Technical Report Documentation Page

1. Report No. FHWA/TX-05/0-4740-2	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle THE EFFECTS OF INCIDENTS ON CONCURRENT FLOW HIGH OCCUPANCY VEHICLE LANE DELAY ON IH-635 (LBJ FREEWAY) IN DALLAS, TEXAS	5. Report Date October 2004
	6. Performing Organization Code
7. Author(s) A. Scott Cothron, Stephen E. Ranft, and David W. Fenno	8. Performing Organization Report No. Report 0-4740-2
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. Project 0-4740
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Technical Report: September 2003-August 2004
	14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Improved Quantification of High Occupancy Vehicle (HOV) Lane Delay Savings
URL: http://tti.tamu.edu/documents/0-4740-2.pdf

16. Abstract

High occupancy vehicle (HOV) lanes provide travel time savings and offer a more reliable trip time to its users. Historically, the determination of travel time savings on HOV lanes as compared to general-purpose lanes is calculated using data collected on days without incidents. The objective of this research is to determine the effect on travel time to users of Dallas' concurrent flow buffer-separated HOV lanes on IH-635 (LBJ Freeway) during incident conditions. The research results will supplement research on Houston's barrier-separated HOV lanes on the same topic which are documented in Report 0-4740-1, developed concurrently.

The data used to determine HOV lane user benefits/disbenefits during incidents included video data of actual peak period incidents from Dallas' Traffic Management Center and corresponding speed and travel time data in the corridor. Only a few incidents were available for intense data analysis due to the unanticipated speed and travel time data limitations. Incidents blocking one or more of the general-purpose lanes showed a maximum additional travel time savings to HOV lane users of 10 minutes per vehicle for incidents with a lane blockage of nearly 1 hour. Shorter duration incidents produced less added travel time savings. Incidents blocking the HOV lane, due to the incident itself or by responding emergency vehicles, resulted in the HOV lane users experiencing a maximum delay of approximately 10 minutes. Incidents in which both the HOV lane and Lane 1 are blocked delays HOV lanes users a maximum of approximately 14 minutes. The overall net benefit offered to concurrent flow HOV lane users when both non-incident and incident days are included in the calculation equates to only about 1 minute round trip travel time savings per vehicle per day.

An unanticipated result of this research is the realization of the importance of proper incident response for maintaining operation of the HOV lane during times of incidents. Simply stated, the HOV lane during certain general-purpose lane incidents appeared to be operating effectively until emergency vehicles came on the incident scene. Suggestions for incident response techniques are offered for maintaining HOV lane operation, including preferred placement of emergency vehicles and directing traffic proactively.

17. Key Words High Occupancy Vehicle Lanes, HOV Lanes, Incidents, Travel Time Savings, Delay, Buffer-Separated HOV Lanes, Concurrent Flow HOV Lanes	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 http://www.ntis.gov

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 50	22. Price

THE EFFECTS OF INCIDENTS ON CONCURRENT FLOW HIGH OCCUPANCY VEHICLE LANE DELAY ON IH-635 (LBJ FREEWAY) IN DALLAS, TEXAS

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Report 0-4740-2
Project Number 0-4740
Project Title: Improved Quantification of
High Occupancy Vehicle (HOV) Lane Delay Savings

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

October 2004

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge was A. Scott Cothron, P.E., (Texas, # 93601).

NOTICE

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA).

The authors wish to acknowledge the following individuals whose insight and assistance contributed to the successful completion of this research project.

- David Fink, P.E. – TxDOT Houston District, Project Director.
- Terry Sams, P.E. – TxDOT Dallas District, Project Coordinator.
- Clint Jumper, P.E. – TxDOT Traffic Division, Austin, member of Project Monitoring Committee.
- Rajesh Gurnani, P.E. – TxDOT Dallas District, member of Project Monitoring Committee.
- Lieutenant Vera Bumpers – Harris County Metropolitan Transit Authority, member of Project Monitoring Committee.

The authors also wish to acknowledge Robert McLain and Aruna Nathu from the Texas Transportation Institute for their valuable assistance with the time intensive task of video data retrieval and data reduction. In addition, Christy Harris of the Texas Transportation Institute provided valuable support and technical assistance in seeing this report through to completion.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1: INTRODUCTION

1.1 PURPOSE

Two goals of a high occupancy vehicle (HOV) lane are to provide travel time savings and a more reliable trip time to its users. Ideally, the travel time on the HOV lane should be less than the travel time on adjacent general-purpose lanes during weekday peak periods. Historically, the calculation of HOV lane travel time and general-purpose lane travel time is done using data collected on days without the occurrence of an incident in the corridor. Realistically, in urban corridors with a lot of congestion, incidents commonly occur and there are few incident-free days. Therefore, a true comparison of HOV lane travel time and general-purpose lane travel time should include data collected on days both with and without incidents. It is likely that travel time benefits of HOV lanes on incident days could far outweigh the benefits on incident-free days. However, in the case of concurrent flow HOV lanes, incidents on the general-purpose lanes can affect the HOV lane as well, particularly when the inside shoulder was removed to allow for the HOV lane. The purpose of this research is to quantify this additional travel time benefit when the HOV lane is not affected by the incident and the decrease in benefit when the HOV lane is affected by the incident.

1.2 BACKGROUND

Short-term (interim) HOV projects implemented by the Dallas District of the Texas Department of Transportation (TxDOT) and Dallas Area Rapid Transit (DART) include buffer-separated concurrent flow HOV lanes that enhance public transportation and overall mobility until permanent treatments can be implemented. The Federal Highway Administration (FHWA) considers these HOV lanes interim projects as they have been retrofitted into the existing freeway facility resulting in design exceptions from normally required standards. IH-635 (LBJ Freeway), a corridor well known throughout the state for its high congestion levels, is one of these facilities and the primary focus of this research.

The topic of priority lane treatment in Dallas has been addressed in several research projects. A one-year project, Project 7-1994, "Implementation and Evaluation of Concurrent Flow HOV Lanes in Texas," examined the operational performance of the two buffer-separated concurrent flow lanes in Dallas, one being the IH-635 HOV lanes (*1*). Two multi-year projects, Project 7-3942 "Investigation of HOV Lane Implementation and Operational Issues" and Project 7-4961, "An Evaluation of Dallas Area HOV Lanes," investigated the operational effectiveness of Dallas' interim HOV lanes (*2*, *3*). Each of these reports address various issues such as person movement, carpool formation, travel time savings, violation rates, safety, and project cost effectiveness. The calculation of travel time savings is of most interest in this research, since each of the noted reports calculates HOV lane travel time savings using data collected on non-incident days.

Recent research conducted by TTI shows the frequency of injury-related crashes increased by 41 percent in the IH-635 corridor following the implementation of the concurrent flow buffer-separated HOV lanes. Using electronic crash data and crash reports, that study concluded that the majority of the increase in crashes occurred in the HOV lane and in the general-purpose lane designated as Lane 1, which is immediately adjacent to the HOV lane. The study also concluded that the increase in injury crashes is likely due to the speed differential between the HOV lane and the general-purpose lanes. The general-purpose lanes experience congestion during peak periods, while the HOV lanes usually operate at the speed limit (*4*).

1.3 PROJECT OBJECTIVES

The objective of this research is to determine the impacts on travel time due to incidents in the IH-635 corridor. First, the additional travel time benefits to concurrent flow HOV lane users when an incident occurs on the general-purpose lanes of IH-635 will be determined. Second, a determination of the impact to concurrent flow HOV lane users when the HOV lane is closed due to an incident, in either the general-purpose lanes or the HOV lane, will be determined. This is particularly important since the implementation of the HOV lane has induced crashes or incidents in the corridor. The results will supplement research on Houston's barrier-separated HOV lanes on the same topic. The Houston findings, developed concurrently, will be documented in Report 0-4740-1.

1.4 ORGANIZATION OF THE REPORT

This report provides the reader a background of the study corridor including design characteristics, vehicle travel patterns, injury crash history, and available intelligent transportation systems necessary for the research. That chapter is followed by a discussion of the data collection efforts including the methodology for collecting visual and electronic data, data reduction, and categorization. The reader is then presented with the data analysis, which includes developing baseline data on incident-free days and the comparison with data collected during times when the corridor is experiencing the effects of an incident. The data analysis is followed by a discussion of proper incident management to maintain HOV lane effectiveness during an incident. That chapter was developed as a result of the research team's visual data reduction efforts earlier in the research. The final chapter of the report offers conclusions and recommendations.

CHAPTER 2:
STUDY CORRIDOR

2.1 INTRODUCTION

IH-635 is typically congested in both directions of travel in the corridor section that has HOV lanes, particularly during the peak travel periods. Incidents also occur nearly every day of the week along the section with the HOV lane, which makes it an ideal location for determining the change in travel time savings offered by HOV lanes due to incidents in the general-purpose lanes. Additionally, since incidents are known to occur in the HOV lane and the adjacent general-purpose lane known as Lane 1, the corridor is ideal for determining any additional delay to HOV lane users due to incidents impacting the HOV lane in some manner (*4*).

2.2 CORRIDOR CHARACTERISTICS

2.2.1 Description

The IH-635 HOV lanes opened in March 1997 and were some of the first of their kind in Texas. The HOV lanes were retrofitted into the existing freeway corridor by narrowing the general-purpose lanes to 11 feet and converting the inside shoulder into an 11-foot HOV lane for both directions of the freeway. Each HOV lane is separated from the general-purpose lanes with a buffer area indicated by painted solid white stripes. This buffer area has a maximum width of 3 feet. Intermediate ingress/egress is possible at locations where the painted buffer changes to a single skip stripe. Figures 1 and 2 show the typical cross section of the facility between Josey Lane and Coit Road, which encompasses most of the facility east of IH-35E (Stemmons Freeway).

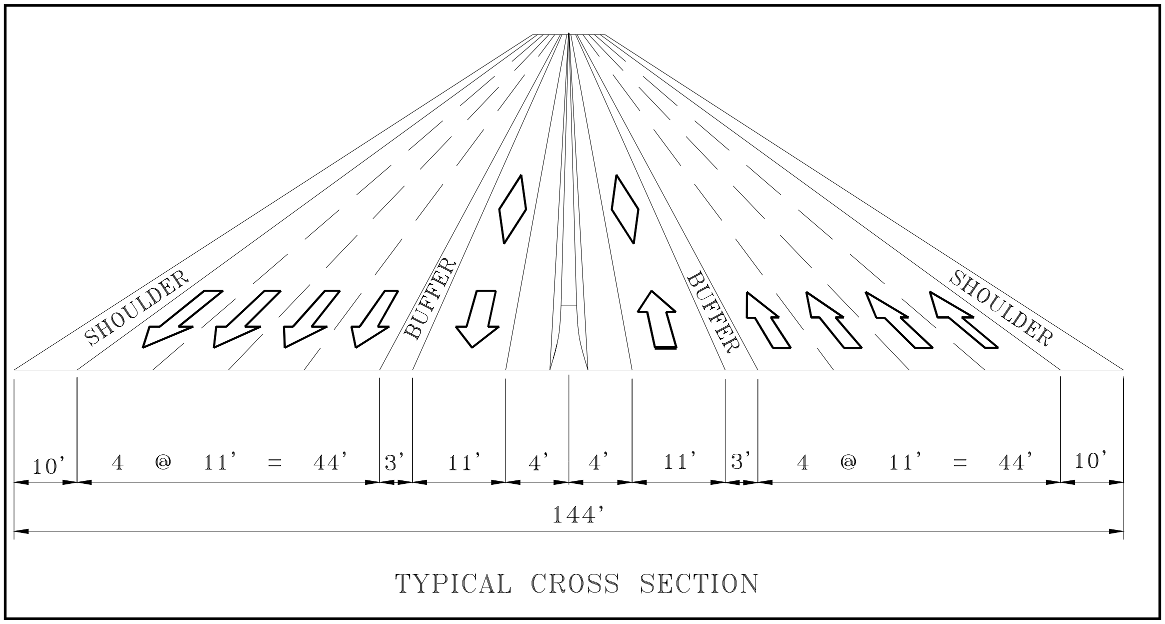

Figure 1. IH-635 (LBJ Freeway) Cross Section between Josey Lane and Coit Road.

