Technical Report Documentation Page

1. Report No. SWUTC/94/60038-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle COST-EFFECTIVENESS AND ENERGY BENEFITS OF DYNAMIC LANE ASSIGNMENT SIGNS		5. Report Date June 1994 6. Performing Organization Code
7. Author(s) Carroll J. Messer, Dayakar Prabhakar, and Vickie A. Morris		8. Performing Organization Report No. Research Report
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0079
12. Sponsoring Agency Name and Address Southwest Region University Transportation Center Texas Transportation Institute The Texas A&M University System College Station, TX 77843-3135		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

Supported by a grant from the Office of the Governor of the State of Texas, Energy Office.

16. Abstract

This research report documents the procedure adopted to identify the most cost-effective Dynamic Lane Assignment Signs (DALAS) system for various freeway design and operations problems. This procedure involves evaluation of the operational effectiveness of the two DALAS systems now operating in Texas cities, estimation of true construction and maintenance costs, performance of cost-effectiveness analysis of the two systems, recommendation of optimal strategies for various typical applications, and estimation of potential energy savings for all designs.

Chapter One , provides background information, discusses the need to identify the most cost-effective DALAS system for various applications, and outlines the objectives of the research program. Chapter Two and Chapter Three discuss the operational effectiveness of the advanced version of DALAS system being used in Houston and the basic version of DALAS system being used in Dallas, respectively.

Chapter Four explains the cost-effectiveness methodology used. Chapter Five provides estimates of the capital costs of the two signage systems. Chapter Six discusses the potential energy savings associated with the use of the DALAS system as compared to the static lane assignment system (the basic system). Chapter Seven documents the conclusions and recommendations of the research.

17. Key Words Dynamic Lane Assignment Signs Electromechanical Signs Fiber optic Signs Traffic Signs	18. Distribution Statement No Restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 87	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

COST-EFFECTIVENESS AND ENERGY BENEFITS OF DYNAMIC LANE ASSIGNMENT SIGNS

Project 60038 Final Report

by

Carroll J. Messer, Ph.D., P.E.
Research Engineer and Professor of Civil Engineering

Dayakar Prabhakar
Research Assistant

and

Vickie A. Morris
Student Technician

Sponsored by Office of the Governor
State of Texas

Southwest Region University Transportation Center
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

May 1994

EXECUTIVE SUMMARY

With traffic demands in urban areas of Texas continuing to increase at nearly 3 percent per year coupled with limited capabilities for increasing the size of existing freeway facilities, the state is faced with major increases in freeway congestion and fuel consumption. Congestion mitigation is rapidly becoming a major urban policy issue.

A critical bottleneck to traffic flow along the freeway frontage road system is located at the multilane approaches to the signalized diamond interchanges. Therefore, more efficient use of one-way frontage road systems with improved traffic management techniques using advanced computer systems for monitoring traffic and traffic control devices for controlling traffic movement is a major goal.

The traffic demand patterns using these signalized interchanges change depending on the nature of the traffic situation. A traffic control signage mechanism is desired that can assign the available lanes of a frontage road approach to the signalized interchanges in an optimal manner for the given traffic flow pattern and traffic conditions. An optimal pattern would effectively increase the traffic movement capacity, thereby reduce traffic congestion and fuel consumption. Dynamic Lane Assignment Signs (DALAS) system could be very effective in serving as such a traffic control signage mechanism. Research was needed to identify the effectiveness of various strategies and assess the cost and cost-effectiveness of viable hardware systems that might be used to implement the lane assignment strategies.

This research report documents the procedure adopted to identify the most cost-effective Dynamic Lane Assignment Signs (DALAS) system for various freeway design and operations problems. This procedure involved the evaluation of the operational effectiveness of two DALAS systems now operating in Texas cities, estimation of true construction and maintenance costs, performance of cost-effectiveness analysis of the two systems, recommendation of optimal strategies for various typical applications, and estimation of potential energy savings for all designs.

Chapter One, provides background information, discusses the need to identify the most cost-effective DALAS system for various applications, and outlines the objectives of the research program. Chapter Two and Chapter Three discuss the operational effectiveness of the advanced version of DALAS system being used in Houston and the basic version of DALAS system being used in Dallas, respectively.

Chapter Four explains the cost-effectiveness methodology used. Chapter Five provides estimates of the capital costs of the two signage systems. Chapter Six discusses the potential energy savings associated with the use of the DALAS system as compared to the static lane assignment system (the basic system). Chapter Seven documents the conclusions and recommendations of the research.

ACKNOWLEDGEMENT

This publication was developed as part of the University Transportation Centers Program which is funded 50% by oil overcharge funds from the Stripper Well settlement as provided by the State of Texas Governor's Energy Office and approved by the U.S. Department of Energy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

The authors would like to acknowledge the work done by all the previous researchers listed in the references, which provided invaluable guidance in conducting this research. Specifically the commendable work done by Mr. Rohini Kumar Jella in his master's thesis at Texas A&M University entitled "An Operational Assessment of Dynamic Lane Assignment Signs in Houston" provided the framework for Chapter Three of this report. Finally, the authors would like to thank Mr. George Wier for his outstanding editorial and graphical assistance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 PROJECT DESCRIPTION

1.1. Problem Statement

With traffic demands in urban areas of Texas continuing to increase at nearly 3 percent per year (1) coupled with limited capabilities for increasing the size of existing freeway facilities, the state is faced with major increases in freeway congestion and fuel consumption. A recent Texas Transportation Institute (TTI) study (2) found that traffic congestion was already a serious operational problem in major cities and the general public was very concerned about its consequences, such as increased energy consumption and reduced air quality. Congestion mitigation is rapidly becoming a major urban policy issue.

As urban freeways carry almost 30 percent of the peak hour traffic, their operation is of major concern to both public officials and traffic management engineers. One-way frontage road systems were originally constructed along urban Texas freeways to stimulate economic development and to reduce right-of-way acquisition costs. The efficient use of one-way frontage road systems is also a major goal. Frontage roads, perhaps with improved traffic management techniques using advanced computer systems for monitoring traffic and traffic control devices for controlling traffic movement, can be used to carry significant traffic volumes during normal rush hours when maintenance/paving work is conducted on the freeways, during freeway reconstruction, and when unexpected incidents (traffic accidents and vehicle breakdowns) occur. A critical bottleneck to traffic diversion along the frontage road system is located at the multilane approaches to the signalized diamond interchanges. Here, major congestion frequently develops because of inefficient traffic control.

The traffic demand patterns using these signalized diamond interchanges change depending on the nature of the traffic situation. Recurrent rush hour traffic flows (AM/PM) are temporal and repetitive, but they normally are widely different between times of the day. Heavy left turn volumes may occur in the morning, but not occur in the mid-day or afternoon. When accidents occur on the freeway mainlanes, as they often do, high volume freeway diversions usually occur (hopefully more will divert in the future using advanced IVHS technology). These diverted volumes along the frontage roads have "flush" patterns (having almost no turning at the interchanges) wherein all frontage approach lanes are needed to serve the additional (frontage road) through traffic.

A traffic control signage mechanism is desired that can assign the available lanes of the frontage road approach to the signalized interchanges in an optimal manner for the given traffic flow pattern and traffic conditions. An optimal pattern would effectively increase the traffic movement capacity, thereby reduce traffic congestion and fuel consumption. Research is needed to identify the effectiveness of various strategies and assess the cost and cost-effectiveness of viable hardware systems that might be used to implement the lane assignment strategies.

1.2. Background and Significance of Work

TTI identified the features of an advanced dynamic lane assignment system (DALAS) in an Energy Research Applications Project (ERAP #97) recently completed. This system has been carried to the prototype stage, full-scale field testing of design options conducted, and one design has recently been implemented along IH-10 in west Houston. This prototype system uses fiber optic signs and micro-controllers to drive the dynamic lane assignment signs. This system is operating effectively, but it is fairly costly to construct and (perhaps) difficult to maintain for most technicians.

Working with this basic concept, the City of Dallas (with the approval of TxDOT-Dallas) recently installed an inexpensive version of DALAS using simple time-based-coordination of the sign displays generated by flip-panel ground-mounted signs that appear passive to motorists at first glance. Early casual observational reports from this cheaper system indicated that its operational performance was in doubt for unknown reasons. Some operational problems were observed. However, all engineers who have looked at either system believe that the basic strategy is good and that variable display signs will achieve major fuel savings, but that the design tradeoffs (cost-effectiveness) need to be better understood before any subsequent major installations are made.

1.3. Study Objectives

To achieve the maximum energy savings possible during urban freeway traffic conditions, the most cost-effective DALAS system needed to be identified for various freeway design and operations problems. To achieve this research goal, this study addressed the following five research objectives:

1. Evaluate the operational effectiveness of the two DALAS systems now operating in Texas cities on the frontage roads to signalized diamond interchanges.
2. Obtain the best estimates of true construction costs of these systems at different bid quantity levels. That is, evaluate them for different purchase quantities.
3. Assess the maintenance history of the signs to obtain estimates of the annual operating costs (power and maintenance).
4. Perform cost-effectiveness analyses of the two systems and recommend optimal strategies and designs for various typical applications.
5. Estimate the potential energy savings for all designs.

The results of this research project are documented in the following sections of this project final report. The results are tailored toward further implementation needs of DALAS within TxDOT, rather than toward its publication in scientific journals. Coordinated effects have been underway for a considerable time with TxDOT towards implementing these systems along large urban freeways in Texas.

2.0 BASIC DALAS SYSTEM

2.1 Introduction

This chapter provides the results of studying a basic (low-cost) dynamic lane assignment system (DALAS) located in North Dallas. The turning traffic patterns at the signalized intersection of the southbound frontage road of North Central Expressway at Mockingbird Lane in Dallas (shown in Figure 1) was found to vary significantly with time of day. Significant change in traffic pattern occurred during the afternoon peak period. Static lane assignment at this location was not efficient as it could only serve reasonably uniform turning movements. Heavy variation in turning traffic resulted in serious congestion at this location. Research conducted by TTI has shown the dynamic lane assignment signs (DALAS) to be an effective tool to help relieve congestion at intersections where varying traffic demand exists. This led to the installation of a basic version of DALAS system by the City of Dallas at this study site.

2.2 Sign Features

The basic version of DALAS system used at the study location is a mechanical flip-panel sign system which has a time-based coordination of its sign displays. The sign panels are black and white regulatory signs made of aluminum, and are ground mounted at three locations along the inside left shoulder of the southbound frontage road.

Changes in the existing sign display are controlled by time of day and are not actuated by traffic detectors. Remote monitoring of the sign's operation is absent. This information could provide the traffic agency with operational feedback in case of bad performance or failure of the signs. Pavement markings showing lane assignments at the stop line were absent on the frontage road.

The southbound frontage road is a three-lane approach. The lane assignment of turning movements on the frontage road approach changes by time of day for the left and the middle lanes. The lane assignment for the right lane is constant such that the right lane is always a shared lane serving through and right turning traffic. The lane assignment for the inside lane from 4:00 p.m. to 6:30 p.m. is an exclusive left turn lane and the middle lane is a shared lane for left turning and through traffic. At 6:30 p.m., the lane assignment is changed such that the inside lane is a shared lane for left turning and through traffic and the middle lane is exclusively for through traffic. This lane assignment remains unchanged until 4:00 p.m. the following day, when the lane assignment is changed again to the double left-turn movement. Figure 2 illustrates these variable lane assignments by time of day for the southbound traffic at Mockingbird Lane in Dallas.

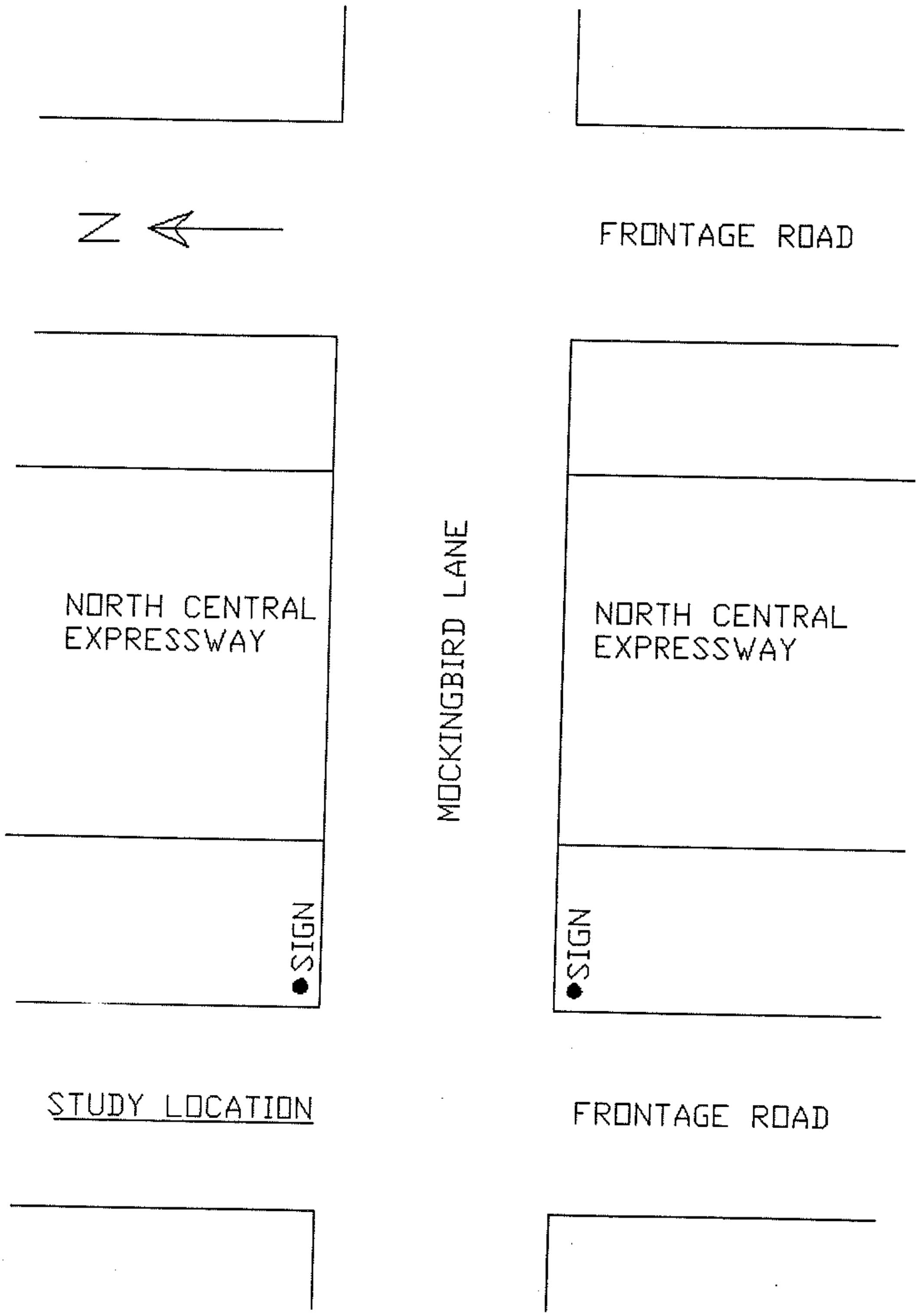
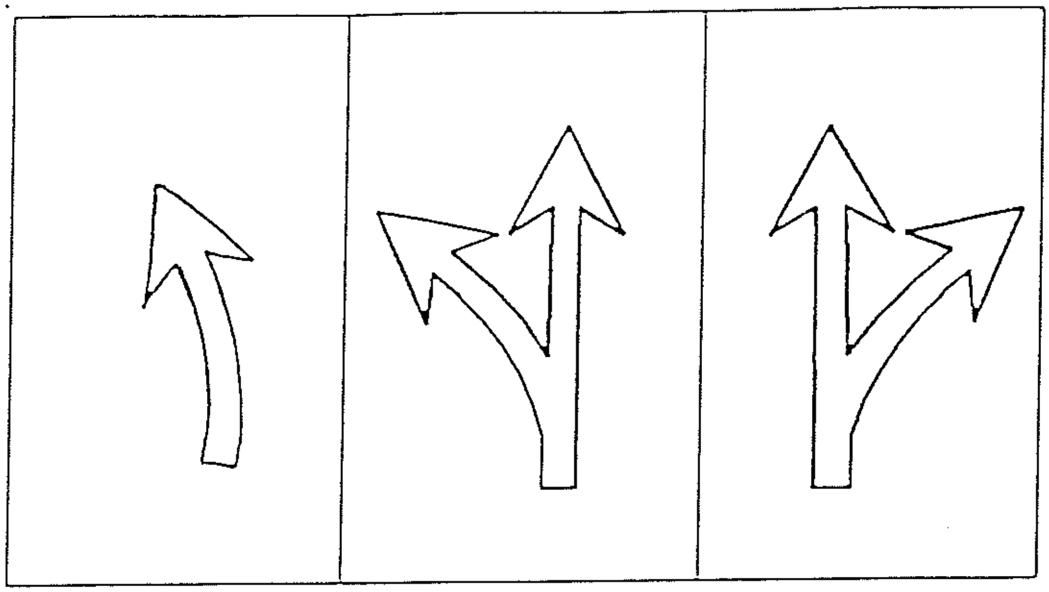
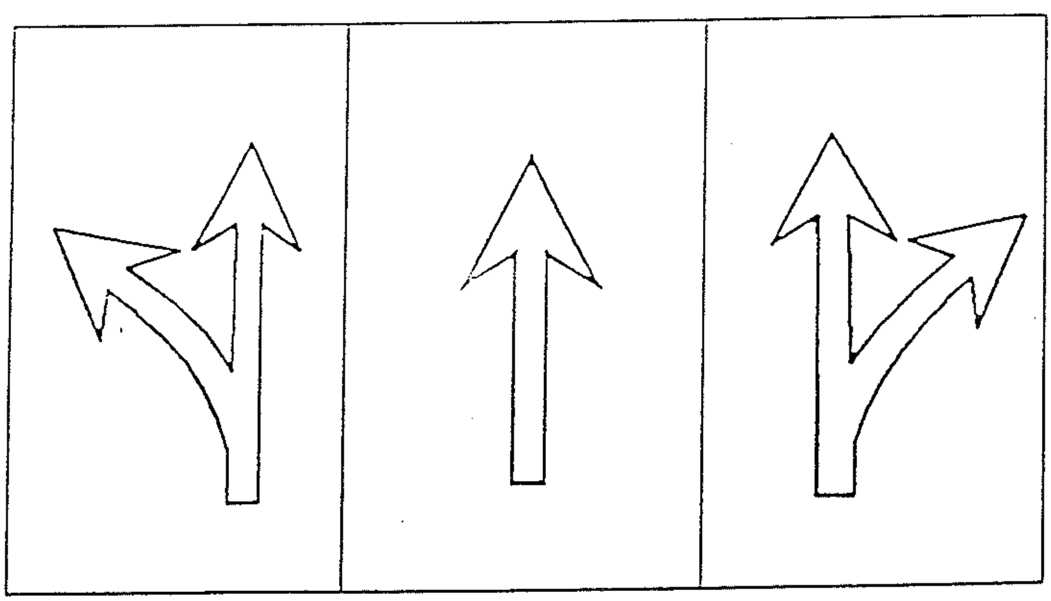


Figure 1. North Central Expressway at Mockingbird Lane, Dallas.



