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16. Abstract <p>In Texas, high-occupancy vehicle (HOV) lanes have emerged as an integral part of the state's current and future transportation system to aid urban mobility. As a result, the issue of HOV lane design and the influence of design on safety has become the focus of much attention in the transportation community.</p> <p>The objective of this research was to develop a better understanding of the safety issues associated with HOV lanes, particularly buffer-separated concurrent flow HOV lanes. The research team increased their understanding of these issues by surveying transportation professionals from across the United States on the topic of HOV lane safety for barrier-separated and buffer-separated facilities. Electronic crash data was analyzed and crash reports from Dallas, Texas, were reviewed to determine crash characteristics both before and after HOV lane implementation in selected corridors.</p> <p>The analysis of the IH-30 corridor with a moveable barrier-separated contraflow HOV lane did not indicate a change in injury crash occurrence. The IH-35E North and IH-635 corridors with buffer-separated, concurrent flow HOV lanes did show a change in crash occurrence with an increase in injury crash rates.</p> <p>Based on the key findings of the crash data analysis, the research team developed guidance for design when implementing HOV lanes similar to those in operation in Dallas, Texas. This guidance indicates desirable corridor characteristics when considering HOV lane implementation and recommends roadway cross-sections.</p>					
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FACILITIES IN TEXAS: METHODOLOGY, FINDINGS, AND
RECOMMENDATIONS**

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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 Texas Department of Transportation (TxDOT) or the U.S. Department of Transportation, Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation. The researcher in charge was A. Scott Cothron.

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EXECUTIVE SUMMARY

In Texas, high-occupancy vehicle (HOV) lanes have emerged as an integral part of the state's current and future transportation system to aid urban mobility. As a result, the issue of HOV lane design and the influence of design on safety has become the focus of much attention in the transportation community. This research report addresses the topic of HOV lane safety by analyzing crash data from Dallas corridors with HOV lanes and provides guidance based on the research findings.

The topic of priority lane treatment in Texas has been addressed in several previous major research studies. Project 0-1353, "An Evaluation of High-Occupancy Vehicle Lanes in Texas," provided comprehensive documentation of the performance characteristics of all existing HOV lanes in Texas. A one-year project, Project 7-1994, "Implementation and Evaluation of Concurrent Flow HOV Lanes in Texas," examined the operational performance of the two new buffer-separated concurrent flow lanes in Dallas. A multi-year project, Project 7-3942 "Investigation of HOV Lane Implementation and Operational Issues" ([1,2,3](#)), investigated the operational effectiveness of Dallas' interim HOV lanes. This research effort first explored safety issues concerning the HOV lanes in Dallas, but only one year of crash data after the HOV lanes had been opened was available for analysis. Therefore, it was determined that additional after data was needed in order to provide a better understanding of the effects of the HOV lanes regarding operational safety. Project 7-4961, "An Evaluation of Dallas Area HOV Lanes" ([4](#)), provided the first good sample of crash data available after the opening of the HOV lanes. This study took a cursory look at injury crash data from each of the HOV lane corridors and several corridors without HOV lanes in Dallas. It compared before and after injury crash rates and crash frequencies with three years of available after data. The results of the crash data analysis indicated that more in-depth research was needed to determine why there was an increase in overall injury crash rates in the two corridors with buffer-separated concurrent flow HOV lanes, thus, leading to this current research study.

Freeway corridors in Dallas, where HOV lanes have been implemented, offer a valuable opportunity to evaluate "before" and "after" crash data and determine whether there has been a change in crash occurrence. The research team analyzed injury crash data from three corridors in the Dallas area with HOV lanes. The IH-30 corridor east of downtown Dallas includes a

moveable barrier-separated contraflow HOV lane that has been in operation since 1991. The IH-35E North and IH-635 corridors both include buffer-separated concurrent flow HOV lanes. Both facilities are bi-directional and have a painted buffer separation. They have been in operation since the mid 1990s. All of these HOV lanes are considered interim projects by the Federal Highway Administration (FHWA) because they were retrofitted into the existing freeway facility resulting in design exceptions from normally required standards.