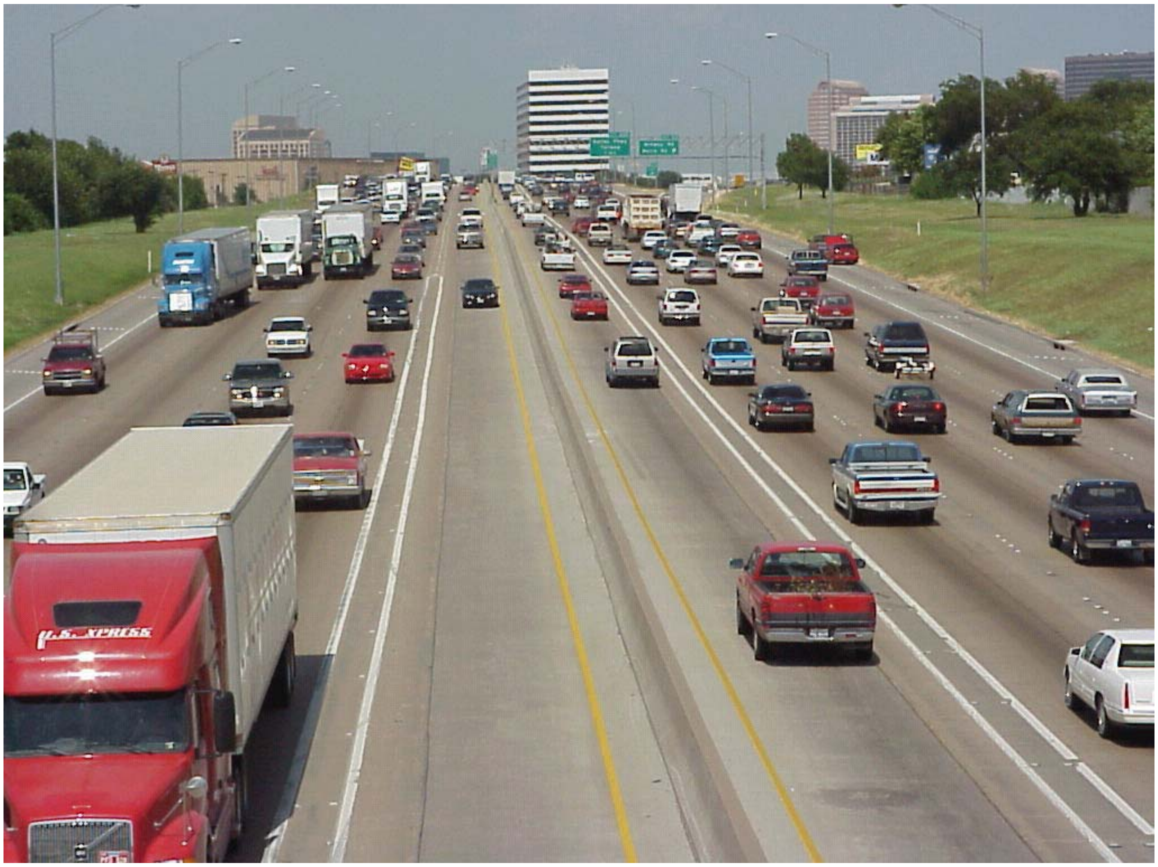

Figure 2. IH-635 (LBJ Freeway) – Photograph.

In November 2000, the HOV lane section was extended to Luna Rd. on the west side of IH-35E. This new section includes a wider inside shoulder area with enough room for parked or disabled vehicles to be completely off the travel lanes.

Since opening, the HOV lanes have provided service to 2+ occupant vehicles 24 hours per day in both directions. The cost to construct the IH-635 HOV lanes was $16.3 million in 1996 dollars (5). Figure 3 shows basic features of the corridor including access locations and vehicle occupancy enforcement zones.

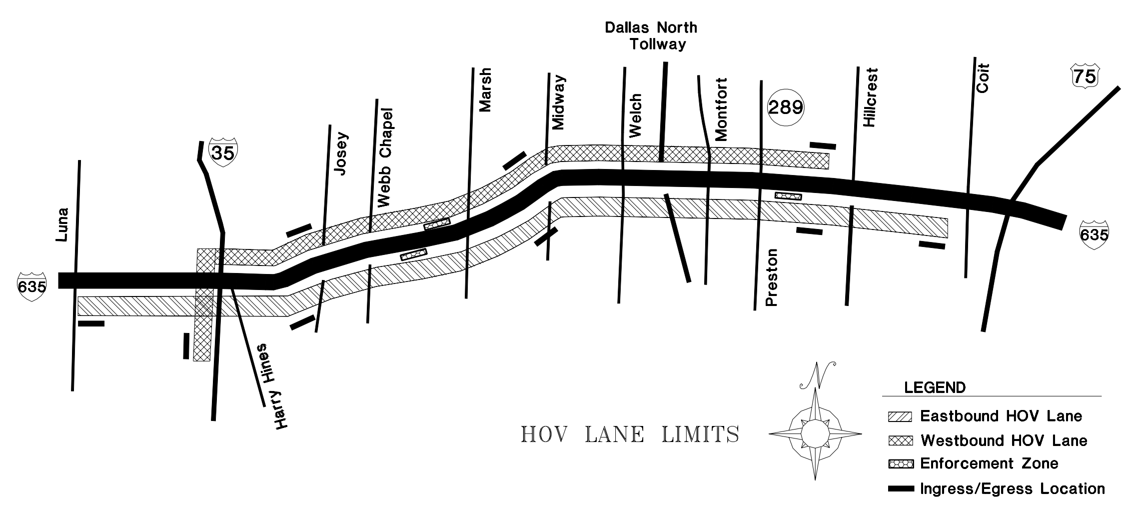

Figure 3. IH-635 (LBJ Freeway) HOV Lane Features.

2.2.2 Historical Traffic Data

IH-635 is a highly congested circumferential corridor serving eastbound and westbound traffic with annual average daily traffic (Year 2000) of 260,000 vehicles in some sections. The bidirectional HOV lanes provide daily service to 19,500 vehicles and 40,700 persons, which equates to an average occupancy of 2.09 persons per vehicle. The eastbound HOV lane extends 6.7 miles, and the westbound HOV lane extends 6.2 miles. According to historical speed data collected from 1998 to 2000, there is a 21-mph speed differential eastbound and a 33-mph speed differential westbound between the HOV lane and the general-purpose lanes during the AM peak hour. The PM peak hour speed differential is 28-mph eastbound and 35-mph westbound (6).

2.2.3 Historical Travel Patterns

In 1994, the Texas Transportation Institute (TTI) conducted an origin/destination study within the IH-635 corridor to determine vehicle trip patterns during the morning period for all vehicle types. That study is approximately 10 years old and predates the implementation of the HOV lanes. However, the study identified that 22 percent of all morning eastbound vehicle trips were less than 4 miles in length and 6 to 10 percent were greater than 12 miles. In the morning westbound direction, 17 to 22 percent of all vehicle trips were less than 4 miles and 14 percent were greater than 12 miles (*7*). This study revealed that short trips were prevalent in the corridor in 1994. It is surmised that similar short trips continue in this corridor today.

2.2.4 Historical Injury Crash Data

Recent research conducted by TTI shows the frequency of injury-related crashes increased by 41 percent in the IH-635 corridor following the implementation of the concurrent flow buffer-separated HOV lane. The HOV lane construction began in June 1995 and ended March 1997. Since then, the IH-635 corridor has experienced a yearly average of 450 injury crashes in the section with the concurrent flow HOV lane. One-third of the corridor injury crashes occurs in the general-purpose lane designated as Lane 1 that is immediately adjacent to the concurrent flow HOV lane and about 12 percent occur in the HOV lane itself. An average of 160 injury crashes occurs each year during the weekday peak periods for this corridor of which 42 percent occur in Lane 1 and 14 percent occur in the HOV lane (*4*).

2.2.5 ITS Coverage

The IH-635 corridor is electronically monitored from the DalTrans Transportation Management Satellite Center, transportation management center (TMC) of TxDOT-Dallas. The goal of DalTrans is to improve the region's mobility, reduce congestion, and improve safety for multiple corridors in the region. Operations personnel can detect unplanned incidents by periodically scanning the traffic images from the closed circuit television (CCTV) cameras. Incident detection may also be provided to the TMC by external sources such as 911 calls, police scanners, the Courtesy Patrols, or coordination with the Dallas Sheriff's Office (DSO) and the Dallas Fire Department (*8*).

The northern section of IH-635 is outfitted with eight CCTV cameras of various spacing. These eight cameras have the ability to pan, tilt, and zoom on locations throughout the corridor to scan for incident occurrence or verify reported incidents.

Figure 4 shows the locations of these cameras with their identifying names of Luna, Harry Hines, Josey, Pedestrian Bridge, Rosser, Welch, Montfort, or Preston. These location names are referred to multiple times throughout the remainder of this report.

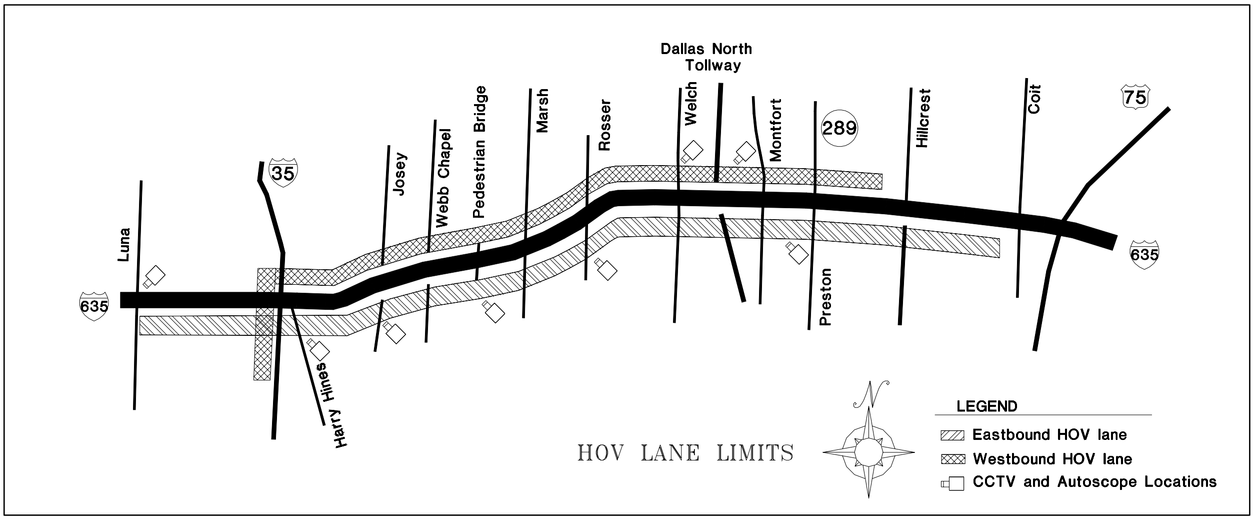

Figure 4. IH-635 (LBJ Freeway) CCTV Camera and Autoscope Locations.

2.2.6 Autoscope Network

TxDOT also monitors traffic characteristics of various corridors using a video image detection system (VIDS), known as Autoscope (9). The Autoscope system uses equipment setup to look over a section of highway and detect various types of traffic data over certain time intervals. This system can detect and record corridor vehicle volumes and vehicle speeds for each of the individual travel lanes or for multiple lanes combined. The Autoscope equipment is in the same location as the CCTV cameras as indicated in Figure 4 above.

