response to switch lane from the middle lane to the left lane.

2. Comply:

   Display Change # 1 produces a driver response to make a left turn from the left lane when it was originally intended to go straight.
   Display Change # 3 produces a driver response to proceed straight ahead from the middle lane when it was originally intended to turn left.

3. Ignore:

   Display Change # 1 produces a driver response to go straight from the left lane, disregarding the display change in the fiberoptic sign.
   Display Change # 3 produces a driver response to turn left from the middle lane, disregarding the display change in the fiberoptic sign.

4. Did Not Notice:

   Display Change # 1 and Display Change # 3 in the fiberoptic sign were not observed by the drivers.

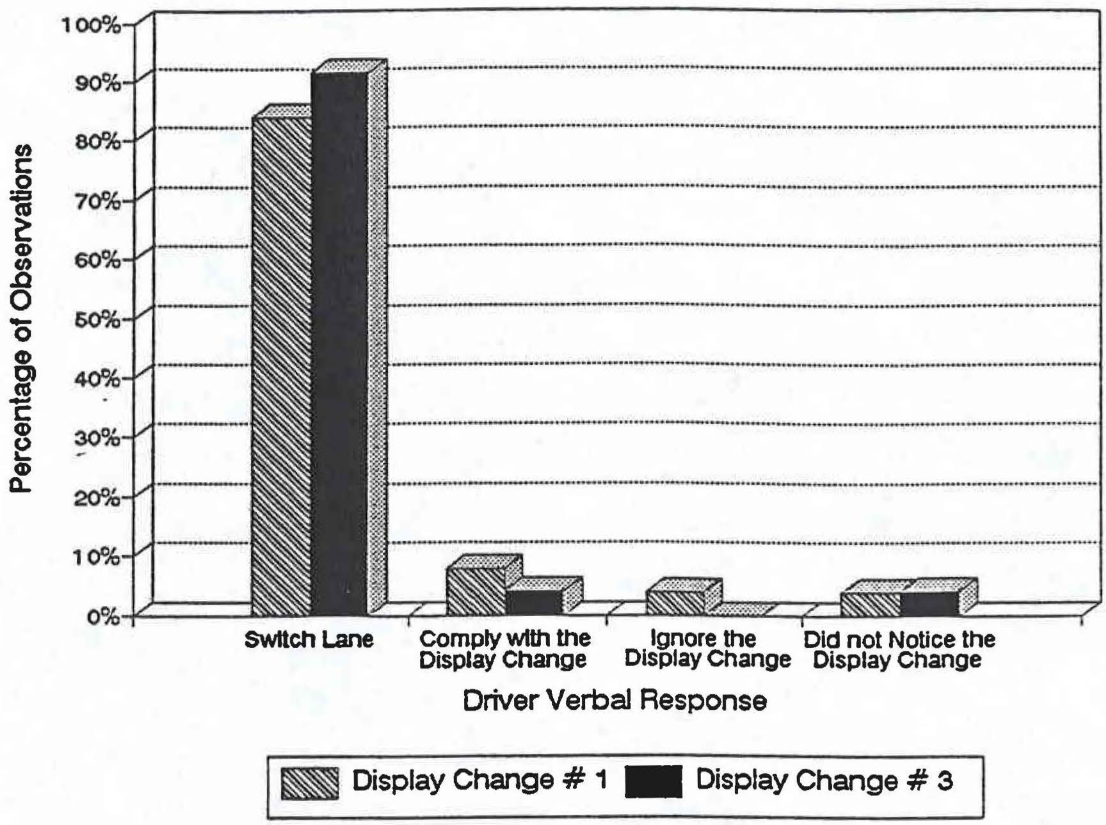
Driver Reactions/Responses to Display Changes in the Fiberoptic Sign

Display changes restricting a lane movement were presented to the drivers. As mentioned earlier, the driver reactions/responses were influenced by the lane they were in at the instant of a display change in the fiberoptic sign. For each display change, the lane movements of only one lane were directly affected. For that lane, the drivers' reactions intending to perform a maneuver that was eliminated are critical (for example a driver intending to go straight in the left lane and observes Display Change 1).

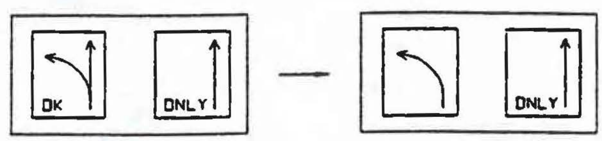
Driver reactions/responses were categorized into two categories. Drivers could observe the display change either in the overhead sign when approaching the intersection or in the roadside-mounted sign after coming to a halt at the intersection. The driver reactions/responses to a display change in the overhead sign are indicated in Figure 13. It clearly indicates that a majority of the drivers preferred to switch lanes. About 80 percent of the subjects in Display Change 1 and 90 percent of the drivers in Display Change 3 switched lanes. A few of the remaining drivers performed the maneuver indicated by the sign regardless of their initial intended maneuver (i.e., complied with the display of the sign). A few drivers on the other hand, performed the maneuver they initially intended, regardless of the display change in the overhead sign (i.e., ignored the display change in the sign). A few subjects did not notice the display change in the overhead sign.

The driver reactions/responses to the same display changes in the roadside-mounted sign were, however, significantly different, as illustrated in Figure 14. This figure clearly indicates a sharp drop in the percentage of drivers trying to switch lanes when compared to the reactions to a display change in the overhead sign. On the other hand, the percentage of drivers complying with the display change increased from 8 and 4 percent to 40 and 60 percent for Display Change 1 and Display Change 3, respectively. Such a situation could be interpreted as an inconvenience and could result in a number of nuisance calls from the general public. Similarly, the number of drivers ignoring the change in the display of the roadside-mounted sign also increased from about 4 percent to about 25 percent for both the display changes.

A chi-square test for independence was conducted to determine if the reactions of the subjects were independent of the type of display change in the sign. A chi-square value of 2.667 was obtained. The tabular value for an alpha of 0.05 and df of 2 was found to be 5.991. Hence, it was concluded that the subject reactions were independent of the type of display change in the roadside-mounted sign i.e., the drivers were likely to react in a similar manner on observing either Display Change 1 or Display Change 3. Hence, the drivers' reactions for the Display Change 1 and Display Change 2 were subsequently combined for future analysis.



Display Change # 1



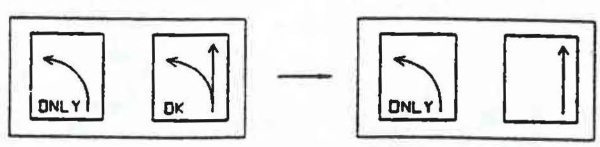
Driver in the Left Lane

Driver intends to Go Straight

Driver Response: **Comply - Turn Left**

Ignore - Go Straight

Display Change # 3



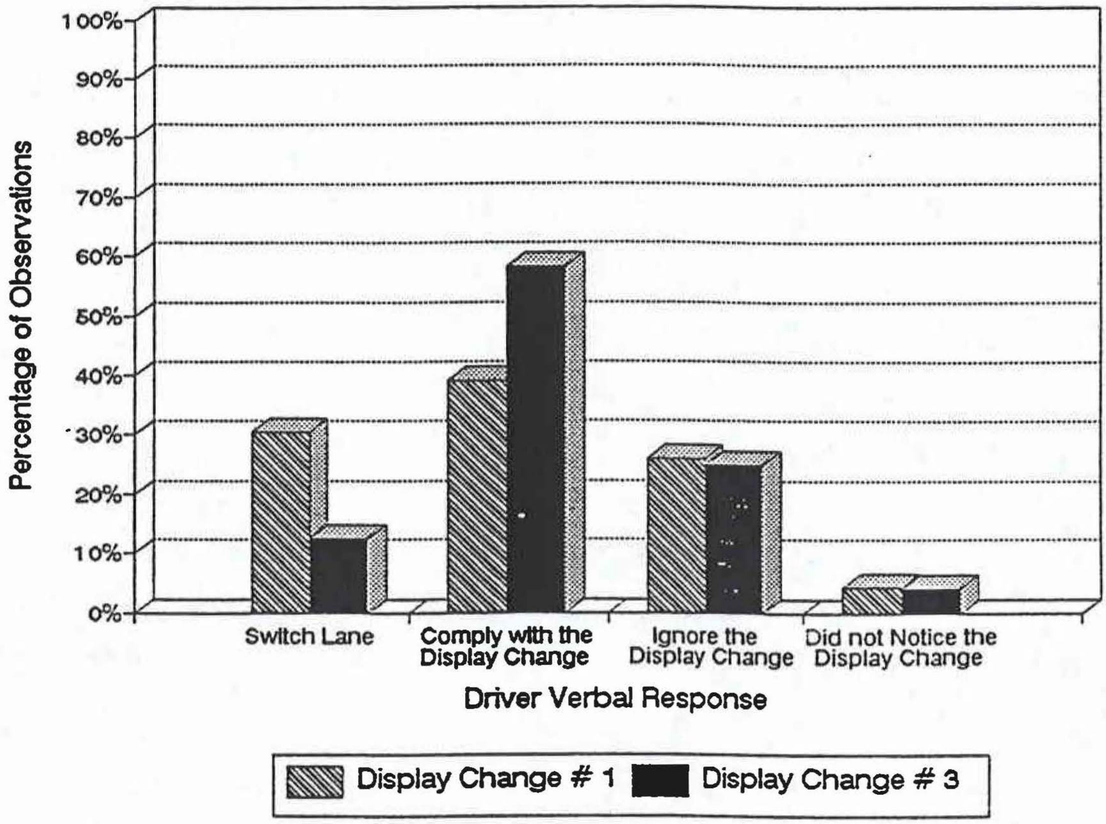
Driver in the Middle Lane

Driver intends to Turn Left

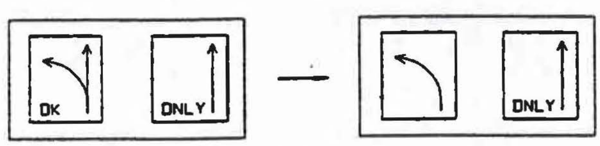
Driver Response: **Comply - Go Straight**

Ignore - Turn Left

Figure 13. Subject reactions/responses to display changes in the overhead sign.



Display Change # 1



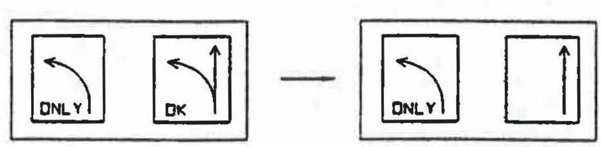
Driver in the Left Lane

Driver intends to Go Straight

Driver Response: **Comply** - **Turn Left**

Ignore - **Go Straight**

Display Change # 3



Driver in the Middle Lane

Driver intends to Turn Left

Driver Response: **Comply** - **Go Straight**

Ignore - **Turn Left**

Figure 14. Subject reactions/responses to display changes in the roadside-mounted sign.

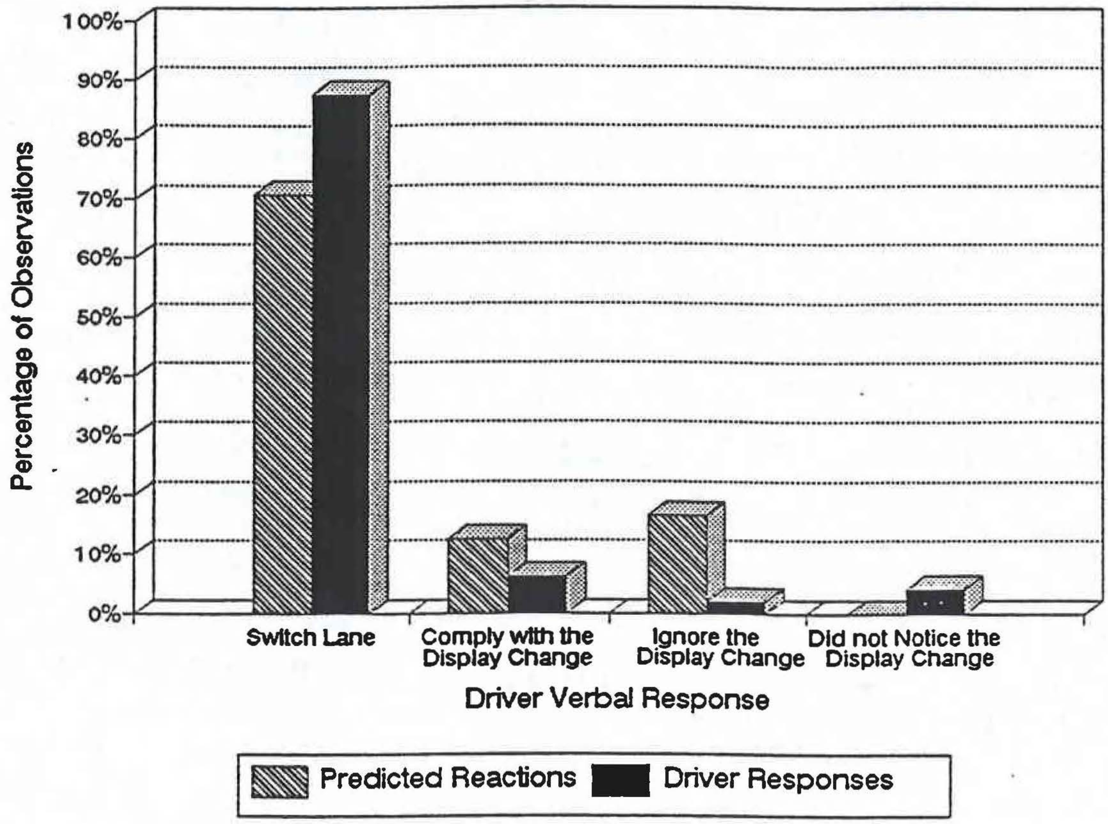
Comparing the Predicted Driver Reactions with the Observed Subject Reactions/Responses

Figure 15 illustrates a comparison between the observed driver reactions/responses with those predicted by the experts for the same display changes in the overhead signs. It is clearly seen that a majority of the experts felt that the drivers would switch lanes. In fact, most of the drivers in the driver study did switch lanes.

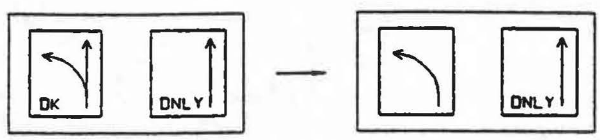
The observed driver reactions/responses were compared with the driver reactions predicted by the experts to a display change in the roadside-mounted sign and illustrated in Figure 16. This figure indicates a wide difference in the experts' predictions and the observed reactions in the case of "ignore" reaction. While almost 60 percent of the experts had predicted that the drivers would ignore the display change and perform the maneuver that was originally intended, only about 25 percent of the drivers actually ignored the display change in the driver study. While 30 percent of the experts expected the drivers to comply with the display change, almost 50 percent of the drivers actually did so in the driver study.

A chi-square list was used to determine if the two distributions were similar, a chi-square test ($x^2=6.829>5.99$ for $\alpha=$, or $df=2$). The null hypothesis was "reactions are independent of whether they are predicted or observed". The null hypothesis was rejected, implying that the experts did not accurately predict the likely driver reactions for the display changes in the fiberoptic signs.

Thus, it can be stated that the experts' opinion as well as the drivers' reactions concurred in response to a display change in the overhead sign (switch lane). However, there was a statistically significant difference on observing the display change in the roadside-mounted sign. It appears that the drivers in the driver study were taking fewer risks than predicted by the experts. One explanation could be that the experts were expecting the change in the sign display in the expert study. On the other hand, the subjects were not expecting the display change and were, hence, surprised and more cautious. The experts were also aware that it would be safe to ignore the display change in the fiberoptic sign. The drivers, on the other hand, had to evaluate the risk of being involved in an accident while performing the driving task.



Display Change # 1



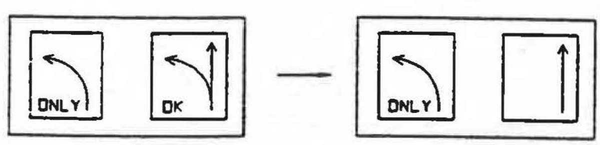
<u>Driver in the Left Lane</u>

Driver intends to Go Straight

<u>Driver Response:</u> Comply - Turn Left

Ignore - Go Straight

Display Change # 3



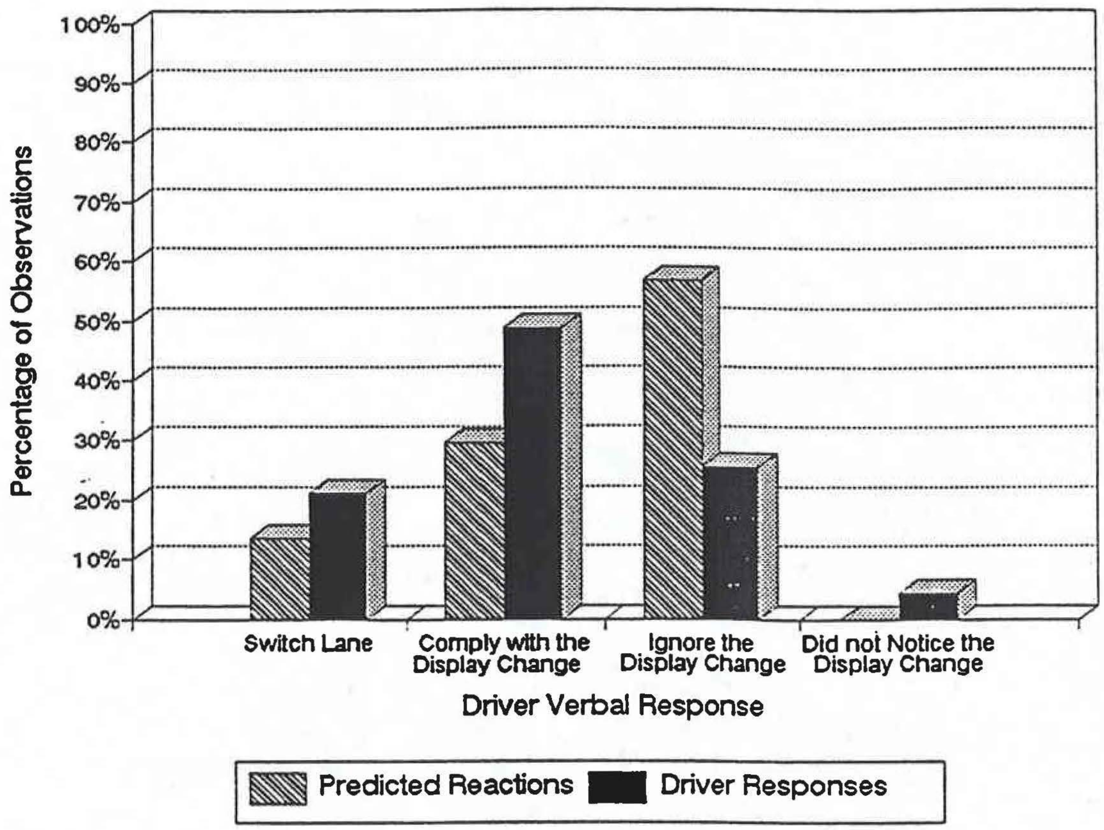
<u>Driver in the Middle Lane</u>

Driver intends to Turn Left

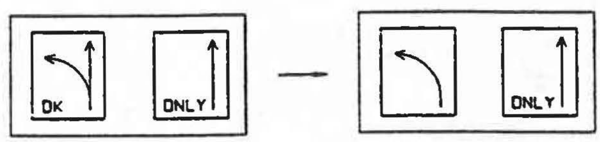
<u>Driver Response:</u> Comply - Go Straight

Ignore - Turn Left

Figure 15. Predicted and observed reactions/responses to display changes in the overhead sign.