The research team obtained electronic crash databases from the Accident Records Bureau (ARB) of the Texas Department of Public Safety (DPS) in Austin, Texas. The electronic crash data are simply the information contained in the DPS mainframe database which is coded from the hard copy crash reports (Form ST-3) that are completed at the time of a crash occurrence.

Injury crash rates from Dallas corridors with HOV lanes were analyzed over multiple years. Using injury crash rates, the research team looked for changes in crash occurrence in these corridors after implementing HOV lanes. The crash data from the IH-30 corridor does not indicate a change in injury crash occurrence, except during the years 1995 and 1996, when it appears that several large construction projects resulted in more crashes in the corridor.

Dallas corridors with buffer-separated concurrent flow HOV lanes did show a change in crash occurrence with an increase in injury crash rates. The IH-35E North corridor experienced a 56 percent increase in the injury crash rate. The IH-635 corridor experienced a 41 percent increase in the injury crash rate.

A closer look at the crash data indicates that the higher injury crash rates were primarily due to the crashes occurring on the HOV lane and on the inside general-purpose lane which is adjacent to the HOV lane. The research team obtained copies of approximately 1,150 crash reports (Form ST-3) covering the years 1997-2000 for both the IH-35E and IH-635 corridors. These are all the crash reports that indicated the location of the crash as occurring on either the buffer-separated concurrent flow HOV lane or the adjacent inside general-purpose lane. The research team conducted a thorough review of the crash reports to better understand the crash characteristics and to examine possible trends. The review of the ST-3s supported the information contained in the crash database.

The research team tried to determine driver intent and contributing factors by reviewing each individual crash report with particular attention given to the crash sketch and narrative prepared by the investigating officer. Although it is impossible to determine driver intent and

crash causes with absolute certainty, the research team was able to obtain a general sense of typical crash characteristics. The research team found that many of the crashes that were occurring in the buffer-separated concurrent flow HOV lane or the adjacent inside general-purpose lane were related to the speed differential between the two lanes.

Based on the analysis of crash data and the copies of crash reports, the research team developed guidance for future design of HOV lanes in the Dallas area. This guidance includes suggestions for corridor characteristics and HOV lane cross-sections for barrier-separated contraflow HOV lanes and painted buffer-separated concurrent flow HOV lanes. In the case of buffer-separated concurrent flow HOV lanes, the cross-sections are intended to lessen the influence of speed differential between the HOV lane and the general-purpose lanes by providing greater width cross-section in the HOV lane area (i.e., inside shoulder, HOV lane, and painted buffer). This increased width provides room for two vehicles to be side by side and may prevent many of the types of crashes studied.

The research team identified three key findings from the crash data analysis of Dallas corridors with buffer-separated concurrent flow HOV lanes.

- Increase in injury crash rate
- Increase in injury crashes primarily focused in the HOV lane and the adjacent general-purpose lane (Lane 1).
- 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.

Higher vehicle speeds and trip reliability in the HOV lane compared to general-purpose lanes are goals of implementing HOV facilities. However, in the case of buffer-separated HOV lanes, the speed differential also contributes to crash potential. Further research is needed to evaluate innovative safety countermeasures that address this operational issue, while still maintaining the mobility benefits of HOV lanes.

CHAPTER 1: INTRODUCTION

1.1 PURPOSE

Over the last three decades, HOV lanes have been built in the Houston and Dallas regions. Similar facilities are being considered for other urban areas in Texas. With the emergence of HOV lanes as an integral part of the state's transportation system, issues related to their design and safety have become the focus of much attention in the transportation community. The implementation of Dallas HOV lanes offers the unique opportunity to evaluate crash data from the contraflow barrier-separated facility and the two concurrent flow buffer-separated facilities both "before" and "after" HOV lane implementation in the corridors.