CHAPTER 3:
DATA COLLECTION

3.1 INTRODUCTION

Data collection efforts for this research required use of the DalTrans CCTV cameras and the Autoscope system along IH-635. The research team was already familiar with both systems from previous work efforts involving Dallas-area freeways. By cross-referencing recordings of video data for incidents in the corridor with speed data available from the Autoscope system, a reasonable determination of travel times and delay was possible for the HOV lanes and the general-purpose lanes. The research team used this information to calculate the change in travel time savings for users of the HOV lane when an incident occurred on the general-purpose lanes only, as well as those that affected the HOV lane.

3.2 DALTRANS CCTV CAMERAS

3.2.1 Methodology

Visual confirmation of incidents along the IH-635 corridor was achieved by using the eight different camera views of CCTV from DalTrans on the weekdays over the 5-month period from September 2003 through January 2004. As noted earlier, the camera views used are designated as Luna, Harry Hines, Josey, Pedestrian Bridge, Rosser, Welch, Montfort, and Preston. The eight views were recorded using two videocassette recorders, four views per VCR in a quad-screen format, during the AM and PM peak periods as shown in Figure 5. The AM peak period was from 6:00 AM to 9:00 AM and the PM peak period was from 4:00 PM to 7:00 PM. The two VCRs were kept in the DalTrans electronic equipment room for the duration of the data collection period. No weekend data were recorded or required given the scope of the research effort.

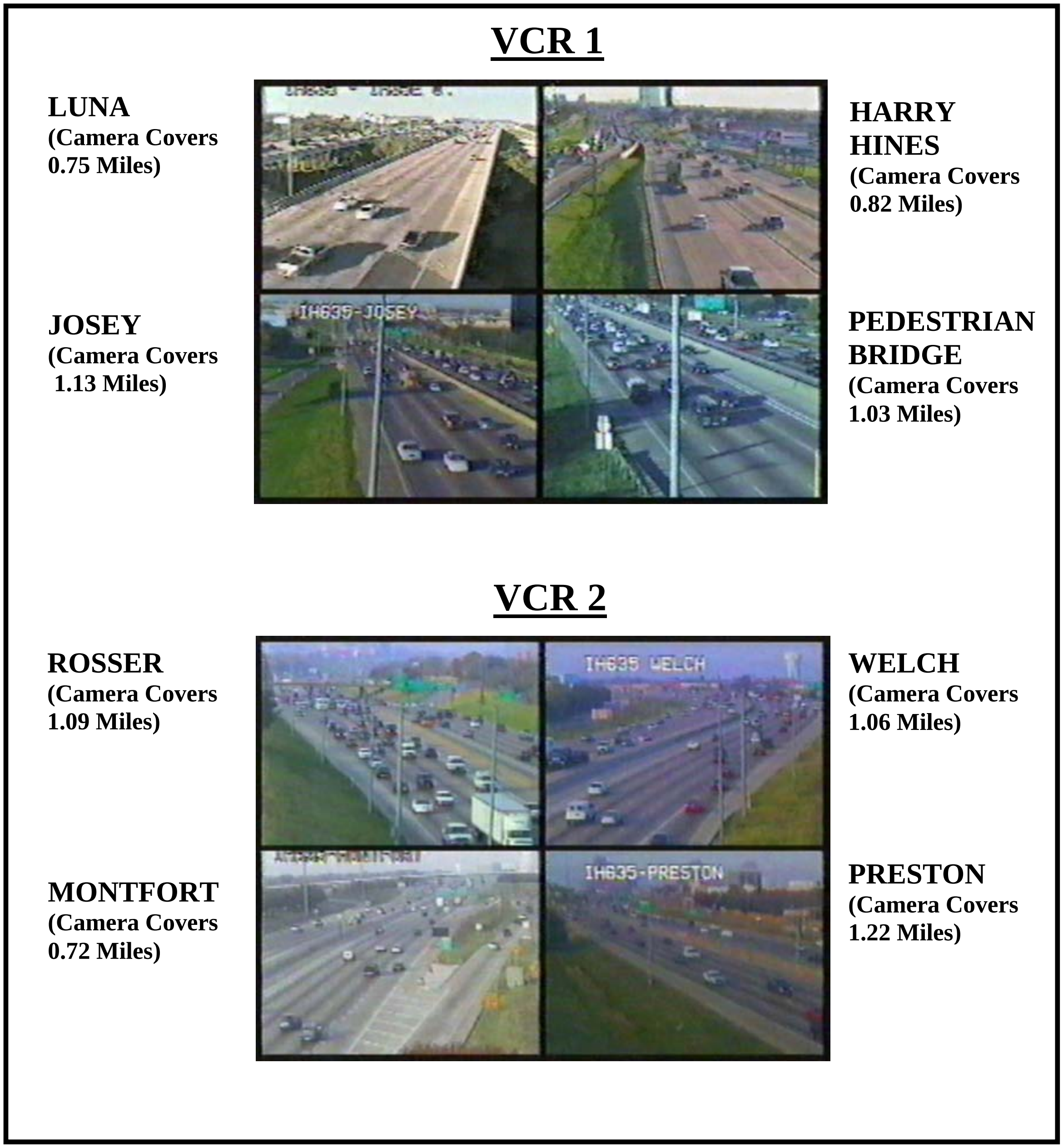

Figure 5. DalTrans Camera Views.

3.2.2 Video Data Reduction

Every two weeks during the data collection period, the recorded video data were retrieved from DalTrans by the research team and each videotape was reviewed to identify incidents. The incidents for this analysis were defined as any event that reduced the freeway capacity, including major or minor traffic crashes, stalled vehicles, spilled loads, and stopped or slowed vehicles on the general-purpose lanes, the HOV lane, or the shoulder areas.

Characteristics of each incident were documented by the research team and included the location, date, beginning and ending time in which there was visual confirmation, lane blockage, and type of incident along with other pertinent information.

3.2.3 Categorize Incidents

A total of 569 incidents were recorded during the weekday peak periods on IH-635 from September 18, 2003, through January 19, 2004 (6:00 to 9:00 AM and 4:00 to 7:00 PM) for this project. This equates to 88 weekdays of recorded peak period video data. It should be noted that there were 17 weekdays during the data collection period where video data were unavailable due to technical problems with DalTrans equipment; thereby, leaving 71 weekdays of usable video data. Thus, the total number of incidents from this data collection effort is actually less than the true number of incidents that occurred during this calendar period. Table 1 shows the incidents categorized by the resulting type of lane blockage and the length of time for blockage that were available from the data collection effort.

Incidents that were observed blocking one of the general-purpose lanes are the most prevalent and result in limiting the vehicle capacity of the freeway general-purpose lanes. Incidents that block the inside shoulder (IS), the outside shoulder (OS), and the inside shoulder enforcement area (ISEA) usually have less impact on traffic movement in the corridor. Of the 569 incidents, 499 were either on the inside or outside shoulder or the inside shoulder enforcement area.

Table 1. Incident Lane(s) Blockage and Duration.

CCTV Observed Blockage Time (min)	ISEA	IS	HOVL	HOVL & Lane 1	2+ Lanes	1 Lane	OS	Other	Total
0-15	20	20	6	2	0	23	238	1	310
16-30	4	3	2	2	1	8	28	1	49
31-45	0	1	2	5	0	2	27	3	40
46-60	0	4	2	2	0	1	14	0	23
61+	1	9	2	1	0	2	130	2	147
Total	25	37	14	12	1	36	437	7	569

The primary objective of reviewing the videotapes was to observe incidents occurring in the general-purpose lanes. However, a number of observed incidents blocked the HOV lane in some manner. This results in limiting the person-movement capacity of the facility and has a direct impact on the travel time savings and reliability of the HOV lane. Even more detrimental to the mobility of the corridor was the number of incidents observed blocking both the HOV lane and Lane 1 of the general-purpose lanes, which is immediately adjacent to the HOV lane.

Table 2 shows incidents categorized by location, direction, and travel period. From the standpoint of corridor direction, the table indicates motorists traveling eastbound were more likely to encounter an incident than those traveling westbound. In addition, motorists were more likely to encounter an incident during the evening peak period. The Pedestrian Bridge camera location recorded the most incidents of all the camera locations. This location, however, includes a section of freeway with a wide inside shoulder, which is used as the HOV lane enforcement area. As a result, many of the recorded incidents on the inside shoulder were HOV lane enforcement related and therefore have lesser affect on operation of the HOV lane or the general-purpose lanes.

Table 2. Incidents by Location, Direction, and Time Period.

Location	AM		PM		Total
	EB	WB	EB	WB	
LUNA	1	1	14	28	44
HARRY HINES	4	0	3	6	13
JOSEY	41	10	35	12	98
PED BRIDGE	76	18	28	16	138
ROSSER	23	3	31	10	67
WELCH	10	8	13	15	46
MONTFORT	3	15	22	17	57
PRESTON	31	11	56	8	106
Total	189	66	202	112	569

Table 3 shows incidents categorized by camera location and the length of time for blockage. As already stated, the Pedestrian Bridge camera location recorded the most incidents of all the camera locations, most of which were actually on the inside shoulder area and related to HOV lane enforcement.

Table 3. Incidents by Locations and Duration.

Clearance Time (min)	LUNA	HH	JOSEY	PED BR.	ROSSER	WELCH	MONTFORT	PRESTON	Total
0-15	26	5	60	90	33	30	27	39	310
16-30	2	3	9	9	9	4	4	9	49
31-45	3	1	5	9	8	3	3	8	40
46-60	7	2	2	4	4	0	3	1	23
61+	6	2	22	26	13	9	20	49	147
Total	44	13	98	138	67	46	57	106	569

Table 4 shows incidents categorized by incident type and the length of time for blockage. The most frequent incident type observed in the corridor was motorists pulling over to the shoulder for unknown reasons. Shoulder incidents do not affect the corridor to the same degree as crashes, emergency response vehicles, or stalled vehicles. The "Emergency Vehicles" category represents cases where emergency response vehicles are seen at an incident scene without being able to tell specifics of the incident. The "Stalled Vehicle" category represents vehicles that are moved off the roadway either by a tow truck or by the Courtesy Patrol. The "Stopped Vehicle(s)" category represents vehicles that are stopped on the roadway for an unknown reason and then are able to continue under their own power. The "Parked Vehicle" category represents abandoned vehicles in the shoulder area. At times, abandoned vehicles were observed at the location over a period of many hours. The "Maintenance" category represents maintenance vehicles stopped while clearing debris from the shoulder area or driving slowly in the shoulder area.

Table 4. Incidents by Types and Duration.

Clearance Time (min)	CRASH	EMERGENCY VEHICLES	STALLED VEHICLE	STOPPED VEHICLE(S)	MOTORIST PULLOVER	POLICE PULLOVER	PARKED VEHICLE	MAINT.	Total
0-15	11	8	14	40	181	40	11	5	310
16-30	6	2	8	10	15	4	4	0	49
31-45	7	3	4	6	12	1	6	1	40
46-60	3	0	0	4	9	3	4	0	23
61+	4	4	3	54	26	4	52	0	147
Total	31	17	29	114	243	52	77	6	569

3.3 AUTOSCOPE

A total of 569 incidents were recorded during the weekday peak periods on IH-635 from September 18, 2003, through January 19, 2004. The research team documented characteristics of each incident, including the location, date, beginning and ending time in which there was visual confirmation, lane blockage, type of incident and other pertinent information. With this critical information, the research team was able to acquire the corresponding speed and vehicle volume data for the corridor, previously archived by TxDOT from the Autoscope system. Although, TxDOT has CCTV at eight locations along this corridor, only six of those locations are outfitted with Autoscope equipment. These six locations are identified as Josey, Pedestrian Bridge, Rosser, Welch, Montfort, and Preston.

3.3.1 Methodology

TxDOT provided the research team archived Autoscope data in two installments in Access database format. The first installment covered the period from September 2003 to mid November 2003. The second installment covered the period from mid December 2003 through January 2004. The archived data from mid November to mid December 2003 was irretrievable from the database. Of the 569 incidents, 154 occurred during the same calendar period as the lost Autoscope speed data.