Display Change # 1



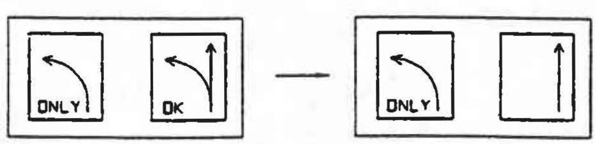
Driver in the Left Lane

Driver intends to Go Straight

Driver Response: **Comply - Turn Left**

Ignore - Go Straight

Display Change # 3



Driver in the Middle Lane

Driver intends to Turn Left

Driver Response: **Comply - Go Straight**

Ignore - Turn Left

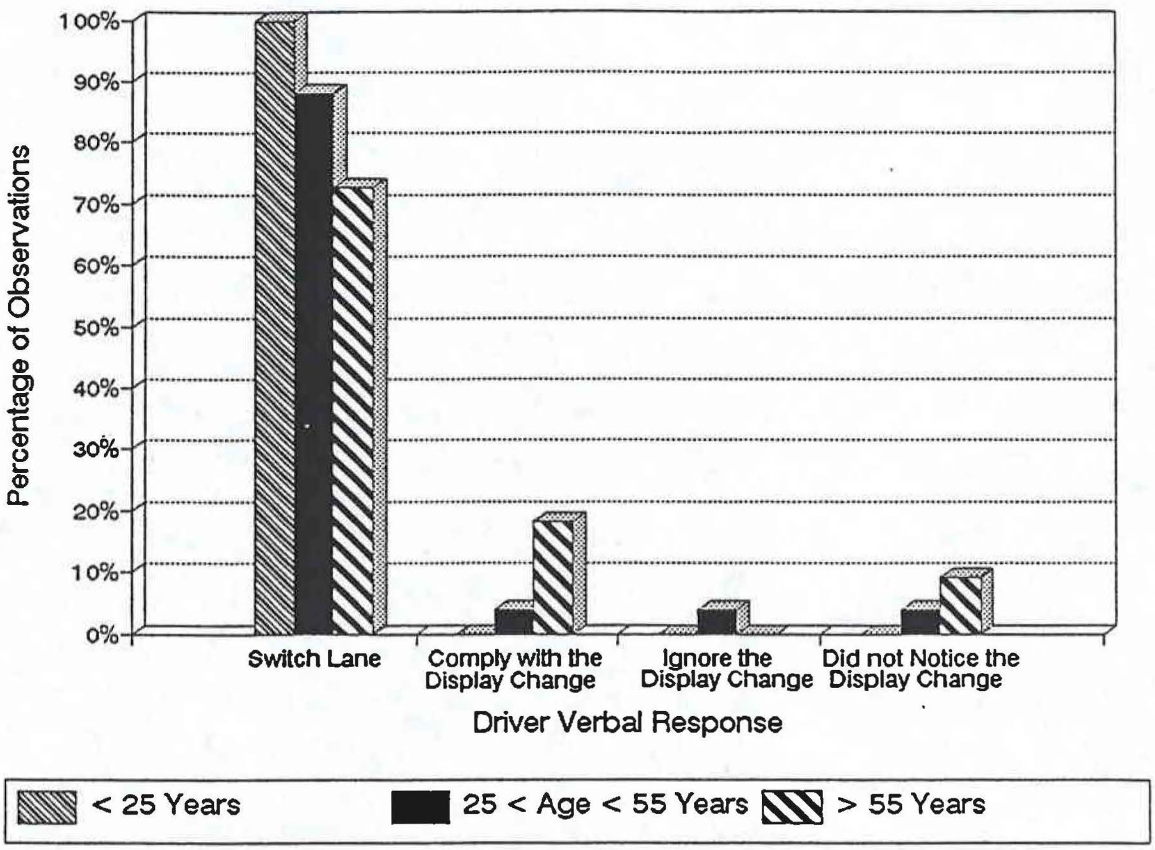
Figure 16. Predicted and observed reactions/responses to display changes in the roadside-mounted sign

Comparing the Subject Reactions/Responses with Age

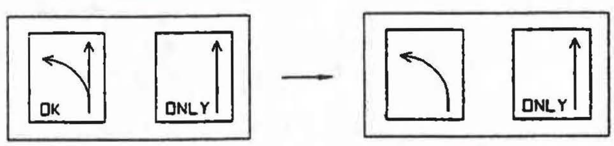
The age of the drivers plays an important role in the way the drivers perceive and react to TCD. While older drivers are more experienced, some of their physical capabilities have diminished. Their vision gets poorer. They take a longer time to understand the TCD and tend to react slower. While they tend to take less risks, they are more likely to miss a sign. They are likely to make more errors in the judgement of the complex situations involved in traffic (i.e., at traffic signals, left turns at stop controlled intersections, and while merging onto the freeways). In the years to come the proportion of the older drivers among the driving population will increase. Thus, it is essential that the design of any new TCD should consider the needs of the older drivers.

Figure 17 shows the distribution by age of the driver reactions/responses to a display change in the overhead signs. It clearly indicates that a majority of the drivers have switched lanes. While all of the drivers under the age of 25 years switched lanes, about 70 percent of the drivers over the age of 55 did the same. The remaining drivers over the age of 55 years either complied with the display change or did not notice the display change. These observations may confirm the earlier statements which stated that older drivers tend to react more slowly. Since most of the drivers switched lanes, it was not necessary to conduct a statistical analysis to determine the independence of driver age and their reactions for a display change in the overhead sign.

The driver reactions/responses by age to a display change in the roadside-mounted sign is indicated in Figure 18. The figure indicates that there is no definite trend in the manner the drivers respond to display changes in the roadside-mounted sign. The figure may suggest that the majority of the middle age group (25 to 55 years) drivers comply with the display change and hence appear to be conservative, by taking the minimum number of risks. A chi-square test was conducted to determine if the variation in the driver reactions/responses was independent of driver age. The null hypothesis was "reactions are independent of the age of the driver" ($x^2=2.204<5.991$ for $\alpha=.05$, $df=2$). Hence, there is insufficient evidence to reject the null hypothesis i.e., the differences observed in the driver reactions/responses by age are not statistically significant.



Display Change # 1



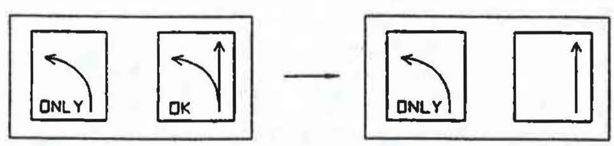
Driver in the Left Lane

Driver intends to Go Straight

Driver Response: Comply → Turn Left

Ignore → Go Straight

Display Change # 3



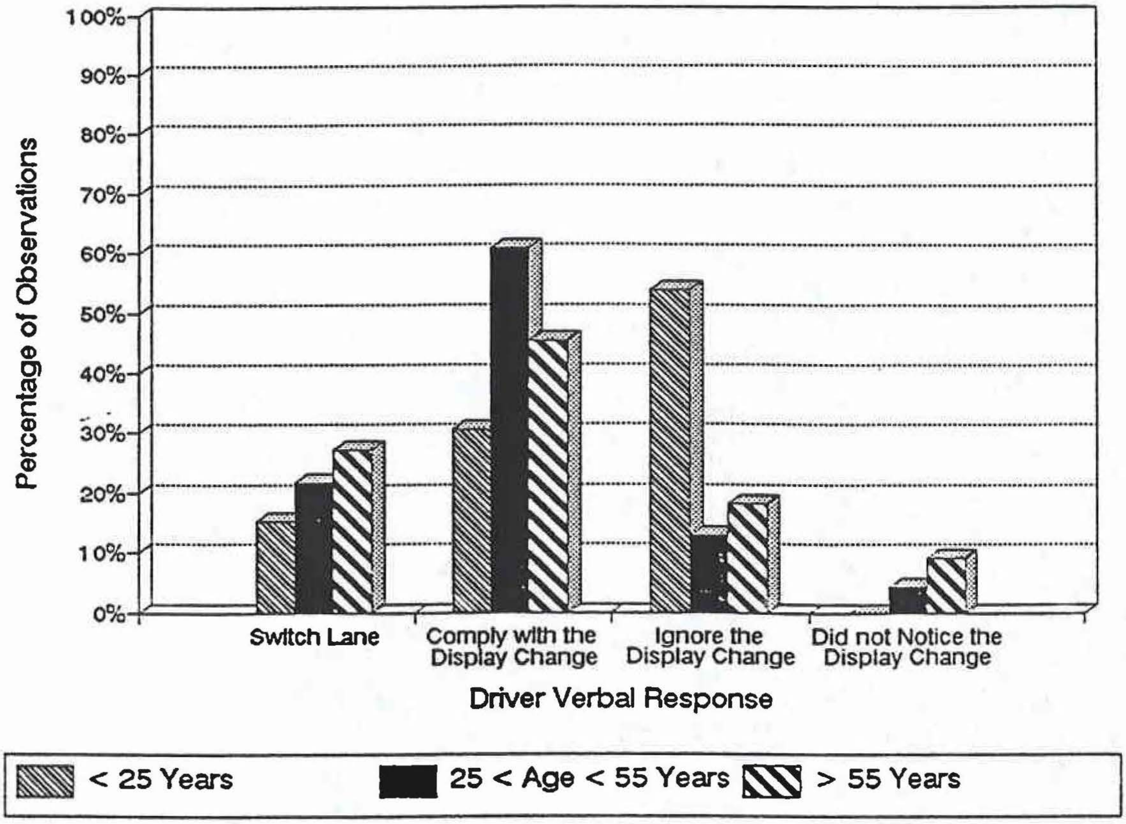
Driver in the Middle Lane

Driver intends to Turn Left

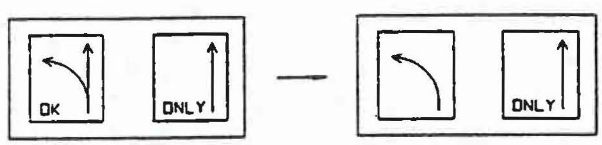
Driver Response: Comply → Go Straight

Ignore → Turn Left

Figure 17. Comparison of subject reactions/responses by age to a display change in the overhead sign.



Display Change # 1



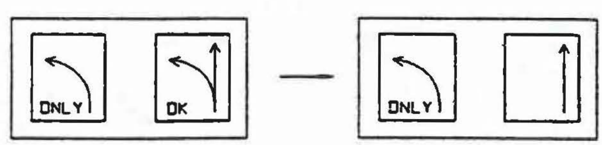
<u>**Driver in the Left Lane**</u>

Driver intends to Go Straight

<u>**Driver Response:**</u> **Comply - Turn Left**

Ignore - Go Straight

Display Change # 3



<u>**Driver in the Middle Lane**</u>

Driver intends to Turn Left

<u>**Driver Response:**</u> **Comply - Go Straight**

Ignore - Turn Left

Figure 18. Comparison of subject reactions/responses by age to a display change in the roadside-mounted sign.

PHASE III - OPERATIONAL ASSESSMENT OF DALAS SIGNS
STUDY DESIGN

Overview

The major thrust of Phase III of this research was to evaluate the effectiveness of Dynamic Lane Assignment (DALAS) under real-world traffic conditions. A site was chosen where significant left turn-through movement volume variations were occurring. The east bound approach to the frontage road intersection at IH-10 and Voss/Bingle in Houston was selected for a Before and After study.

Before studies were conducted prior to the installation of the experimental signs. Twelve-hour turning movement counts provided needed volume data. Traffic movements on the study approach were recorded by video tape during morning peak and afternoon off-peak and peak periods for four days. Queue length observations were visually made to complement video taping.

The experimental signs were installed in June 1992, and traffic was allowed to stabilize before beginning the After studies.

In August 1992, the data collection process used for the Before studies was repeated to obtain After data for the Before and After comparison study.

Model of Operation

The primary problem at the study site had arisen due to the extreme variation in the turning volumes. The static lane assignment satisfied the morning peak period traffic, which existed for two hours, from 7:00 a.m. to 9:00 a.m. As shown in Figure 19, the through volumes were very high on the eastbound frontage road during this period. Hence, the inner lane was designated as a shared lane for through and left turning vehicles, the middle lane was assigned exclusively for through vehicles, and the outer lane was designated as a shared lane for through and right turning vehicles. This lane assignment serves the morning peak period traffic efficiently but during other times of the day, a significant increase in left turning traffic causes congestion.

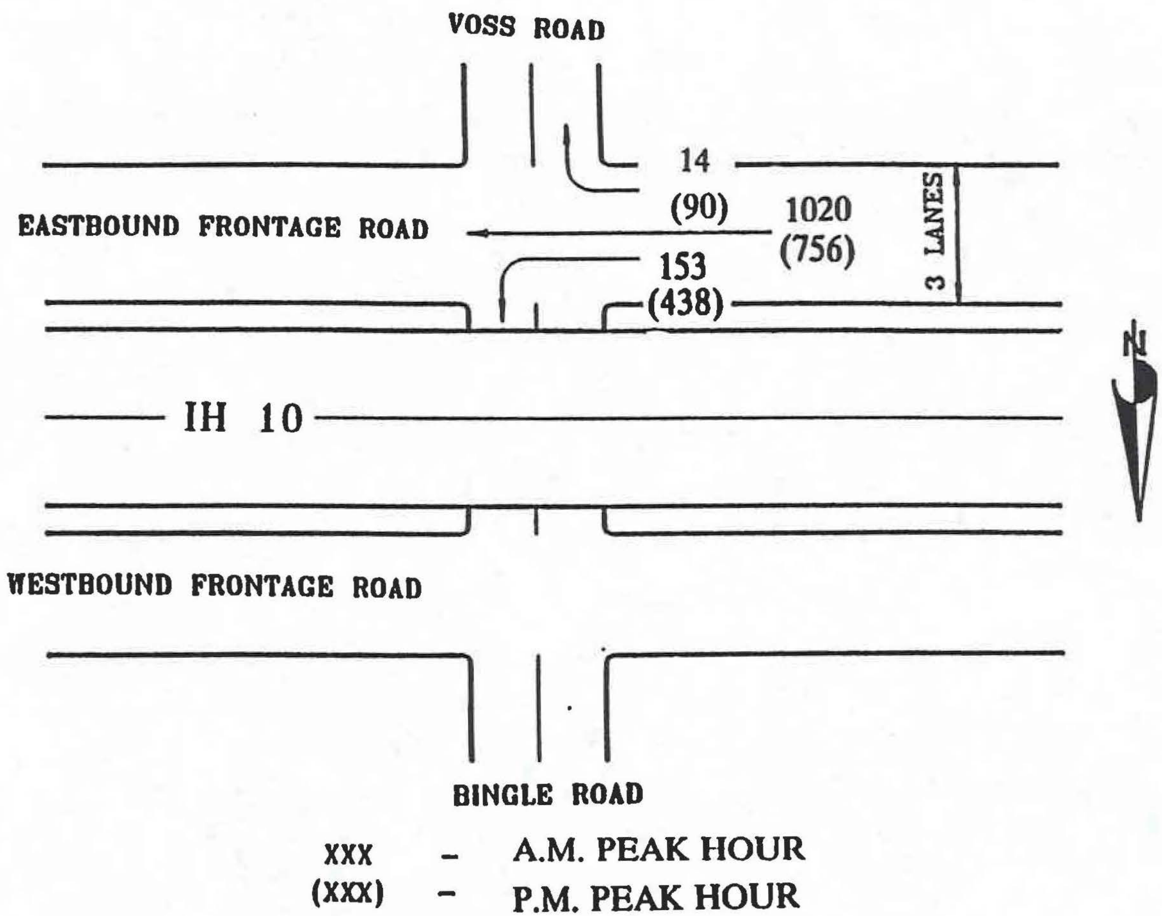


Figure 19. Turning volume counts at the intersection of IH-10 and Voss/Bingle.

Identification of Measures of Effectiveness

The purpose of implementing the DALAS signs was to satisfy the varying traffic demands at the site. The space management concept using DALAS signs would reduce the imbalance in the queue lengths and delays in different lanes, which would result in shorter queues and lower approach delays. Hence, the queue lengths at the onset of green (in terms of vehicles in queue) and delays were identified as the primary MOEs for comparison between the traffic conditions before and after the implementation of DALAS. Owing to the limited time frame covered by this research, a Before and After accident analysis is not possible.

Data Collection Effort

Data were collected to estimate the values of the identified MOE necessary for evaluating the traffic behavior before the implementation of the DALAS signs. The data collection was done in three parts. Turning volume data were collected for the intersection of Voss/Bingle with eastbound frontage road of IH-10 to identify the general characteristics of the traffic at the intersection. The intersection data were collected manually by TTI personnel. The 15-minute volume counts were made between 6:00 a.m. and 6:00 p.m. on November 26, 1991. The peak periods were established visually from the traffic count data. For the east bound approach, the morning peak period was 7:00 a.m. to 9:00 a.m., and the predominant flow pattern was a through movement. The afternoon peak, having high left-turn volumes occurred between 12:00 noon and 3:00 p.m. Also, 15- minute volume counts were made for the peak periods at the intersection of Voss/Bingle with westbound frontage road. The data are shown in Appendix D.

The data collection plan was prepared to video tape traffic movements in the peak periods. The camera setup for the collection of data is shown in Figure 20. Two cameras were used. While Camera 1 covered the area of the eastbound frontage road near the intersection, Camera 2 covered the area upstream of the intersection. A portion of the area covered by Camera 1 was also covered by Camera 2 to have a common reference point for coordination of the two video cassettes from the two cameras. This enabled viewing a significant portion of the approach at any time by displaying the two video cassettes on different television screens simultaneously. The recording was done in the peak periods identified from the previously collected data. Since long queues could not be estimated accurately, the queues at the onset of effective green were measured in the field. Since the volume data were required to check the peaking characteristics of the traffic, Camera 1 was used to record continuously during the day. During this period, it was not necessary to measure the delays and the queue lengths. Hence, Camera 2 covering the upstream of the intersection was used only to record the traffic characteristics in the identified peak periods, and no manual queue counts were made in the off-peak periods.

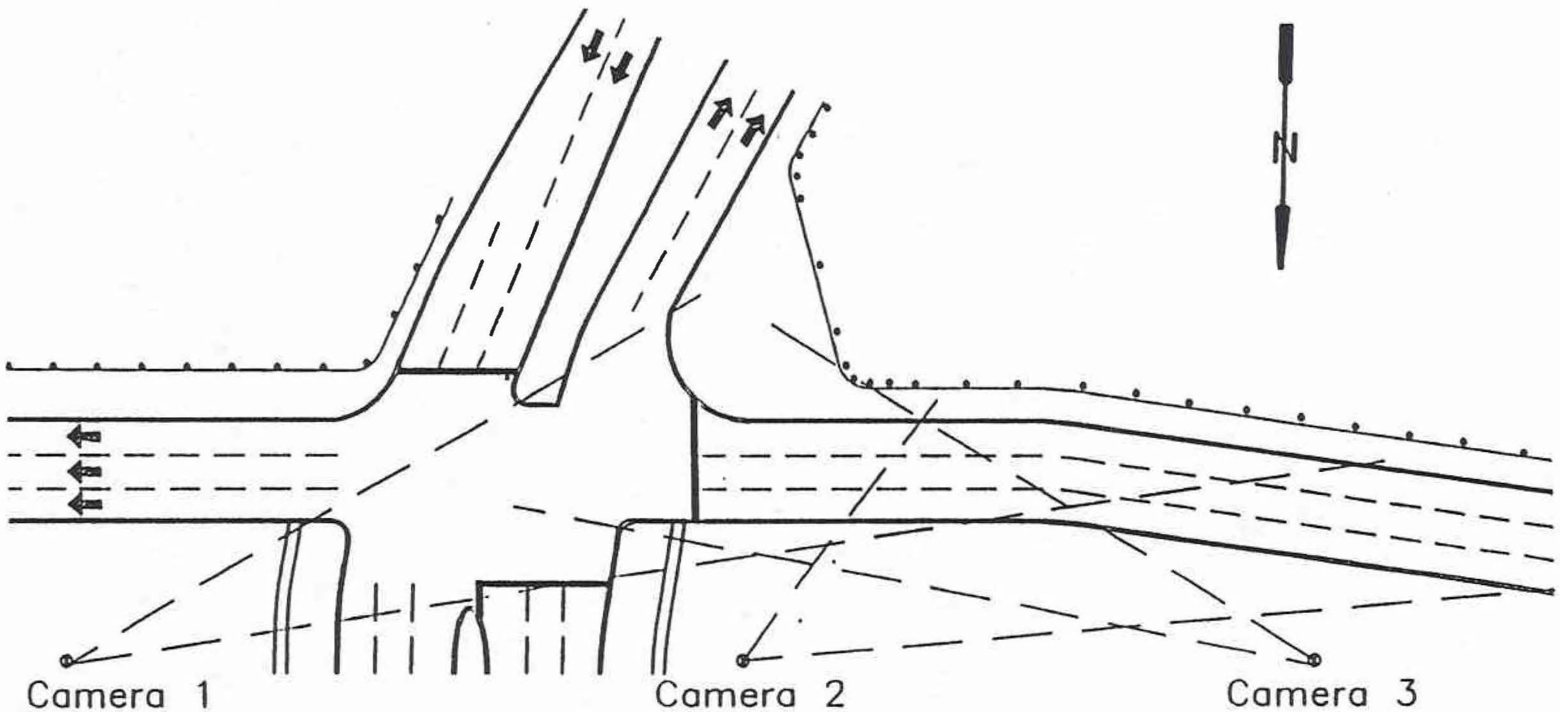


Figure 20. Camera setup for data collection under actual traffic conditions.