Lane Assignment from 4:00 p.m. to 6:30 p.m.



Lane Assignment During All Other Times

Figure 2. Variable Lane Assignment Sign Displays in Dallas.

2.3 Principal Procedures of Study

The overall objective of the field study was to evaluate the operational effectiveness of the basic version of the DALAS system installed at the study site on North Central Expressway in Dallas. The following tasks were involved in the successful achievement of this objective:

1. Collecting volume data by traffic movement on the southbound approach of the westside frontage road of the diamond interchange of North Central Expressway at the Mockingbird Lane in Dallas from 5:00 p.m. to 6:00 p.m. and observing traffic behavior during this period;
2. Collecting volume data by movement at the study site between 6:30 p.m and 7:00 p.m., observing traffic behavior during this period, and recording any traffic violations of the sign's display;
3. Collecting volume data between 7:00 a.m. and 8:00 a.m. the following day and observing the traffic behavior during this period; and
4. Assessing the effects of the change in the lane assignment on traffic operations.

2.4 Data Collection Effort

The traffic movements at the study location were videotaped from an elevated position on the roadside. The video camera was powered with batteries which were charged prior to data collection. The video camera was loaded with a 8 mm video cassette. The spirit levels on the camera were adjusted and the focus button was set on auto focus. The eye piece was also adjusted while viewing through it such that the view of traffic operations along the frontage road was clear. The camera was so positioned and zoom adjusted such that the required view could be seen in the eye piece. The video recording and the clock in the camera were started so that time could be seen in the recording. The recording was stopped after each specified time period of study.

Data were collected on July 20, 1993 from 5:00 p.m. to 6:00 p.m. before the sign display changed and from 6:30 p.m. to 7:00 p.m. after the sign display changed. On July 21, 1993, data were collected from 7:00 a.m. to 8:00 a.m. During the video recording from 6:30 p.m. to 7:00 p.m. on July 20th, another video camera, which was positioned at a distance of approximately 100 feet upstream of the intersection, was used to record traffic data from 6:45 p.m. to 7:00 p.m. These data were recorded to observe the driver's reaction in changing lanes and to the building up of queues along the frontage road.

Photographs were also taken to illustrate the traffic conditions existing at the site. Photographs of the changeable lane assignment signs were taken before, during, and after the change in sign display.

2.5 Data Reduction

The recorded data were transferred from the 8 mm cassettes to regular video cassettes. The tape was then played and volume counts made by turning movement for the specific time intervals. The counts were manually recorded using counter boards. Any violations of the sign display occurring during the study period were recorded.

The traffic data collected for North Central Expressway were reduced to 15 minute intervals as summarized in Table 1. The data collected between 6:30 p.m. and 7:00 p.m. on July 20th and between 7:00 a.m. and 8:00 a.m. on July 21st were further reduced on a per cycle basis, as given in Tables 2 and 3.

2.6 Data Analysis

The signal volume-to-capacity ratios (v/c) were calculated for the left turns from 5:00 p.m. to 6:00 p.m. and from 6:30 p.m. to 7:00 p.m. The lane assignment between 5:00 p.m. and 6:00 p.m. was such that the inside lane was an exclusive lane serving left turning traffic and the middle lane was a shared lane serving left turning and through traffic. The saturation flow rate for left turns was assumed to be 1700 vphgpl due to the restrictive turning geometry. Volume-to-capacity ratios were calculated for 15 minute periods during the study period as follows:

v = volume observed in a 15 minute period x 4 periods per hour

c = capacity = saturation flow rate x (green time/cycle length)

A cycle length of 128 seconds and an effective green time of 19 seconds was observed and used for the southbound approach of the frontage road. Both the inside lane and middle lane were considered while determining left turning volumes and capacity between 5:00 p.m. and 6:00 p.m. At 6:30 p.m., when the lane assignment was changed such that the inside lane was a shared lane for left turning and through traffic while the middle lane was exclusive for through traffic, left turns were still observed being made from the middle lane. Hence, while calculating the v/c ratio for left turning volumes, the left turns (violations) being made from the middle lane serving through traffic were included in the overall left turn demand volume. However, the phase capacity serving the left turn traffic was computed considering only the assigned inside lane. The v/c ratios for the various 15 minute time periods during which data were collected are summarized in Table 4.

The traffic volumes from 5:00 p.m. to 6:00 p.m. and 6:30 p.m. to 7:00 p.m. were input into PASSER III and simulation runs were made. Mock data were used for all of the other movements except for the frontage road which was being studied. The outputs for these simulation runs are included in the appendix. It was observed from these outputs that the v/c ratio for the left turns was higher between 6:30 p.m. and 7:00 p.m. than the v/c ratio between 5:00 p.m. and 6:00 p.m.

Table 1. Fifteen Minute Volume Counts for Intersection of Southbound Frontage Road of North Central Expressway with Mockingbird Lane, Dallas on July 20, 1993.

Time (P.M.)	Lanes										Violations Cars
	Inside		Center				Right				
	Left Turn		Left Turn		Thru		Thru		Right Turn		
	Cars	HV	Cars	HV	Cars	HV	Cars	HV	Cars	HV	
5:00 - 5:15	60	0	33	0	12	1	4	1	40	0	0
5:15 - 5:30	46	0	25	0	12	1	0	1	32	0	0
5:30 - 5:45	48	0	28	0	10	1	2	0	48	1	0
5:45 - 6:00	51	0	30	0	12	1	3	1	47	1	0

DATE : 07/20/93
TIME : 5:00 P.M. 6:00 P.M.

Time (PM)	Lanes										Violations Cars
	Inside				Center		Right				
	Left Turn		Thru		Thru		Thru		Right Turn		
	Cars	HV	Cars	HV	Cars	HV	Cars	HV	Cars	HV	
6:30 - 6:45	70	2	0	0	25	5	0	0	77	0	22
6:45 - 7:00	57	1	0	0	8	0	0	0	58	0	22

DATE : 07/20/93
TIME : 6:30 P.M. 7:00 P.M.

Time (A.M.)	Lanes										Violations Cars
	Inside				Center		Right				
	Left Turn		Thru		Thru		Thru		Right Turn		
	Cars	HV	Cars	HV	Cars	HV	Cars	HV	Cars	HV	
7:00 - 7:15	12	1	0	0	11	6	0	0	42	0	0
7:15 - 7:30	12	0	5	0	18	2	0	0	43	0	0
7:30 - 7:45	8	0	12	0	30	1	0	1	37	1	0
7:45 - 8:00	12	0	38	4	68	5	1	1	71	0	1

DATE : 07/21/93
TIME : 7:00 A.M. 8:00 A.M.

Table 2. Volume Counts by Cycle for Intersection of Southbound Frontage Road of North Central Expressway with Mockingbird Lane, Dallas on July 20, 1993.

Cycle #	Cycle End Time	Lanes										Violations
		Inside				Center		Right				
		Left Turn		Thru		Thru		Thru		Right Turn		
		Cars	HV	Cars	HV	Cars	HV	Cars	HV	Cars	HV	Cars
1	6:34:32	8	0	0	0	2	0	0	0	5	0	2
2	6:36:40	7	0	0	0	3	0	0	0	9	0	5
3	6:38:49	8	0	0	0	4	1	0	0	3	0	1
4	6:40:56	5	1	0	0	3	0	0	0	7	0	2
5	6:43:07	8	0	0	0	0	2	0	0	13	0	1
6	6:45:14	7	0	0	0	3	0	0	0	9	0	2
7	6:47:21	8	1	0	0	3	0	0	0	12	0	5
8	6:49:29	8	0	0	0	0	0	0	0	9	0	0
9	6:51:37	7	0	0	0	0	0	0	0	9	0	3
10	6:53:47	9	0	0	0	2	0	0	0	8	0	5
11	6:55:55	8	0	0	0	3	0	0	0	6	0	5
12	6:58:01	8	0	0	0	0	0	0	0	7	0	1
13	7:00:10	9	0	0	0	0	0	0	0	7	0	3

DATE : 07/20/93
TIME 6:30 P.M. TO 7:00 P.M.

Table 3. Volume Counts by Cycle for Intersection of Southbound Frontage Road of North Central Expressway with Mockingbird Lane, Dallas on July 21, 1993.

Cycle #	Cycle End Time	Lanes										Violations
		Inside				Center		Right				
		Left		Thru		Thru		Thru		Right		
		Cars	HV	Cars	HV	Cars	HV	Cars	HV	Cars	HV	Cars
1	7:01:59	1	0	0	0	0	0	0	0	1	0	0
2	7:03:33	1	0	0	0	3	1	0	0	6	0	0
3	7:05:09	2	0	0	0	0	1	0	0	2	0	0
4	7:06:55	2	0	0	0	3	0	0	0	7	0	0
5	7:08:43	3	0	0	0	2	0	0	0	3	0	0
6	7:10:31	1	0	0	0	0	0	0	0	6	0	0
7	7:12:19	0	0	0	0	1	0	0	0	4	0	0
8	7:14:07	0	1	0	0	1	1	0	0	9	0	0
9	7:15:56	2	0	0	0	1	3	0	0	4	0	0
10	7:17:43	0	0	0	0	5	0	0	0	7	0	0
11	7:19:31	1	0	0	0	2	0	0	1	5	0	0
12	7:21:19	3	0	1	0	2	0	0	0	3	0	0
13	7:23:08	3	0	1	0	0	0	0	0	3	0	0
14	7:24:55	1	0	2	0	2	1	0	0	4	0	0
15	7:26:43	0	0	0	0	1	0	0	0	7	0	0
16	7:28:32	2	0	1	0	1	1	0	0	6	0	0
17	7:30:20	2	0	0	0	5	1	0	0	8	0	0
18	7:32:08	0	0	0	0	2	0	0	0	7	0	0
19	7:33:56	2	0	3	0	1	0	0	0	3	0	0
20	7:35:44	0	0	2	0	1	0	0	0	1	0	0
21	7:37:32	0	0	1	0	6	0	0	1	2	0	0
22	7:39:20	3	0	0	0	6	0	0	0	3	0	0
23	7:41:09	2	0	1	0	2	0	0	0	6	1	0
24	7:42:56	1	0	2	0	7	0	0	0	6	0	0
25	7:44:44	0	0	3	0	5	1	0	0	9	0	0
26	7:46:32	1	0	2	1	4	1	0	0	5	0	0
27	7:48:22	1	0	5	0	8	1	0	0	6	0	0
28	7:50:08	4	0	3	1	5	1	1	0	8	0	0
29	7:51:56	0	0	4	0	8	0	0	0	7	0	0
30	7:53:46	2	0	4	0	12	0	0	0	10	0	0
31	7:55:32	1	0	5	1	10	0	0	0	6	0	0
32	7:57:20	1	0	7	0	8	0	0	0	10	0	0
33	7:59:09	1	0	6	0	7	1	0	0	10	0	1
34	8:00:56	1	0	2	1	6	1	0	0	9	0	0

DATE : 07/21/93
TIME 7 A.M. TO 8 A.M.

Table 4. Left Turn Volumes, V/C Ratios and Violations of Sign Display During the Study Period.

Time	Left-Turn Volumes (including violations)	V/C Ratio for Left Turns	Left Turn Violations
5:00 - 5:15 pm	372	0.74	0
5:15 - 5:30 pm	284	0.56	0
5:30 - 5:45 pm	304	0.60	0
5:45 - 6:00 pm	324	0.64	0
6:30 - 6:45 pm	376	1.49	22
6:45 - 7:00 pm	320	1.27	22
7:00 - 7:15 am	52	0.21	0
7:15 - 7:30 am	48	0.19	0
7:30 - 7:45 am	32	0.13	0
7:45 - 8:00 am	52	0.21	1

2.7 Study Results

The data indicate that the left turning volumes were heavy between 5:00 p.m. and 6:00 p.m. and reduced only slightly between 6:30 p.m. and 7:00 p.m. However, the phase capacity serving this left turn traffic was significantly reduced as the lanes serving left turning volume were reduced from two to one lane by the sign's operation. Therefore, the volume-to-capacity (v/c) ratios were as high as 1.49 between 6:30 p.m and 7:00 p.m.

Two graphs, one illustrating the relationship observed between time of day and violations, and the other illustrating the relationship observed between v/c ratio and violations are plotted in Figures 3 and 4, respectively. Figure 3 indicates that the violations increased as the time of day changed and decreased significantly for the time period observed the next morning. It is observed that 22 violations of the sign display occurred in each of the two 15 minute periods immediately following the display of the restricted lane assignment for the heavy left turn movement. In Figure 4, as the v/c ratio increases, the number of observed violations increase significantly when the v/c ratio exceeds 1.0.

No violations were observed between 5:00 p.m. and 6:00 p.m. However, after the change in sign display to the more restrictive left turn operation, when the inside lane (which initially was a left turn lane only) became a shared lane for left and through traffic, left turns were still being made from the middle lane, violating the sign display. Fortunately, all vehicles in the left lane were left turning vehicles, otherwise collisions may have occurred with the violators. The number of violations observed between 6:30 p.m. and 7:00 p.m. was very high. The data recorded between 6:30 p.m. and 6:45 p.m. using a second hand held camera indicate that, as the median (left) lane queues got longer, drivers bypassed around the queue by moving into the middle lane, which had been reassigned exclusively for through vehicles. The data collected between 7:00 a.m. and 8:00 a.m. on July 21 indicate a dramatic decrease in the number of violations during this time. There was only one violation observed during the one hour of data collection. It was also observed that during this period the number of through vehicles in the inside lane, which is a shared lane for left and through traffic, increased substantially. This effect could be attributed to the absence of any significant queue of left turning vehicles.

One possibility for the large number of violations observed to be occurring during congested conditions is that the drivers of vehicles were not able to read the signs clearly because of the distance that separated them from the signs due to the presence of long queues. Another more likely possibility is that the violators of the sign displays were able to see the signs, but still disregarded them because of the presence of long queues which would cause them extra delay if they did not clear the intersection on the next signal phase.

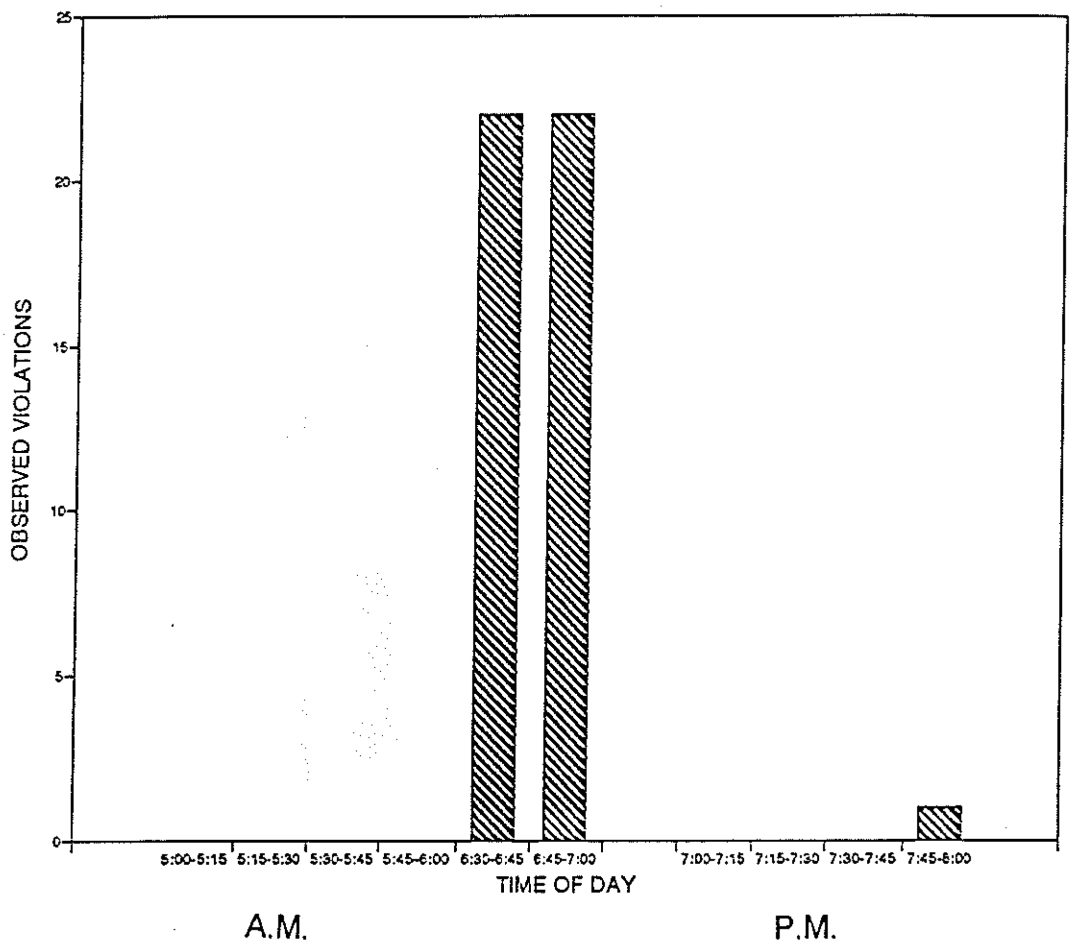


Figure 3. Relationship Between Time of Day and Observed Violations of the Sign Display.