3.3.2 Data Reduction

The Access database of the archived Autoscope data contained information from all active Autoscope equipment locations from around the Dallas freeway system. The data concerning only the IH-635 corridor were parsed out for ease in manipulating the data. The data were then separated to coincide with the six separate Autoscope locations of interest along the corridor. The research team was able to move forward with the data analysis by having the data in this simplified format.

CHAPTER 4:
DATA ANALYSIS

4.1 INTRODUCTION

Incidents that blocked one or more of the general-purpose lanes or the HOV lane were the main focus of the analysis with shoulder incidents of little consequence given the scope of this research. A number of incidents were identified by the research team from the list of 569 incidents as good candidates for further analysis of travel time and delay characteristics. The goal was to compare the speed and travel time characteristics of these incident days with data collected on typical non-incident days. The data from non-incident days served as the baseline information for the analysis.

4.2 GENERAL-PURPOSE LANES BASELINE

The baseline data for the IH-635 corridor or the typical non-incident day traffic characteristics are needed to compare to traffic data gathered during the occurrence of an incident. Unfortunately, the IH-635 corridor routinely experiences one or more incidents somewhere along the corridor almost every day during peak periods. However, a review of the list of incidents documented from late September 2003 to mid January 2004 shows that no incidents were visually confirmed for 16 different peak period time periods, some of which were for the AM peak period with the remaining for the PM peak period. These 16 periods would provide the needed non-incident day data to develop the baselines.

4.2.1 Corridor Typical Day Determination

Upon first review, the research team anticipated that the 16 time periods should have provided 10 periods for the AM peak period baseline and 6 periods for the PM peak period baseline for all six Autoscope locations along the corridor. However, this was not the case. Autoscope data were missing from the electronic Access database for many of the locations during these particular time periods. As a result, the baseline for each location and each time period was developed using anywhere from two to six time periods. Although the baselines were developed using limited data, the research team felt that the baselines were adequate for comparison with incident data based on previous knowledge of speed characteristics for the corridor from previous research (6). Table 5 shows the 16 original time periods, although many of them were not used in the development of the corridor baselines.

Table 5. Baseline Information Availability on Non-incident Days and Periods.

DATE	TIME (AM)	DATE	TIME (PM)
9-25-03	6:00 – 9:00 AM	9-23-03	4:00 – 7:00 PM
9-29-03	6:00 – 9:00 AM	10-3-03	4:00 – 7:00 PM
10-24-03	6:00 – 9:00 AM	10-8-03	4:00 – 7:00 PM
10-28-03	6:00 – 9:00 AM	10-9-03	4:00 – 7:00 PM
11-7-03	6:00 – 9:00 AM	10-24-03	4:00 – 7:00 PM
11-19-03	6:00 – 9:00 AM	11-4-03	4:00 – 7:00 PM
11-21-03	6:00 – 9:00 AM		
12-01-03	6:00 – 9:00 AM		
12-16-03	6:00 – 9:00 AM		
12-23-03	6:00 – 9:00 AM		

4.2.2 Typical Day Graphical Representation

By using the data from the days without incidents, the research team was able to develop 24 different baselines for the corridor. The total 24 was for the six locations by AM or PM peak period and by direction, either eastbound or westbound. Figure 6 shows an example of one of the typical non-incident day baselines used in the analysis. This example is for the Autoscope data from the Preston site during the AM peak period in the westbound direction for the general-purpose lanes only. The graph shows the instantaneous traffic speeds at different time periods converted to travel time and weighted by the length of camera coverage as shown in Figure 5. The peaks on the graph indicate the times of lowest speeds and the highest travel times occurring for this section of roadway.

On incident-free days, the speed on the HOV lanes is expected to remain relatively stable throughout the peak period. Historical data indicate that the HOV lane is usually moving around 60 mph (6). This speed is converted to travel time and represented on the graph as simply a constant travel time with which to compare to the general-purpose lane travel times. On the graph, for a particular time period, the difference between the line for general-purpose lanes travel time and the line for the HOV lane travel time represents the typical travel time savings available to HOV lane users on incident-free days for that particular location. For instance, an HOV lane user can expect to save a maximum of approximately 0.6 minute or 36 seconds over a 1.22-mile section near Preston in the westbound direction at 7:45 AM on a typical non-incident day for that 5-minute time increment.

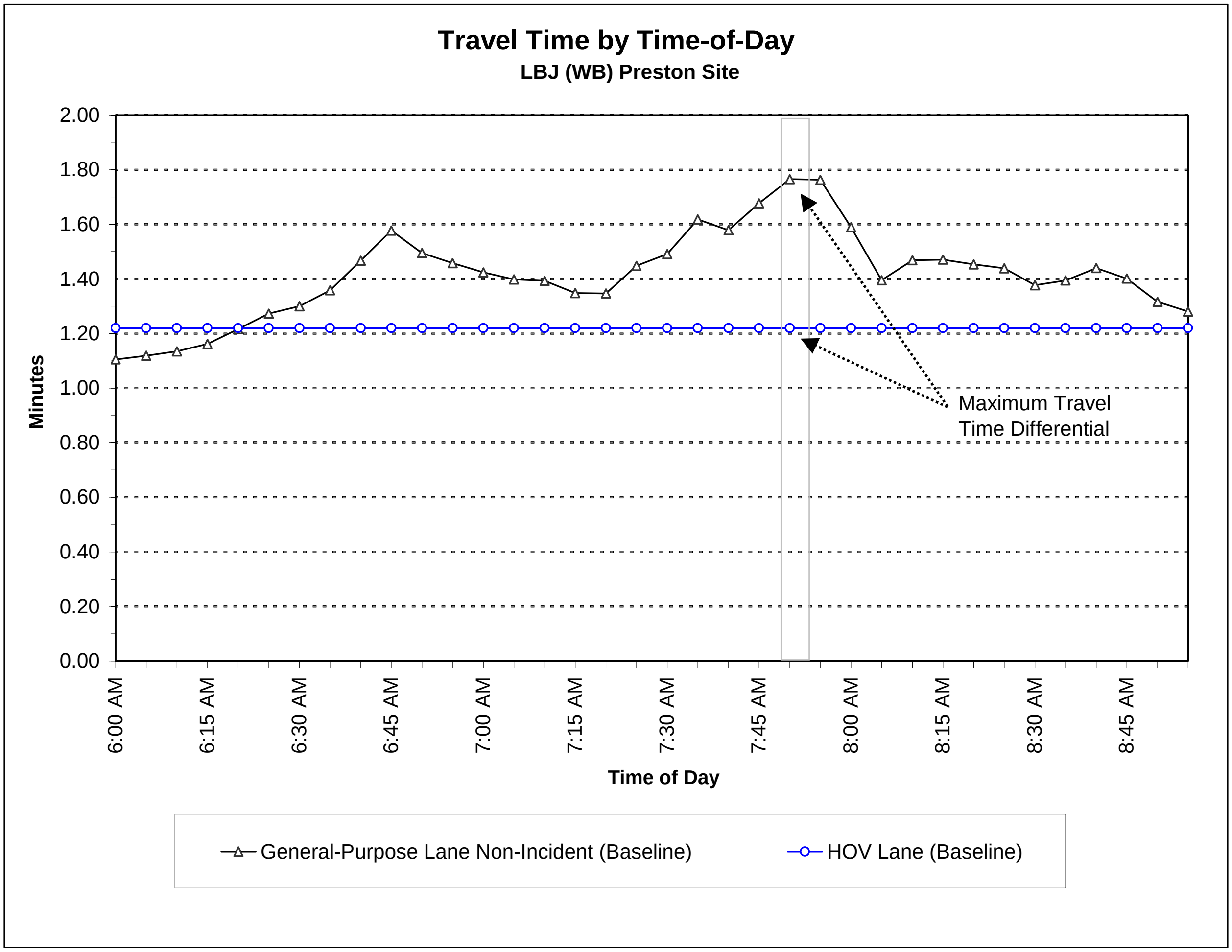

Figure 6. Baseline Delay.

4.3 REPRESENTATIVE INCIDENT FOR GENERAL-PURPOSE LANE BLOCKAGE

4.3.1 Increased General-Purpose Lane Delay

The increased delay due to incidents on the general-purpose lanes equates to increased travel time savings for HOV lane users that are unaffected by the incident. This is due to the decreased speeds on the general-purpose lanes while the HOV lane speeds remain relatively unchanged. By including the data for decreased general-purpose lane speeds on the baseline graph, the research team was able to visualize and better understand the impact of incidents with respect to travel time in the corridor. Figure 7 shows a typical general-purpose lane incident that does not affect the operation of the HOV lane as seen from the DalTrans cameras.

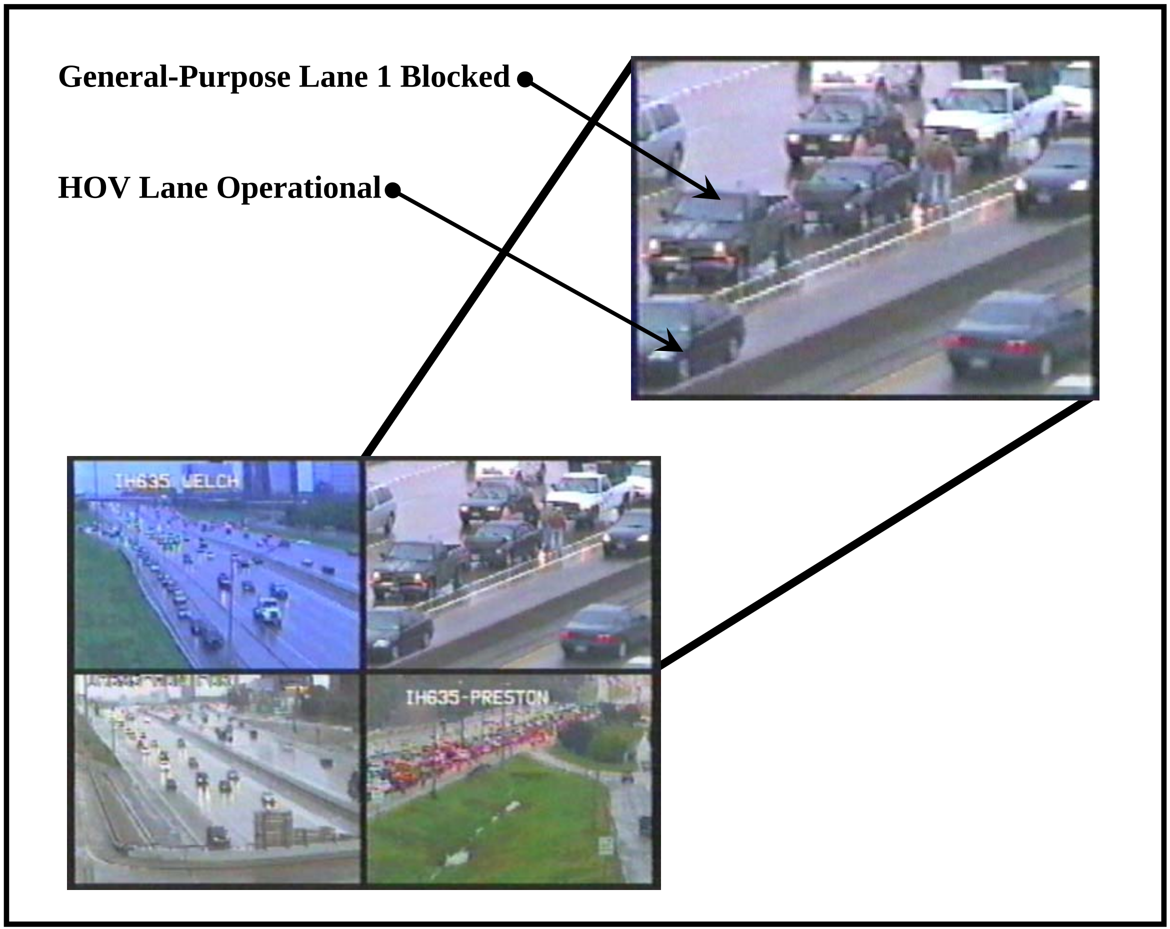

Figure 7. Incident Blocking General-Purpose Lane Only.