To obtain data representing the typical traffic behavior and to minimize the error in estimation of the MOEs from the data influenced by some external features or events, data were collected on more than one day. For the Before study, data for a.m. peak period and p.m. peak period were collected on three and four days respectively. For the After study, four days of a.m. peak data and six days of p.m. peak data were collected.

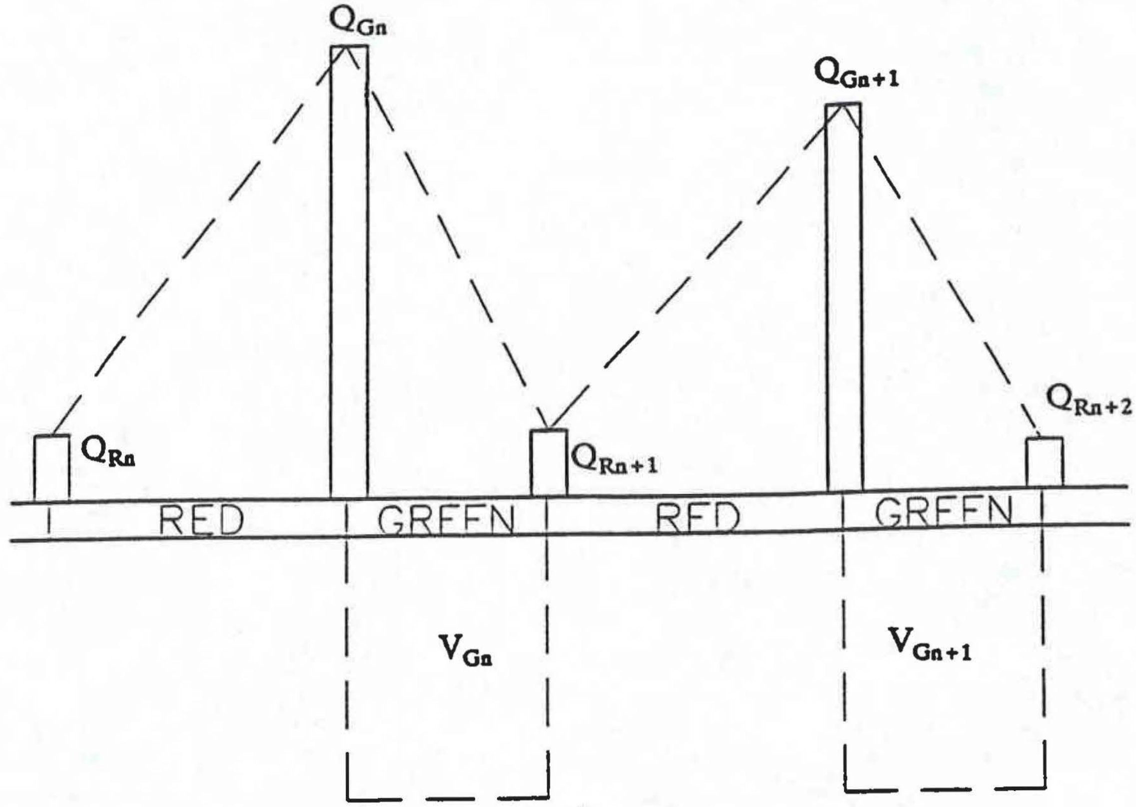
Data Reduction

The purpose of installing the DALAS signs was to more uniformly distribute the vehicles among different lanes and hence, reduce delays and queue lengths for the left lane. Thus, the MOEs were quantified for individual lanes. The peaking characteristics were observed on each day and an analysis period of 15 to 30 minutes was selected in each morning and afternoon peak periods. The queue lengths at the onset of green were determined for each lane.

Several traffic and signal timing parameters were required for determining delays for the eastbound frontage road. These were cycle length, green time, volumes arriving in green and red, and volumes served in each green interval in different lanes. The vehicles served in each cycle, and the queues at the onset of red on the frontage road were obtained from the video cassette recorded from Camera 1. The green splits and the cycle lengths in the analysis period were obtained from the video cassette from Camera 1. In this analysis, a cycle was assumed to start at the onset of red and end at the onset of the next red for the frontage road approach.

The number of vehicles arriving on the frontage road in each green and red interval was estimated using simple mathematical equations. Figure 21 helps explain the procedure adopted for calculating the arrival volumes. Assume that there are Q_{Rn} vehicles stopped at the onset of red in n^{th} cycle. Queues start building up on the approach till the end of the red interval when the vehicles are allowed to leave the approach. Assume that there are Q_{Gn} vehicles standing in the queue at the onset of green in that cycle. Once the signal turns green, the vehicles move out and the queue starts dissipating. Assume that there are Q_{Rn+1} vehicles in queue at the end of the cycle or the onset red for the $(n+1)^{th}$ cycle.

The vehicles arriving during the red interval cause the increase in queue length from Q_{Rn} to Q_{Gn}. Hence, the number of vehicles arriving in red (A_{Rn}) can be calculated as the difference in the queue lengths at the onset of red and green. When the signal turns green, all the queued vehicles and the vehicles arriving in green (A_{Gn}) would want to be served at the onset of green but may or may not be served in that cycle due to the early termination of the green. Thus, some vehicles may have to wait until the next green. Hence, the number of vehicles served in n^{th} cycle (V_{Gn}) can be given by the equation



where,

Q_{Gn} = Queue at the onset of green in n^{th} cycle

Q_{Rn} = Queue at the onset of red in n^{th} cycle

V_{Gn} = Volume served in the green for approach in n^{th} cycle

A_{Gn} = Arrivals on the approach in green in n^{th} cycle

A_{Rn} = Arrivals on the approach in red in n^{th} cycle.

Hence,

$$A_{Rn} = Q_{Gn} - Q_{Rn}$$

$$A_{Gn} = V_{Gn} - (Q_{Gn} - Q_{Rn+1})$$

Figure 21. Queue diagram for calculation of arrival rates.

$$V_{Gn} = Q_{Gn} + A_{Gn} - Q_{Rn+1}$$

or, the number of vehicles arriving during the green can be given by the equation,

$$A_{Gn} = V_{Gn} - (Q_{Gn} - Q_{Rn+1})$$

As mentioned earlier, the queue lengths at the onset of red and volumes served in each cycle could be observed from the video cassettes. The queue lengths at the onset of green were observed in the field. Hence, the arrival rates could be estimated, following the above procedure. Table 3 shows the reduced data observed in the morning peak of February 19, 1992. The negative numbers for arrivals during green were due to lane changes made before they were served at the intersection.

Procedure Adopted for Calculating Delays

Figure 22 illustrates the queuing model. The basic cumulative arrival pattern with time is given by A(t) and cumulative service pattern by D(t). The effect of the signal is shown in the service pattern D(t). Since there is no further increase in the cumulative number of serviced vehicles, the pattern is horizontal at regular intervals. The area enclosed between the two curves indicates that some vehicles are waiting in the queue. The vertical axis gives the length of the queue or the number of vehicles in the queue at any particular instant. Also, the vehicles joining the queue would leave the queue at a time given by the horizontal separation between the curves. In other words, the area between the two curves gives the total vehicle seconds lost waiting in queue or is simply stated as the total approach delay.

The difference between the cumulative number of vehicles being served and arriving on the approach is the net number of vehicles in the queue at the intersection. Hence, Figure 22 can also be drawn as Figure 21, for the purpose of calculating delays. It was assumed that the arrivals were uniform over the green and red intervals. While this assumption may not always be true, the arrivals were more or less uniformly distributed over the intervals, and this procedure would estimate the delay with accuracy within normal engineering requirements.

Table 3. Reduced data for a.m. peak on February 19, 1992.

Tr	Qr			Tg	Red	Qg			Ar			Vg				Ag		
	L	T	R			L	T	R	L	T	R	L	T	R	Green	L	T	R
4.24	0	1	1	5.34	1.10	3	6	4	3	5	3	5	7	4	0.29	2	1	0
6.03	0	0	0	7.12	1.09	3	4	2	3	4	2	4	9	4	0.31	1	5	2
7.43	0	0	0	8.53	1.10	2	7	4	2	7	4	2	6	5	0.30	0	-1	1
9.23	0	0	0	10.33	1.10	9	7	3	9	7	3	10	11	7	0.31	1	4	4
11.04	0	0	0	12.13	1.09	4	6	2	4	6	2	8	10	4	0.30	4	4	2
12.43	0	0	0	13.53	1.10	2	7	4	2	7	4	5	12	7	0.31	3	5	3
14.24	0	0	0	15.32	1.08	4	5	4	4	5	4	8	10	7	0.32	4	5	3
16.04	0	0	0	17.11	1.07	7	9	7	7	9	7	9	9	8	0.32	2	0	1
17.43	0	0	0	18.52	1.09	13	14	6	13	14	6	13	13	9	0.31	0	-1	3
19.23	0	0	0	20.32	1.09	11	18	12	11	18	12	14	16	12	0.32	3	1	0
21.04	0	3	0	22.12	1.08	11	16	11	11	13	11	12	15	13	0.31	1	-1	2
22.43	0	0	0	23.52	1.09	9	7	6	9	7	6	14	15	11	0.32	5	8	5
24.24	0	0	0	25.32	1.08	8	9	7	8	9	7	8	12	8	0.31	0	3	1
26.03	0	0	0	27.12	1.09	11	20	10	11	20	10	13	15	16	0.31	2	-4	6
27.43	0	1	0	28.52	1.09	13	18	15	13	17	15	16	17	18	0.31	3	-1	3
29.23	0	0	0	30.33	1.10	14	18	9	14	18	9	16	15	16	0.30	2	-3	7
31.03	0	0	0	32.13	1.10	13	13	11	13	13	11	14	14	14	0.30	1	1	3
32.43	0	0	0	33.52	1.09	9	15	10	9	15	10	12	17	14	0.31	3	2	4
34.23	0	0	0	35.34	1.11	6	9	8	6	9	8	10	12	10	0.30	4	4	4
36.04	0	1	2	37.13	1.09	21	18	21	21	17	19	17	16	17	0.30	-2	2	0
37.43	2	4	4	38.52	1.09	22	23	19	20	19	15	14	17	18				

Notation used:

Tr =Time at onset of red
Tg =Time at onset of green
Qr =Queue at onset of red
Qg =Queue at onset of green
Red=Red interval

Ar =Arrivals in red
Ag =Arrivals in green
Vg =Volumes served in green
Green=green interval

L -Left or inner lane
M -Middle lane
R -Right or outer lane

Note: Time is given as "minutes.seconds"

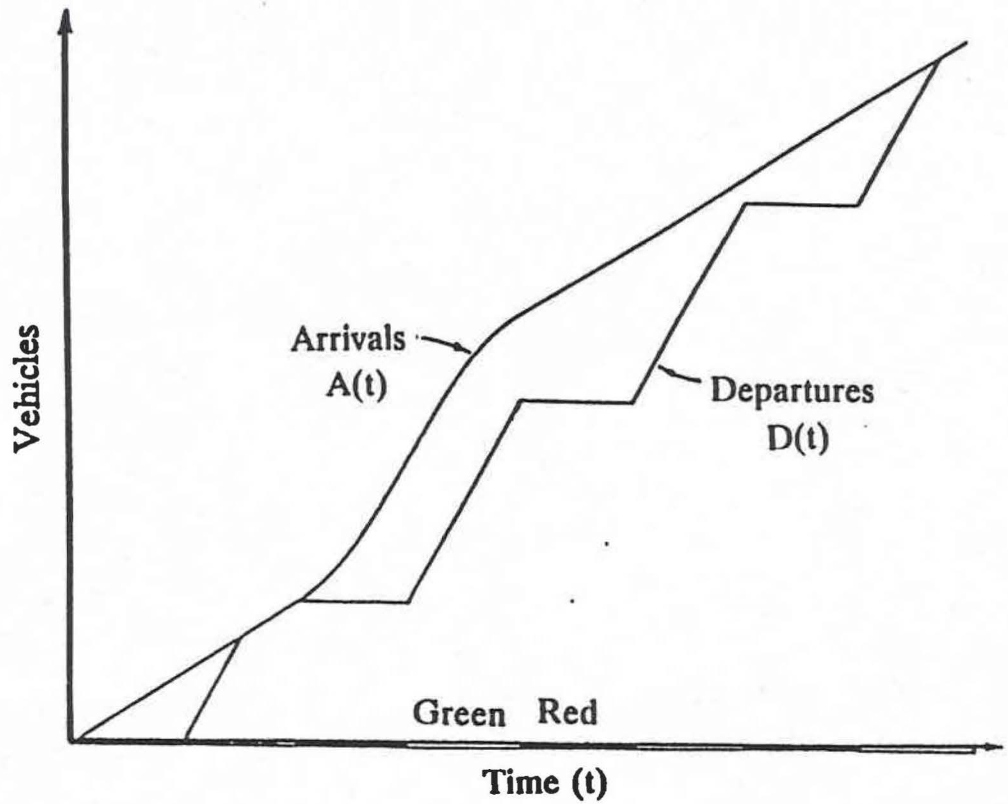


Figure 22. Input-output model for calculation of delays.

The reduced data were adequate for drawing a the straight line for queue build up since the slope is equal to the arrival rate in red. However, the rate at which the approach can serve the vehicles needs to be determined for drawing a line for queue dissipation. Hence, the next step in the calculation of delays was to find the service rate on the approach.

The service rate or the saturation flow rate, expressed as the "number of vehicles served per unit time" is the inverse of the time required to serve each vehicle, the headway. The HCM procedure was followed for the estimation of the saturation flow rates. The headways for all vehicles served in an interval of time were noted with respect to the lanes. The average of headways of fourth vehicle to the last vehicle in queue on each lane was calculated. The inverse of the average headway gave the saturation flow rate. Table 4 shows the data and the calculation of the saturation flow rate for the morning peak period on February 19, 1992.

The queue dissipation rate is the difference of the service rate and the arrival rate during the green phase. Hence, the other line was drawn with the appropriate slope, and the areas were measured using simple trigonometry to find the delays. The calculated delays with respect to lanes are shown in Table 5 for the morning peak period of February 19, 1992. The data collected in other peak periods were reduced in a similar manner.

Table 4. Calculation of saturation flow rates in a.m. peak on February 19, 1992.

Left Lane, A.M.Peak, 02/19/92 (7:26:03 to 7:32:42)					
	Headways (secs)				
Vehicle	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
1	0	0	0	0	0
2	1.97	2.35	1.42	2.58	2.52
3	1.86	2.74	2.08	2.03	2.36
4	1.86	1.70	1.97	1.48	2.41
5	1.92	1.86	0.21	2.69	1.75
6	1.81	1.32	1.81	1.09	2.35
7	3.18	2.69	1.92	1.86	2.47
8	1.64	1.48	1.26	1.92	2.03
9	1.64	1.21	1.09	1.26	
10	1.53	1.31	1.64	1.31	
11	2.75	1.59	1.86	2.96	
12		1.59	1.59	2.19	
13		1.59	1.70	2.47	
14			1.75		
Middle Lane, A.M.Peak, 02/19/92 (7:26:03 to 7:32:42)					
1	0	0	0	0	0
2	2.14	1.97	3.07	2.19	3.34
3	1.92	2.74	3.62	2.74	2.03
4	3.07	2.08	1.37	2.14	2.19
5	1.69	1.64	1.15	1.64	1.59
6	1.81	1.42	1.92	3.18	1.53
7	1.37	1.48	1.21	2.19	2.08
8	2.14	1.37	1.81	2.03	0.76
9	2.52	1.26	2.63	1.26	0.82
10	2.58	1.97	1.64	1.09	3.29
11	1.59	1.53	1.86	2.58	1.53
12	1.81	1.21	1.32	1.42	1.97
13	1.15	2.41	2.58	0.60	0.98
14	1.15	1.92	0.93		1.75
15	1.81	0.87	2.85		1.42
16		1.58			

Summary Table

Lane	Tot.Hdwy.	# veh	Av.Hdwy	Sat.Flow
Left	70.29	39	1.80	1997
Middle	91.89	54	1.70	2116
Right	71.76	35	2.05	1756
Sat. flow of approach =				5869

Table 5. Delays observed on February 19, 1992 with respect to lanes.

Total Qg	Tq	Total Delay	Average Delay	Left			Middle			Right		
				Tq	Tot.del	Av.del	Tq	Tot.del	Av.del	Tq	Tot.del	Av.del
13	8.51	510.34	31.90	6.17	114.26	22.85	10.85	242.54	34.65	8.20	156.40	39.10
9	6.56	340.02	20.00	5.74	112.11	28.03	9.38	156.76	17.42	4.73	73.73	18.43
13	7.97	506.83	38.99	3.60	73.60	36.80	11.27	284.45	47.41	8.80	157.61	31.52
19	14.18	799.71	28.56	17.22	392.50	39.25	15.26	298.42	27.13	8.36	117.55	16.79
12	9.25	469.52	21.34	9.49	156.98	19.62	13.21	246.62	24.66	4.75	73.75	18.44
13	10.19	521.25	21.72	4.37	74.37	14.87	16.42	302.46	25.21	10.23	160.46	22.92
13	10.36	509.32	20.37	9.31	154.61	19.33	11.59	198.97	19.90	10.15	156.31	22.33
23	14.97	942.65	36.26	14.22	284.26	31.58	15.31	370.42	41.16	15.33	288.17	36.02
33	21.08	1486.26	42.46	23.43	600.80	46.22	22.58	641.09	49.31	15.35	253.04	28.12
41	27.24	1972.88	46.97	23.86	510.71	36.48	32.35	911.35	56.96	24.60	561.62	46.80
38	24.27	1753.13	43.83	21.05	489.77	40.81	25.81	820.73	54.72	25.99	516.95	39.77
22	20.60	985.65	24.64	22.58	412.11	29.44	20.73	314.06	20.94	18.10	261.30	23.75
24	15.99	1007.85	35.99	14.42	329.67	41.21	18.33	388.50	32.38	15.37	291.79	36.47
41	27.31	1974.38	44.87	22.43	502.89	38.68	27.91	969.06	64.60	33.99	514.93	32.18
46	31.31	2308.44	45.26	28.38	632.97	39.56	29.04	881.28	51.84	38.37	835.02	46.39
41	28.67	2145.53	45.65	28.68	690.75	43.17	26.18	869.69	57.98	35.38	583.80	36.49
37	25.28	1768.45	42.11	24.93	617.03	44.07	23.45	607.44	43.39	28.37	624.03	44.57
34	25.37	1604.37	37.31	19.65	398.91	33.24	28.67	732.55	43.09	27.88	484.39	34.60
23	18.70	1031.50	32.23	14.23	255.70	25.57	19.81	412.52	34.38	22.57	374.29	37.43
60	36.80	3121.33	62.43	33.79	1071.73	63.04	34.55	922.07	57.63	43.06	1130.74	66.51

Notation used: Qg =Number of Vehicles waiting in queue at the onset of green
Tq =Time to clear the queue(minutes.seconds)

ANALYSIS AND RESULTS OF PHASE III

The results of Phase III of this research reflect the volume conditions that appear to justify the implementation of DALAS. Further, a comparison of the measures of effectiveness for the Before and After studies offer evidence of the operational benefits that may be derived from its implementation.