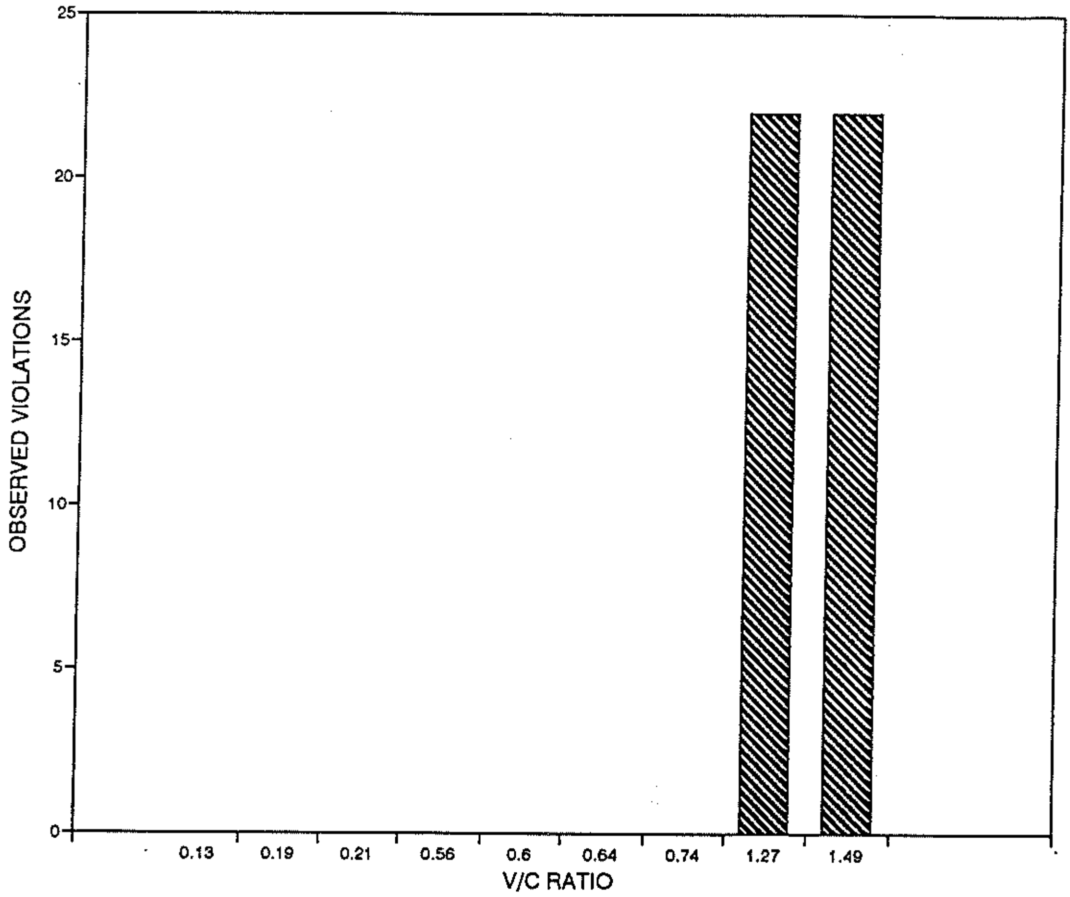


Figure 4. Relationship Between V/C Ratios and Observed Violations of the Sign Display.

From an analysis of the data, it can be observed that the number of violations increased as the v/c ratio increased. Hence, there is some reason to believe that had the lane assignment been changed at a later time (when the v/c ratio had come down appreciably) then the number of violations might have been significantly less. One more factor that supports this premise is that a large percentage of the left turning traffic at this time of day comprises commuter traffic who are very familiar with local operations and options available, both legal and illegal.

During the formulation of the field study plan, it was expected that the rush hour traffic would decrease by 7:00 p.m. However, it was observed that this assumption was not true. In retrospect, it is felt that traffic volume data desirably should have been collected for another hour after 7:00 p.m. to record any reduction in traffic volumes and v/c ratio that may have occurred, especially for the left turning movement. If the violations observed were lower at the time when v/c ratio reduced appreciably, then it would have enabled us to draw a firm conclusion as to whether the violations were primarily a function of the v/c ratio which is in turn a function of the time of day. However, changes that have occurred along the North Central Expressway due to major freeway reconstruction efforts prevent meaningful additional follow-up studies of this issue to be conducted.

3.0 ADVANCED DALAS SYSTEM

3.1 Introduction

A similar traffic operational condition exists along IH 10 in west Houston. Extreme variations in turning movement volumes occur on the eastbound frontage road of IH-10 at the intersection with Voss/Bingle. The turning movement volume counts on the eastbound frontage road are shown in Figure 5. The morning peak period traffic existed for two hours, from 7:00 a.m. to 9:00 a.m. The through volumes are very high on the eastbound frontage road during this period.

To initially address this demand imbalance, 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 static lane assignment served the morning peak period traffic efficiently, but during other times of the day a significant increase in left turning traffic caused congestion.

To improve the traffic operations at this location, TTI and TxDOT installed an Advanced Dynamic Lane Assignment Signing (DALAS) system at this location. In order to evaluate the operational effectiveness of this signing system, Before studies and After studies were conducted by TTI prior to, and after the installation of the experimental signs. The results from these studies were compared to evaluate the effectiveness of the experimental signs. The experimental signs were installed in June 1992, and traffic was allowed to stabilize before beginning the After studies.

3.2 Sign Features

The advanced version of DALAS system used at this study location consisted of a fiber optic sign system, having ground mounted and overhead signs. These signs were operated by a Naztek Series 900 closed-loop signal controller. The signing system has a fiber optic sign display which disperses light from a point light source through glass fiber bundles to form messages on the surface of the sign, resulting in a display of uniform light intensity. The signals at the intersection were also operated by another Naztek 900 series controller. The timers from these two controllers were modified in order to facilitate communication between them. The fiber optic signs as well as the signals from the computer could be monitored by the Naztek closed loop system. The overhead signs were located at a distance of 200 feet upstream of the stop line; whereas, the ground mounted sign was located in the far left corner of the eastbound frontage road. Figure 6 illustrates the layout of the DALAS system at the Bingle/Voss study site in Houston.

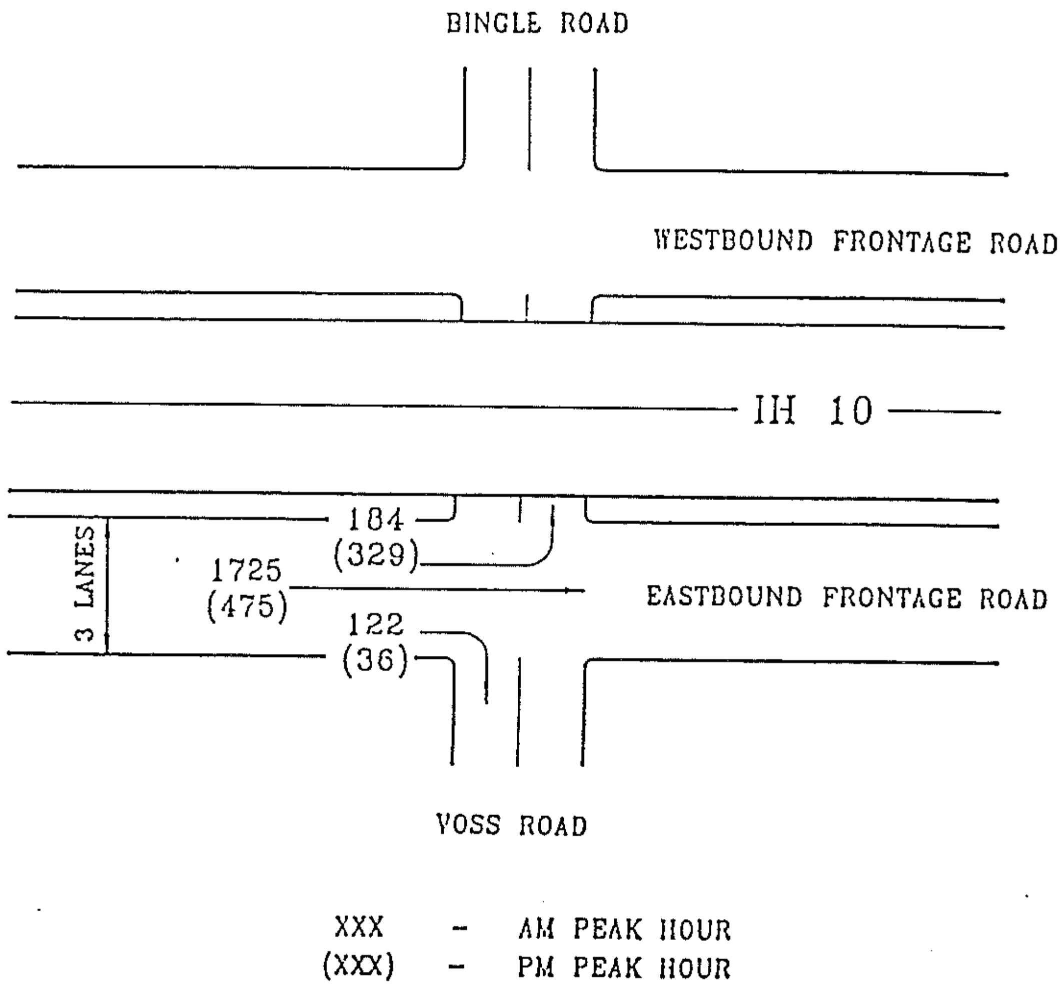


Figure 5. Turning Volume Counts at the Intersection of IH 10 and Voss/Bingle.

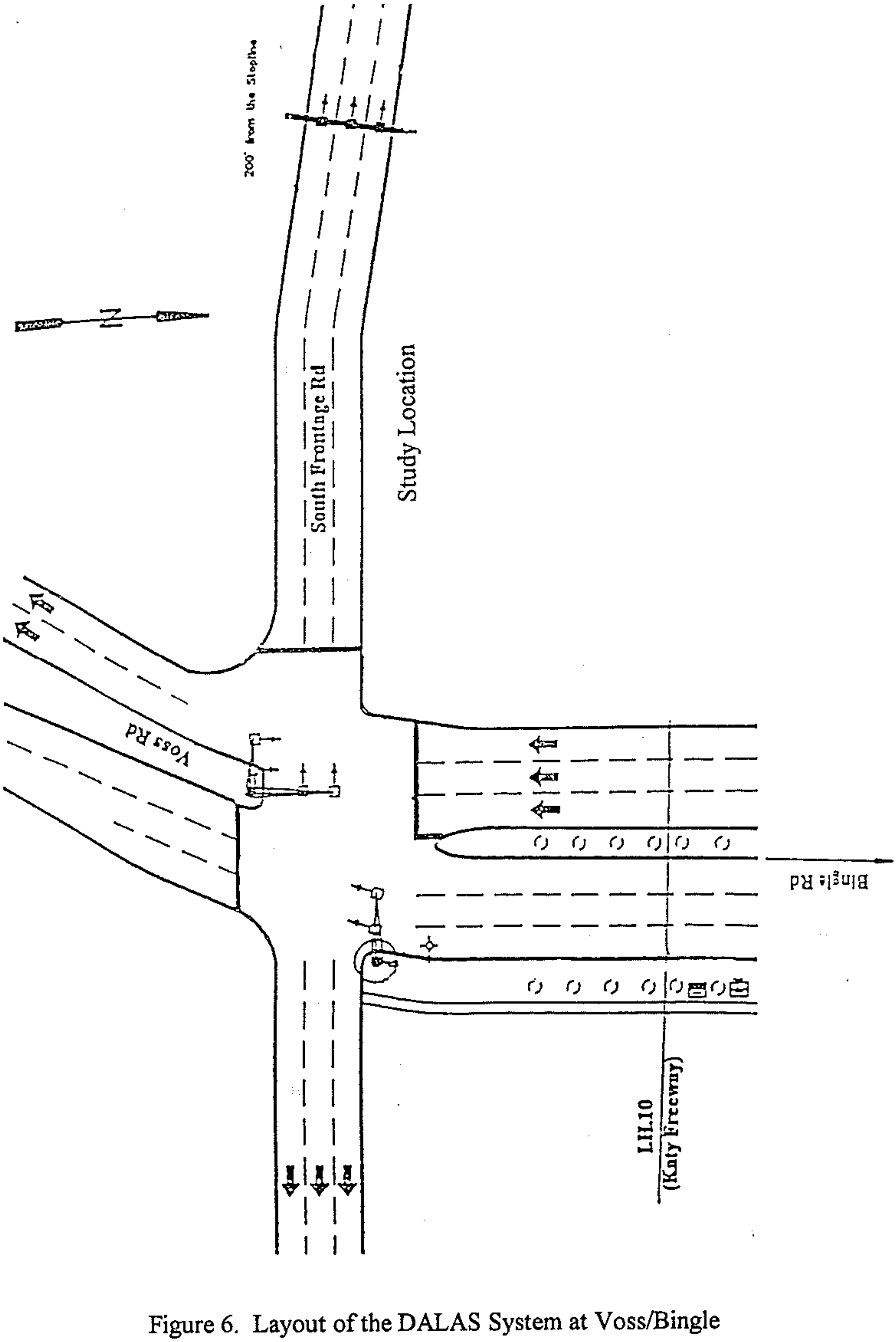


Figure 6. Layout of the DALAS System at Voss/Bingle

The eastbound frontage road is a three lane approach. The lane assignment on the frontage road approach changes by time of day for the inside and middle lanes while the lane assignment remains unchanged for the right lane. The lane assignment from 6:00 a.m. to 10:00 a.m. was such that the inner lane was a shared lane for left turns and through traffic. A transition phase assigning the inner lane as an exclusive left turn lane and middle lane as an exclusive through traffic lane was displayed for 2 to 3 cycles just before 6:00 a.m. and just after 10:00 p.m. For the remaining part of the day, the lane assignment was such that the inner lane was assigned for exclusive left turns and the middle lane was a shared lane serving left turning and through traffic. The right lane is a shared lane serving through and right turning traffic. Figure 7 illustrates these variable lane assignments sign displays.

3.3 Principal Procedures of Study

The overall goal of this field study was to evaluate the operational effectiveness of the advanced version of DALAS system installed at the study site in Houston. This goal could be achieved through the successful accomplishment of the following principal study procedures:

1. Identification of Measures of Effectiveness (MOE) which serve as the criteria for the evaluation of traffic conditions before and after the installation of the DALAS system;
2. Evaluation of the traffic conditions before and after the installation of the signs based on the MOEs identified above; and
3. Comparison of the before and after traffic conditions obtained from procedure 2.
4. Comparison of observed violations of the sign display, if any, for before and after conditions to observe the effect the DALAS system had on lane violations.

3.4 Identification of Measures of Effectiveness

An earlier study conducted by TTI (1) identified queue length at the onset of green (in terms of vehicles in queue) and delay as the primary MOEs for comparison between the traffic conditions before and after the implementation of DALAS. The space management concept using DALAS signs should reduce the imbalance in the queue lengths and delays observed in different lanes. This effect should result in shorter queues and lower approach delays. However, a before and after accident analysis was not considered for evaluating traffic conditions owing to the limited time frame covered by this research and since no safety complaints by the local police have been reported.

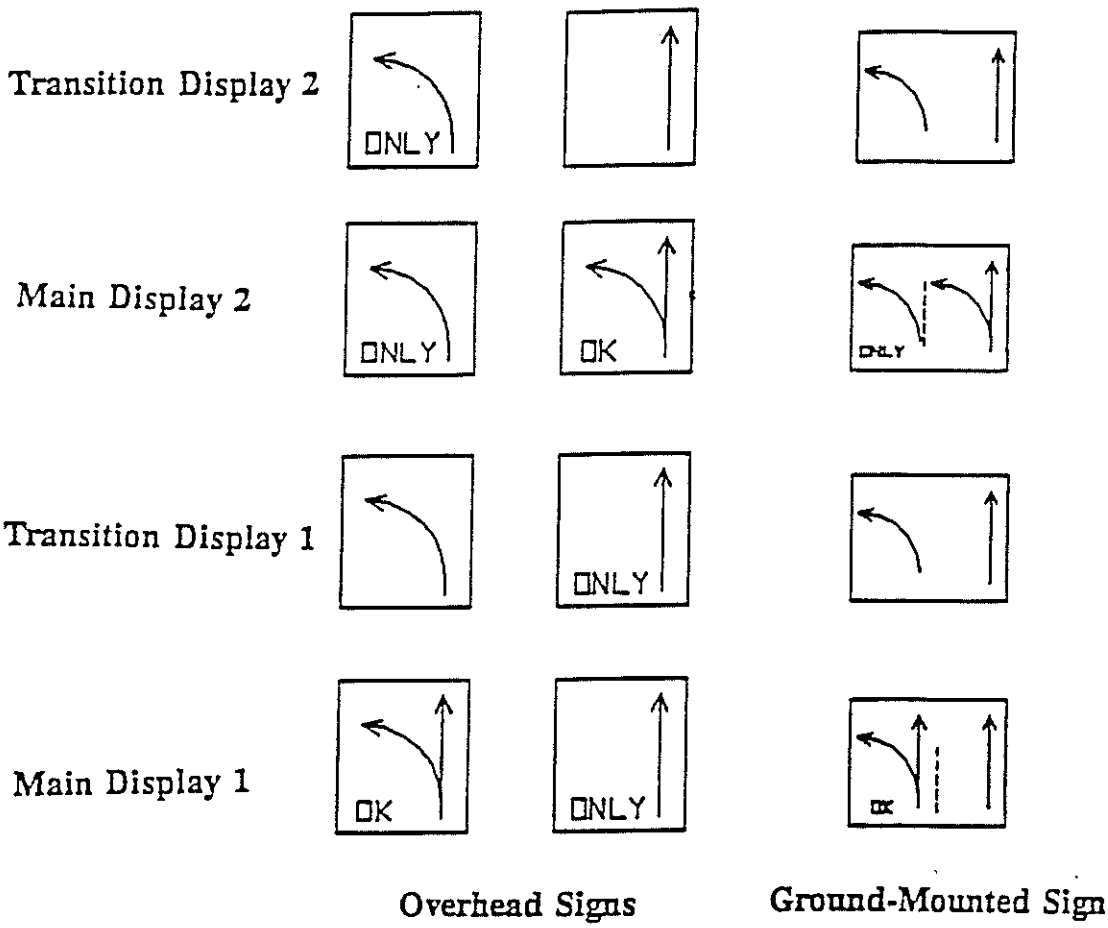


Figure 7. Sequence of the Displays Generated in Fiber Optic Signs.