4.3.2 General-Purpose Lane Delay Graphical Representation

Figure 8 portrays a typical example of a general-purpose lane incident and the impact on travel time as compared to the typical non-incident general-purpose lanes day and the typical travel times on the HOV lane. This particular incident blocked two general-purpose lanes and was visually detected by DalTrans personnel at 6:17 AM using the CCTV cameras at the Preston location. By viewing the Autoscope data from the graph, it would seem that the incident actually occurred at 6:15 AM. Since two lanes were blocked, the speed on the general-purpose lanes quickly slowed and increased the travel time as shown on the graph. The incident was cleared from the roadway at 6:44 AM, and the general-purpose lanes were back to normal operation by about 7:00 AM.

The highest peak on the general-purpose lane incident data represents the greatest slow down in speeds and the longest travel times. The difference in the peak and the corresponding data point on the line representing typical non-incident general-purpose lane conditions gives the additional delay on the general-purpose lanes during an incident. For this example, this equates to an additional 4.2-minutes travel time savings westbound at Preston at 6:50 AM for the HOV lane users during that 5-minute time increment.

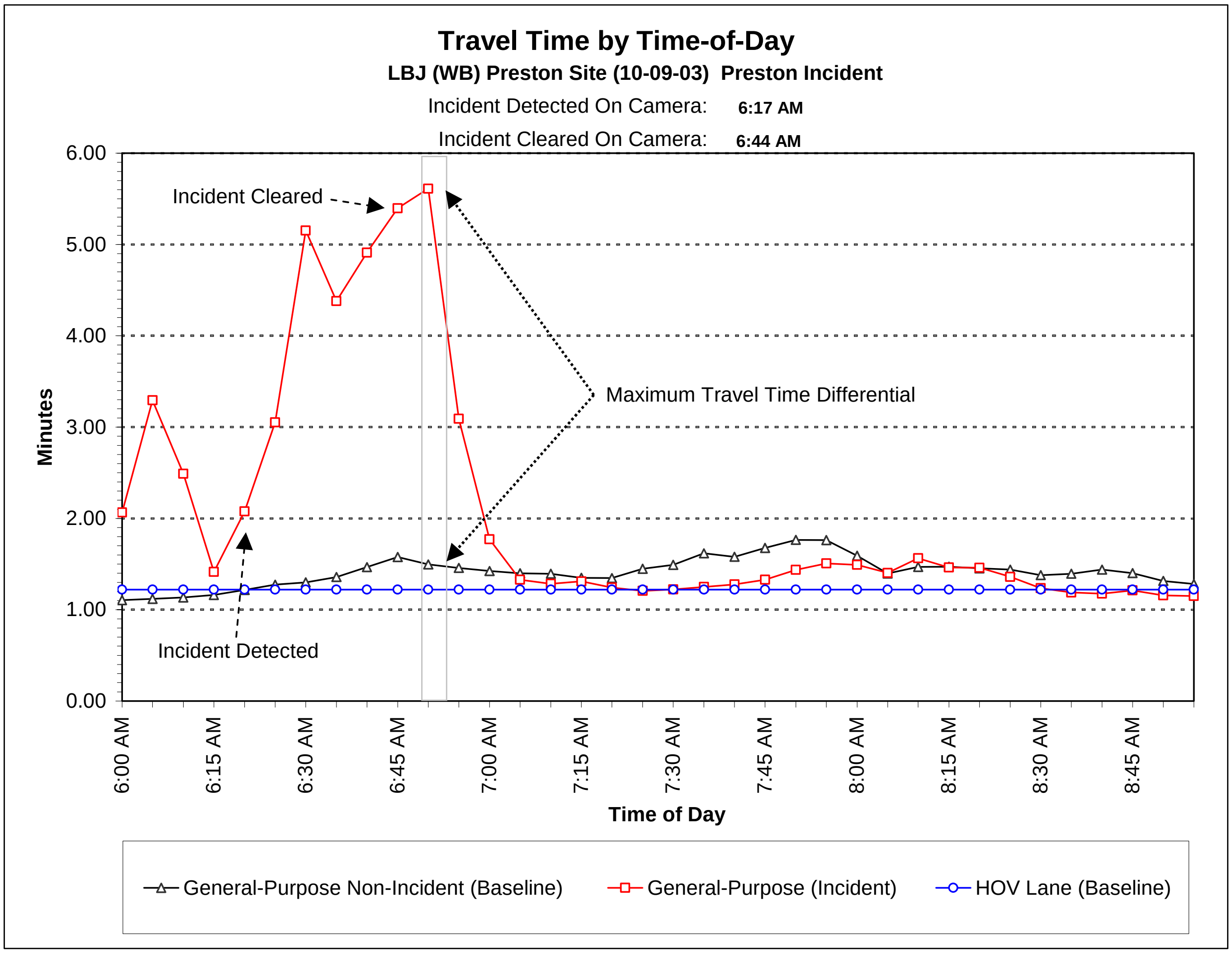

Figure 8. Incident Causing General-Purpose Lanes Delay.

4.3.3 General-Purpose Lanes Delay Calculated for Representative Incidents

Table 6 shows the calculated additional delay for representative incidents chosen for the analysis. There were a limited number of usable incidents due to the limited amount of data from the Autoscope database. Therefore, each cell of the table corresponds to data characteristics of one particular incident. The data in the table represent the difference in the peak or maximum recorded general-purpose lane travel time due to the incident and the corresponding data for the typical (baseline) non-incident days on the general-purpose lanes. Simply stated, these data represent the maximum additional delay each vehicle in the general-purpose lanes is experiencing as a result of the incident for the one camera location where the incident can be visually monitored, roughly over a 1-mile section. Conversely, these data represent the additional travel time savings offered to each HOV lane vehicle as a result of an incident in the general-purpose lanes.

Table 6. Additional Incident Delay (Minutes) for General-Purpose Lanes.

Location of Blockage			
Incident Duration (minutes)	1 GP Lane Blocked	2+ GP Lanes Blocked	Outside Shoulder
0-15	1.0	NA	0.6
16-30	1.4	4.1	1.4
31-45	2.1	NA	1.6
46-60	3.7	5.0	1.2

Note: Data for outside shoulder incidents shown for comparison

Only incidents of 60 minutes or less are shown in the table. The research team determined that incidents longer than 1 hour did not yield reasonable Autoscope speed data that could be directly attributed to the incident. The graphical representations of the extended time frame lane blocking incidents did not match video data of the incident when compared to incidents causing lane blockage of less than 60 minutes. As previously shown in Table 1, there were only five incidents from the data set that resulted in blocking the HOV lane, the HOV lane and Lane 1, or the general-purpose lanes for this incident duration category. With the low number of incidents in this category and the atypical graphs, the research team chose not to continue with further analysis of this category.

4.4 INCIDENTS RESULTING IN BLOCKING THE HOV LANE

4.4.1 HOV Lane Delayed

In the case of concurrent flow HOV lanes with a painted buffer separation, incidents occurring on the general-purpose lanes can adversely affect the operation of the HOV lane. Recent research conducted by TTI shows that this type of HOV lane design has increased the frequency of injury-related crashes in the corridors studied. The IH-635 corridor was a part of that study as well. The majority of the increase in crashes occurred in the general-purpose lane designated as Lane 1, which is immediately adjacent to the HOV lane (*4*). Not only are many crashes occurring in Lane 1, it appears that emergency vehicles will purposely block Lane 1 and the HOV lane to provide a safe haven to work the crash when responding to incidents that are only blocking Lane 1. In these cases, the users of the HOV lane do not gain additional travel time benefits due to an incident occurring in the general-purpose lanes. The HOV lane users are affected adversely by having to merge back into the now extremely congested general-purpose lanes; thus, they lose the travel time benefits as well as the trip reliability, which are two of the primary goals of implementing HOV lanes. Obviously, incidents that occur on the HOV lane adversely affect the users by the same reasoning to a lesser degree. However, the HOV lane is actually blocked due to the incident itself and not due to positioning of emergency response vehicles. Figure 9 shows a typical HOV lane incident as seen from the DalTrans cameras.

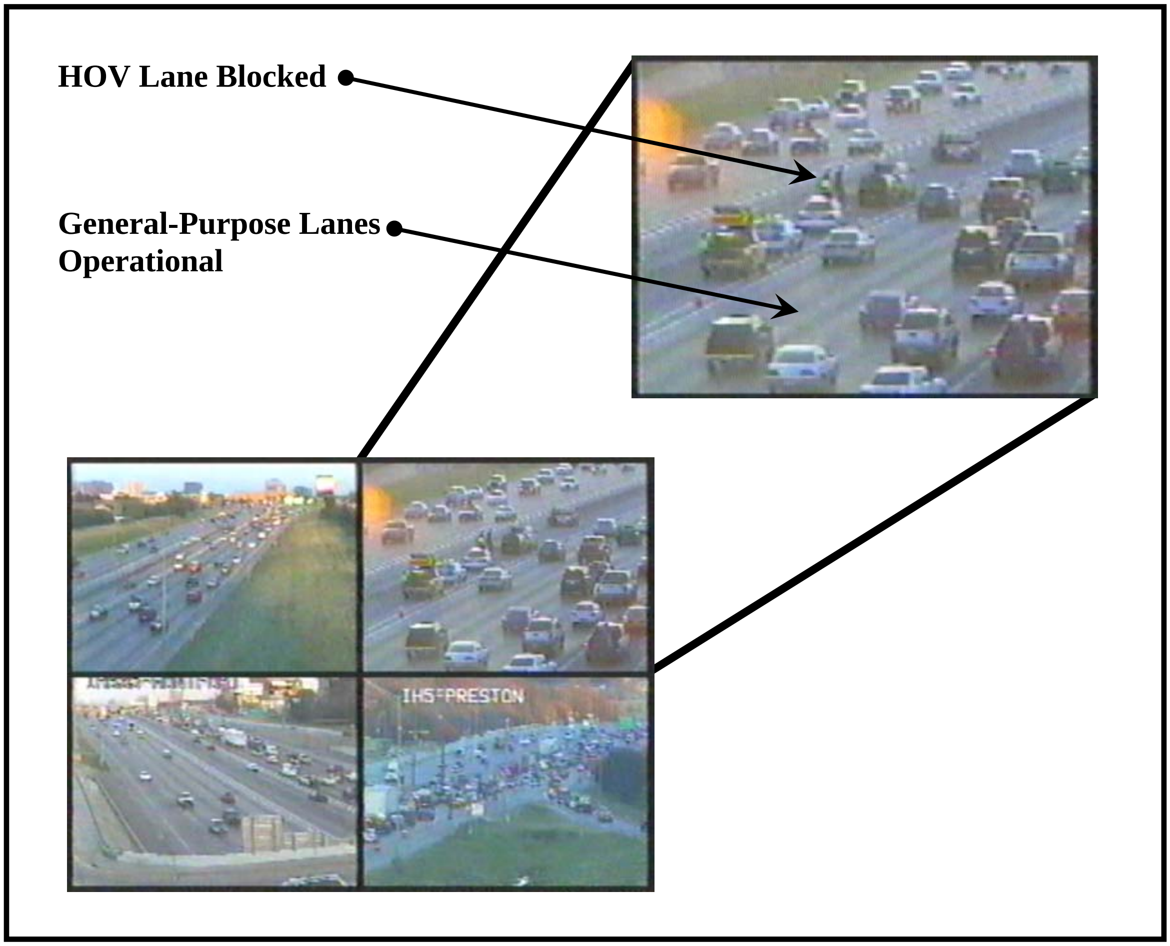

Figure 9. Incident Blocking HOV Lane.