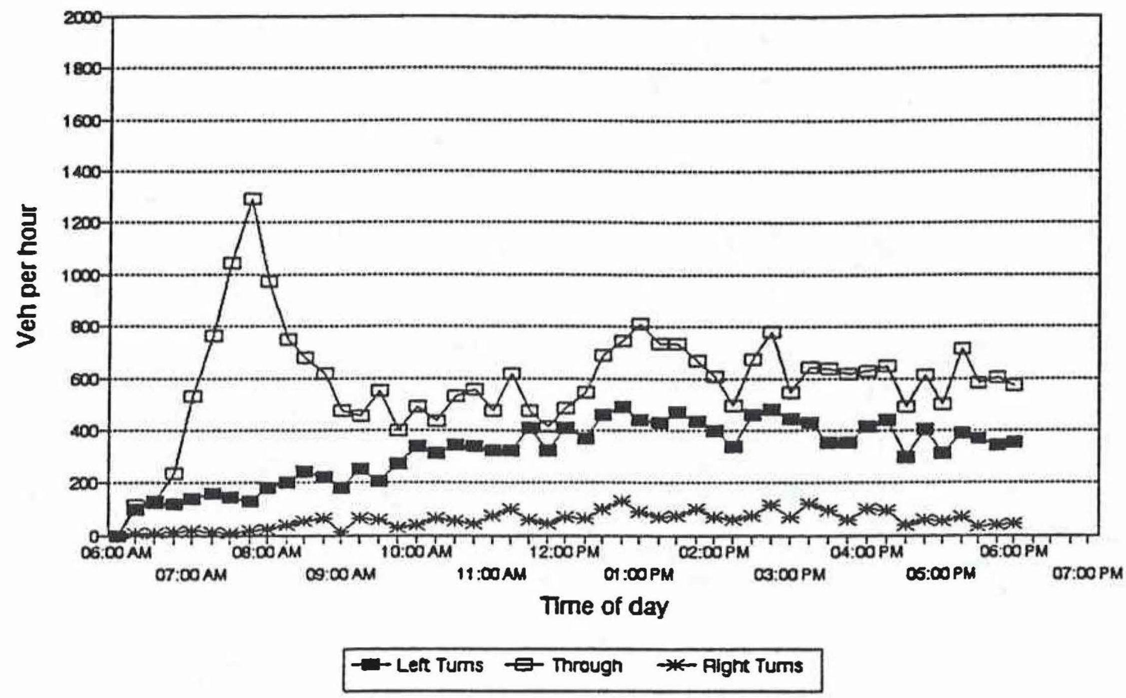
As a preliminary part of this research, traffic volume counts were made at the intersection of IH-10 South Frontage Road and Voss/Bingle Road over a period of 12 to 14 hours. These volumes were recorded for 15-minute periods for each lane, and further classified by intersection movement. The results of these counts are illustrated in Figures 23 and 24.

A "typical day" or the conditions most often observed are illustrated in Figure 23a. It is noted that a very pronounced morning peak period occurs between the hours of 7:00 and 9:00 am. Typically there is no pronounced PM peak. However, on an "atypical day" as illustrated in Figure 23b, both morning and after peaks occur, and they are substantially larger than as indicated for the typical day. In both the typical and atypical day, the excesses or major variations appear to be in the through movement. The left-turn volumes grow substantially at mid morning and remain rather high throughout the day. This change appears to be valid justification for implementation of DALAS as it has been implemented in this specific case, i.e., operation on a pre-determined timing plan.

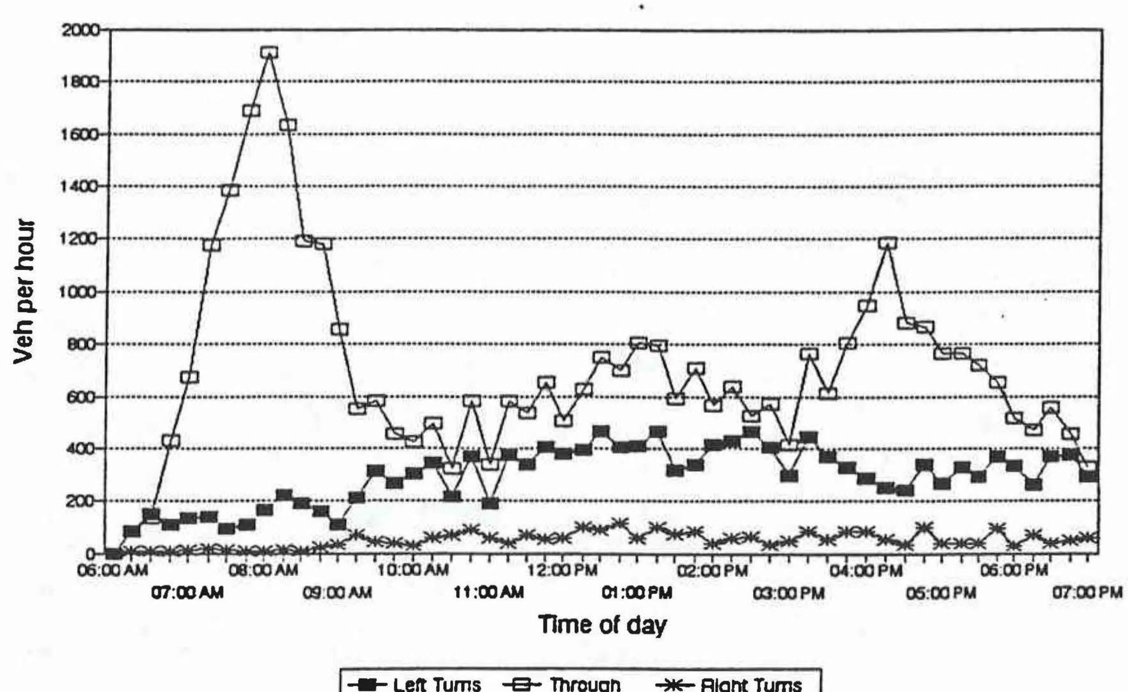
The fluctuations in through movement appear to be in direct relation to traffic conditions on the freeway. Thus, the "atypical day" variation appears to be justification for using DALAS as a real-time, dynamic responsive management tool as suggested by IVHS objectives.

Figure 24 illustrates the relative lane usage throughout the day for the Before conditions. It is noted that the inside lane handles substantially larger volumes except for the AM peak period. Again, this justification for pursuing the DALAS concept for intersections displaying similar characteristics.

Signal timing was observed for both the Before and After conditions, and the results are shown in Table 6. It is noted that timing and cycle length remained the same for the AM peak throughout both the Before and After studies. For PM peak, the cycle length changed substantially, from an approximate 130 second cycle for the Before study to 80 seconds in them After study. There is no readily apparent explanation for this difference, and no indication that it influenced the outcome of the research.



a. Typical day



b. Atypical day

Figure 23. Variation in turning volumes with time of day on a typical and an atypical day.

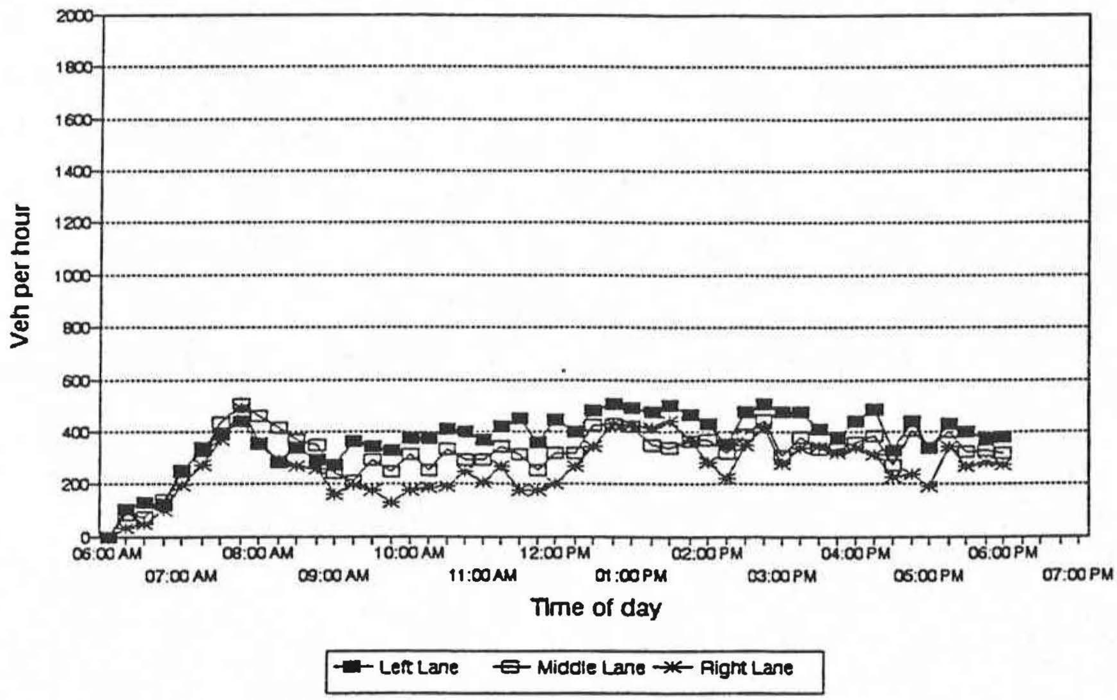


Figure 24. Variation in lane usage with time of day.

Table 6. Signal time (secs) observed on different days.

Date	A.M.Peak			P.M.Peak		
	Red	Green	Cycle	Red	Green	Cycle
Before study						
02/19/92	70	30	100	50	30	80
02/26/92	70	30	100	95	40	135
04/22/92				95	32	127
04/23/92	70	30	100	96	31	127
After study						
08/04/92				55	25	80
08/05/92	70	30	100	54	26	80
08/06/92	70	30	100	56	24	80
08/11/92				55	25	80
08/12/92	70	30	100	55	25	80
08/13/92	70	30	100	53	27	80

Comparisons of Queue Length and Delays

The observed delays and queue lengths were used as measures of effectiveness, but it was recognized that they are directly influenced by volume conditions and cycle lengths. Therefore, regression analyses were used to correlate delay and queue length with demand volume in vehicles per cycle. In this manner, it was then possible to make comparisons between the AM and PM peaks for each lane and for the total approach. These comparisons are provided in Figures 25 and 26 for the AM peak and Figures 27 and 28 for the PM peak. As expected, there were no significant differences in delays and queue lengths for the AM peak, since there was no change in the lane assignments from the Before to After condition. Although not significant, there was a consistently higher queue length and delay associated with Before conditions.

For the PM peak, Figure 27 shows that the delays for the entire approach were reduced significantly by the implementation of DALAS, and the reduction in delay for the inner lane was even more pronounced. Delays in the middle and outer lanes was unchanged.

Queue lengths, as illustrated in Figure 28, were much less affected by the implementation of DALAS. The only significant change was in the queue lengths observed in the inside lane.

Other Observations

During the After study it was noted that a large number of vehicles changed lanes fairly close to the intersection rather than near the overhead signs. This suggests that drivers are for some reason more responsive to the roadside-mounted sign than the overhead signs. However, there may be other reasons that should be determined through further applications and observations.

In development of the concept of DALAS, one of the primary concerns was the possibility or likelihood that introducing a variable lane assignment may produce a conflict between reality and expectancy of the driver, especially during the period when the drivers must modify their expectancies and driving habits. To analyze this hypothesis, observations were made of lane violations on the videotapes for Before and After conditions. To determine any transient effects, a second After study was conducted in October 1992, two months after the first After study. The results of all three studies are illustrated in Table 7.

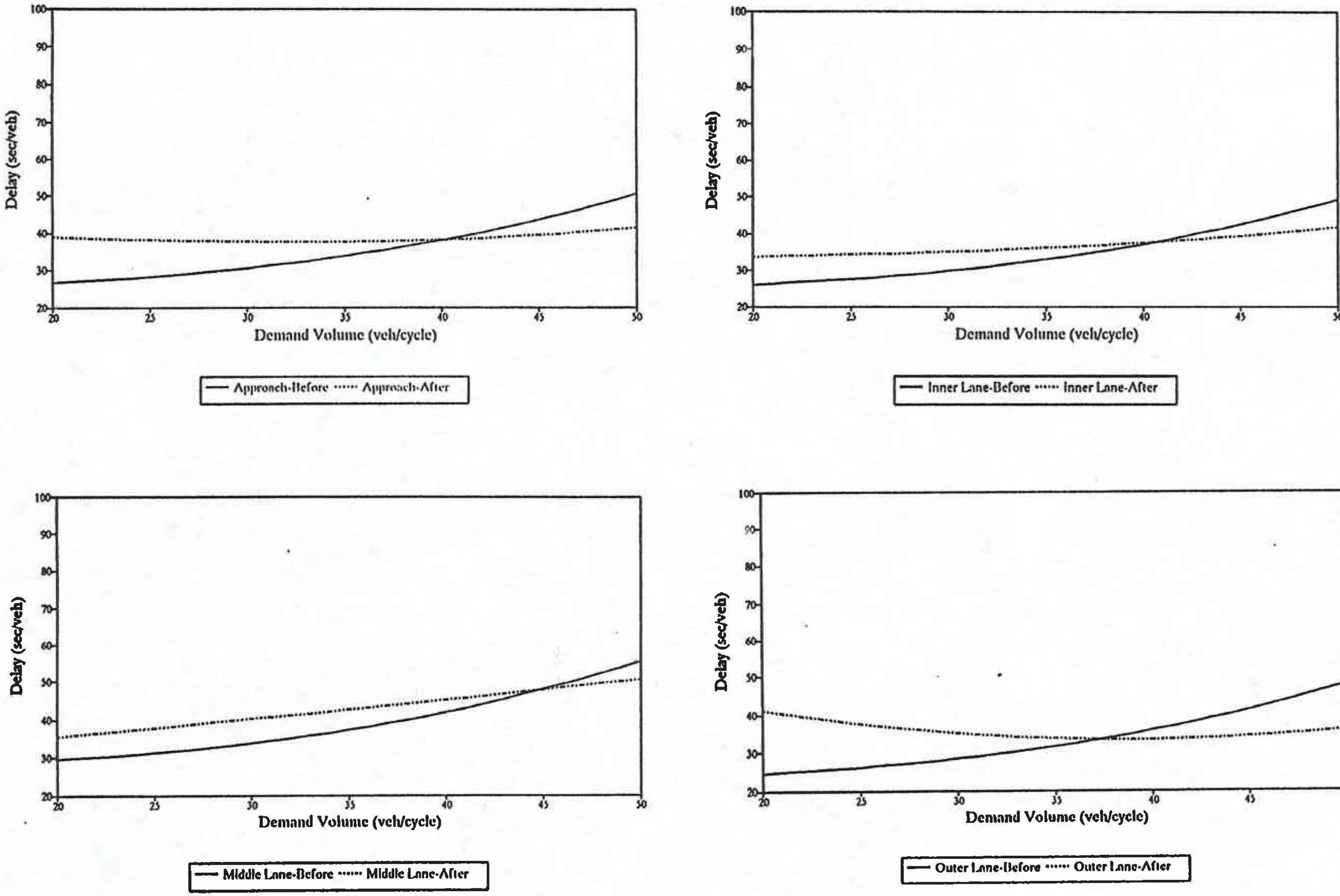


Figure 25. Delays before and after implementation of DALAS for a.m. peak, by lane position.

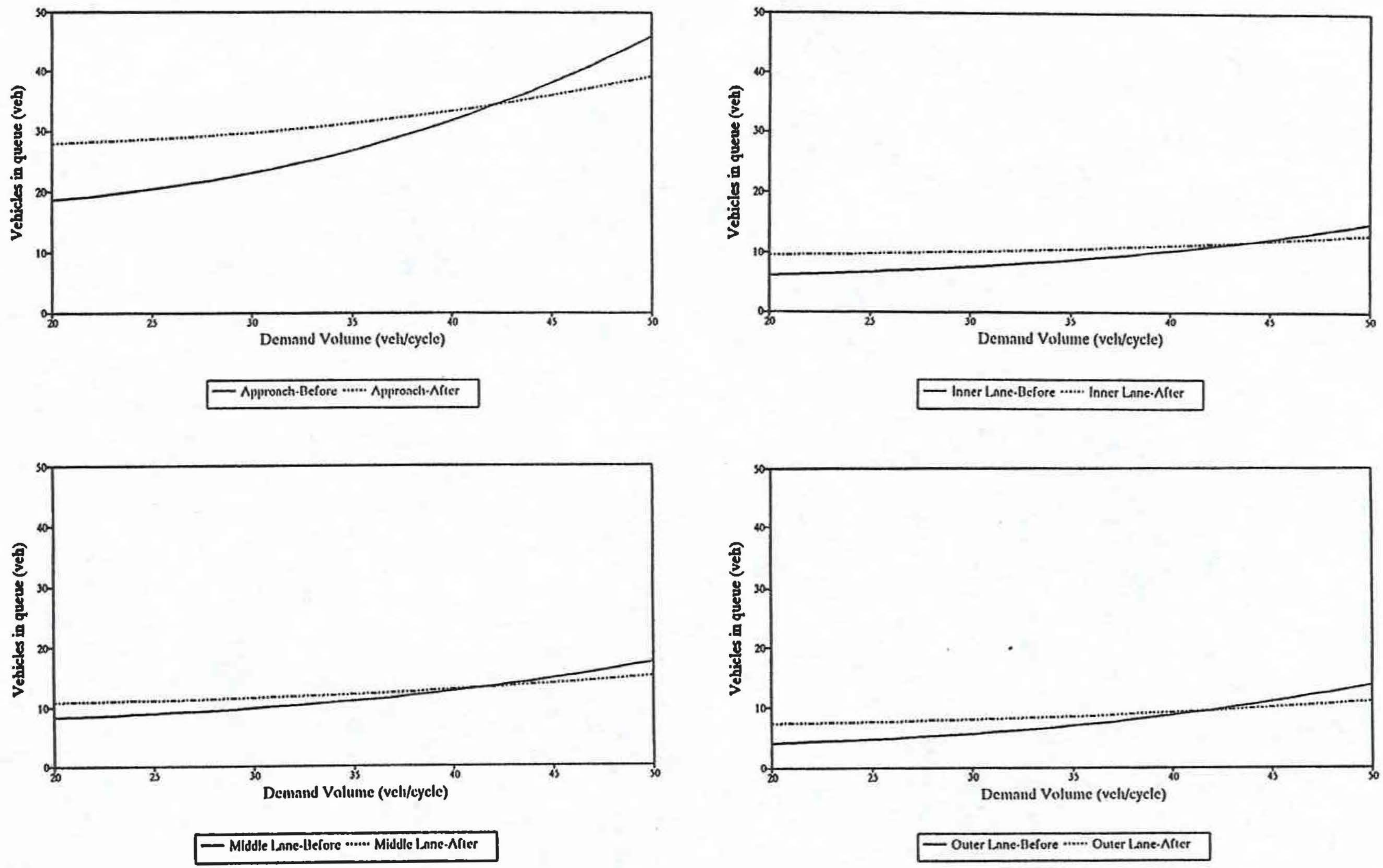


Figure 26. Queue lengths before and after implementation of DALAS
for a.m. peak, by lane position.

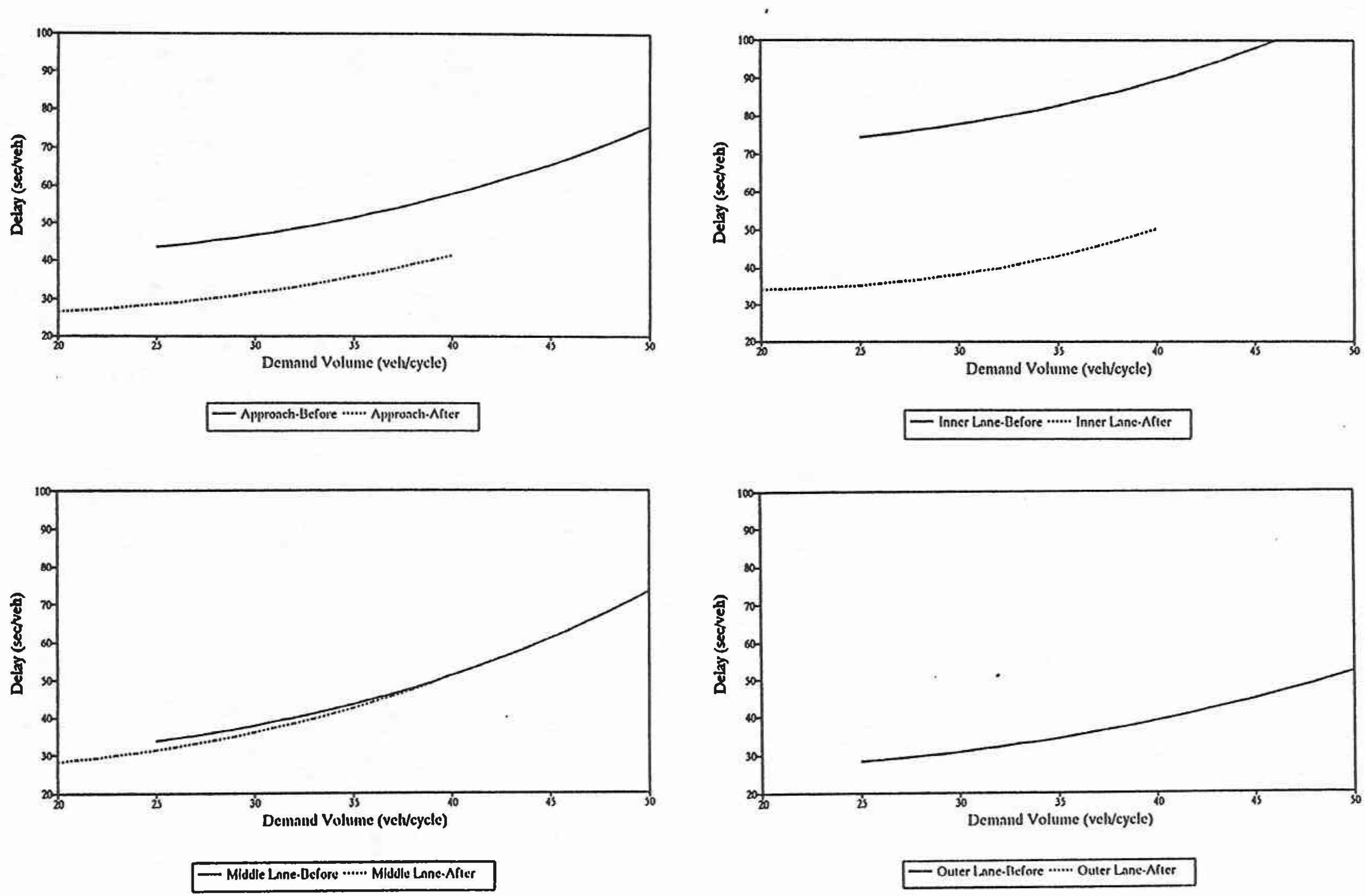


Figure 27. Delays before and after implementation of DALAS for p.m. peak, by lane position.