3.5 Data Collection Effort

In the earlier study conducted by TTI (3) 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 turning volume data were collected for the eastbound frontage road of IH-10 at the intersection with Voss/Bingle to identify the general characteristics of the traffic at the intersection. The intersection data were collected manually by TTI personnel. Volume counts for 15-minute periods were made between 6:00 a.m. and 6:00 p.m. on November 26, 1991. The peak periods were identified by observing the traffic count data. For the one way 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 summarized in Tables 5 and 6.

The data were collected during the peak periods by video taping the traffic movements. The camera setup for the collection of data is shown in Figure 8. Two cameras were used for the collection of data. 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 simultaneously displaying the two video cassettes on different television screens. The recording was done during the peak periods identified previously. 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.

Data were collected on more than one day in order 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. 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.

When the lane assignment changed from a configuration where the inner lane was an exclusive left turn lane and the middle lane was a shared lane serving left turning and through traffic to a configuration where the inner lane was a shared lane for left and through traffic and the middle lane was an exclusive lane serving through traffic, it was observed that some left turns were still being made from the middle lane. Observations of these violations of sign display were made on the videotapes for the 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.

Table 5. Fifteen Minute Volume Counts for Intersection of Eastbound Frontage Road of IH 10 with Voss/Bingle, Houston on November 26, 1991.

	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 6. Fifteen Minute Volume Counts for the Intersection of Westbound Frontage Road with Voss/Bingle, Houston on February 26, 1992.

	Frontage Road				Southbound		Northbound	
	Inner Lane		Outer Lane		Bingle		Bingle	
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								

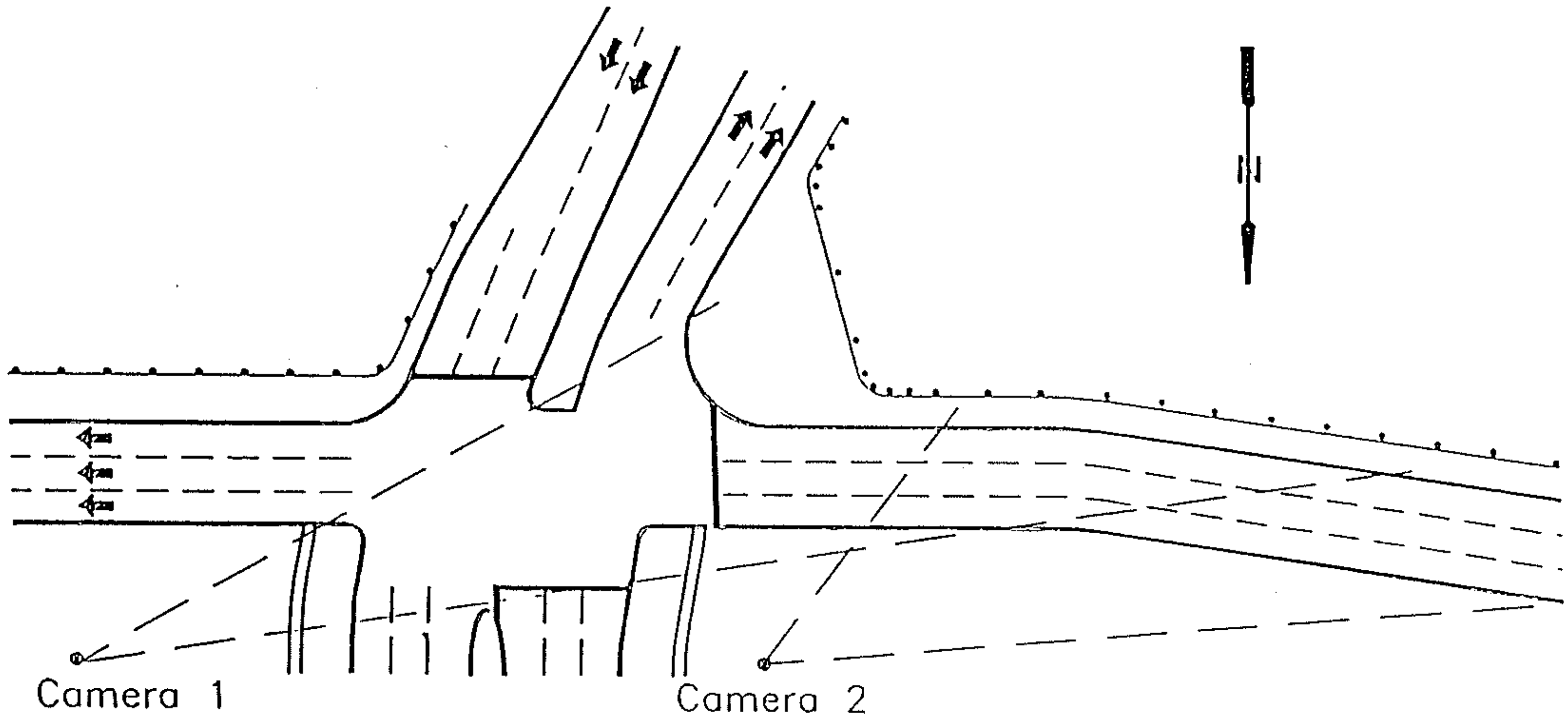


Figure 8. Final Camera Setup for Data Collection.

Table 7. Comparison of Lane Violation Before and After Installation of DALAS Signs.

	Before	After	After-2
No. of cycles	44	66	25
Violations	0	0	0
Violations/cycle	0	0	0

a. In A.M. Peak

	Before	After	After-2
No. of cycles	61	120	38
No. of vehicles	2455	3772	1772
Violations	15	27	10
Violations/cycle	0.246	0.225	0.263
Violations/veh	0.00611	0.007158	0.005643

b. In P.M. Peak

Comparison of Violations of Sign Display

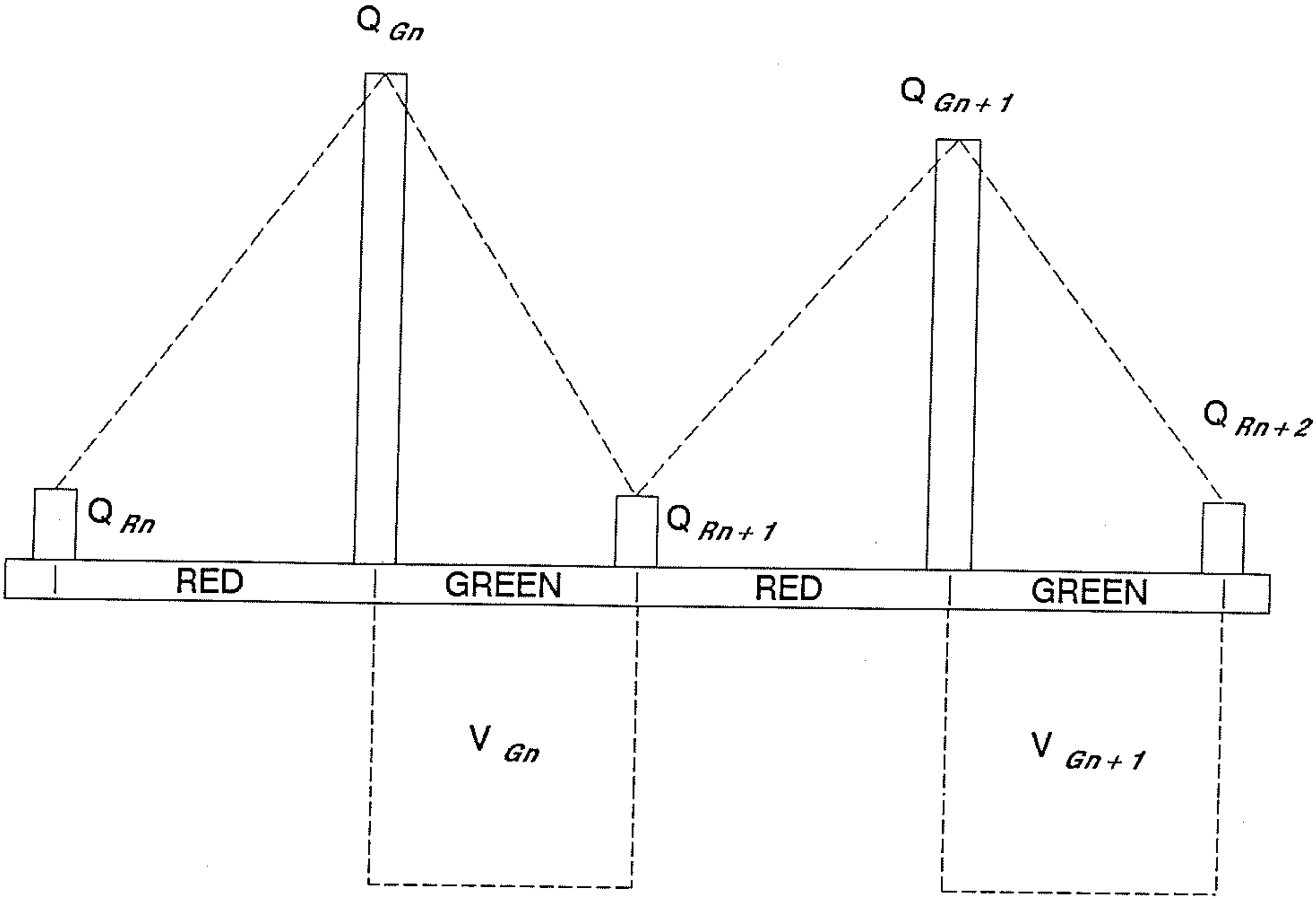
This study shows that there were no violations in either the Before or After study during the morning peak period. No change should be expected, because the lane assignment does not change during these periods. During the afternoon peak period when the display was changed to a dual left-turn assignment, 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.

3.6 Data Reduction

The data collected in the earlier study were reduced for analysis. The MOEs were quantified for individual lanes because 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. The peaking characteristics were observed for each day and an analysis period of 15 to 30 minutes was selected for each morning and afternoon peak period. The queue lengths at the onset of green were determined for each lane.

Several traffic and signal timing parameters, such as cycle length, green time, volumes arriving in green and red, and volumes served in each green interval in different lanes, were required for determining delays for the eastbound frontage road. 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 9 helps explain the procedure adopted for calculating the arrival volumes. It is assumed that there are Q_{Rn} vehicles stopped at the onset of red in the n^{th} cycle. Queues start building up on the approach until the end of the red interval when vehicles are allowed to leave the approach. It is assumed 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 start moving out and the queue starts dissipating. It is assumed 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.



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 9. Queue Diagram for Calculation of Arrival Rates

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 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

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

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

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

The queue lengths at the onset of red and volumes served in each cycle can be observed from the video cassettes as mentioned earlier. The queue lengths at the onset of green were observed in the field. Hence, the arrival rates can be estimated following the above procedure. Table 8 shows the reduced data observed in the morning peak. The negative numbers for arrivals during green were due to lane changes made before they were served at the intersection.

3.7 Analysis Procedure

<u>Evaluation of Traffic Conditions</u>

The earlier TTI study identified the following procedure for calculation of delays. Figure 10 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). The pattern is horizontal at regular intervals since there is no further increase in the cumulative number of vehicles serviced. 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, vehicles joining the queue 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 while waiting in queue or is simply the total approach delay.

Table 8. Reduction Data for A,M. Peak on February 19, 1992.

Tr	Qr			Tg	Red	Qg			Ar			Vg			Green	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"

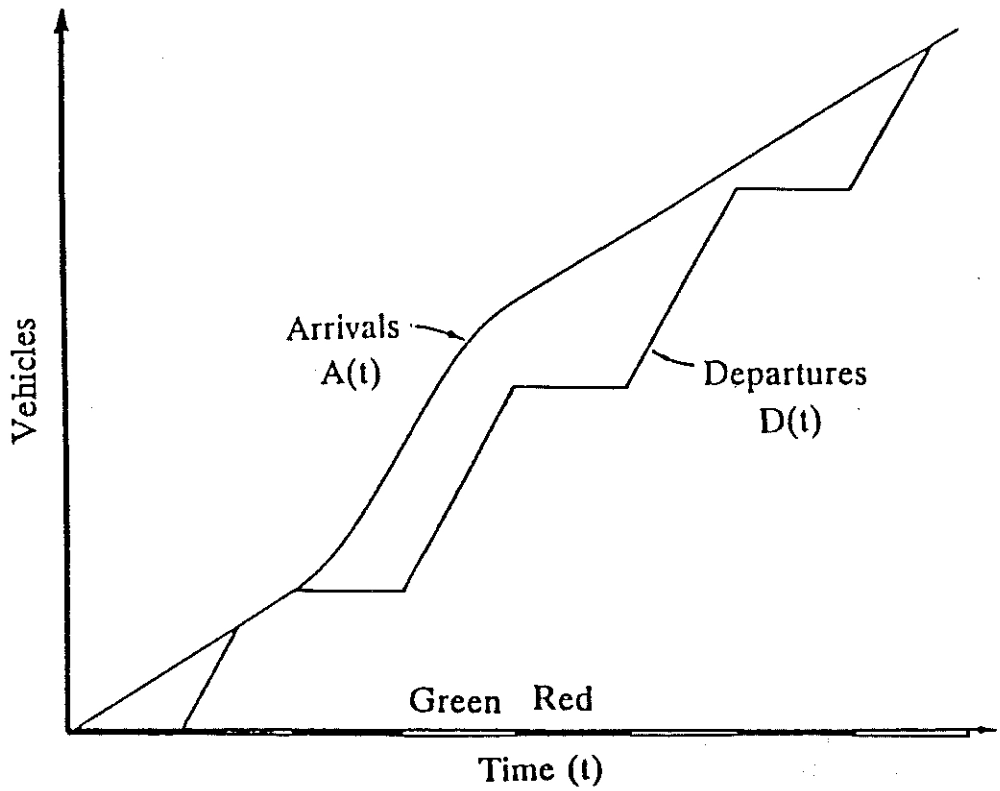


Figure 10. Input-Output Model for Calculation of Delays.

The difference between the cumulative number of vehicles arriving and being served on the approach is the net number of vehicles in the queue at the intersection. Hence, Figure 10 can also be drawn as Figure 9 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 should estimate delay with accuracy sufficient for normal engineering requirements.

The reduced data were adequate for drawing a the straight line for queue build up since the slope is equal to the arrival rate during 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, or the headway. The Highway Capacity Manual 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 gives the saturation flow rate. Table 9 shows the data and the calculation of the saturation flow rate for the morning peak period.

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 10 for the morning peak period. The data collected in other peak periods were reduced in a similar manner.

<u>Comparisons of Queue Length and Delays</u>

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 11 and 12 for the AM peak and Figures 13 and 14 for the PM peak.

Table 9. 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 10. 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)

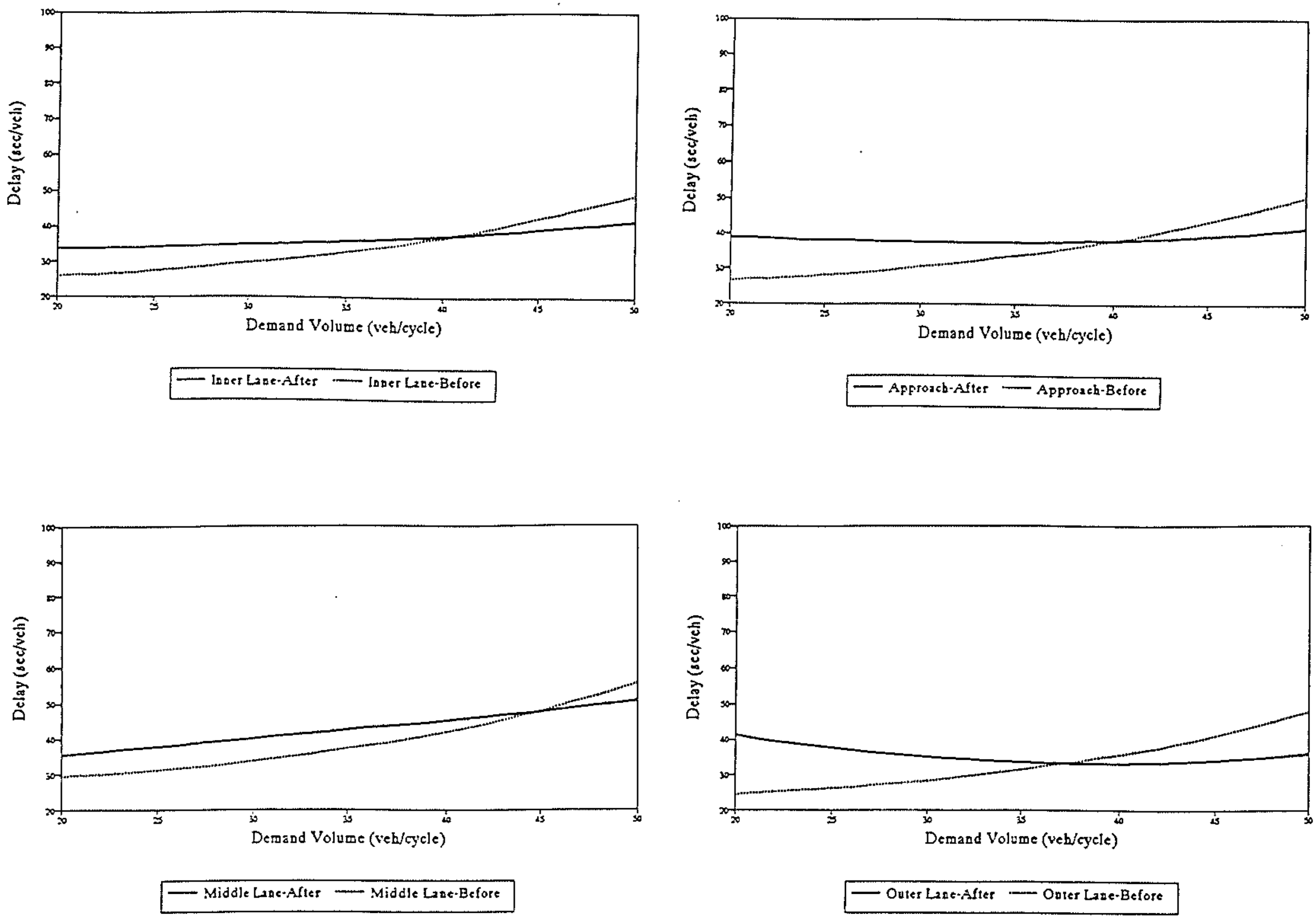


Figure 11. Delays Before and After Implementation of DALAS for A.M. Peak, by Lane Position.