4.4.2 HOV Lane Delay Graphical Representation

Figure 10 graphically represents data for a typical example of an incident on the HOV lane and the impact on speeds and travel time on the HOV lane and the general-purpose lanes as compared to the typical non-incident day. DalTrans personnel visually detected the incident at 4:00 PM through the CCTV cameras at the Welch location. Since the video recording of the corridor always began in the afternoon at 4:00 PM, the incident had been in place for an undetermined amount of time. Since the HOV lane was blocked, the speeds quickly dropped and the travel time increased for both the HOV lane and the general-purpose lanes as shown on the graph. The incident was cleared at 4:59 PM. The HOV lane travel time returned to normal and speeds were back to free flow by about 5:10 PM, and the general-purpose lanes travel time returned and speeds were free flow by about 5:55 PM.

For this incident, the HOV lane speeds are lower and travel times are shown to be longer than even the general-purpose lanes. In this case, the highest peak on the HOV lane incident data represents the greatest slow down in speeds and the highest travel times. The difference in the peak and the typical HOV lane speeds and travel time gives the maximum delay to HOV lane users at this camera location. As shown previously in Section 4.3.2, the highest peak on the general-purpose lane incident data represents the greatest slow down in speeds and the longest travel times. The difference in the peak and the corresponding data point on the line representing typical non-incident general-purpose lane conditions gives the additional delay on the general-purpose lanes during an incident.

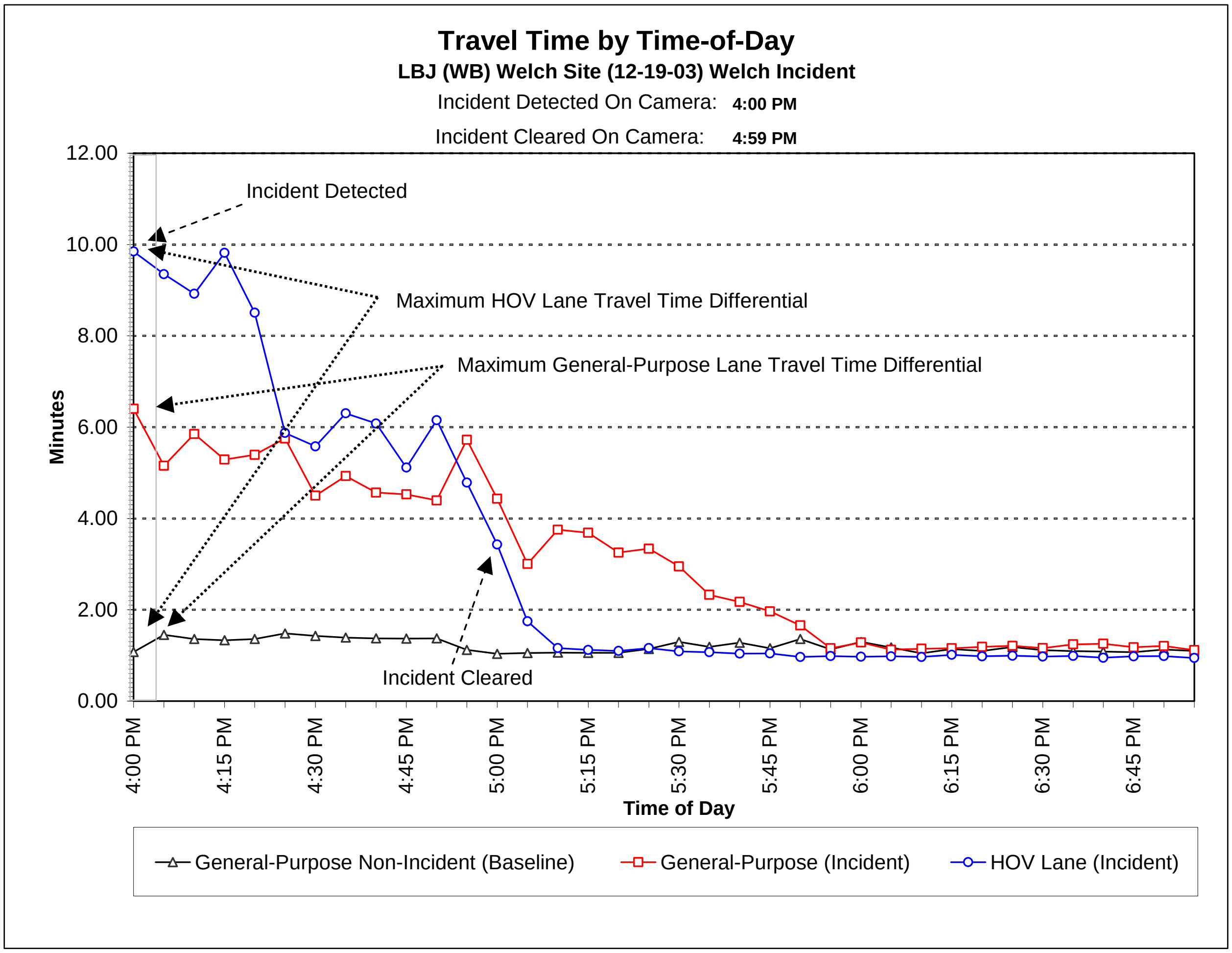

Figure 10. Incident Causing HOV Lane and General-Purpose Lanes Delay.

4.4.3 HOV Lane Delay and General-Purpose Lanes Delay Calculated

Table 7 shows the calculated delay for representative incidents. There were a limited number of usable incidents due to the limited amount of data from the Autoscope database. Therefore, each cell of the table corresponds to data characteristics of one particular incident. For the HOV lane, the data in the table represent the difference in the peak recorded HOV lane travel time due to the incident and the typical HOV lane travel time for non-incident conditions. For the general-purpose lanes, the data in the table represent the peak recorded general-purpose lane travel time due to the incident and the typical general-purpose lanes travel time for non-incident conditions. Only incidents with duration of less than 1 hour are shown in the table. The research team determined that incidents with duration longer than 1 hour did not yield reasonable Autoscope data that could be directly attributed to the incident, as was explained in Section 4.3.3.

As seen from Table 7, the incidents involving the HOV lane in some manner result in the HOV lane users actually experiencing more delay than the general-purpose lane users. Incidents with a duration of 45 to 60 minutes in which only the HOV lane is blocked show the HOV lane delay twice that of the delay in the general-purpose lanes. Incidents in both the HOV lane and Lane 1 show the HOV lane delay about 45 percent more than the general-purpose lanes. Therefore, the HOV lane users are experiencing additional travel time delay near an incident location when the incident impacts the HOV lane operation. This increased delay can be factored into the benefits calculation on both non-incident days and incident delay savings for HOV lane users when a general-purpose lane is blocked.

Table 7. Incidents Delaying (Minutes) HOV Lane and General-Purpose Lanes.

Location of Blockage						
Incident Duration (minutes)	HOV Lane Blocked		HOVL and Lane 1 Blocked		Inside Shoulder/ Enforcement Area	
	GP Lane	HOV Lane	GP Lane	HOV Lane	GP Lane	HOV Lane
0-15	3.4	3.8	3.3	2.3	0.2	0.4
16-30	NA	NA	12.9	12.2	0.2	0.0
31-45	4.9	5.6	14.5	14.3	NA	NA
46-60	4.2	8.8	6.7	9.7	NA	NA

Note: Data for inside shoulder/enforcement area incidents shown for comparison

4.5 UPSTREAM DELAY DUE TO INCIDENTS

4.5.1 Upstream Delay for HOV Lane and General-Purpose Lanes

An incident’s greatest impact to freeway operations is most obvious in the section of roadway in the vicinity of the incident, as was shown in previous sections. However, there may be additional effects seen upstream of the incident for a great distance. A freeway traffic queue resulting from an incident can extend 1 or 2 miles or even further if the required clearance time is very long. The residual effect of an incident can continue long after the incident has been cleared, particularly during peak periods of a congested corridor such as IH-635.

4.5.2 Upstream Delay Graphical Representations

Figure 11 shows data graphically at the Montfort location approximately 1 mile upstream of the Welch incident blocking the HOV lane that was presented previously in Section 4.4.2. Again, this incident was visually detected by the CCTV cameras at the Welch location by DalTrans personnel at 4:00 PM and the incident was cleared at 4:59 PM. At the upstream Montfort location, the HOV lane shows some adverse affects of the incident. However, the users of the HOV lane are still obtaining speed and travel time benefits over that of the general-purpose lanes.

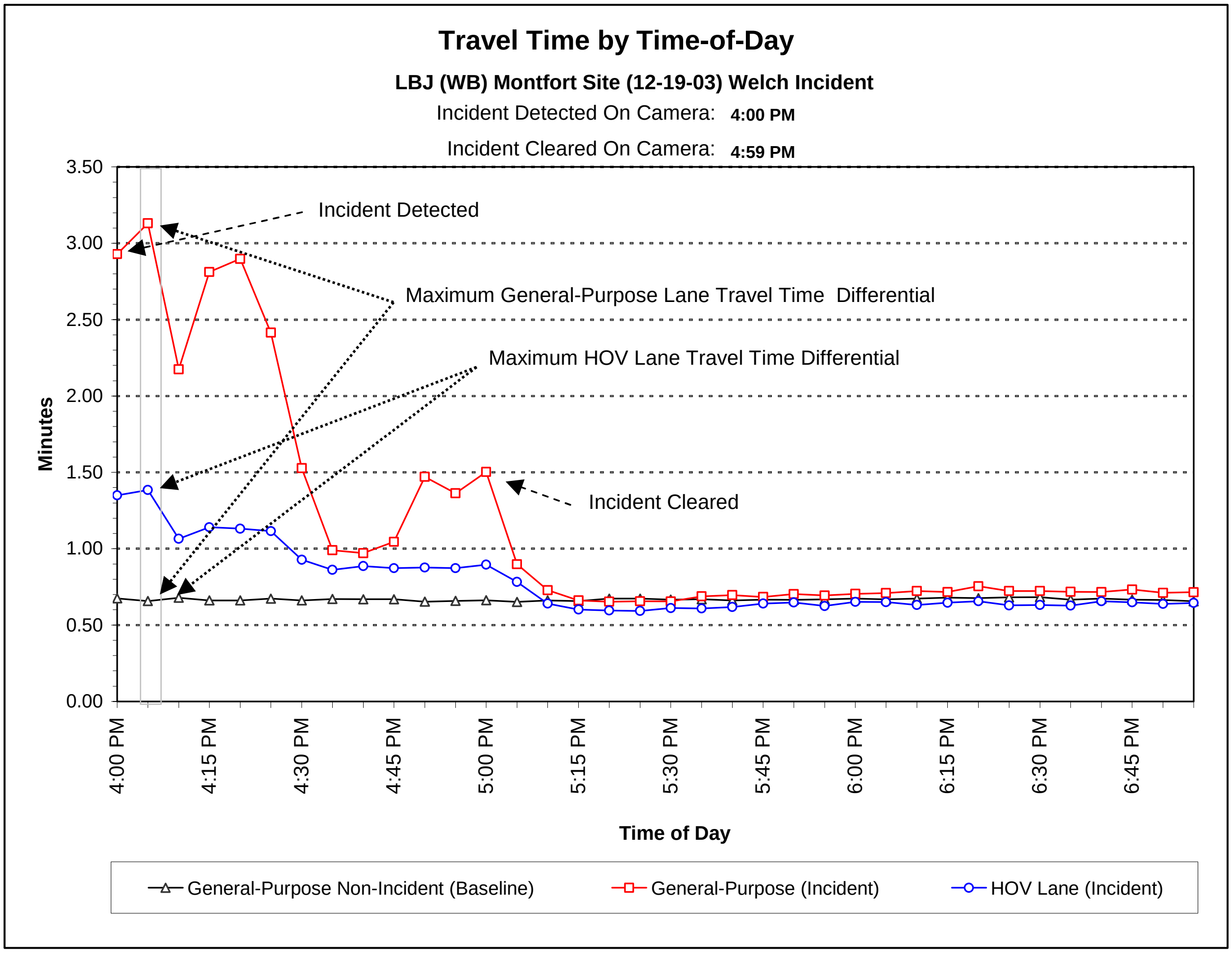

Figure 11. Delay Upstream of Incident – One Mile (Approximately).