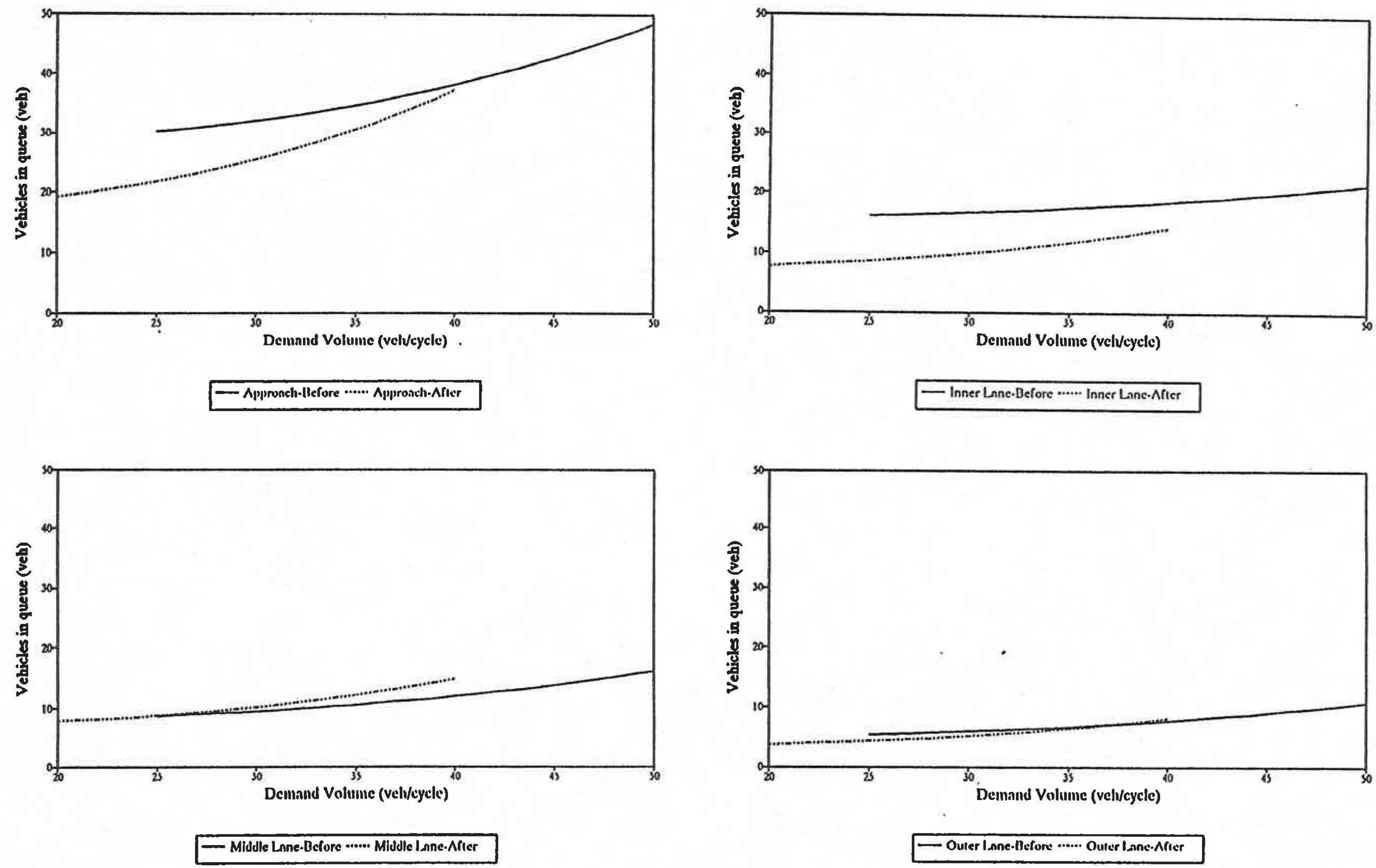


Figure 28. Queue lengths before and after implementation of DALAS for p.m. peak, by lane position.

Table 7. Comparison of lane violation Before and After installation of DALAS signs.

	Before	After
No. of cycles	44	66
Violations	0	0
Violations/cycle	0	0

a. In A.M. Peak

	Before	After
No. of cycles	61	120
Violations	15	27
Violations/cycle	0.246	0.225

b. In P.M. Peak

The study shows that there were no violations in either the Before or After study during the morning peak period. No change should be expected, because the lane assignment does not change during these periods. During the afternoon peak period when the display was changed to a dual left-turn assignment, the Before and After studies reflect a substantial number of violations - approximately one per four signal cycles. The first After study actually shows a slight reduction in rate, but the second After study reflects a return to the previously observed violation rate. From these data, it cannot be concluded that the DALAS signs had any effect on violation rates.

FINDINGS AND RECOMMENDATIONS

This research on the Dynamic Lane Assignment Sign (DALAS) system was performed in three phases. The first phase involved the design and development of the fiberoptic changeable message sign, and identifying the appropriate layout and operational features for optimal legibility, understandability and target value. The second phase of the research involved the development of an operating strategy for the DALAS system, particularly for the transitional phasing and timing for changing lane assignments. Finally, the third phase involved an evaluation of the effectiveness of the signs under actual traffic conditions at a diamond interchange.

The first phase of the research showed that sign brightness, light output, target value, and legibility of the fiberoptic sign are all related. Sign brightness is proportional to light output, and light output is proportional to input voltage for the lamp circuits. While sign brightness is directly proportional to target value, it is inversely proportional to legibility. Therefore, it is important that provisions be made to vary the input voltage of the sign to provide optimal sign brightness, consistent with ambient light conditions.

For the relatively dark environment of the experimental test facility, the best viewing conditions for night operations were achieved by operating the sign at 35 to 65 volts, based on a nominal 110 volt AC supply. Thirty five volts provided the best legibility, but 65 volts provided the best target value.

Placement of the fiberoptic signs relative to the traffic signals is critical to the proper operation and effectiveness of both components.

The findings of the glance legibility studies indicate a strong dichotomy in the legibility of the symbols versus the words. In general, the subjects could discern the shape of the arrows at 800 feet, but the word messages remained a blur until the subjects were 200 feet from the sign. For the word messages to have a desirable effect, there is a need to increase their legibility. Letter size and spacing are key factors, and need to be explored further.

The difference in legibility between the letters of the word messages was attributed to their proximity to other letters in the word and to the complexity of their shape. This indicates that minimum visual acuity of an object is related to the total light output per unit area within the object. The procedures used in this research to identify the point of irradiation for the fiberoptic displays could be used to relate minimum visual acuity, light output per unit area, and the overall dimensions of letters and symbols. This information could be used to develop a standard letter series for use with fiberoptic signing.

The number of rows of pixels, either one or two, used to form the arrows does not have any appreciable effect on legibility. Neither does pixel spacing; however, the closer pixel spacing provides the aesthetic quality of smoothness in the symbol. Single row pixels for the symbols, 0.70 inch spacing of pixels, and six-inch letters with single row pixels were specified for the design of the second generation signs. To assure continuity of service, every other pixel in a given arrow or line were connected to an alternate light source (lamps). In this manner, two lamps will be used to form an arrow or line of a symbol. When one of the lamps fails, the symbol is maintained with half the pixels operational.

The second phase of the research has shown that the overhead fiberoptic signs should be separated from the traffic signals longitudinally, placing the signs in advance of the signals. Separating the overhead signs from the traffic signals enabled drivers to observe the lane assignment status early enough to perform lane change maneuvers. Separation would also reduce cluttering of information at the intersection. Based on the requirements of deceleration distance and the visual angle analysis, a minimum spacing of 200 feet between the overhead signs and the stop line at the intersection should be provided for an approach speed of 40 mph.

The overhead signs need to be tilted forward to avoid reflecting the light from the sky into the driver's eyes. Tilting the signs forward minimizes the departure angle of the line of vision from the driver to the sign. An angle of 4° is appropriate where the overhead sign is placed 18 feet above the roadway. Such an angle minimizes the departure angle when viewing the sign from a distance of 200 to 250 feet.

The sequence of the displays is intended to provide a safe transition of traffic from one lane assignment to the other. Studies showed that all the displays generated by the overhead fiberoptic signs were easily understood. According to a few experts, the displays in the roadside-mounted fiberoptic sign could be improved with additional graphics in the transition phases. The absence of the lane stripe in the roadside-mounted sign in the transition phases was confusing.

Simultaneous changes in the fiberoptic sign and the traffic signal should be avoided so as not to cause a heavy work load for the driver. The attention value of a traffic signal is higher than that of the fiberoptic sign. Accordingly, any display change in the fiberoptic sign should occur after a change in the red indication of the traffic signal. A lag of 2 seconds between the onset of red in the traffic signal and a display change in the fiberoptic sign was found to be most appropriate for this study.

In Phase III of the research, an analysis of the MOE's for the Before study provided the following:

1. in the a.m. peak period, the delays and queue lengths were uniform over different lanes, indicating that the lane assignment was appropriate for the traffic in that period.

2. in the p.m. peak period, the delays and queue lengths were significantly higher in the inner lane as compared to the other two lanes, indicating that the lane assignment was not serving the traffic effectively.

The results of the analysis of After data revealed that the differences across the lanes and between a.m. and p.m. peaks were significantly reduced. This reduction of differences could be attributed to the change in the lane assignment in the p.m. peak. Also, the implementation of DALAS signs resulted in the reduction of overall delays and queue lengths.

Other findings related to the operation of DALAS signs were as follows:

1. Traffic showed immediate responses to the change in the sign display. In other words, as soon as approaching drivers became aware that they could not make a particular movement, due to the changed display, they made the needed lane changes. These responses indicated that the transition displays were effectively communicating the information to the drivers and that the transition display could change the lane assignment without adverse effect on safety.

2. When left turning volumes were high, there were significant numbers of illegal left turns made from the middle lane before the installation of the DALAS signs. There was a potential conflict between the through vehicles in the inner lane and left turning violators from the middle lane. As the differences in delays and queue lengths among different lanes would decrease with the installation of these signs, it was expected that the number of violations would decrease. However, after the implementation of the signs, there were still some through vehicles in the inner lane which had potential conflict with the left turning vehicle from the middle lane. Presumably, these violations are made by commuters who would take some time to readjust to the changed lane status and reduce the number of violations.

3. An equilibrium analysis, i.e., an analytical determination of the expected maneuvers based on the distribution of movements, was done for the intersection approach. While the expected number of left turns from the middle lane in the analysis period was 1.45 veh/cycle, the observed number was 1.37 veh/cycle. The number of through movements in the outer lane was expected to be 10.5 veh/cycle but only 8.5 veh/cycle were observed. Hence, while it could be said that the system is not operating at optimal level, the benefits from the DALAS signs were significant.

Conclusions

1. The DALAS sign concept is a proven technique for effective space management. This concept has been used effectively to alleviate congestion at intersections with varying turning volume demand. Typical diamond interchanges in Texas, associated with frontage roads, have the problem of highly varying turning volume demand and hence, the DALAS signs were evaluated in a diamond interchange setting. However, the problem of variable demands in traffic movements and the applicability of DALAS signs is not confined to diamond interchanges.

2. Dynamic Lane Assignment technology is effective in redistributing vehicles uniformly over approach lanes of an intersection. This normally results in significant reductions in delays and queue lengths. Also, since the time advantage resulting from lane violations is minimized, the chances of lane violations would be reduced significantly, thus improving the safety. Hence, DALAS has a high potential of being an effective ATMS tool.

3. The transition displays developed in this research for changing lane assignments were effective in providing a safe environment for traffic operation at the time of change in lane assignment. Displays should not be changed at the time of a signal phase change, but approximately two seconds after the onset of red.

Recommendations

Based on the experiences gained in this research, it is recommended that future experimentation and applications be pursued as follows:

1. The roadside-mounted sign should be re-designed to provide a consistent graphic representation of the lane line dividing the two indicated movements. This would reduce any confusion that might arise due to lack of uniformity. The suitability or necessity of the word messages in the displays should be investigated.

2. Accident studies should be performed to evaluate the safety effects of DALAS. The limited time frame of this research did not permit a detailed accident analysis.

3. Due to unforeseen technical problems, a dimming device could not be implemented in the field installation at the Voss/Bingle location. Observations have shown that dimming is a desirable feature for night-time operations. Any future applications should include dimming capability.

4. Observations at the Voss/Bingle location indicate that adequate communication of dynamic lane assignment might be accomplished successfully by using roadside mounted signs identical to the re-designed ground-mounted sign at the intersection.

Future installations should be designed using this as an alternative to the overhead signs. This will reduce the overall cost of the signs and support structures, and the maintenance costs.

5. A simpler sign control mechanism should be used for dynamic lane assignment. Presently, a traffic signal controller is being used exclusively to operate the signs. Experience with this installation has shown that this control strategy can be replaced using a simpler timing mechanism. However, at some point in time, a traffic signal controller which can simultaneously operate the traffic signals as well as the DALAS signs may be more cost effective.

6. The dynamic lane assignment concept should be applied at major intersections in urban areas where there is significant variation in traffic movements.

7. The benefits due to the installation of the DALAS signs could be further improved by making both the traffic signals and signs operate in a traffic responsive mode. Automated response for dynamic lane assignment could be based on electronic measurement of queue lengths for individual approach lanes.

8. Dynamic lane assignment should be considered as a proven tool in future corridor traffic management strategies. It can be activated from either a system control center or a local control mechanism. It would be a powerful tool to accommodate traffic which must be diverted from the freeway due to some isolated incident.

Future Applications

The application of changeable message signs to change the lane assignment status at congested intersections is an additional tool to alleviate congested conditions in urban areas. The traditional approach to control traffic at busy intersections by *time-management techniques* (i.e., improving signal timing plans of the intersections) needs to be supplemented by *space-management techniques* (i.e., changing lane assignments to fit the demand). It is essential to utilize the space available in a more efficient manner.

In this age of increasing sophistication in traffic control technology, traffic engineers are considering alternative methods of traffic management. The concept of Intelligent Vehicle Highway Systems (IVHS) is based on determining better ways to manage traffic. The improvement in surveillance techniques to identify trouble spots, the improvement in the ability to communicate to and from a trouble spot, and the rising traffic demands have furthered the need to utilize the techniques of Advance Traffic Management Systems (ATMS). The ability to change the lane assignment at an intersection in real time in response to dynamic traffic conditions is an ATMS tool. While this concept is still in its infancy stage, it has the potential to provide the traffic engineer with the flexibility needed to utilize available resources in a more optimal manner.

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APPENDIX A

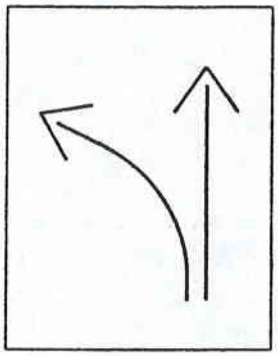
SURVEY FOR FIRST SUBJECTIVE ANALYSIS

SURVEY FOR FIRST SUBJECTIVE ANALYSIS

DEFINITIONS

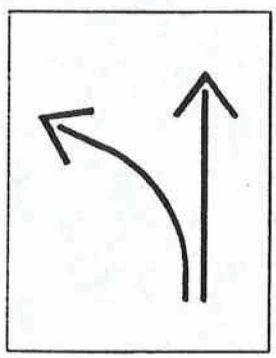
LEGIBILITY	-	The ability to read and/or discern the actual appearance of the sign face.
TARGET VALUE	-	The ability of a sign to compete with its surroundings for the attention of the driver.
UNDERSTANDABILITY	-	The ability of the driver to understand the message being conveyed.

1/2 INTENSITY



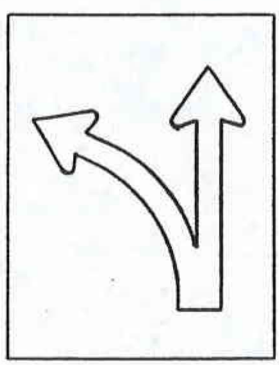
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

FULL INTENSITY



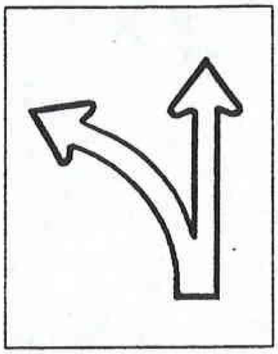
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

1/2 INTENSITY



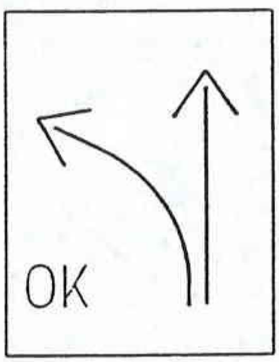
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

FULL INTENSITY



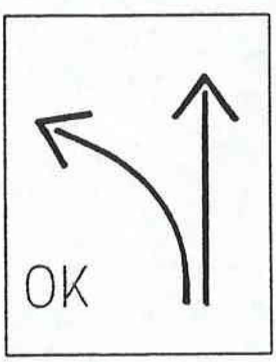
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

1/2 INTENSITY w/ SINGLE-ROW OK



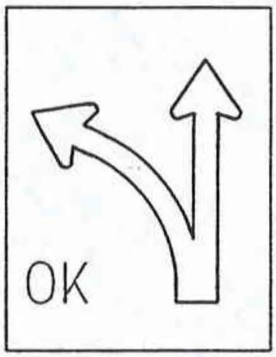
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

FULL INTENSITY w/ SINGLE-ROW OK



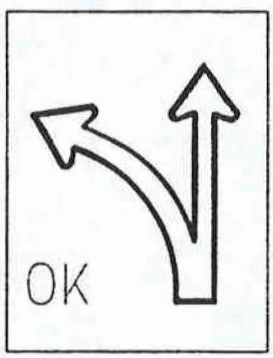
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

1/2 INTENSITY w/ BOLD OK



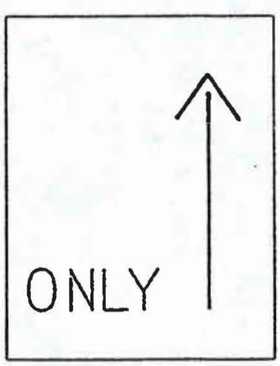
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

FULL INTENSITY w/ BOLD OK



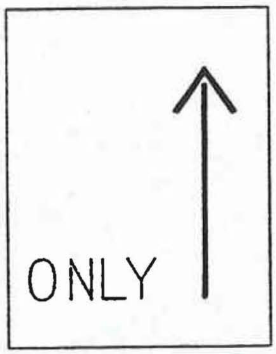
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

1/2 INTENSITY w/ SINGLE-ROW ONLY



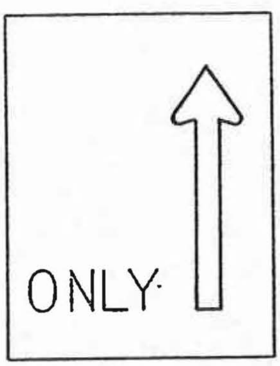
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

FULL INTENSITY w/ SINGLE-ROW ONLY



	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

1/2 INTENSITY w/ BOLD ONLY



	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

FULL INTENSITY w/ BOLD ONLY

	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5
Understandability	1	2	3	4	5

1. We have considered two ways of forming the combination through-and-left turn arrow: (1) from a single shaft branching into two and (2) using two single-row shafts beginning in close proximity to each other. The latter is much easier to construct but may be a source of confusion.