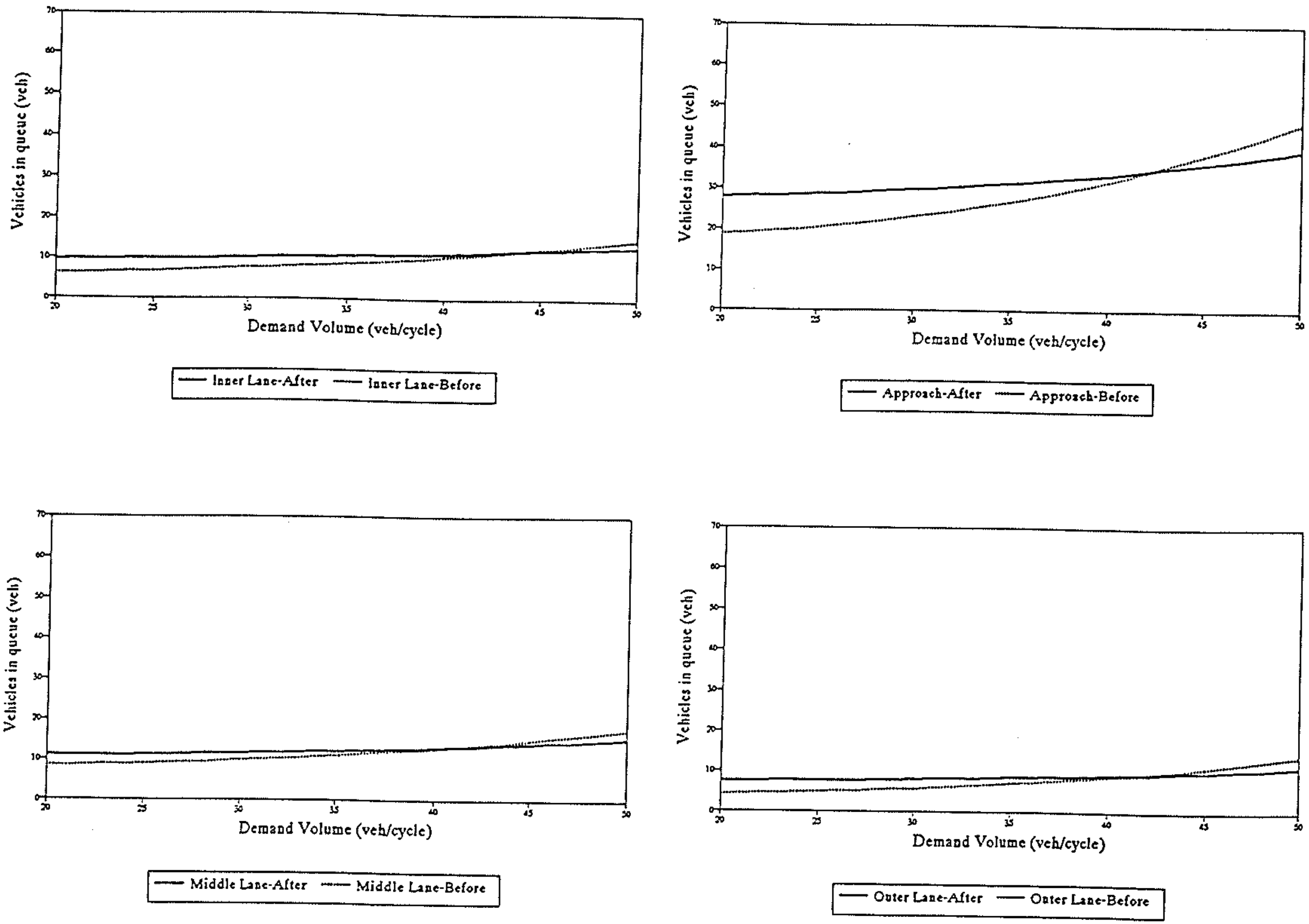


Figure 12. Queue Lengths Before and After Implementation of DALAS for A.M. Peak, by Lane Position.

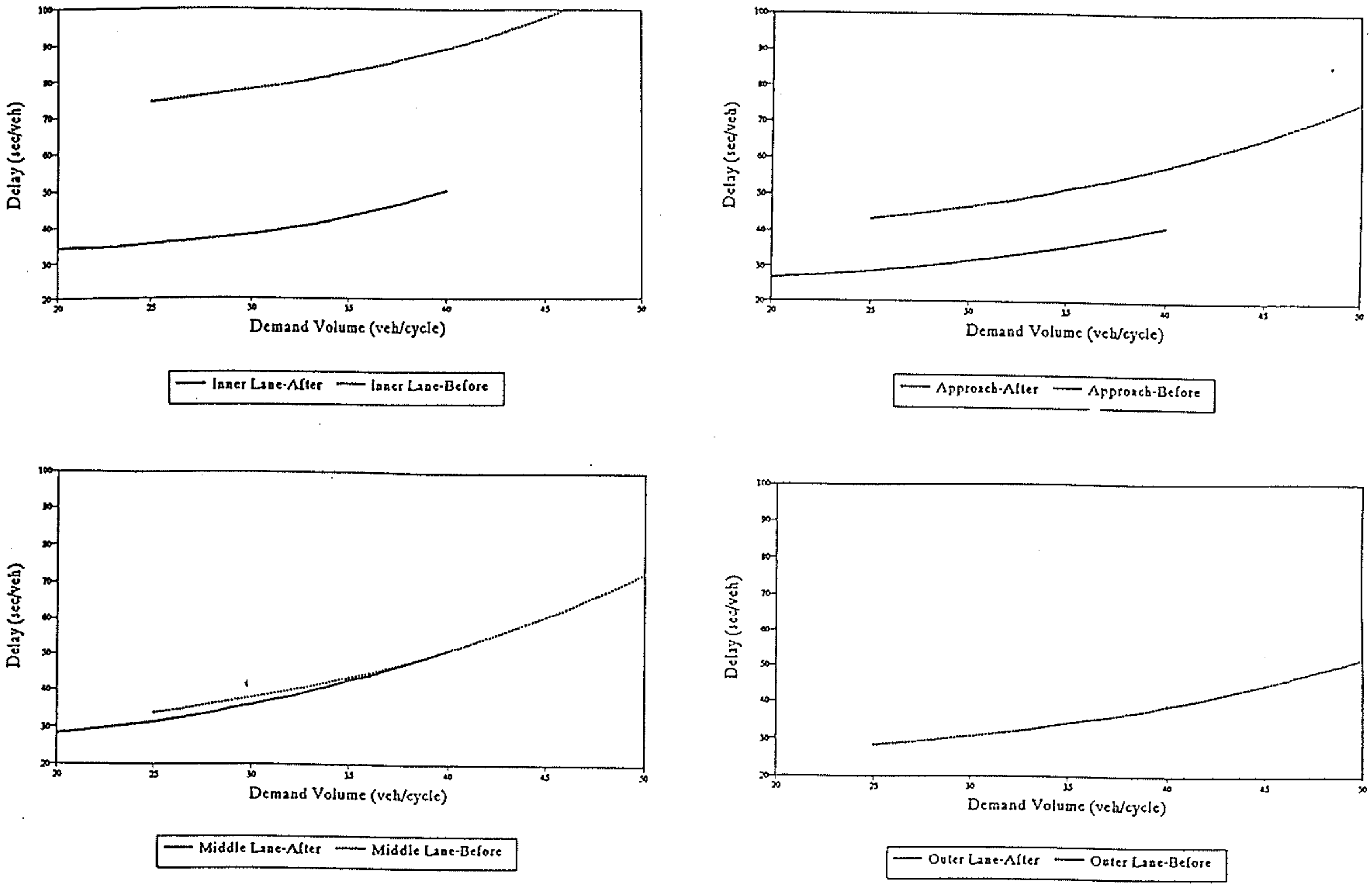


Figure 13. Delays Before and After Implementation of DALAS for P.M. Peak, by Lane Position.

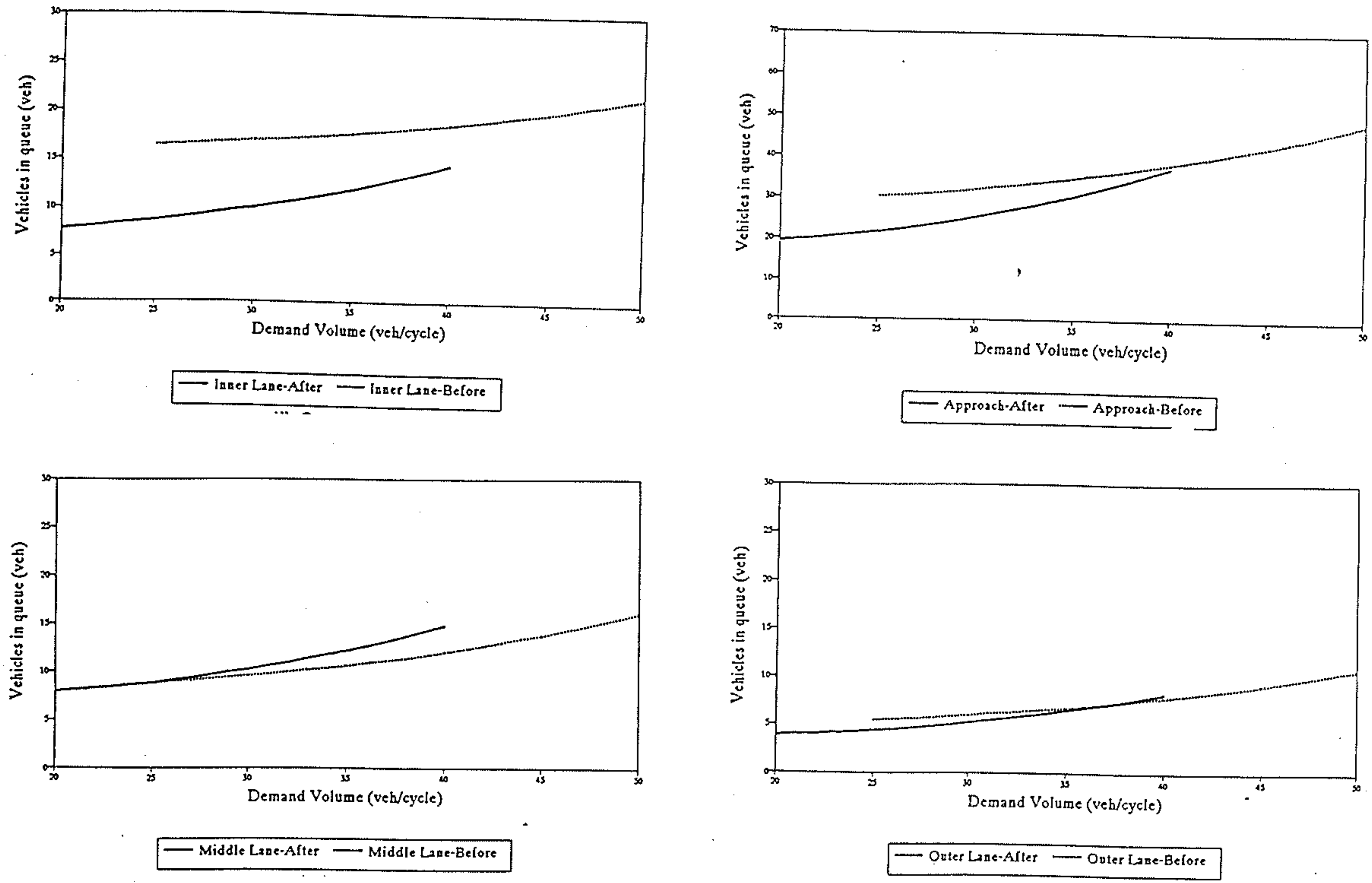


Figure 14. Queue Lengths Before and After Implementation of DALAS for P.M. Peak, by Lane Position.

3.8 Study Results

The results of the Houston study were:

1. 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
2. For the PM peak 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 as shown in Figure 13. Delays in the middle and outer lanes were unchanged.
3. Queue lengths were much less affected by the implementation of DALAS as illustrated in Figure 14. The only significant change was in the queue lengths observed in the inside lane.
4. The implementation of DALAS system seemed to have little or no effect on the violations of sign display.

3.9 Interpretation of Results

The results of comparison of Before and After data revealed that traffic delays were significantly reduced. Although not significant, there was a consistently higher queue length associated with the Before conditions. This reduction in delays and queue lengths and the reduction in overall delays and queue lengths could be attributed to the implementation of DALAS system at the study site. Traffic showed immediate response to the change in the sign display. This response of the traffic to the change in sign display 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 the safety.

4.0 COST-EFFECTIVENESS METHODOLOGY

4.1 Introduction

The purpose of this chapter is to provide information about appropriate cost-effectiveness analysis techniques for Dynamic Lane Assignment Signs (DALAS) so that consistent methodology is used to evaluate various system designs. Improvements using DALAS directly impact the efficiency of the roadway in which they are used. Selection of the most cost-effective design option for a particular situation is important because most agencies have limited funds. The decision is made more complex due to the fact that not only are there several variations of DALAS available as described in the previous chapter, but the benefits they provide are also difficult to assign monetary values.

Cost-effectiveness analysis (C/E) will be demonstrated as designed to accommodate these difficulties in a consistent and unbiased procedure. The cost-effectiveness techniques also provide a method for comparison of alternative solutions, such as timer controlled electromechanical signs or traffic demand controlled fiber optic signs. Also, discussion of these alternatives and how they will influence the overall cost of the system will illustrate the many variations that can be taken into consideration.

Decisions made on transportation improvements, such as DALAS, based only upon initial costs, maintenance costs and public demand will undoubtedly not represent the total benefits received from them. Traffic delay, pollutant levels and other various advantages and savings should also be accounted for to fully represent the need for dynamic lane assignments. Problems will arise when these benefits are aggressively assigned monetary values to justify the initial capital expenditures for the equipment. This type of allocation of values to nonquantifiable benefits leaves a wide domain for personal bias and inconsistency to enter into the analysis process.

These evaluation obstacles are diminished with the use of cost-effectiveness (C/E) analysis due to the fact that C/E is designed for the following complex situations:

1. When outputs of projects are difficult to assign monetary values.
2. Actual value judgements are left to the decision-makers (not the analyst).
3. The project is under the premise that the less the cost of any means to achieve a given goal, the more cost-effective is that means.

The procedure of cost-effectiveness analysis is generally well suited for transportation research projects of this type.

4.2 Cost-Effectiveness Analysis

The cost-effectiveness analysis procedure primarily involves the determination of several input values. Only basic mathematics are required to accomplish the computations involved. Comparisons of the monetary and nonmonetary dimensions of impact are achieved by dividing the latter into the former thus yielding the cost-effectiveness ratio (4).

Monetary Dimensions

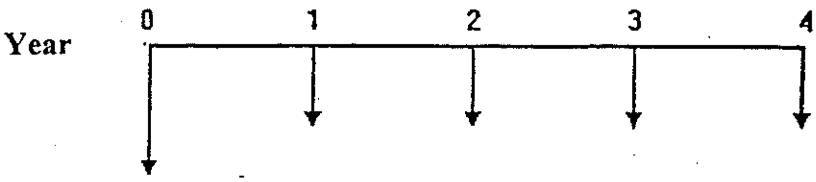
The monetary dimensions involved with DALAS include the initial cost of the system and the future maintenance/operations costs. Also, any other various costs that could contribute in the initial years can be added to the monetary dimensions. Any basic economic analysis procedure can be used to determine the initial costs and maintenance costs to attain an input value for monetary dimensions. A representative format is seen in Figure 15 using present worth analysis (5). It is important to point out that additional factors of initial costs may be utilized at this point. Also, the type of procedure used can vary according to what is most appropriate for the particular situation involved. Regardless of the procedure, the analyst must determine an end value which effectively represents the actual monetary dimension. Only then may this value be used in the C/E ratio.

Nonmonetary Dimensions

Evaluating the nonmonetary dimensions for use in the C/E ratio is more complex than monetary dimensions and will greatly vary with each situation. The primary objective of DALAS is to reduce traffic delay. This reduction can be measured in several ways, such as the amount of traffic able to pass through the intersection in a given amount of time or the average travel time through the intersection. Another way to determine the nonmonetary dimension is the reduction of queues. Queues are the distance that traffic is backed up due to the intersection's operation. If more cars are getting through the intersection each signal phase then the queues will be dramatically reduced.

Also, the detrimental environmental impacts will be lessened by the installment of DALAS. The shorter the amount of time a car is stopped and idling, the smaller the amount of pollutants released into the atmosphere. Although data collection on this environmental aspect is arduous, the benefit is significant enough so that designers should include it as a factor in their decision making process.

PRESENT WORTH METHOD IN COST EFFECTIVENESS ANALYSIS



Initial Cost = Pic **Maintenance Costs = A**

1. **Select an interest rate, i.**
   Most agencies have an interest rate standard for use in evaluating projects.

2. **Select number of years in which the system will be evaluated, n.**
   It is important to take into consideration that the cost-effectiveness ratio will be based on present day data collection. Therefore, it is not recommended to use an extended length of time that would outlast the effectiveness of the data.

3. **Calculate the present worth of the maintenance/operations costs, Pm.**

$$Pm = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

4. **Adding the value calculated in step 3 to the initial cost, Pic, gives the total Present Worth, Ptotal.**

$$Ptotal = Pic + Pm$$

Figure 15. Present Worth Method in Cost Effectiveness Analysis (5)

The nonmonetary dimension should be reduced to one number. As stated above, this final number can be in the form of anything from a length of time to a measure of pollutants. Choice of parameters should reflect the availability of data and the concerns of the decision-makers. These parameters must be chosen carefully to demonstrate all of the various significance the DALAS will be generate.

4.3 Applications

It is important to consider all of the aspects that are involved in the complete sign assessment costs rather than limited attention to the manufacturing and maintenance costs. Obviously the quality of sign transmission will become the most important of the these aspects to consider. Under this consideration the separation between fiber optic and electromechanical DALAS will be most apparent. Many alternatives to help increase the capacity of the system are available to use for electromechanical or fiber optic systems. A few of these alternatives are listed in Table 11. The use of these alternatives would then be used to improve the nonmonetary dimensions of the C/E analysis ratio.