Figure 12 shows data graphically for the Preston location approximately 2 miles upstream of the Welch incident blocking the HOV lane. Again, the HOV lane speed and travel time is showing effects of the downstream incident. However, the users of the HOV lane are still getting measurable travel time benefits over that of the general-purpose lanes.

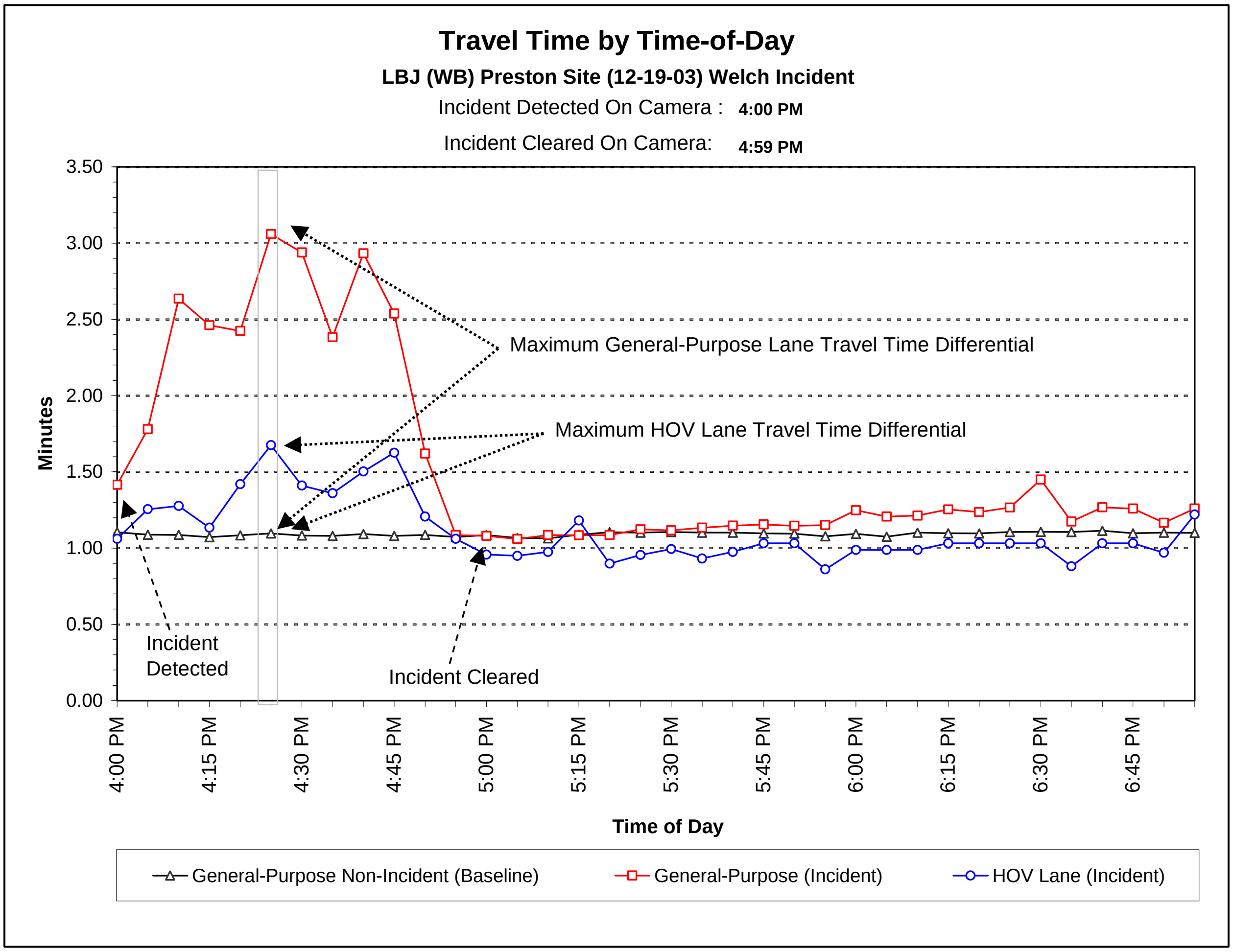

Figure 12. Delay Upstream of Incident – Two Miles (Approximately).

4.5.3 Upstream Delay Calculated

Table 8 shows the calculated delay for both the HOV lane and the general-purpose lanes approximately 1 mile and 2 miles upstream of representative incidents. As before, each cell in the table corresponds to data characteristics of one particular incident. For the HOV lane, the data in the table represent the difference in the peak recorded HOV lane travel time due to the incident and the typical HOV lane travel time for non-incident conditions. For the general-purpose lanes, the data in the table represent the peak recorded general-purpose lanes travel time due to the incident and the typical general-purpose lanes travel time for non-incident conditions.

Data were available 2 miles upstream for only two incidents, which are in the 46 to 60 minute incident duration category.

As seen in Table 8, 1 mile or 2 miles upstream of an incident, the HOV lane users are experiencing an additional travel time benefit whether the incident blocked a general-purpose lane or blocked the HOV lane in some manner. Again, this was not the case in Table 7, which shows delay in the immediate vicinity of an HOV lane related incident. In that case, the HOV lane users are not experiencing additional travel time savings.

Table 8. Delay (Minutes) Upstream of Incident.

Location of Blockage					
Incident Duration (minutes)	1 GP Lane Blocked	HOVL Blocked		HOVL and Lane 1 Blocked	
	GP Lane	GP Lane	HOV Lane	GP Lane	HOV Lane
0-15	2.6 - One Mile	NA	NA	3.2 - One Mile	1.6 – One Mile
16-30	0.2 - One Mile	NA	NA	NA	NA
31-45	1.1 - One Mile	NA	NA	NA	NA
46-60	2.5 - One Mile 3.8 - Two Miles	2.5 - One Mile 2.0 - Two Miles	0.7 – One Mile 0.5 - Two Miles	4.4 - One Mile	3.9 – One Mile

Note: Data for 2+ GP Lane Blocked not available.

4.6 COMBINED TOTAL DELAY

4.6.1 Incident Site Delay Plus Upstream Delay

Table 9 shows the calculated incident delay plus any other delay that was verified upstream of the incident to give a total quantifiable delay related to the incident. Incidents blocking only general-purpose lanes and not affecting the HOV lane provide data values that can be used for determining additional travel time savings for HOV lane users. For example, the cell for incidents with a lane blockage of 46 to 60 minutes shows additional general-purpose lane delay of 10 minutes. This is derived by summing the incident delay value of 3.7 minutes found in Table 6 with the additional 1 mile and 2 mile upstream delay values of 2.5 and 3.8 minutes, respectively, found in Table 8 for the incident duration of 46 to 60 minutes. Conversely, this equates to an additional travel time savings of 10 minutes for each HOV lane vehicle due to an incident in the general-purpose lanes.

Table 9. Total Quantifiable Delay (Minutes).

Incident Duration (minutes)	Location of Blockage					
	GP Lane Blocked[1]		HOVL Blocked[2]		HOVL and Lane 1 Blocked[2]	
	1 GP Lane Blocked	2+ GP Lanes Blocked	GP Lane	HOV Lane	GP Lane	HOV Lane
0-15	3.6	NA	3.4	3.8	6.5	3.9
16-30	1.6	4.1	NA	NA	12.9	12.2
31-45	3.2	NA	4.9	5.6	14.5	14.3
46-60	10.0	5.0	8.7	10.0	11.1	13.6
Average	**4.6**	**4.6**	**5.7**	**6.4**	**11.3**	**11.0**

Note: (1) Sum of respective cells from Table 6 and Table 8.
(2) Sum of respective cells from Table 7 and Table 8.

Table 9 also shows that the total HOV lane delay for incidents involving the HOV lane in some fashion experience approximately the same delay as the general-purpose lanes. Again, the total delay includes the delay experienced 1 or 2 miles upstream, if available, that provided additional travel time savings for HOV lane users. For example, the HOVL Blocked cell for incidents with a lane blockage of 46 to 60 minutes shows HOV lane delay of 10.0 minutes. This is derived by summing the incident delay value of 8.8 minutes found in Table 7 with the additional 1 mile and 2 mile upstream delay values of 0.7 and 0.5 minutes, respectively, found in Table 8 for the incident duration of 46 to 60 minutes. Unfortunately, the extreme unusual delay experienced by HOV lane users near an HOV lane related incident overshadows any travel time savings provided upstream.

It should be noted again that the data in Table 9 are representative of only one particular incident per cell. Logically, the delay times should increase for longer blockage times. However, this cannot be determined because there were a limited number of incidents for analysis due to the limited amount of Autoscope data.

CHAPTER 5:
ANOTHER NOTABLE ISSUE - INCIDENT RESPONSE

5.1 INTRODUCTION

The main purpose of this research was to determine the additional travel time savings offered to users of the HOV lane due to incidents occurring on the general-purpose lanes. This required the research team to view video of incidents as seen from the DalTrans cameras. Data concerning the amount of time for incident blockage were noted according to when the incident was visually confirmed by DalTrans personnel until the time the incident was cleared from the roadway, including any responding emergency vehicles. The positioning of emergency response vehicles at the scene of an incident became a source of intrigue during the data reduction process given the scope of this research. The research team realized that the method of incident response on certain occasions might actually be impacting the freeway adversely from the standpoint of capacity more than is necessary. Simply stated, the HOV lane during certain general-purpose lane incidents appeared to be operating effectively until emergency vehicles came on the incident scene.

5.2 HOV LANES AND INCIDENT RESPONSE

5.2.1 Closing HOV Lane Unnecessarily

Figure 13 shows an incident blocking Lane 1, immediately adjacent to the HOV lane, and Lane 2 of the general-purpose lanes. With only these two lanes blocked, general-purpose Lane 3 and Lane 4 continued to be operational. In addition, the HOV lane continued to be operational, thereby offering additional travel time savings to the users. This additional travel time savings could be as much as 10 minutes per HOV lane vehicle as shown in Section 4.6.1. Upon arrival of emergency vehicles, the HOV lane was closed due to the angled positioning of a ladder fire truck. In this case, it would seem that the HOV lane was closed unnecessarily.

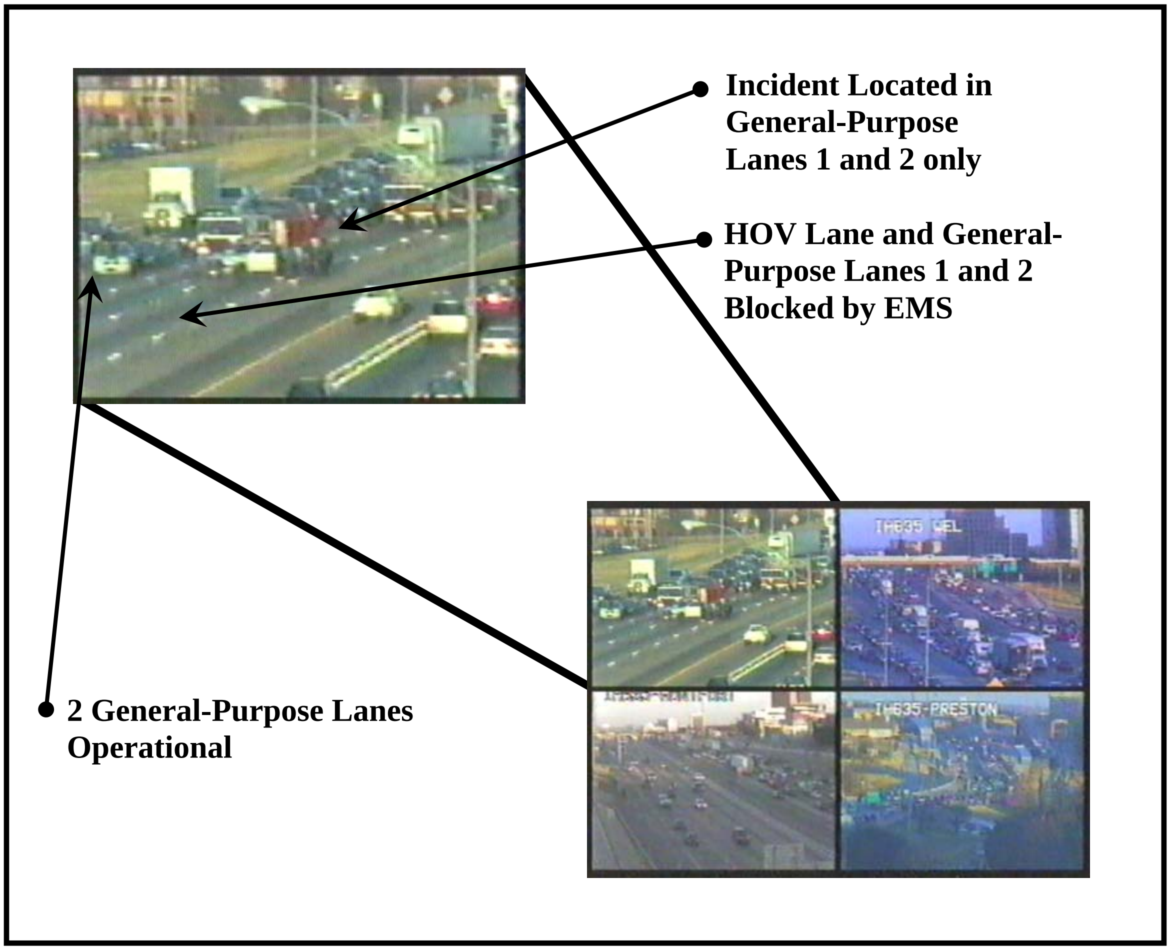

Figure 13. Closing HOV Lane Unnecessarily.