(A) Did you notice separate shafts for the single-row, combination left and through indication at half intensity? Yes_____ No_____

If you answered "NO" to question (A), proceed to question #2.

(B) If you did notice individual shafts, were they discernable under all conditions? Yes_____ No_____

(C) If "YES", identify specific conditions under which you were able to identify the individual shafts.

____

____

____

____

(D) Was the appearance of separate shafts a source of confusion?

Yes_____ No_____

If "YES", what was confusing?

____

____

____

____

____

2. (A) While you were observing the various displays, did any single display seem to overpower the traffic signal or the static display sign. Yes_____ No_____

(B) If "YES", identify which display(s) appeared to be overpowering?

____

____

____

____

____

(C) Do you think these displays are <u>more</u> or <u>less</u> effective when the luminous output is reduced?

3. There is some question as to how a black background affects driver perception of the position of the sign relative to that of the traffic signal.

(A) Did you feel there was any confusion generated as to the relative position of the sign with respect to the traffic signal? Yes___ No___

(B) If "YES", explain.

____

____

____

____

____

____

____

4. We examined several different alternative arrow combinations and indications, both with and without word messages.

(A) Do you think the word messages are effective in reinforcing the arrow indications associated with them? Yes_____ No_____

(B) If "YES", could they be improved? How?

____

____

____

____

____

(C) If "NO", do you feel that the word messages could be improved, or should they be removed?

IMPROVED ________

REMOVED ________

(D) If you think the word messages could be improved, how?

____

____

____

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____

____

____

5. This sign is capable of displaying two different classes of indications, i.e., single-row and outline displays. Each class of sign requires a different arrowhead design.

(A) Of the two arrowhead designs, do you feel that one was more effective than the other in terms of providing a more readable display?

Yes_____ No_____

(B) If "YES", which design provided a more readable alternative? Why?

____
____
____
____
____
____
____

6. (A) In comparing the dynamic display sign with the static display sign, was either of the two signs more effective in providing a more legible message than the other?

Yes_____ No_____

(B) If YES, which provides a more legible display? Why?

____
____
____
____
____
____

7. Please provide any general comments you have concerning the dynamic display sign.

8. Please provide any comments concerning the content of this questionnaire. Comments and constructive criticisms will be greatly appreciated.

APPENDIX B

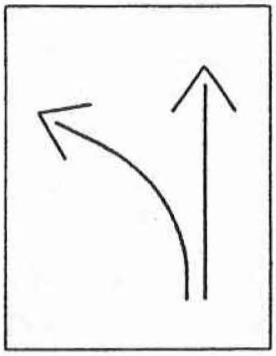
SURVEY FOR SECOND SUBJECTIVE ANALYSIS

SURVEY FOR SECOND SUBJECTIVE ANALYSIS

DEFINITIONS

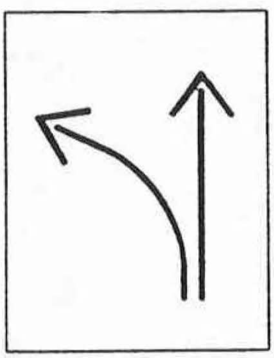
LEGIBILITY	-	The ability to read and/or discern the actual appearance of the sign face.
TARGET VALUE	-	The ability of a sign to compete with its surroundings for the attention of the driver.
UNDERSTANDABILITY	-	The ability of the driver to understand the message being conveyed. This will not be evaluated as a part of this study.
DISABILITY GLARE	-	Glare that is so severe that it adversely affects a driver's ability to safely operate a vehicle.
DISCOMFORT GLARE	-	Glare that does not hinder the driver's ability to safely operate a vehicle but is nevertheless uncomfortable.

SINGLE ROW DISPLAY @ 50%-tile VOLTAGE



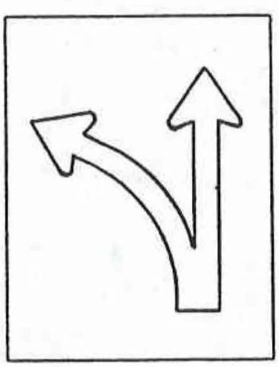
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5

SINGLE ROW DISPLAY @ 85%-tile VOLTAGE



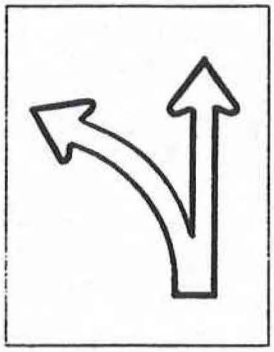
	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5

BOLD DISPLAY @ 50%-tile VOLTAGE



	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5

BOLD DISPLAY @ 85%-tile VOLTAGE



	EXCELLENT		ACCEPTABLE		UNACCEPTBALE
Legibility	1	2	3	4	5
Target Value	1	2	3	4	5

RANK ORDER THE FOLLOWING TYPES OF DISPLAYS w/r TO:

	SINGLE	REFLECTIVE	BOLD
TARGET VALUE			
LEGIBILITY			

1. We have considered two ways of forming the combination through-and-left turn arrow: (1) from a single shaft branching into two and (2) using two single-row shafts beginning in close proximity to each other. The latter is much easier to construct but may be a source of confusion.

(A) Did you notice separate shafts for the single-row, combination left and through indication at half intensity? Yes_____ No_____

If you answered "NO" to question (A), proceed to question #2.

(B) At what voltage level was this level of detail discernable?

50%-tile 85%-tile Both

(C) Was the appearance of separate shafts a source of confusion?

Yes_____ No_____

2. We examined several different alternative arrow combinations and indications, both with and without word messages.

(A) Do you think the word messages are effective in reinforcing the arrow indications associated with them? Yes_____ No_____

(B) If "NO", do you feel that the word messages could be improved, or should they be removed?

____
____
____
____
____
____

3. Did you feel that the use of 1" pixel spacing adversely affected:

(A) Target Value Yes_____ No_____

(B) Legibility Yes_____ No_____

4. Evaluate the glare caused by the traffic signals based on the scale below (refer to the first page of this handout for definitions) with regard to how they affect your ability to discern the sign legend:

	DISABILITY GLARE		DISCOMFORT GLARE		NO GLARE
50%-tile	1	2	3	4	5
85%-tile	1	2	3	4	5

5. Evaluate the target value at each of the signal settings:

	EXCELLENT		ACCEPTABLE		UNACCEPTABLE
50%-tile	1	2	3	4	5
85%-tile	1	2	3	4	5

6. Please provide any comments concerning the content of this questionnaire. Comments and constructive criticisms will be greatly appreciated.

____
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APPENDIX C

EVALUATION OF THE LABORATORY LAYOUT OF DYNAMIC LANE ASSIGNMENT PROJECT

Name : ____

Evaluation of the Laboratory Layout of

Dynamic Lane Assignment Project.

Questionnaire for Expert Evaluation

DEFINITIONS

LEGIBILITY -	The ability to read and/or discern the actual appearance of the sign face.
TARGET VALUE -	The ability of a sign to compete with its surroundings for the attention of the driver.
UNDERSTANDABILITY -	The ability of the driver to understand the message being conveyed.

We will be exhibiting the various displays of the fiberoptic signs involved in HPR Project 1232 at the Riverside Campus. We will also be evaluating the general layout of the same. The objective is to simulate the approach of a frontage road to a diamond interchange. A number of objective questions will be asked. The answers would be more of a subjective nature. An explanation of the testing process will be given wherever it is necessary. Suggestions and constructive criticism would be appreciated.

I. We will be testing the legibility and the target value of the overhead fiberoptic signs at different voltages across the traffic signals and the fiberoptic signs. First the voltage across the signals will be varied to determine the optimum viewing conditions. Then the fiberoptic signs will be displayed at three different voltages across them. The legibility as well as the target value of the fiberoptic signs are to be evaluated.

(A). In your opinion was there any change in the legibility of the overhead fiberoptic sign at various intensities of the traffic signal?

YES —————————— NO——————————

If the answer to (A) is NO, proceed to (C).

(B). At which intensity of the traffic signal was the fiberoptic sign more legible?

Case I (100%) —————————— Case II (50%)——————————

(C) In your opinion was there any change in the target value of the overhead fiberoptic sign at different intensities of the traffic signal?

YES —————————— NO——————————

If the answer to (C) is NO, proceed to (E).

(D). At which intensity of the traffic signal was the target value of the fiberoptic sign maximum?

Case I (100%) —————————— Case II (50%)——————————

The signals will then be set at a desired voltage and the fiberoptic signs will be displayed at three different voltages across them. The legibility as well as the target value of the fiberoptic signs will then be evaluated.

(E). Did you notice any appreciable change in the legibility of the fiberoptic signs in Case I (100%) and Case II (60%)?

YES ________________ NO ________________

If the answer to (E) is NO, proceed to G.

(F). In which case were the fiberoptic signs more legible?

Case I (100%) ________________ Case II (60%) ________________

(G). Did you notice any appreciable change in the target value of the fiberoptic signs in Case I (100%) and Case II (60%)?

YES ________________ NO ________________

If the answer to (G) is NO, proceed to I.

(H). In which case did the fibre optic signs have a higher target value?

Case I (100%) ________________ Case II (60%) ________________

(I). Did you notice any appreciable change in the legibility of the fiberoptic signs in Case II (60%) and Case III (50%)?

YES ________________ NO ________________

If the answer to (I) is NO, proceed to K.

(J). In which case were the fiberoptic signs more legible?

Case II (60%) ________________ Case III (50%) ________________

(K). Did you notice any appreciable change in the target value of the fiberoptic signs in Case II (60%) and Case III (50%)?

YES ________________ NO ________________

If the answer is NO, proceed to II.

(L). In which case did the displays have a higher target value?

Case II (60%) ________________ Case III (50%) ________________

II. This question is intended to measure the understandability of the dynamic lane assignment displays. It is important that the drivers perceive the meaning of the signs accurately. As each display will be shown, please give us your opinion as to the meaning of the display. Your interpretation of the display may differ from that of an average driver. Please give us your opinion as to how you think an average driver will interpret the display.

Display 1

Meaning: ______________________________

____

____

Display 2

Meaning: ______________________________

____

____

Display 3

Meaning: ______________________________

____

____

Display 4

Meaning: ______________________________

____

____

Do you have any suggestions for improving the individual displays?

____

____

____

III. We will now be evaluating a change in the overhead fiberoptic signs with respect to a change in the display in the traffic signal downstream of the overhead signs. The aim is to obtain the proper coordination of a change in the signs and signals in order to minimize any driver error in observing and safely reacting to the changes. Provision has been made to have a change in the fiberoptic signs at the onset of yellow, at the onset of red, and about 10 seconds after the onset of red in the traffic signals. These three scenarios will be displayed and some questions will be asked regarding the most appropriate coordination. Please answer the following questions.

(A). In your opinion, how will a driver approaching the intersection perceive a change in the display of the overhead signs at the onset of yellow in the traffic signals?

____

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____

(B). In your opinion, how will a driver approaching an intersection perceive a change in the display of the overhead signs at the onset of red in the traffic signals?

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(C). In your opinion, how will a driver approaching an intersection perceive a change in the display of the signs, 10 seconds after the onset of red in the traffic signals?

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____

(D). In your opinion, what is the optimum status of the traffic signal in order to have a change in the display of the signs?

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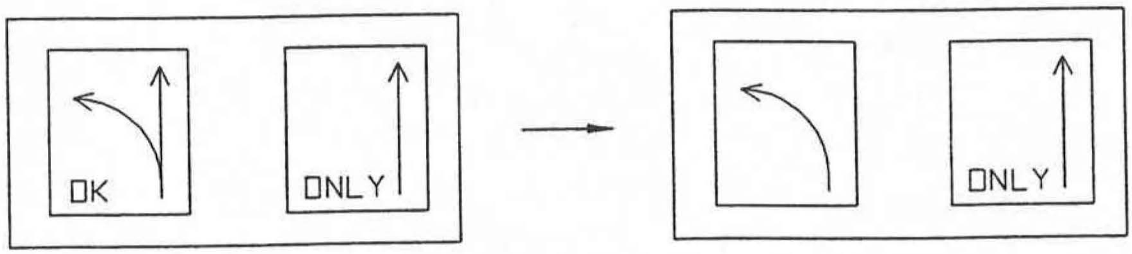
____

____

IV. This question deals with the manner in which drivers will respond to a change in the dynamic lane assignment display. It is realized that the reactions of a driver in such conditions are very subjective. Please give us your opinion as to how the average driver will react to a change in the displays of the fiberoptic signs. Please complete the questions that follow as each change in the displays are made. Any suggestions or comments regarding the existing setup for the change in the displays of fiberoptic signs would be appreciated.

Change #1: This change is the real-time change from Display I to the Transition Display I. The duration of the Transition Display I is approximately 120 seconds (1 Cycle Length) in real-time.



(A). In your opinion how do you think the driver will perceive and react to the change in the overhead fiberoptic sign display if he/she was in the **left lane?**

Answer: ____

____

____

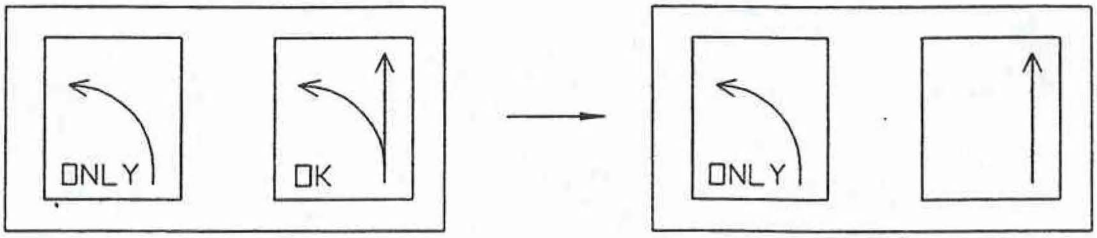
(B). In your opinion how do you think the driver will perceive and react to the change in the overhead fiberoptic sign display if he/she was in the **center lane?**

Answer: ____

____

____

Change #2: This change is the real time change from Display II to Transition Display II. The duration of the Transition Display II is approximately 120 seconds (1 Cycle Length) in real time.



(A). In your opinion how do you think the driver will perceive and react to the change in the overhead fiberoptic sign display if he/she was in the **left lane?**

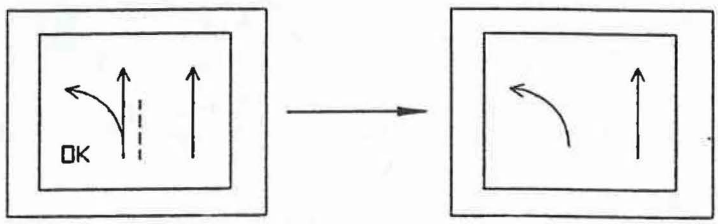
Answer:____

(B). In your opinion how do you think the driver will perceive and react to the change in the overhead fiberoptic sign display if he/she was in the **center lane?**

Answer:____

V. This question deals with the effectiveness of the ground-mounted sign in order to provide a confirmatory display of the lane assignment status. The understandability/ interpretation of the displays and the possible reactions of the driver are to be determined. Any suggestions or comments regarding the existing setup for the change in the displays of the ground-mounted fiberoptic sign would be appreciated.

Change #1: This change is the real-time change from Display I to the Transition Display I. The duration of the Transition Display I is approximately 120 seconds (1 Cycle Length) in real-time.



(A). In your opinion how do you think the driver will perceive and react to the change in the ground-mounted fiberoptic sign display if he/she was in the **left lane?**

Answer: ______________________________

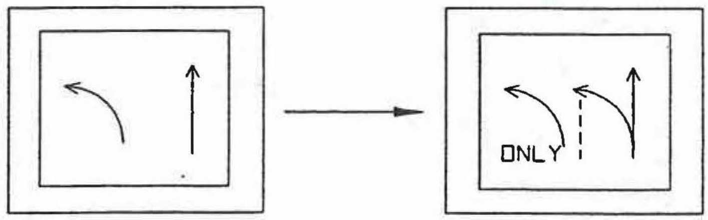
____
____
____
____

(B). In your opinion how do you think the driver will perceive and react to the change in the ground-mounted fiberoptic sign display if he/she was in the **center lane?**

Answer: ______________________________

____
____
____
____

Change #2: This is the real-time change from Transition Display I to Display II. Display II will last for a period over which a high percentage of left turning traffic exists.



(A). In your opinion how do you think the driver will perceive and react to the change in the ground-mounted fiberoptic sign display if he/she was in the **left lane?**

Answer: ____

____

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____

____

(B). In your opinion how do you think the driver will perceive and react to the change in the ground-mounted fiberoptic sign display if he/she was in the **center lane?**

Answer: ____

____

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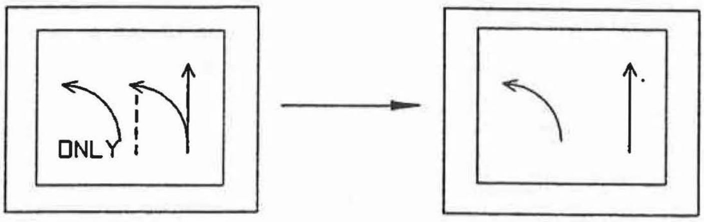
Change #3: This change is the real time change from Display II to Transition Display II. The duration of the Transition Display II is approximately 120 seconds (1 Cycle Length) in real time.



(A). In your opinion how do you think the driver will perceive and react to the change in the ground-mounted fiberoptic sign display if he/she was in the **left lane?**

Answer: ____

____

____

____

____

____

(B). In your opinion how do you think the driver will perceive and react to the change in the ground-mounted fiberoptic sign display if he/she was in the **center lane?**

Answer: ____

____

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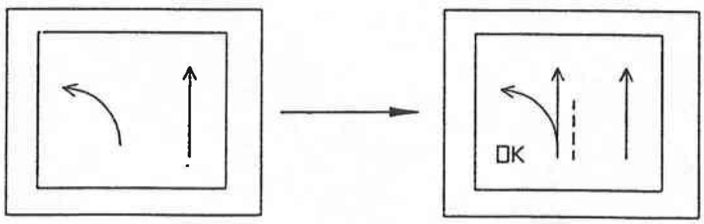
Change #4: This is the real-time change from Transition Display II to Display I. Display I will last for a period over which a high percentage of through traffic exists.



(A). In your opinion how do you think the driver will react to the change in the ground-mounted fiberoptic sign display if he/she was in the **left lane**?

Answer: ____

____

____

____

____

____

(B). In your opinion how do you think the driver will react to the change in the ground-mounted fiberoptic sign display if he/she was in the **center lane?**

Answer: ____

____

____

____

____

____

VI. Any comments on the spacing between the sign tower and the signal tower?

VII. Any comments on the design of the ground-mounted sign?

VIII. Any comments on the position of the ground-mounted sign?

IX. Any comments regarding the sign-signal coordination aspects?

X. Any other comments regarding the general layout of the laboratory?

XI. Any comments / suggestions about the questionnaire? Constructive criticism would be appreciated.

APPENDIX D

INTERCHANGE DATA

Table D-1. Fifteen minute turning volume counts for intersection of eastbound frontage road with Voss/Bingle.