<u>Summative Evaluation</u>

The most fundamental use of C/E is in judging whether programs are worthwhile. This process, called summative evaluation, simply uses the C/E ratio that is explained above to achieve a cost per benefit for understanding of the system. The format of summative formulation is as follows:

1. Calculate monetary dimensions, M. (Format shown in Figure 15.)
2. Determine nonmonetary dimensions, N. (Procedure discussed in "Nonmonetary dimensions.")
3. Determine the cost-effectiveness ratio, M/N.

Use of these computed ratios are then utilized by the decision-maker to weigh whether the benefit stated is worth the amount calculated. Although simple and direct, this method is not believed to be detailed enough to evaluate more complex DALAS systems.

Table 11. Alternatives for Increasing Capacity.

ALTERNATIVE	DESCRIPTION
Visibility	Ability to attract drivers attention
Selection	Number of display messages
Type of controller	Timer or traffic demand controlled
Driver response	Authority of sign / Low number of violations
Low Maintenance	Little or no annual cost for maintenance
Remotely Relampable*	Replacement of bulbs easily accessible
Efficiency	Ability to report problems in the system

* This is only for fiber optic signs

Formulative Evaluation

The use of C/E analysis to determine the best version of a program is termed formulative evaluation. The key concept in formulative evaluation is the cost-effectiveness ratio changes for comparing the differences in costs between two alternatives and the differences in the benefits. The format on how to use formulative evaluations is shown below:

1. **Calculate the monetary dimensions of each project** (This procedure is shown in Figure 15).

2. **Find the difference between the monetary dimensions.**

   M project 1 - M project 2 = Delta M

   Typically the project with the larger monetary value will be chosen as project 1. This is done to avoid interpreting negative numbers.

3. **Find the difference in nonmonetary dimensions.**

   Benefits of project 1 - Benefits project 2 = Delta N

4. **Find the cost-effectiveness ratio using the differences calculated in step 2 & 3.**

   $$\frac{\text{Delta M}}{\text{Delta N}} = \text{cost-effectiveness ratio}$$

The ratio that results is how much money per benefit that would be needed to use the more expensive system. When decision-makers see the ratio, they should evaluate if they think it is worth spending that certain amount of money for the extra benefits received.

5.0 COSTS OF THE TWO SIGNAGE SYSTEMS

The purpose of this chapter is to provide practical cost data obtained from sign manufacturers to estimate the total construction costs for a variety of DALAS systems.

5.1 Study Methodology

The first step was the determination of the true construction costs for the installation of DALAS systems. The first approach taken was to evaluate similar signs. Many types of fiber optic signs, which do not function exactly like the DALAS systems, are currently in use all over the country. In addition, competitive price estimates for actual DALAS systems were obtained from various commercial sign distributors. Also, bid prices for actual DALAS signs installed in Arlington, Texas were obtained. Next, various specifications for fiber optic signs were collected. The types of DALAS systems were split into two categories, electromechanical and fiber optic.

5.2 Electromechanical

Many distributors and manufacturers who work with fiber optic and electromechanical signs were contacted. Most of these contacts were fruitless due to the fact that several companies have decided to no longer work with fiber optic signs. Downing Manufacturing, located in Tulsa, Oklahoma, was the only successful source of information about the distribution of electromechanical DALAS signs.

Signs manufactured by Downing Manufacturing can be seen in Figure 16. These signs, constructed primarily from aluminum, can be mounted in various ways as shown in Figure 17. These signs are designed to operate under temperature conditions of -40 to 140 degrees Fahrenheit. The sign may be temporarily disabled if there are large amounts of snow and ice. Therefore, Downing Manufacturing offers an optional heater for areas that would experience this trouble. The display can be controlled by a clock timer, remote signal, manually, or by sensor device. Reflective or non-reflective sheeting can be chosen for the sign face. All components of the sign face conform to the Manual on Uniform Traffic Control Devices for regulatory lane assignment signs. These signs appear to be almost like black/white static regulating signs upon first inspection. Motorists may not even recognize their variable message display capabilities. This sign design was installed at the North Central Expressway site in Dallas, as described in Chapter 2. The double message sign depicted in the bottom center of Figure 18 best represents an electromechanical DALAS system.

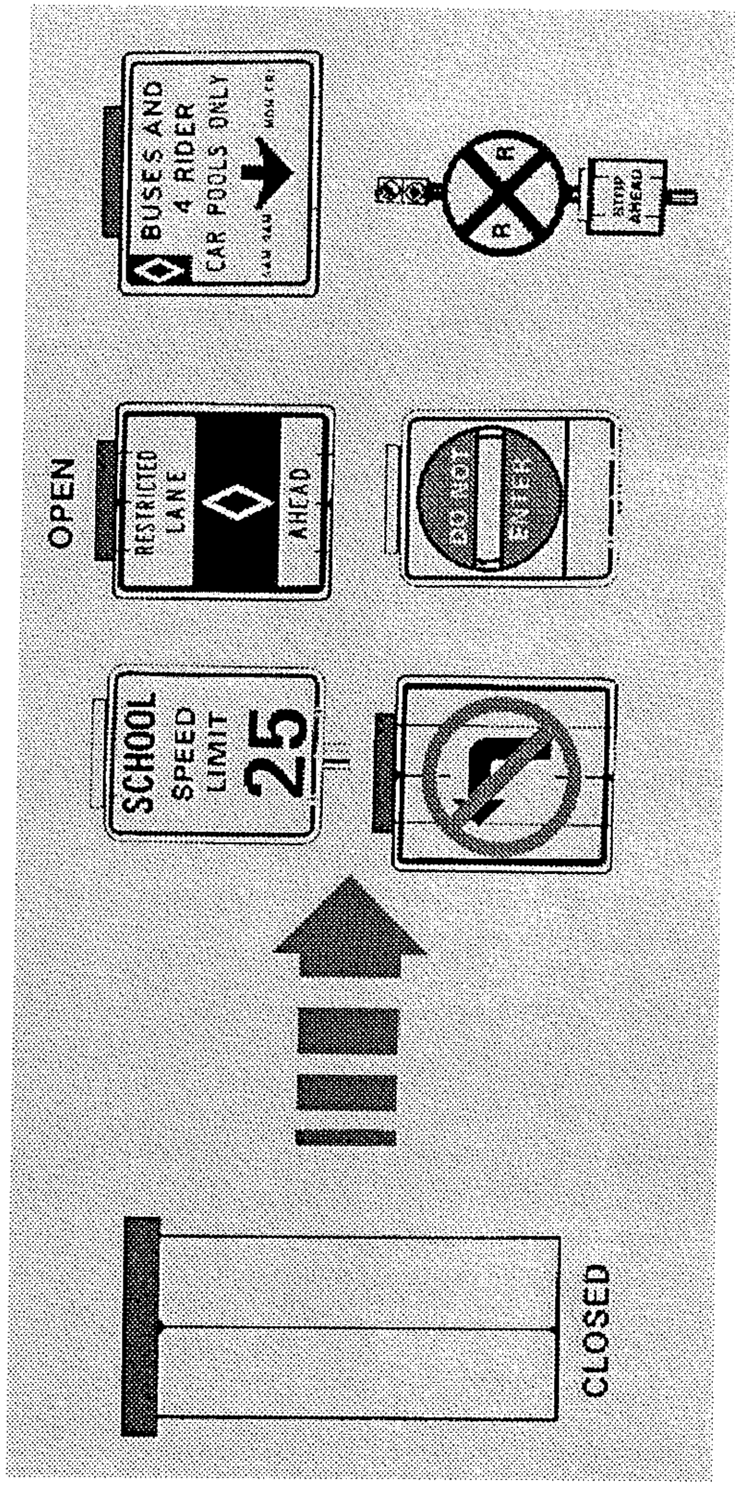


Figure 16. Downing Electromechanical Signs, Tulsa, Oklahoma.

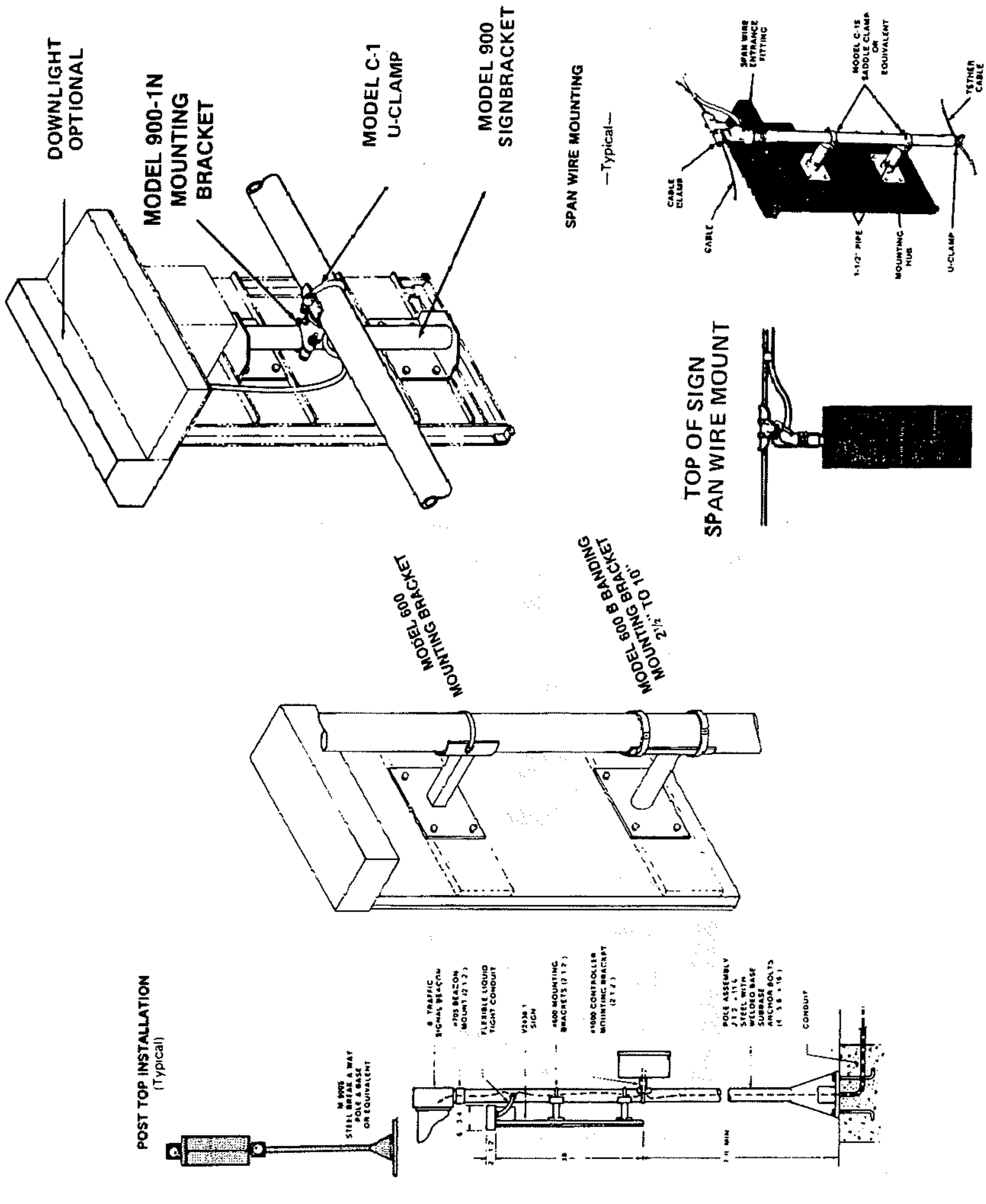


Figure 17. Methods of Mounting Signs

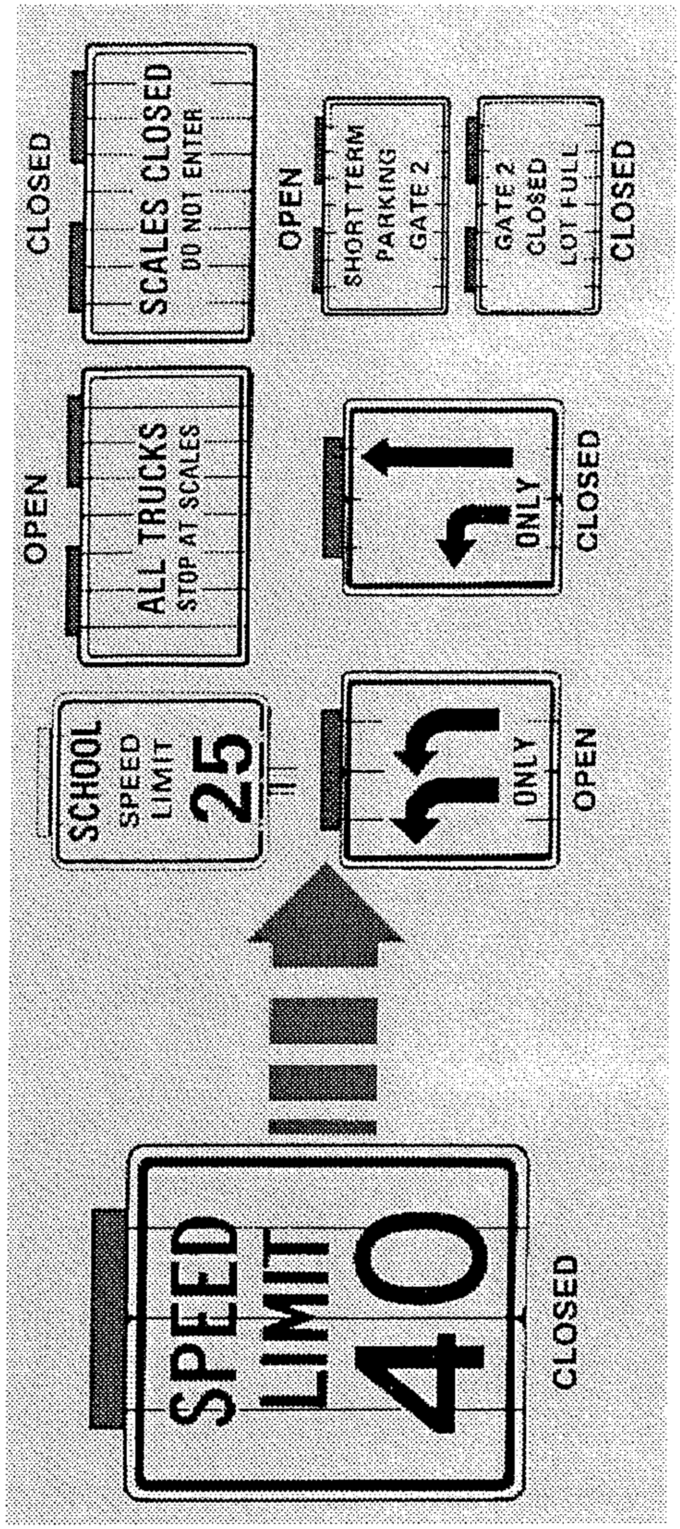


Figure 18. Double Message Sign that Best Represents an Electromechanical DALAS System.

Prices quoted for various sizes are included in Table 12. These prices were obtained via a telephone conversation with a Downing representative on March 31, 1993. The representative indicated that these prices were for individual sales and that the cost would be considerably less if bought in quantity. These reductions are figured on a bid-by-bid basis according to the customer and the specific item in question.

Even though these signs are fairly inexpensive and could be helpful for many types of traffic needs, they have not been widely used. Studies on driver response to these signs are needed to fully evaluate this Basic type of DALAS. For example, the opening and closing time of the sign panels is approximately six seconds, which might contribute to driver confusion. Also, the sign appears passive; a driver who frequently passes the sign may not immediately notice any change in display. These factors should be taken into consideration when a cost analysis is performed on electromechanical DALAS.

5.3 Fiber Optic

DALAS systems using fiber optics are much more complex than the electromechanical systems. Most fiber optic systems investigated use high quality step index glass or glass optical fiber. These fibers are grouped into bundles which are then ground smooth for optimum light transmission. The bundles come in a range of sizes which typically vary from 1.2 mm to 3.0 mm. Step-down voltage transformers are also needed to drive the small light generator units. The typical electrical input voltage is 115 volts AC to the transformers, which is then reduced to an average of 10.8 volts AC to the lighting units. High intensity quartz lamps that range from 40 to 50 watts are used for the light source. The prices for these individual projector units vary greatly according to the manufacturer.

As mentioned before, many systems using fiber optics are available to perform many different functions. Competitive bids for these signs can easily be obtained. These prices, however, are based on the assumption of mass production of the signs, and therefore are not representative of individual DALAS prices. The uniqueness of the fiber optic DALAS sign would add considerably to the price. This is seen in Table 13, which consists of the actual bid prices of DALAS systems in Arlington, Texas. The wide distribution of these prices raises the question of such a wide cost differential. The sign manufactured and distributed by Wells Manufacturing, of Vancouver, Washington, is depicted in Figure 19, while the sign manufactured and distributed by American Electronic, of Spokane, Washington, is depicted in Figure 20. The difference in workmanship or quality of fiber for each could constitute the difference in the bid prices.

Table 12. Downing Manufacturing's Standard Electromechanical Sign Sizes and Cost Estimates.

Sign Size	Square Feet	Price
24" x 24"	4	$ 500 range
24" x 30"	5	$ 500 range
24" x 36"	6	$ 500 range
24" x 38"	6.33	$ 500 range
24" x 42"	7	$ 500 range
24" x 48"	8	$ 500 range
30" x 24"	5	$ 501.61
30" x 30"	6.25	$ 545.90
30" x 36"	7.5	$ 742.63

Note : Costs do not include post mounting or installation.

Table 13. Arlington, Texas Competitive Bid Prices for Fiber Optic Signs for Lane Assignment Control.

LOCATION	DATE INSTALLED	MANUFACTURER	DISTRIBUTOR	PRICE
Lamar/Cooper	99-92	American Electronic Sign Co.	American Electronic Sign Co.	$1,680
Cooper/Sublett	2-12-92	Wells Signs & Manufacturing	Wells Signs & Manufacturing	$3,800
I20/GOB.	N/A*	Electro Fiberoptics Corp.	Consolidated Traffic Controls Inc.	$2,819
Division/Stadium	N/A*	N/A	Hi-Tech	$1,550
Copeland/Collins	N/A*	American Electronic Sign Co.	American Electronic Sign Co.	$1,380

*N/A - Not applicable. Signs have been purchased, but not yet installed.