5.2.2 Taking Additional General-Purpose Lane Unnecessarily

Figure 14 shows an incident blocking both Lane 1 of the general-purpose lanes and the HOV lane. Lanes 2, 3, and 4 of the general-purpose lanes remain operational even after arrival of the TxDOT Courtesy Patrol. The Courtesy Patrol truck with its electronic arrow board in operation is positioned immediately behind the incident. Courtesy Patrol personnel set out orange traffic cones to channel traffic past the incident. When an ambulance arrives at the scene, it is positioned immediately in front of the incident and does not cause any additional disruption of the general-purpose lanes operation. However, upon arrival of the fire truck, it is positioned in a way that blocks Lane 2 of the general-purpose lanes. In this case, it would seem that an additional travel lane was taken away unnecessarily.

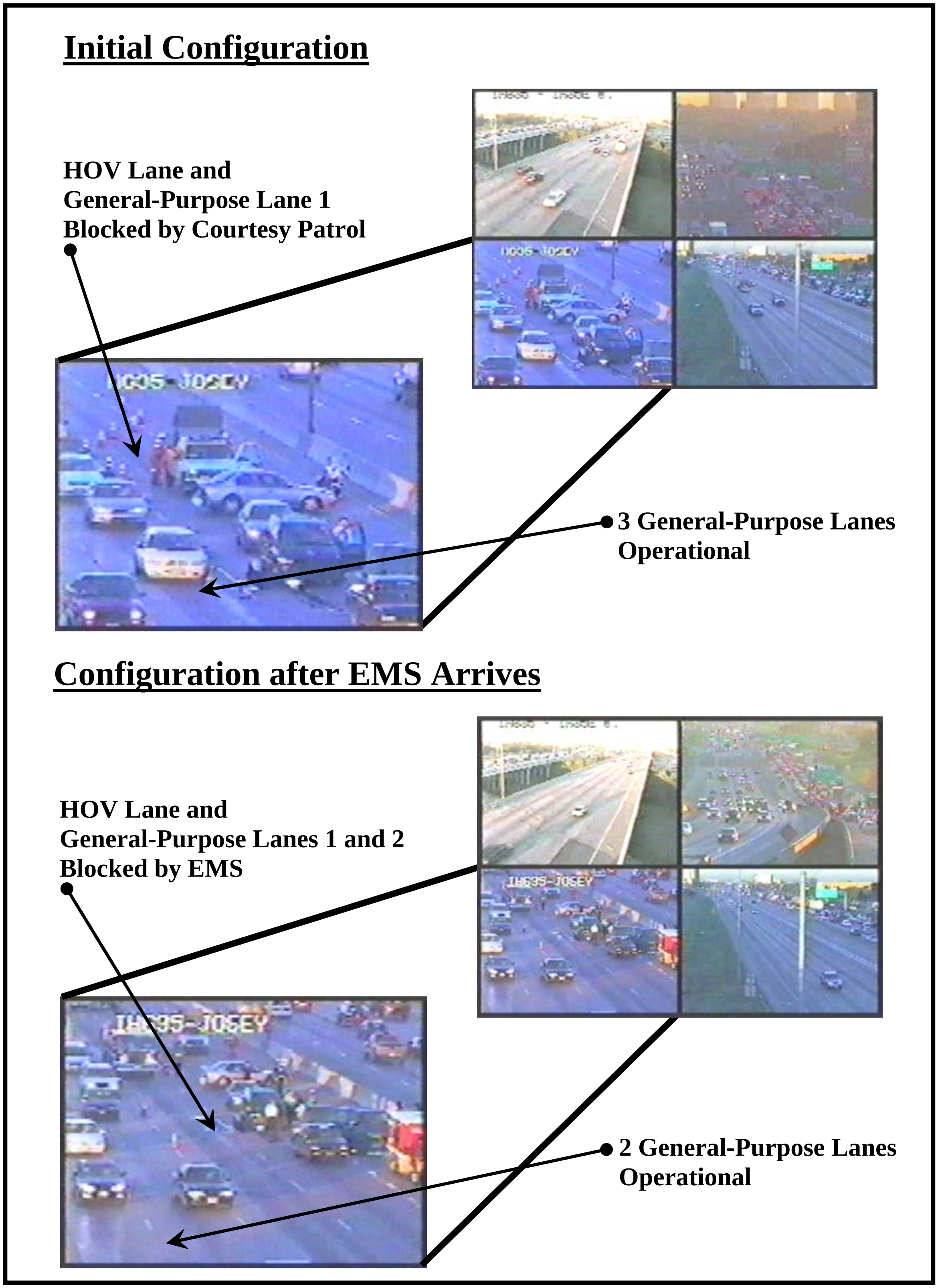

Figure 14. Taking Additional General-Purpose Lanes Unnecessarily.

CHAPTER 6:
CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

In this report, it is a given that two primary goals of HOV lanes are to provide travel time savings and a more reliable trip time to its users. Ideally, the travel time on the HOV lane should be less than the travel time on adjacent general-purpose lanes during weekday peak periods. This should be the case on both non-incident days and days with incidents in the corridor. This research quantifies the additional travel time benefits offered to HOV lane users during incidents on the general-purpose lanes. The effects of incidents causing HOV lane blockage are also addressed.

6.2 NUMBER OF INCIDENTS ON IH-635

A total of 569 peak period incidents were documented on IH-635 from September 2003 through mid January 2004. It should be noted that this most likely underestimates the true number of incidents in the corridor, since these are only the incidents that were visible by DalTrans personnel using CCTV cameras. A total of 63 of the 569 incidents resulted in blocking the HOV lane and/or the general-purpose lanes, almost one per weekday considering there were 71 weekdays of good video data. Only a handful of the 63 incidents offered both usable and reliable information sufficient for a thorough data analysis. This is due to numerous technical difficulties with DalTrans video data of incidents and limited Autoscope speed and travel time data for the corridor. As a result, the conclusions offered from this research for additional travel time savings for HOV lane users during incident conditions are only applicable to the IH-635 corridor.

6.3 BENEFIT TO CONCURRENT FLOW HOV LANE USERS

The increased delay due to incidents on the general-purpose lanes equates to increased travel time savings for HOV lane users that are unaffected by the incident. This data analysis showed a **maximum additional travel time savings of 10 minutes for HOV lane users in the IH-635 corridor** during incidents with the general-purpose lanes blocked for 45 to 60 minutes.

Shorter duration incidents provide less of an additional travel time savings. Again, this is based on limited available data.

6.4 CONCURRENT FLOW HOV LANE DELAY DUE TO INCIDENTS

It is inherent to the design of concurrent flow, buffer-separated HOV lanes that incidents in the general-purpose lanes may impact the HOV lane operation due to the lack of physical separation. A number of incidents in the corridor were shown to block the HOV lane and/or Lane 1 of the general-purpose lanes immediately adjacent to the HOV lane. **Incidents in which only the HOV lane is blocked showed the HOV lane users' delay to be a maximum of approximately 10 minutes. Incidents in which both the HOV lane and Lane 1 are blocked delay HOV lane users a maximum of approximately 14 minutes.**

As already noted in Section 3.2.3, there were 71 weekdays of video data that were usable for incident determination. Table 5 showed there were 16 peak periods of non-incident video data or eight weekdays without incidents. On non-incident days, HOV lane users can expect to save 15 minutes in travel time over the general-purpose lanes (6). Table 1 showed the number of incidents causing lane blockage. By combining the frequency of lane blockage with the average delay values from Table 9, an overall net benefit of the HOV lanes can be determined. The benefits calculation is shown in Table 10. Each HOV lane vehicle saved a total of 68 minutes over a period of 71 days. This equates to about only 1 minute round-trip travel time savings per day over the analysis period.

Table 10. Net Benefit for Concurrent Flow HOV Lane User.

(8 days without lane blocking incident) x (15 minutes round-trip travel time savings) =	+120 minutes
(37 days with general-purpose lane incident) x (4.6 minutes additional travel time savings) =	+170 minutes
(14 days with HOV lane incident) x (6.4 minutes average delay) =	-90 minutes
(12 days with HOV lane/Lane 1 incident) x (11.0 minutes average delay) =	-132 minutes
Net benefit per HOV lane vehicle over 71 days =	+ 68 minutes

There are a number of examples in this analysis where the incident actually only blocked one or more of the general-purpose lanes. In these cases, the HOV lane initially continued to operate effectively, thereby maintaining the usual travel time savings and the additional travel time savings attributed to the incident in the general-purpose lanes. However, upon arrival of emergency vehicles (e.g., fire truck) on the scene, typically an additional travel lane, either a general-purpose lane or the HOV lane, is blocked while emergency personnel attend to the incident. Many times, it appears that blocking additional lanes was unnecessary and did not really provide any higher level of safety than existed prior to arrival. During peak traffic periods, the unnecessary blocking of travel lanes can severely hinder freeway operation. Several suggestions for maintaining operation of the HOV lane during general-purpose lane incidents are provided next.

6.5 SUGGESTIONS FOR INCIDENT RESPONSE AFFECTING HOV LANES

It is the philosophy of emergency service personnel in Dallas to use emergency response vehicles, particularly fire trucks, as a safety barrier. Typically, emergency vehicles will be placed upstream of the incident and angled to block multiple lanes and force freeway traffic to only one side of the incident. The primary reason for this practice is to ensure errant vehicles do not encroach or move through the incident scene. This indeed makes sense during non-peak hours when traffic speeds can remain high even near an incident. However, during peak periods of the IH-635 corridor, there are multiple roadway sections where daily congestion already decreases vehicle speeds substantially and incidents bring traffic to a crawl. With this in mind, the research team offers the following suggestions for better incident response for maintaining effective HOV lane operation and freeway capacity during peak periods:

- Upon arrival to the incident scene during peak periods, emergency service personnel should assess traffic conditions in the immediate vicinity of the incident. **In known areas of daily congestion, every effort should be made not to close additional travel lanes unnecessarily.** For example, an incident occurring in Lane 2 of the general-purpose lanes probably requires closing only Lane 1. Closing the HOV lane, as shown in Figure 13, is unnecessary.

- **While emergency services are on an incident scene, there should be a concerted effort for traffic direction by police, the Courtesy Patrol, or unoccupied fire personnel.** Simply waving freeway traffic past an incident may reduce the overall delay associated with the incident.

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