	Frontage Road						Southbound Voss		Northbound Voss	
	Inner Lane		Middle Lane		Outer Lane					
Time	Left	Thru	Left	Thru	Thru	Right	Thru	Left	Thru	Rights
06:00 AM										
06:15 AM	25	1		20	7	1	26	42	20	26
06:30 AM	31	2		19	11	1	34	51	25	28
06:45 AM	30	1		35	22	3	76	80	31	40
07:00 AM	35	26		62	45	4	85	101	48	59
07:15 AM	40	45		82	65	3	108	122	64	71
07:30 AM	36	61	1	109	91	2	152	128	87	89
07:45 AM	32	78		127	119	4	215	133	112	115
08:00 AM	45	43		115	85	5	206	124	121	121
08:15 AM	50	21		103	64	10	195	111	105	107
08:30 AM	60	25		92	53	13	180	115	116	100
08:45 AM	55	19	1	87	48	16	151	102	105	93
09:00 AM	45	23		60	36	3	140	84	83	52
09:15 AM	63	28		53	33	16	134	92	83	83
09:30 AM	51	35		74	29	15	112	89	100	69
09:45 AM	68	14		61	25	7	89	103	74	63
10:00 AM	84	10		78	34	9	89	80	92	46
10:15 AM	78	16		63	30	16	99	72	97	47
10:30 AM	86	16	1	83	34	13	72	67	89	50
10:45 AM	84	15		74	50	11	107	74	90	56
11:00 AM	81	12		74	33	19	101	99	94	47
11:15 AM	80	25		86	40	24	90	93	112	53
11:30 AM	102	11		78	29	15	110	94	127	62
11:45 AM	81	9		63	32	11	112	112	127	70
12:00 PM	102	9	1	79	33	17	115	99	122	56
12:15 PM	93	7		79	50	16	78	83	107	56
12:30 PM	115	5		106	61	25	92	90	133	78
12:45 PM	123	3		108	75	32	87	82	109	46
01:00 PM	110	13	1	105	84	22	92	94	155	66
01:15 PM	108	10		87	87	17	89	93	137	71
01:30 PM	117	8		85	91	19	97	87	131	57
01:45 PM	109	7		91	69	24	93	78	141	52
02:00 PM	99	8		92	52	18	87	84	137	53
02:15 PM	85	4	1	79	41	15	88	86	110	49
02:30 PM	115	3		97	68	19	123	84	150	60
02:45 PM	120	6	1	112	76	28	98	78	141	66
03:00 PM	111	8		77	51	18	94	85	123	59
03:15 PM	108	11		95	54	30	105	62	146	62
03:30 PM	89	13		83	63	23	97	68	144	57
03:45 PM	88	7		83	64	15	108	66	127	50
04:00 PM	103	7		90	59	25	104	60	152	27
04:15 PM	110	11	1	96	55	23	108	84	147	55
04:30 PM	75	7		68	48	9	122	67	116	39
04:45 PM	101	9		101	43	15	127	82	169	87
05:00 PM	78	7		84	34	13	122	76	135	38
05:15 PM	97	10	1	99	69	17	123	108	164	35
05:30 PM	93	6	1	80	59	8	123	61	156	45
05:45 PM	86	8	1	82	61	10	116	77	142	37
06:00 PM	88	7		79	57	11	104	69	139	36

Table D-2. Fifteen minute turning volume counts for intersection of westbound frontage road with Voss/Bingle.

	Frontage Road				Southbound Bingle		Northbound Bingle	
	Inner Lane		Outer Lane					
Time	Left	Thru	Thru	Right	Thru	Right	Thru	Left
06:00 AM								
06:15 AM								
06:30 AM								
06:45 AM								
07:00 AM								
07:15 AM	73	19	10	15	175	20	60	15
07:30 AM	55	9	4	17	258	18	54	41
07:45 AM	71	9	3	12	271	13	72	14
08:00 AM	58	17	4	15	225	18	99	33
08:15 AM	65	20	7	21	214	26	103	29
08:30 AM	67	16	4	23	183	10	91	16
08:45 AM	87	9	4	20	145	9	89	32
09:00 AM	81	17	4	16	139	11	79	26
09:15 AM								
09:30 AM								
09:45 AM								
10:00 AM								
10:15 AM								
10:30 AM								
10:45 AM								
11:00 AM								
11:15 AM								
11:30 AM								
11:45 AM								
12:00 PM								
12:15 PM	60	32	27	37	61	89	76	94
12:30 PM	44	24	24	45	43	114	100	100
12:45 PM	41	19	26	52	39	97	110	97
01:00 PM	52	24	31	60	45	101	109	101
01:15 PM	69	25	27	63	40	97	121	111
01:30 PM	77	29	29	69	51	88	98	91
01:45 PM	52	17	20	35	42	88	82	73
02:00 PM	63	9	30	52	50	99	101	106
02:15 PM	74	9	27	52	35	80	108	123
02:30 PM	53	11	35	55	37	75	100	111
02:45 PM	61	15	29	49	41	79	89	96
03:00 PM	88	27	39	63	54	91	96	107
03:15 PM								
03:30 PM								
03:45 PM								
04:00 PM								
04:15 PM								
04:30 PM								
04:45 PM								
05:00 PM								
05:15 PM								
05:30 PM								
05:45 PM								
06:00 PM								

APPENDIX E

REGRESSION ANALYSIS

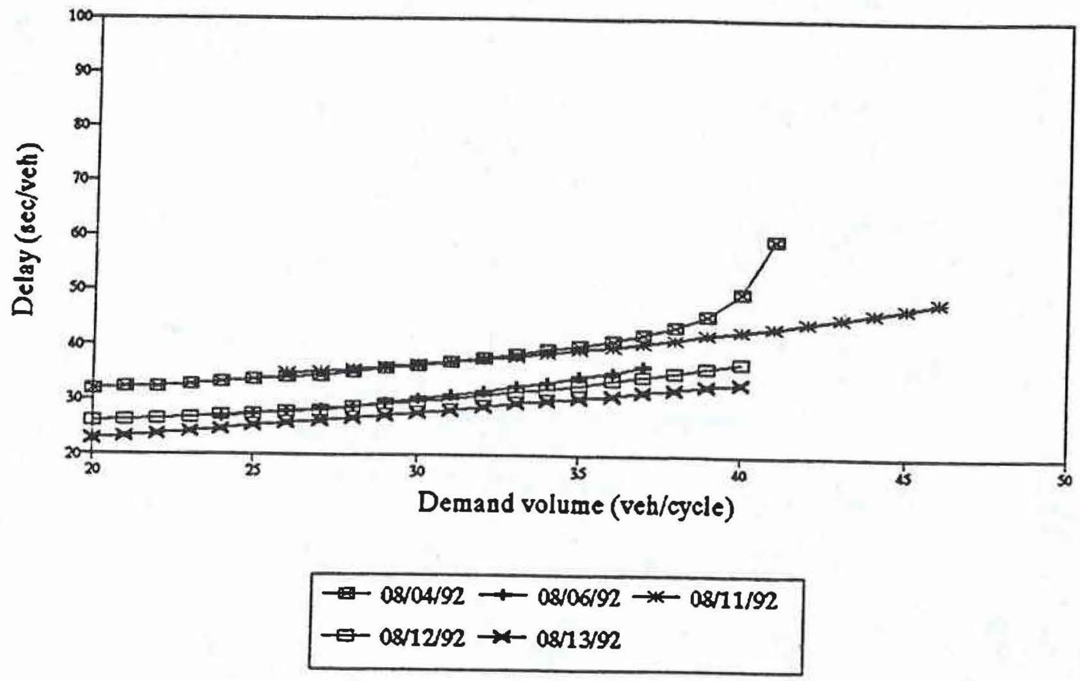
Testing for Uniformity

The data collected on a particular day might not represent the usual traffic characteristics at the site. Some external features or special events might affect the data. Hence, in a field study, data should be collected on several days (the number of days depending on the feasibility and the precision required) and the conclusions must be based on the average of these data. This would minimize the random error in the data collected.

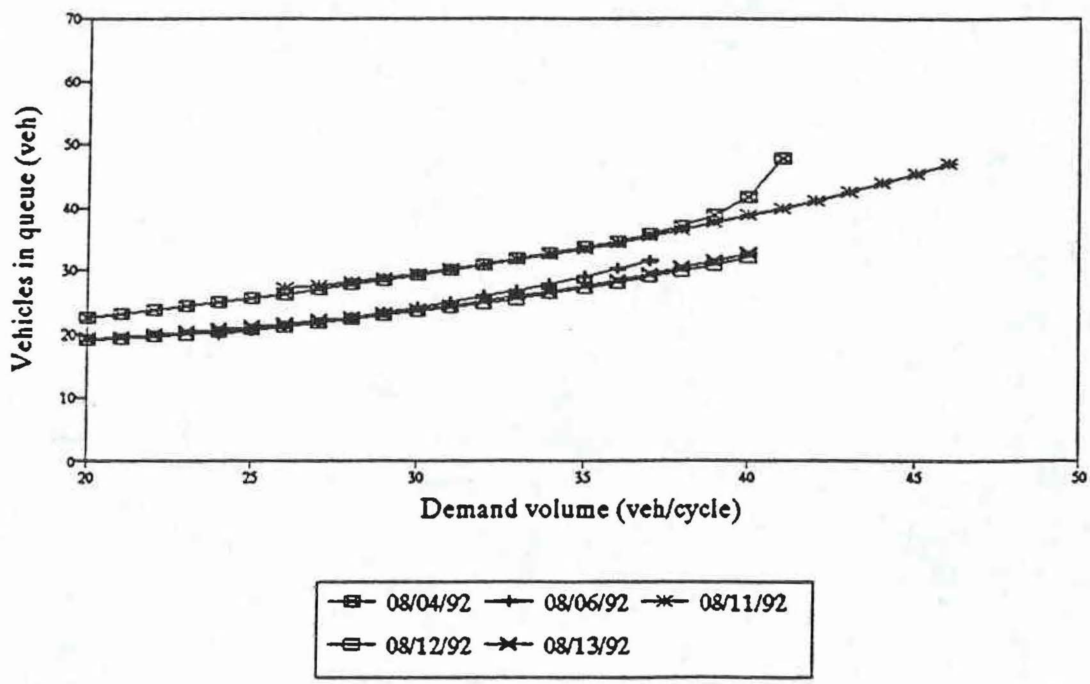
Data for evaluating the traffic operations were collected on seventeen different peak periods: Three morning peaks and four afternoon peaks for the pre-implementation traffic operations evaluation and on four morning and six afternoon peaks for post-implementation traffic operation evaluation. The data collected on different days were combined to obtain the data representing each of the four groups of data mentioned above.

A data set collected when the traffic was adversely affected by some external features would bias the data and would not represent the normal traffic behavior. Hence, such atypical data sets must be separated before combining the data collected on different days.

Regression equations were developed for each data set and graphs were drawn to illustrate the changes in the MOEs with respect to the demand volume. The curves for data sets collected on different days were compared to find the similarities. Figure E-1 shows the delay and queue length on different days for p.m. peak period after the installation of the DALAS signs. The data collected on different days were more or less uniform on the five periods. This would mean that the data obtained on these five peak periods could be combined so as to obtain the mean performance measures.



i) Delays



ii) Queues

Figure E-1. Delay and queue curves for p.m. peak in After studies on different days.

Testing for Differences Between A.M. and P.M. Peak Periods

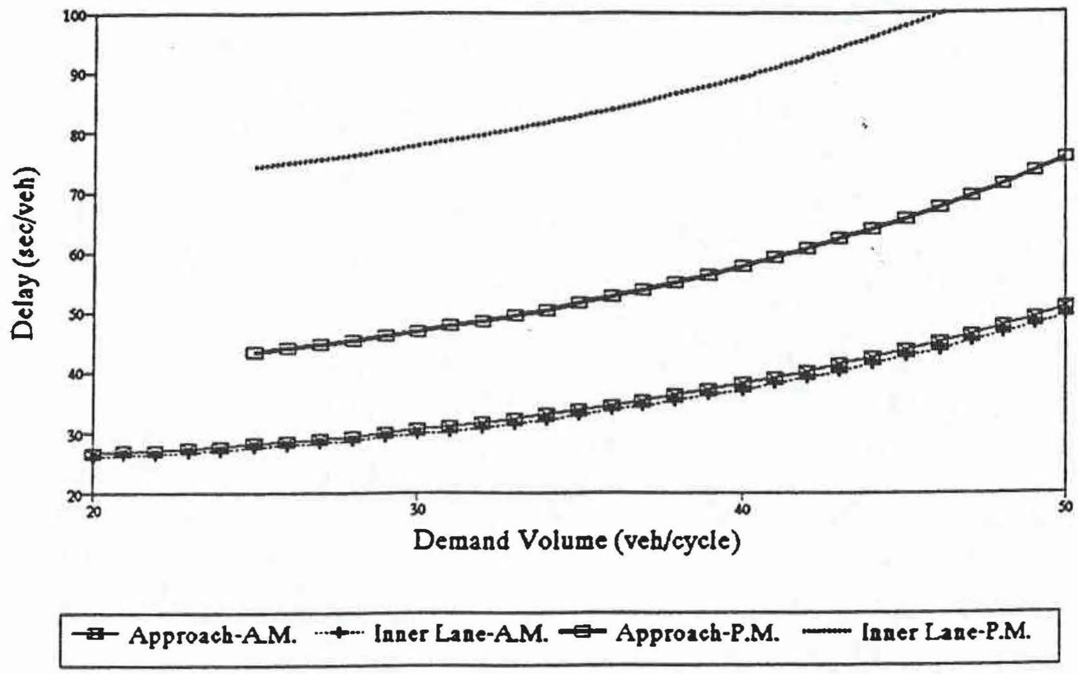
One factor justifying the installation of the DALAS signs was the substantial variability of left-turn volumes during the day.

Regression analyses were performed to see if there existed significant differences in delays and queue lengths between a.m and p.m. peak periods. Regression curves were developed and the curves for a.m. and p.m. peak periods were compared. Figure E-2a shows the delays and queue lengths with respect to the demand volume/cycle for the data collected before the installation of the signs. The delays in the p.m. peak were significantly higher as compared to those in a.m. peak.

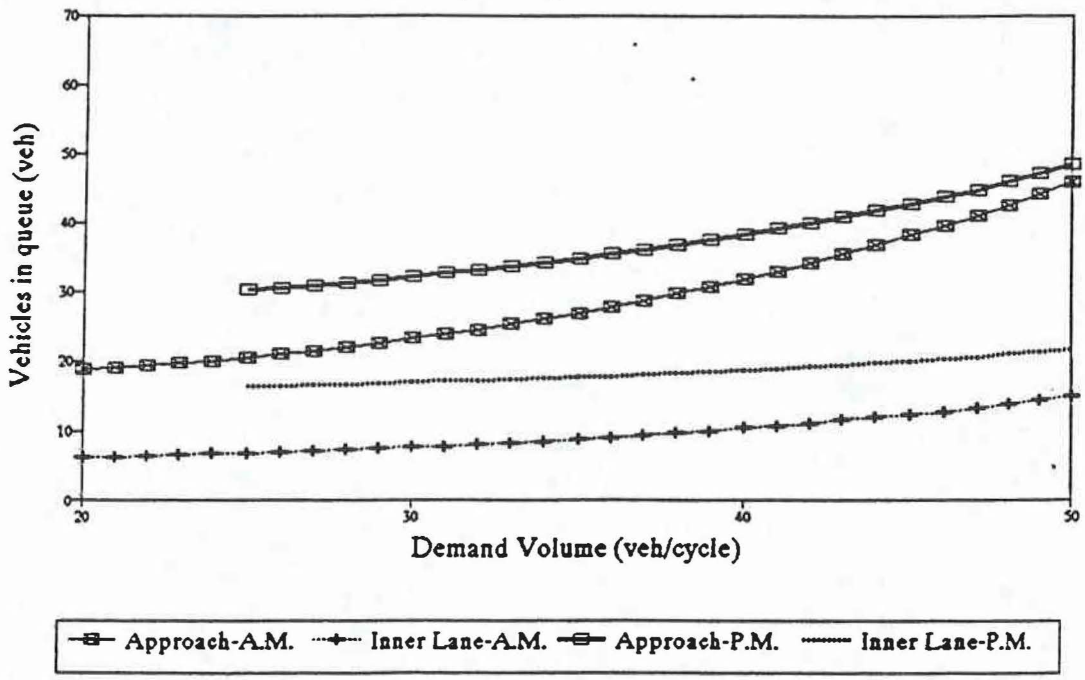
Testing for Differences Across the Lanes

The second factor justifying the implementation of the DALAS signs was the imbalance in number of vehicles among the lanes. This imbalance arose due to the high variation in turning volume combined with the fact that the static lane assignment sign was designed based on the traffic volumes in morning peak only.

Regression equations were developed for observed queue lengths and delays for each lane. Figure E-3a and E-3b show the comparison of MOEs for the a.m. peak period before and after installation of the signs, respectively. Similar delays and queue lengths were observed on different lanes in both cases individually. However, in the p.m. peak period before the installation of the signs, (Figure E-3c) it could be observed that significantly higher delay and queue length occurred in the inner lane as compared to the middle lane. Similarly more delay and queue length were observed in the middle lane as compared to the outer lane. Figure E-3d shows the comparison for p.m. peak after the installation of the signs. Unlike the results of the Before studies, the delays and queue lengths were similar in the inner and middle lanes.

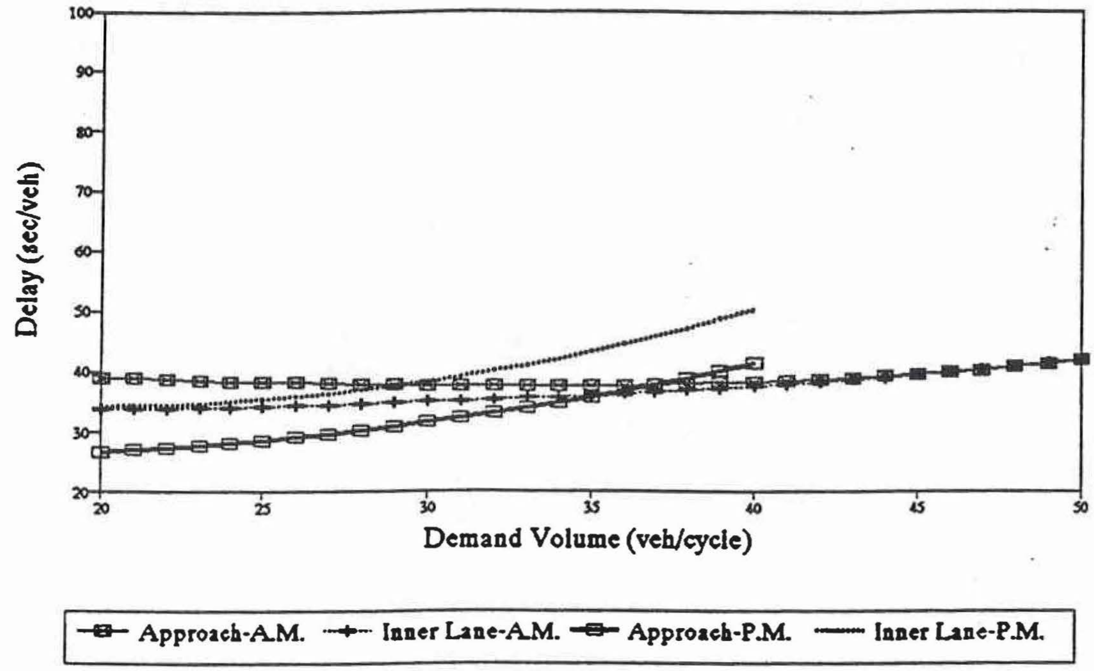


i) Delays

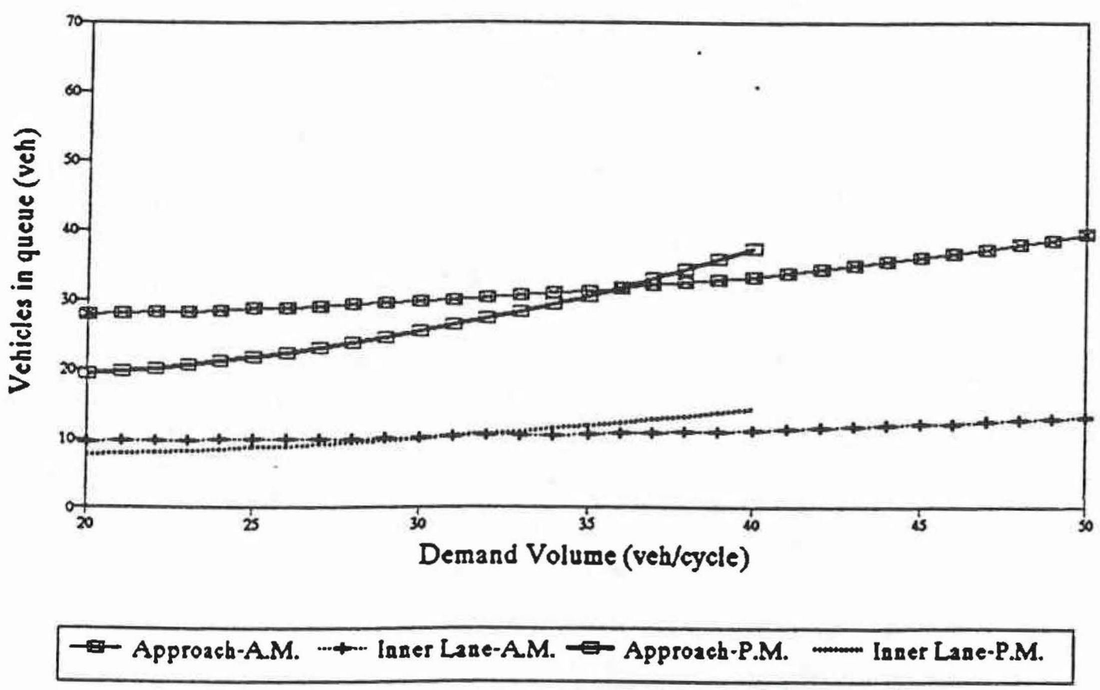


ii) Queues

Figure E-2a. Comparison of MOEs observed in a.m. and p.m. peak periods for Before conditions.