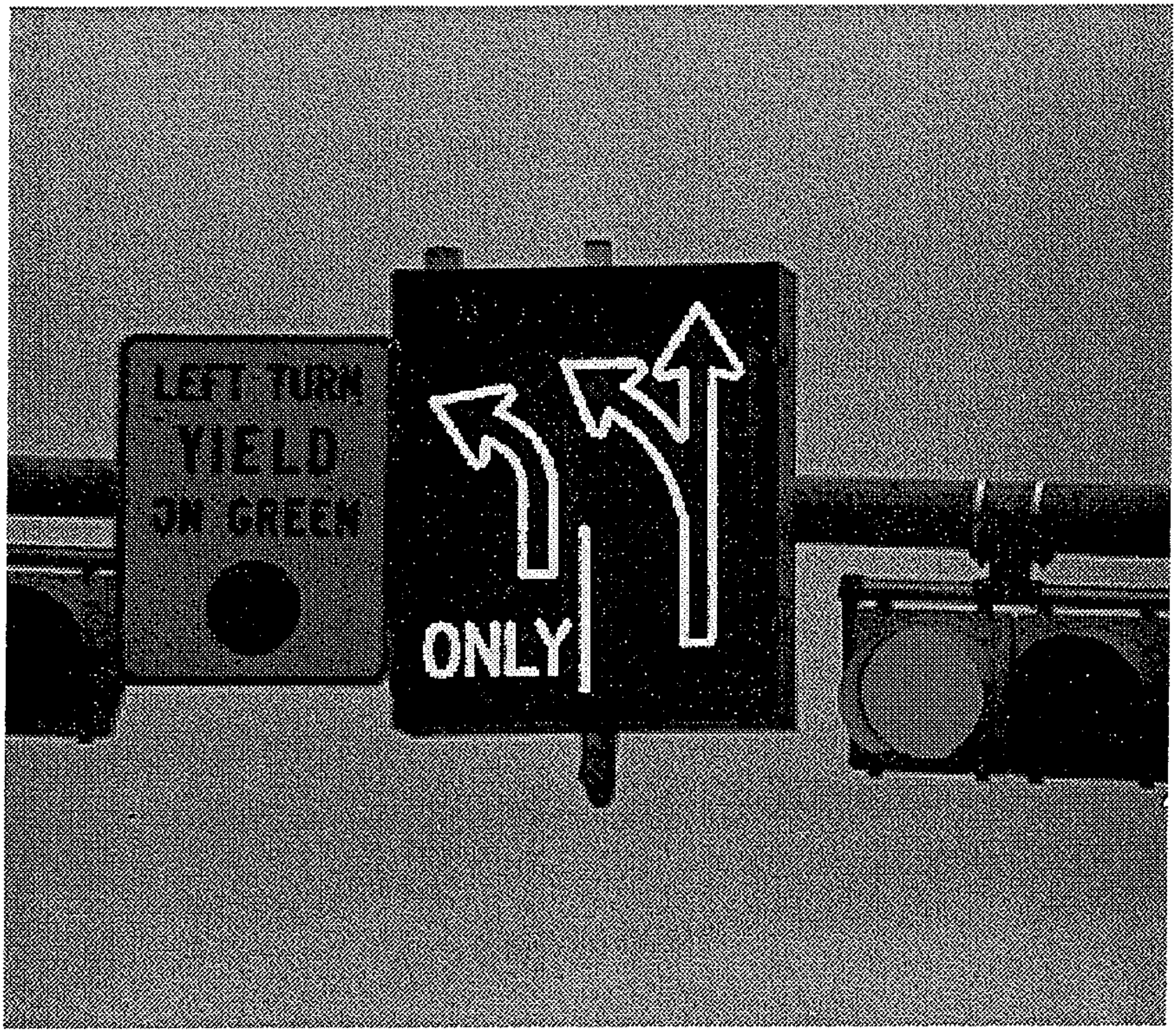


Figure 19. Sign Manufactured and Distributed by Wells Manufacturing, Vancouver, Washington.

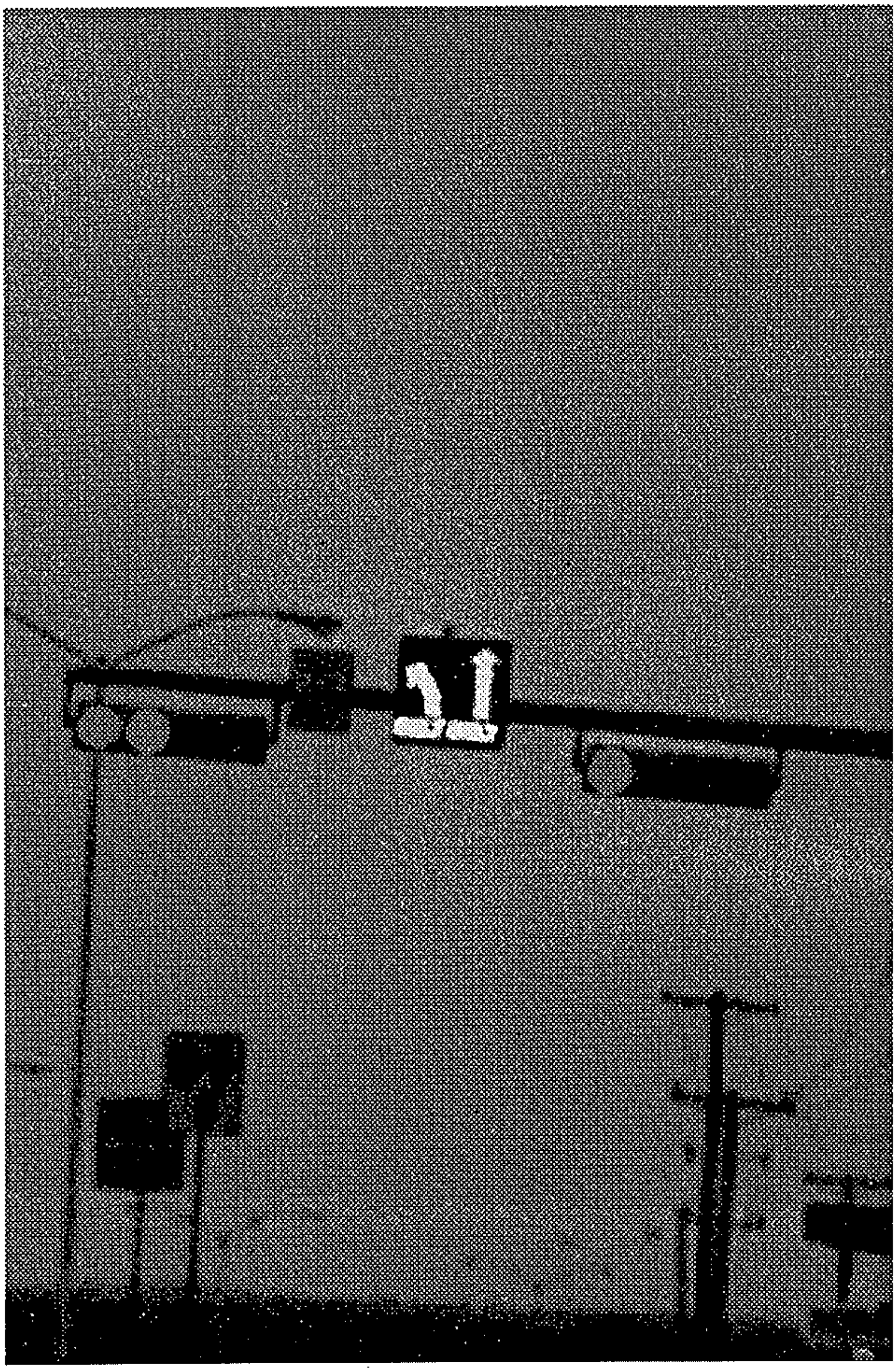


Figure 20. Sign manufactured by American Electronic, Spokane, Washington.

C.J.Hood Company, of Hartford, Connecticut, was an excellent source of information for the fiber optic technology. Figure 21 illustrates remotely relampable system for fiber optic signs. Prices for this system were discussed with Dr. Neilon J. Rowan of Texas Transportation Institute on April 26, 1993. For a fiber optic sign that displayed an "X" the price would be approximately $1700 per sign, and with the remotely relampable system included the price would be $6500 per sign. Even though these cost estimates are not figures for a DALAS system, per se, they provide a picture of what adding this system feature (remote relamping) to the sign might cost. This addition would improve the fiber optic DALAS systems due to the fact that future maintenance costs would be diminished greatly.

There is still much to learn concerning DALAS systems. However, the uniqueness of these systems makes it a challenge to arrive at true construction costs for an urban freeway traffic environment. These systems may provide an operational answer to many traffic problems that plague urban areas.

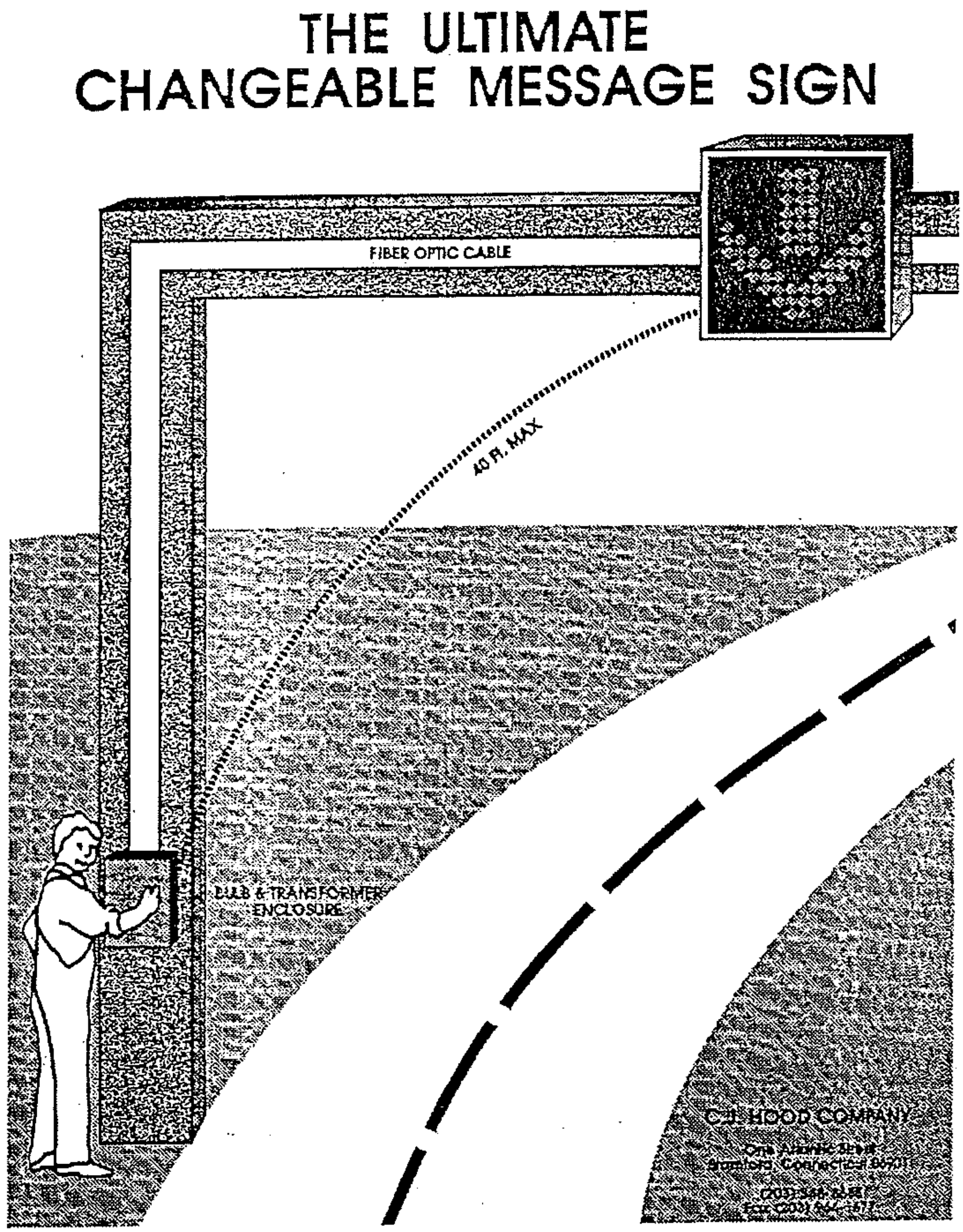


Figure 21. Remotely Relampable Sign for Fiber Optic Signs.

6.0 ENERGY BENEFITS OF DALAS

6.1 Introduction

The U.S. transportation sector's petroleum consumption is about 60% of all U.S. petroleum use. There is a need to conserve fuel on account of such a major share of petroleum consumption by the transportation sector, and limited petroleum resources. Further, heavy fuel consumption by vehicles causes environment damage and also increases economy's vulnerability to oil price shocks.

This study was focussed on assessment of energy benefits associated with the use of DALAS signs at signalized intersections with varying turning volume demand. In this study, the DALAS signs are assessed at a diamond interchange because typical diamond interchanges in Texas with frontage roads have the problem of highly varying turning volume demand.

6.2 Principal Procedures of Study

The principal objective of this study was to assess the energy benefits of DALAS signs over static lane assignment system. The successful achievement of this objective involves the following principal study procedures:

1. Establishing turning volume demands representing highly varying turning traffic at diamond interchanges for low, medium, and high volume conditions;
2. Selecting lane assignment strategies that are typically used on frontage roads at diamond interchanges;
3. Estimating fuel consumption for all combinations of turning patterns and lane assignment strategies for low, medium, and high volume conditions on an yearly basis; and
4. Comparing the costs of the signage systems, energy consumption for each signage system.

6.3 Study Design

In order to represent highly varying traffic demand volumes at diamond interchanges, four cases of different turning percentages were assumed for a three lane one way frontage road. Turning percentages for the four cases are as shown below:

Case 1.	Case 2.	Case 3.	Case 4.
Left Turns - 60%	Left Turns - 25%	Left Turns - 25%	Left Turns - 15%
Through - 25%	Through - 60%	Through - 30%	Through- 65%
Right Turns - 15%	Right Turns - 15%	Right Turns - 45%	Right Turns - 20%

Turning demand volumes were established in each of the above cases for low (v/c = 0.5), medium (v/c = 0.7), and high (v/c = 0.9) volume conditions, assuming a cycle length of 90 seconds and a green time of 30 seconds. The saturation flow rates for each of the three lanes of the frontage were calculated assuming the left turn and right turn factors to be 0.95 and 0.85 respectively. The capacity of each lane was computed using the following equation

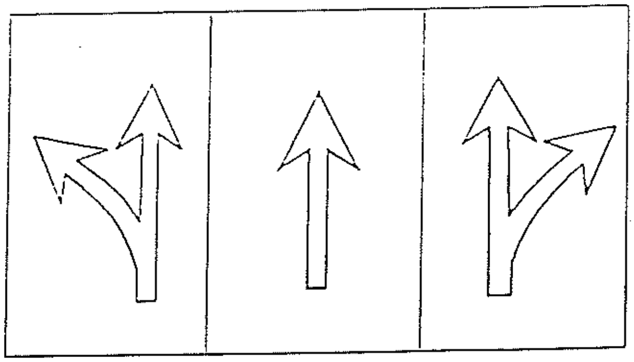
$$c = \text{capacity} = \text{saturation flow rate} \times (\text{green time}/\text{cycle length})$$

The capacity for the approach is the sum of individual capacities of all the three lanes. The total approach volume equals total capacity times v/c ratio. The v/c ratios for low, medium, and high volume conditions were assumed to be 0.5, 0.7, and 0.9 respectively. The approach volumes thus obtained for the above three volume conditions were split into left turning, through, and right turning traffic as per the turning percentages assumed in each of the four cases that were considered.

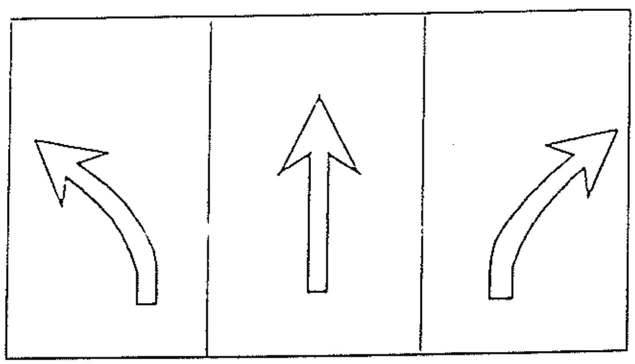
Three lane assignment strategies that are typically used on frontage roads at diamond interchanges were selected. Figure 23 illustrates these three strategies. Each of these strategies, if used separately represents static lane assignment. A combination of these strategies represents a dynamic lane assignment system where each of these strategies is used for certain period of time. Among all the available lane assignment options, DALAS chooses that lane assignment for the approach which results in least delay and fuel consumption per approach.

Saturation flow rates per movement were computed for all combinations of volume conditions and selected strategies using PASSER III-90. A spreadsheet which takes demand, cycle length, phase time, and saturation flow rate as inputs and computes delay per vehicle and fuel consumption per hour was prepared. Table 14 illustrates the format of spreadsheet. The shaded cells of the spreadsheet contain input where as the remaining cells contain computed values.

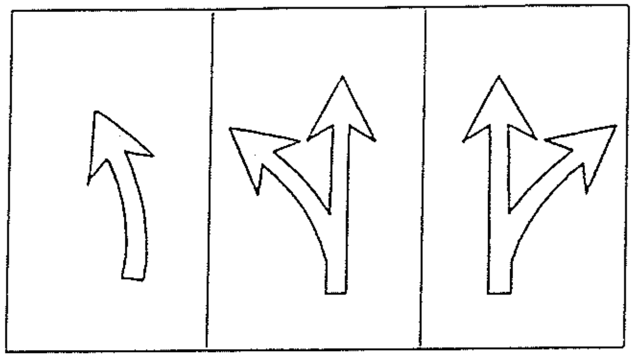
Delay and fuel consumption values per movement were computed using the above spreadsheet for all combinations of turning patterns and lane assignment strategies for low, medium, and high volume conditions. Average delay and fuel consumption values per approach were then calculated. These results are summarized in Table 15, Table 16, Table 17 for low, medium, and high volume conditions, respectively.