1.2 BACKGROUND

The Dallas District of TxDOT and Dallas Area Rapid Transit (DART) have implemented short-term (interim) transit projects, such as buffer-separated concurrent flow HOV lanes that have enhanced public transportation and overall mobility until permanent treatments can be implemented. Dallas' two buffer-separated facilities are considered interim projects by the Federal Highway Administration as they have been retrofitted into the existing freeway facility resulting in design exceptions from normally required standards. A moveable barrier-separated HOV lane has also been in operation in Dallas as an interim project since 1991.

The topic of priority lane treatment in Texas has been addressed in several previous major research studies. Project 0-1353, "An Evaluation of High-Occupancy Vehicle Lanes in Texas," provided comprehensive documentation of the performance characteristics of all existing HOV lanes in Texas. A one year project, Project 7-1994, "Implementation and Evaluation of Concurrent Flow HOV Lanes in Texas," examined the operational performance of the two new buffer-separated concurrent flow lanes in Dallas. A multi-year project, Project 7-3942 "Investigation of HOV Lane Implementation and Operational Issues" ([1,2,3](#)), investigated the operational effectiveness of Dallas' interim HOV lanes. This research effort first explored safety issues concerning the HOV lanes in Dallas, but only one year of crash data after the HOV lanes had been opened was available for analysis. Therefore, it was determined that additional after data was needed in order to provide a better understanding of the effects the HOV lanes

regarding operational safety. Project 7-4961, “An Evaluation of Dallas Area HOV Lanes” (4), provided the first good sample of crash data available after the opening of the HOV lanes. This study took a cursory look at injury crash data from each of the HOV lane corridors and several corridors without HOV lanes in Dallas. It compared before and after injury crash rates and crash frequencies with three years of available after data. The results of the crash data analysis indicated that more in-depth research was needed to determine why there was an increase in overall injury crash rates in the two corridors with buffer-separated concurrent flow HOV lanes, thus, leading to this current research study.

1.3 PROJECT OBJECTIVES

The objective of this research is to better understand the safety issues associated with HOV lanes, particularly buffer-separated facilities. This objective was accomplished by analyzing crash data over multiple years from three urban freeways in Dallas, Texas. A large sample of hard copy crash reports was examined in detail to determine important characteristics attributed to crashes in these corridors with HOV lanes.

1.4 ORGANIZATION OF THE REPORT

This report provides the reader a background of the topic of HOV lane safety, beginning with a discussion of available literature. This section is followed by a discussion of the current attitudes and safety issues as identified by transportation professionals from across the country on the topic of HOV lane safety. With an understanding of current safety issues, the reader is presented with crash data taken from HOV lane corridors in Dallas, Texas. The [final section](#) of the report offers conclusions and recommendations based primarily on the available crash data from Dallas.

CHAPTER 2: LITERATURE FINDINGS

2.1 SAFETY OF BUFFER-SEPARATED HOV LANES

Previous studies throughout the country regarding the safety of HOV lane projects have been relatively inconclusive due to data limitations in both quality and quantity. Some studies have concluded that concurrent flow buffer-separated lanes are as safe as other types of HOV lane projects, while other studies have indicated a safety concern with concurrent flow HOV lane projects.

One research study compared the frequency and characteristics of crashes “before” and “after” an HOV lane was added to Riverside Freeway State Route 91 (SR 91) in the Los Angeles area. The HOV lane was created by taking the inside shoulder of the roadway. The study concluded that the HOV lane project did not have an adverse effect on the safety of the corridor, and the changes in crash characteristics were attributed to the change in location and timing of traffic congestion (5).

Another study conducted by California Polytechnic State University reported the effects HOV lanes have on the safety of selected California freeways. The study suggested the observed crash pattern resulted from differences in traffic flow and congestion rather than geometric and operational characteristics of the HOV facilities (6). The crash “hot spots” during the peak periods of freeways with and without HOV lanes were a result of localized congestion (6).