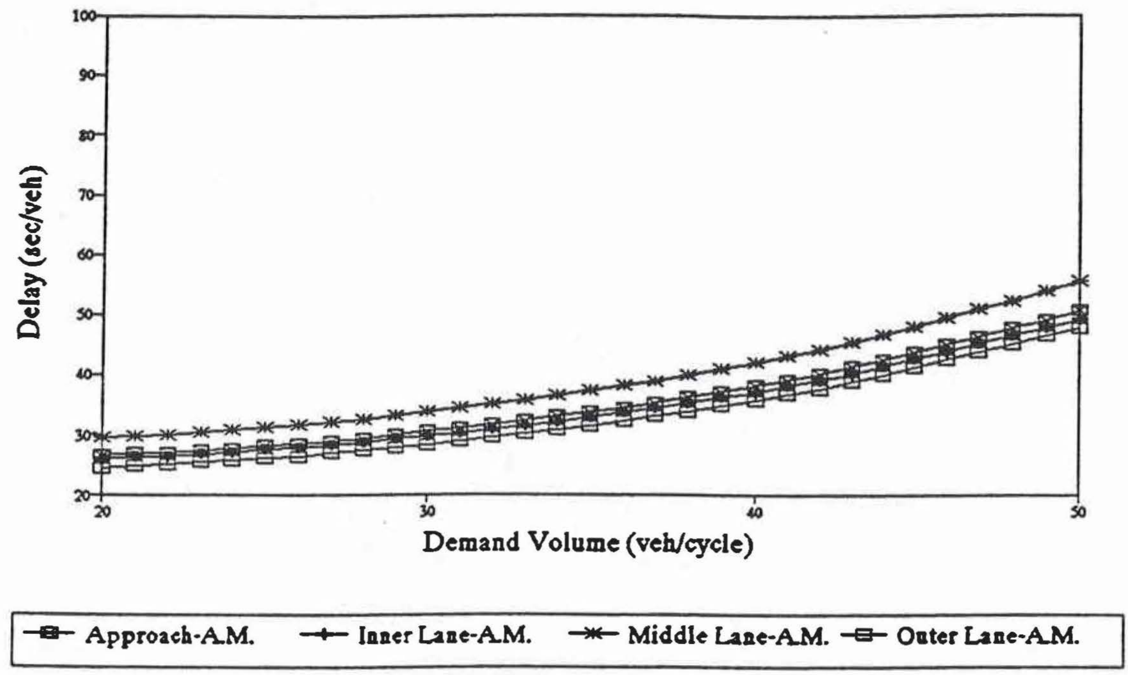


i) Delays

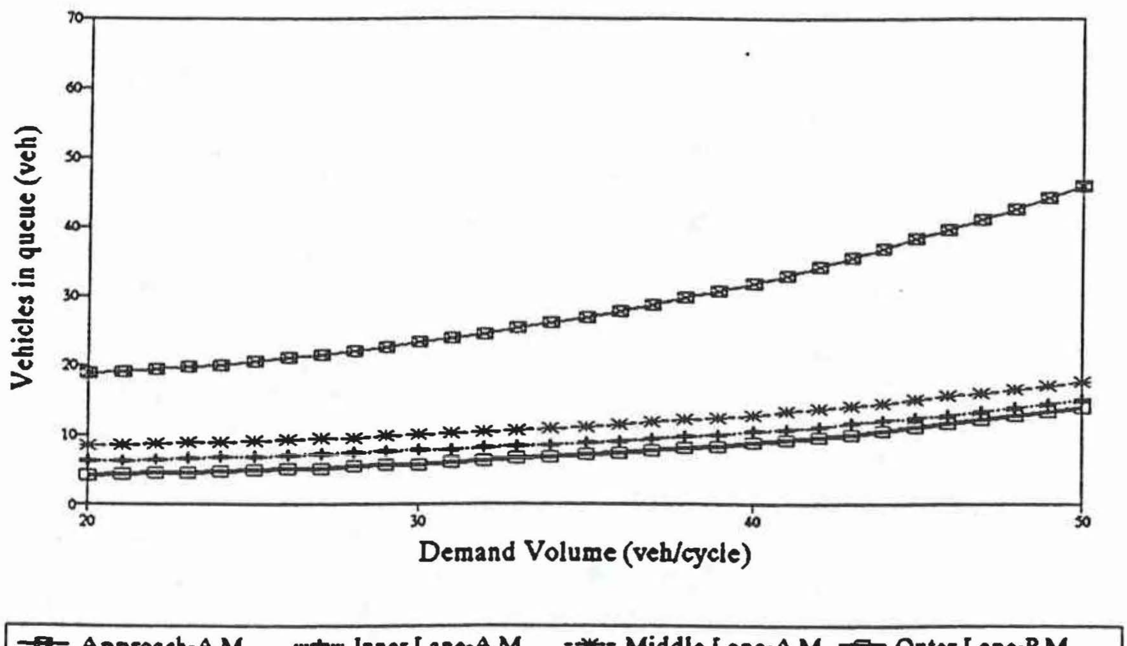


ii) Queues

Figure E-2b. Comparison of MOEs observed in a.m. and p.m. peak periods for After conditions.

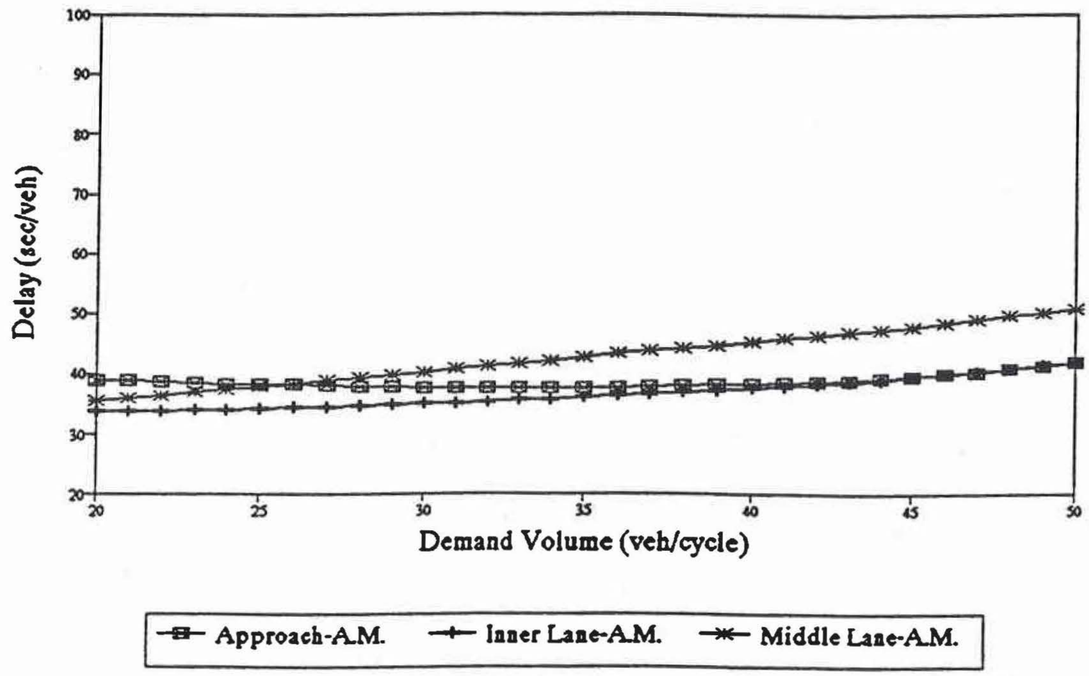


i) Delays

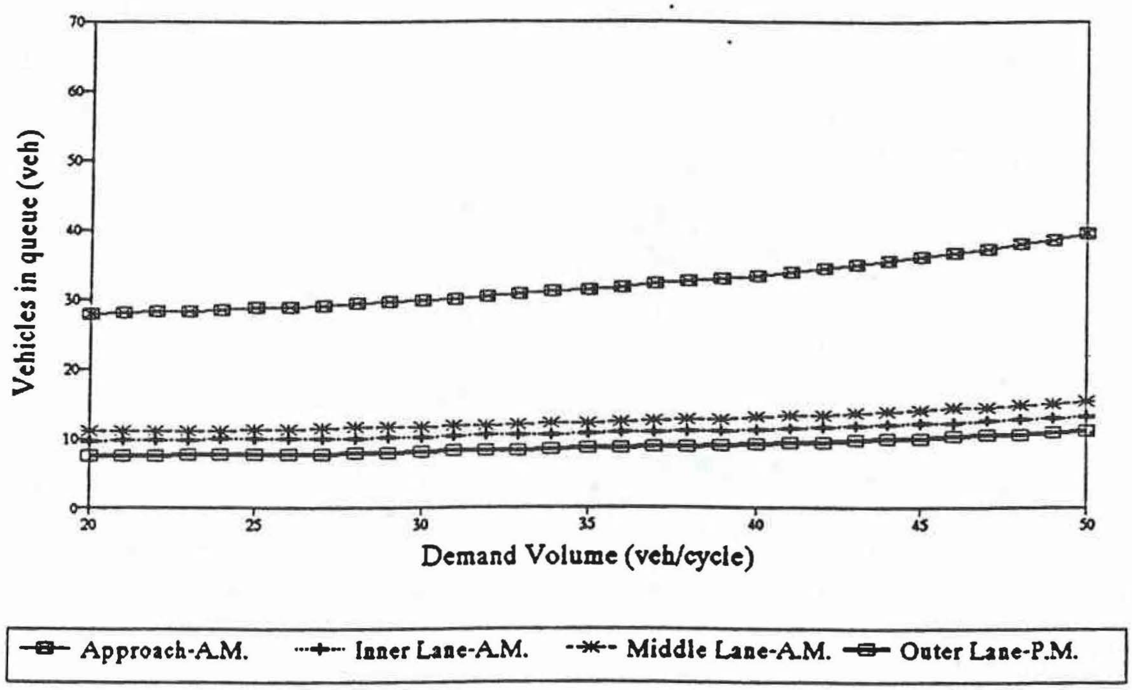


ii) Queues

Figure E-3a. Comparison of MOEs between lanes for a.m. peak period in Before conditions.

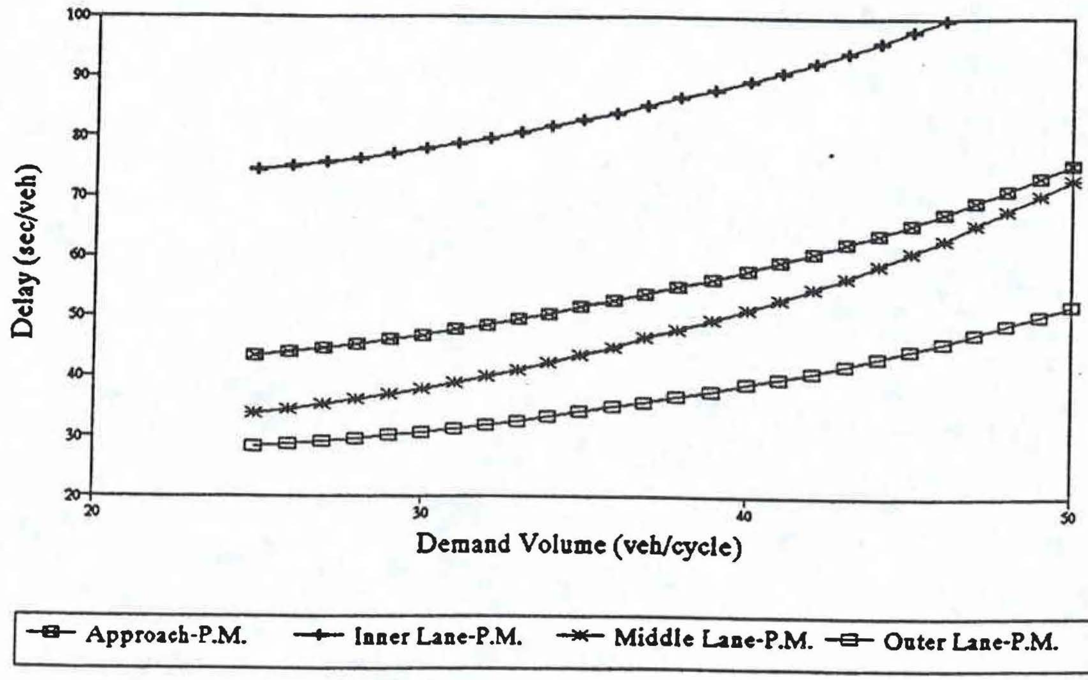


i) Delays

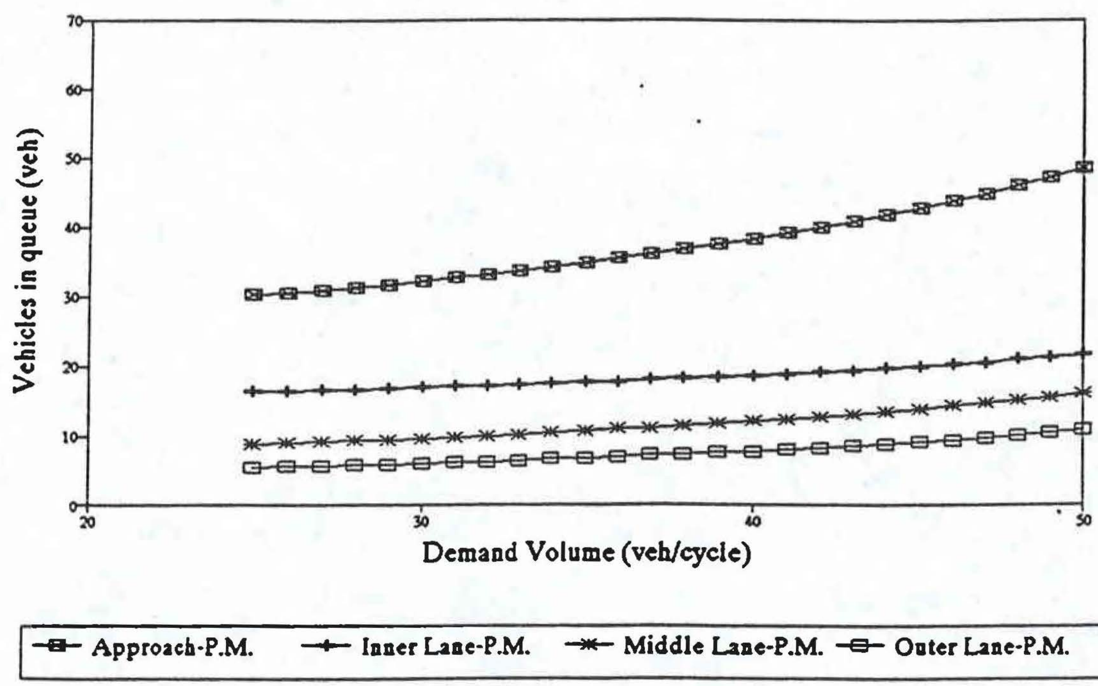


ii) Queues

Figure E-3b. Comparison of MOEs between lanes for p.m. peak period in Before conditions.

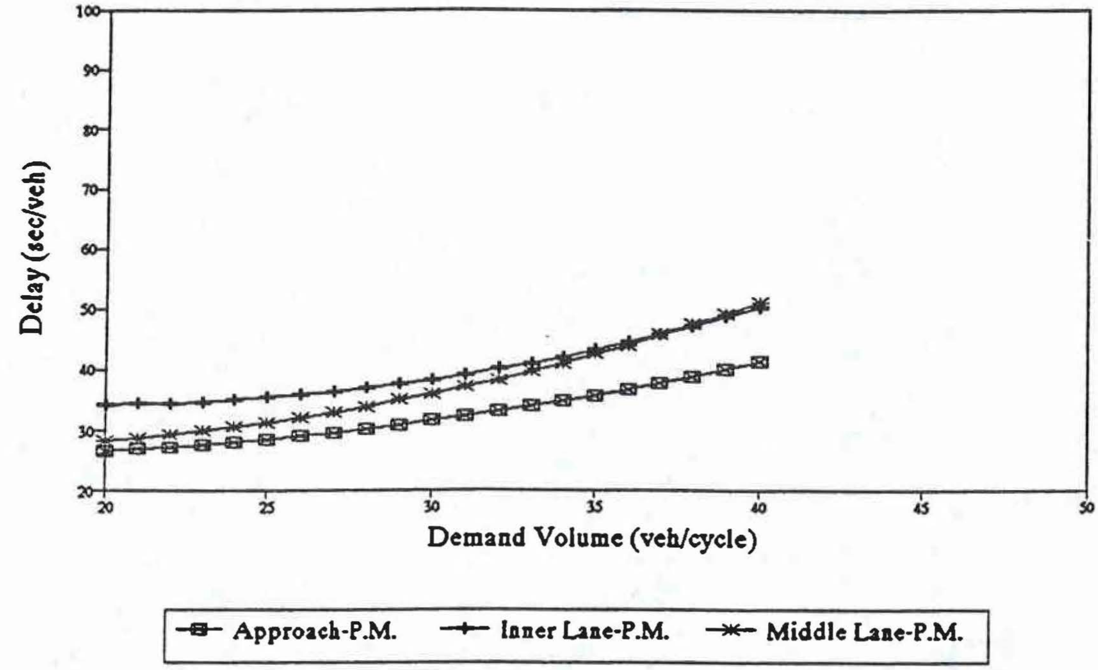


i) Delays

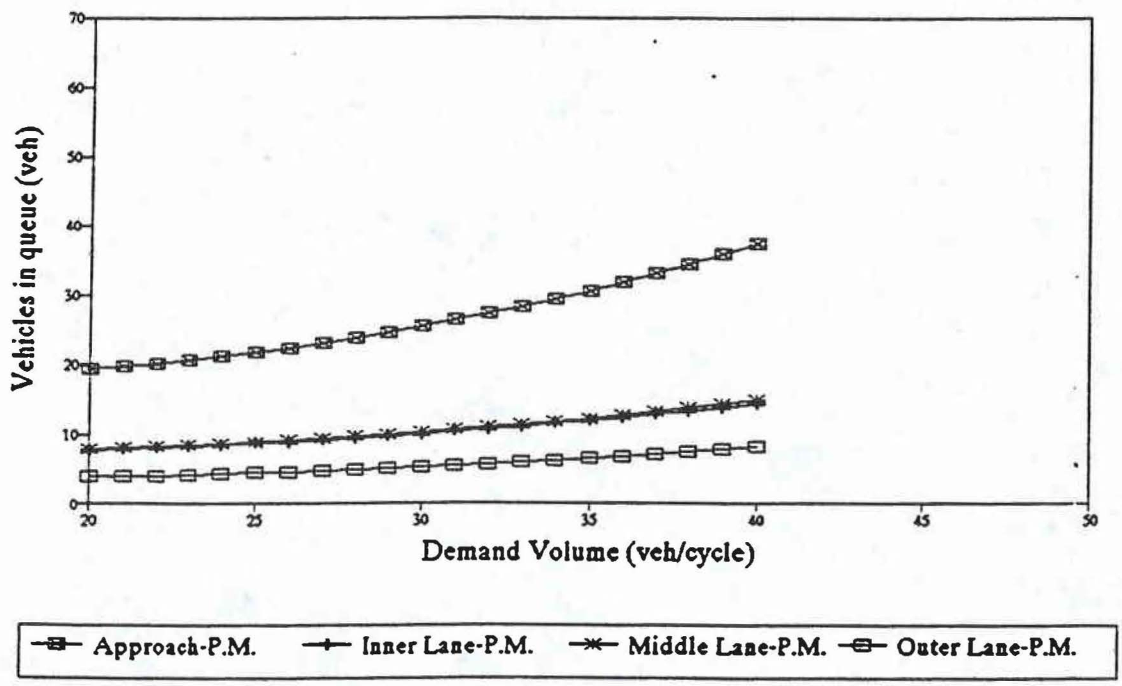


ii) Queues

Figure E-3c. Comparison of MOEs between lanes for a.m. peak period in After conditions.



i) Delays



i) Delays

Figure E-3d. Comparison of MOEs between lanes for p.m. peak period in After conditions.