Strategy A



Strategy B



Strategy C

Figure 23. Typical Lane Assignment Strategies used at a Diamond Interchange.

Table 14. Spreadsheet to Calculate Delay and Fuel Consumption.

	Left Side				Right Side			
Movement #	A	B	C	A+C	A	B	C	A+C
Demand (q)	115	615	205	1300	205	1530	516	828
Saturation F.R (s)	1530	2793	1039	3600	1039	5046	1710	3600
Green time (g)	30	30	34.5	63.5	23.7	26	39.5	63.2
Cycle Length	90	90	90	90	90	90	90	90
Capacity(Q = s * g/c)	510	931	398	2540	274	1458	751	2528
Speed (mph)	30	30	30	30	30	30	30	30
Distance (feet)	100	100	100	100	100	100	100	100
Distance (miles)	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Total Travel (vmph)	2.195	11.737	3.912	24.809	3.912	29.198	9.847	15.802
x = q/Q	0.23	0.66	0.51	0.51	0.75	1.05	0.69	0.33
Z = x-1	-0.77	-0.34	-0.49	-0.49	-0.25	0.05	-0.31	-0.67
y	0.08	0.22	0.20	0.36	0.20	0.30	0.30	0.23
No	1.02E-04	8.53E-02	6.97E-02	1.12E-03	3.94E-01	1.49E+00	1.36E-01	2.31E-06
h (Ave. stops/veh)	0.65	0.77	0.70	0.41	0.90	0.95	0.73	0.35
Stops per Mvmt./hr	75	476	144	539	184	1459	378	288
Delay (secs/veh)	21.7	27.3	4.4	0.0	40.0	74.2	5.8	0.2
Delay per Mvmt (veh-hr/hr)	0.69	4.66	0.25	0.00	2.28	31.56	0.83	0.04
Fuel Cons. (gal /hr)	1.010	6.525	1.140	4.002	2.844	32.377	3.104	2.272
Queue Length	2.07	13.23	4.01	14.98	5.10	40.53	10.50	8.01

Table 15. Comparison of Delay and Fuel Consumption per Approach for Low Volume Conditions and Lane Assignment Strategies (v/c = 0.5).

Traffic Case	Strategy A		Strategy B		Strategy C	
	Delay (sec/veh)	Fuel Con (gal/hr)	Delay (sec/veh)	Fuel Con (gal/hr)	Delay (sec/veh)	Fuel Con (gal/hr)
I	24.62	5.545	24.65	5.53	22.67	5.208
II	22.6	5.197	24.25	5.486	22.7	5.224
III	23.3	5.324	23.34	5.326	23.34	5.326
IV	22.65	5.211	25.09	5.631	23.3	5.33

Table 16. Comparison of Delay and Fuel Consumption per Approach for Medium Volume Conditions and Lane Assignment Strategies (v/c=0.7).

Traffic Case	Strategy A		Strategy B		Strategy C	
	Delay (sec/veh)	Fuel Con (gal/hr)	Delay (sec/veh)	Fuel Con (gal/hr)	Delay (sec/veh)	Fuel Con (gal/hr)
I	30.99	9.14	31.05	9.154	24.34	7.765
II	24.29	7.911	31.09	9.343	24.74	8.024
III	26.23	8.071	26.28	8.08	26.28	8.08
IV	24.3	7.918	35.01	10.101	25.87	8.293

Table 17. Comparison of Delays and Fuel Consumption per Approach for High Volume Conditions and Lane Assignment Strategies (v/c=0.9).

Traffic Case	Strategy A		Strategy B		Strategy C	
	Delay (sec/veh)	Fuel Con (gal/hr)	Delay (sec/veh)	Fuel Con (gal/hr)	Delay (sec/veh)	Fuel Con (gal/hr)
I	70.34	20.52	70.44	20.552	26.63	10.327
II	26.44	10.623	54.83	17.15	27.16	10.819
III	34.58	12.596	34.66	12.607	34.66	12.607
IV	26.45	10.639	87.14	24.302	30.13	11.643

In order to represent the highly varying traffic demand volumes at a diamond interchange, each of the four traffic flow cases was assumed to prevail for six hours a day. Each of the static lane assignments were compared with DALAS by estimating the energy savings that would result if DALAS were used instead of one of the three strategies. The difference in the amount of fuel consumed in the case of DALAS and a specific strategy is energy saved per hour against that strategy. The energy savings resulting from the use of DALAS instead of a particular strategy for the whole day is the sum of energy savings for six hours for all the four cases. An estimate of energy savings of DALAS against a strategy for one year was obtained by multiplying the energy savings per day by the number of days in an year.

Estimates of energy savings of DALAS against each of the three strategies for one year are illustrated in Figure 24, Figure 25, and Figure 26 for low, medium, high volume conditions. It can be seen from these figures that the higher the traffic volumes, the greater are the energy savings obtained by the use of DALAS. It may also appear from the figures that the energy savings are not substantial when DALAS is used instead of Strategy C. As such, use of DALAS is not justified, keeping in view their installation and maintenance costs. However, it has to be noted that each of the four cases considering different turning percentages were assumed to prevail for six hours in a day. It is possible that volume conditions for one of these cases during which Strategy C is not efficient, might prevail for most part of the day. In such an event use of DALAS would certainly offer substantial energy benefits.

In order to estimate the average energy benefits of DALAS over static lane assignment signs over a period of one year per intersection, the probability of each of the three lane assignment strategies being used at a location is assumed to be equally likely. Therefore, the average energy benefits of DALAS over static lane assignment signs would be the mean of energy benefits of DALAS over each lane assignment strategy that was considered. These values were computed to be 911, 4131, and 24981 gallons per year per intersection for low, medium, high volume conditions, respectively. Further, to estimate the energy savings for an average day, it is assumed that each of the low, medium and high volume conditions prevail for one third part of a day for urban freeway conditions. The energy savings on an average day would then be 10000 gallons per year per approach. If the cost of a typical DALAS is $5000 including the installation costs, then the pay back time in energy savings for two of these signs per approach would be one year.

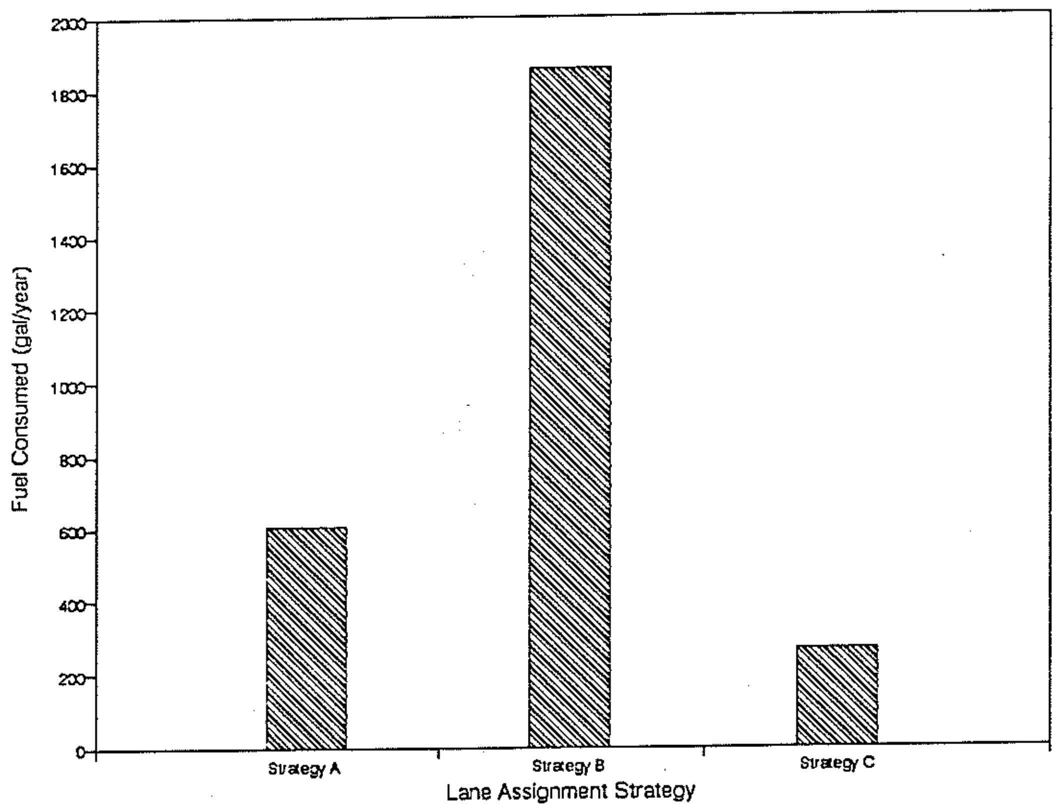


Figure 24. Energy Benefits of DALAS over Static Lane Assignment Strategies for Low Volume Conditions.

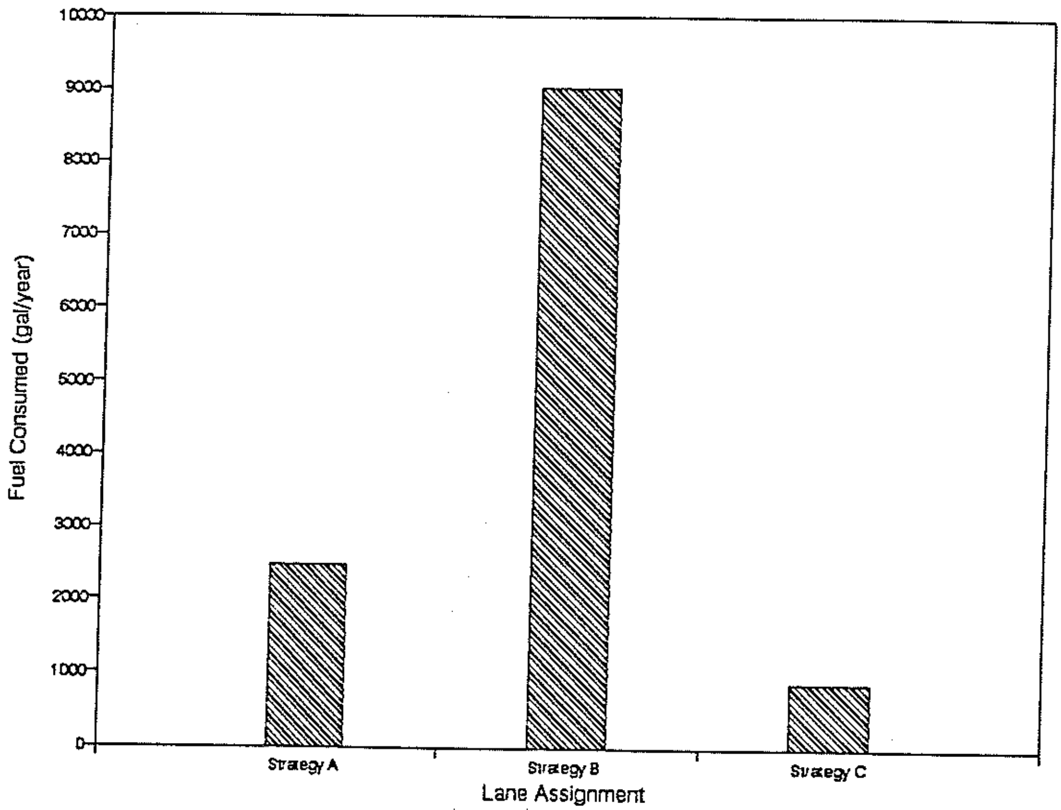


Figure 25. Energy Benefits of DALAS over Static Lane Assignment Strategies for Medium Volume Conditions.

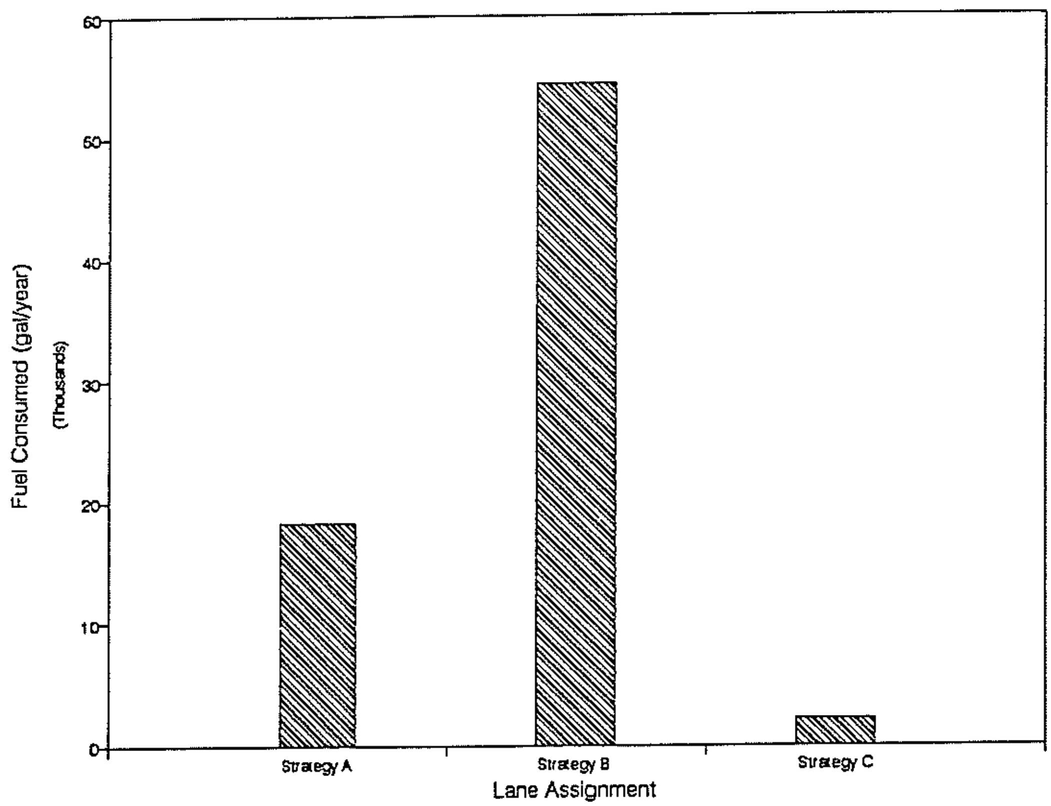


Figure 26. Energy Benefits of DALAS over Static Lane Assignment Strategies for High Volume Conditions.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The operational effectiveness of the advanced version of DALAS operating in Houston and the basic version operating in Dallas were evaluated for signalized diamond interchanges. Best estimates of true construction costs of the two systems were obtained at different bid levels and cost-effectiveness analyses were performed. Potential energy savings of DALAS over static lane assignment signs were estimated for various traffic conditions.

The following are the conclusions drawn from this research:

1. When significant variations in turning demand volumes at interchanges occurs, DALAS as compared to the use of static lane assignment signs were found to be very effective in substantially reducing delays and queue lengths.
2. Significant numbers of violations of static sign display could be attributed to high v/c ratio, or to the passive sign display, or both.
3. Presence of long queues can result in violations of sign display due to either one or both of the following reasons
   (a) Inability of the drivers of vehicles to read the signs clearly because of the distance separating them from the signs due to the presence of long queues.
   (b) Violators disregarding the sign display, inspite of being able to see them clearly in an attempt to avoid the extra delay due to the presence of long queues.
4. The advanced version of DALAS currently being used in Houston is more effective in communicating information to drivers than the basic version that is being used in Dallas.
5. Electromechanical DALAS are relatively inexpensive as compared to fiberoptic DALAS and are relatively simple to operate.
6. Fiber optic DALAS systems provide better visibility than electromechanical DALAS system in terms of visibilty. Also, they can better handle unpredictable variations in turning demand volumes because they can be traffic actuated. Electromechanical devices would have to be designed to operate basic systems.
7. Addition of the remote relamping feature to fiber optic DALAS increasese initial costs by a substantial amount. Future maintenace costs, however, would be greatly reduced.
8. The energy savings associated with the use of DALAS as compared to static lane assignement signs are substantial, when there is significant variation in turning demand volumes. It is estimated that these energy savings on an average would be 911, 4131, and 24981 gallons per year per approach for low, medium and high volume conditions, respectively, considering the assumptions made in Chapter Six. An average savings of 10000 gallons per approach per year should occur.
9. The higher the traffic volumes, the greater are the energy savings associated with DALAS.
10. The mean pay back time for installation of two signs (typical DALAS) would be one year assuming low, medium, and high volume conditions prevail for one third of a day.

7.2 Recommendations

Keeping in view the energy benfits and reduction in delays associated with the use of DALAS at locations where the turning demand volumes vary significantly, Fiber optic DALAS provide better service than the electromechanical DALAS. However, they are much more expensive and complex to operate than electromechanical DALAS. Keeping in view these factors, use of fiber optic DALAS should be considered a viable option when the variation in turning demand volumes at an interchange is highly unpredictable and electromechanical DALAS which are operated by time of day are judged inefficient in handling the dynamic traffic demands. It would be economical to use fiber optic DALAS at those locations where traffic detectors already exist with actuated signal control.

Use of electromechanical DALAS system at an interchange is a good option when the variation in turning demand volumes is fairly predictable by time of day and when traffic detectors are absent at the interchange. Further studies on driver response to these signs are needed to fully evaluate their capability in communicating information to drivers clearly and to identify what can be done to improve their performance. Manual traffic studies should be routinely conducted to insure that movement capacities provided by the signs are not exceeded when provided by time-of-day control.

It is very important to consider all the above mentioned issues and perform cost-effectiveness analysis as discussed in Chapter 4.0 before considering installation of DALAS at locations where the turning demand volumes vary significantly.

REFERENCES

1. Herrick, G.C., "Strategies for Improving Traffic Operations at Oversaturated Signalized Diamond Interchanges." A Thesis in Civil Engineering, Texas A&M University, May 1992.
2. Hanks, Jr., J. W. and T.J. Lomax. "Roadway Congestion in Major Urban Areas, 1982 to 1988." Texas Transportation Institute Research Report 1131-3, 1990.
3. Jella, K. R., "An Operational Assessment of Dynamic Lane Assignment Signs in Houston" A Thesis in Civil Engineering, Texas A&M University, December 1992.
4. Thompson S. M., Benefit-Cost Analysis for Program Evaluation (Beverly Hills: Sage Publications, 1980) 221-248.
5. Thompson 230-231.
6. Newnan, G. D., Engineering Economic Analysis (San Jose: Engineering Press, Inc., 1991) 60-64.