An FHWA study conducted in 1979 indicates that the lack of physical separation between the HOV lane and the general-purpose lanes can create several operational and safety problems. The speed differential and the merging into and out of the HOV lane were thought to contribute to increased crash potential. Slow vehicles merging into a high-speed HOV lane of faster vehicles or the HOV lane vehicles having to decelerate rapidly to merge into the general-purpose lanes can result in either side-swipe or rear-end crashes (7).

The purpose of a 1995 study conducted by the Hampton Roads Planning District Commission in Virginia was to determine the safety effects of implementing a buffer-separated HOV lane. Data from HOV lane facilities around the country were reviewed to determine the impact of varying buffer widths separating the HOV lane and the general-purpose lanes. The following HOV lane designs were reviewed: 3 to 8 foot buffer, 8 foot buffer raised 6 inches off

the pavement, 13 foot buffer, and 0 to 2 foot buffer. The results indicated that the impact of the first three designs was inconclusive. However, the use of a buffer of 0 to 2 foot in width appeared to contribute to an increase in crash rates when compared to the pre-HOV crash rates for the freeways of interest. The speed differential between the HOV lane and the general-purpose lanes was identified as the possible cause of the crash rate increase (8).

In 2002, TTI completed a multi-year research Project 7-4961, “An Evaluation of Dallas Area HOV Lanes.” In this study, injury crash rates were compared from before and after buffer-separated HOV lanes were implemented in two corridors. There was an increase in injury crash rate for the after condition. However, the data were not analyzed to determine whether the increase was statistically significant. Several factors were identified that may have contributed to an increase in crash rates. These factors included the loss of the inside shoulder and a reduction in general-purpose lane width from 12 feet to 11 feet for implementation of the buffer-separated HOV lane (4).

Other recent research conducted by the Midwest Research Institute (MRI) studied crash data from California on freeways where the inside shoulder was converted to a travel lane and the other lanes were reduced in width. All of the freeways examined statistically used the converted inside lane as a concurrent flow HOV lane. The analysis indicated that crash frequencies increased after the freeways were changed in this manner. However, the MRI research team did not attempt to explain the increase in the number of crashes (9).

2.2 SAFETY OF BARRIER-SEPARATED HOV LANES

Traffic crashes in the general-purpose lanes do not typically disrupt operation of barrier-separated HOV lanes. Barrier-separated roadways protect the HOV lane traffic and the general-purpose lanes from the considerable speed differential that may exist between the two traffic streams with concurrent flow HOV lanes (10). However, there has been some concern that physically separated roadways are detrimental to traffic flow when an incident occurs in either the HOV lane or mixed-flow facility, as the barrier limits the ability of traffic to maneuver around an incident (10). The 1979 FHWA study indicated that barrier-separated HOV facilities offered a high degree of safety for the general-purpose lanes and particularly for vehicles within the HOV lane (7).

CHAPTER 3: ASSESSMENT OF ISSUES AND ATTITUDES FOR HOV LANE SAFETY

3.1 INTRODUCTION

A thorough understanding of the issues and attitudes of transportation professionals regarding the topic of HOV lane safety is valuable in determining future implementation of the various designs of HOV lanes. The two HOV lane designs of particular interest for obtaining safety information are buffer-separated and barrier-separated. Buffer-separated HOV lanes are defined as facilities with buffers of varying widths, with or without delineators, and/or channelizers separating adjacent traffic flow. Barrier-separated HOV lanes are defined as facilities with fixed or moveable concrete barriers separating adjacent traffic flow.

3.2 SURVEY METHODOLOGY

The research team developed survey questions on the topic of buffer-separated and barrier-separated HOV lane safety for distribution to transportation professionals from around the country that are knowledgeable of the research topic. The draft survey questions were distributed to the members of the project's research monitoring committee for comments and revised based on those comments. The survey was automated using *Survey Solutions for the Web* software from Perseus Development Corporation (<http://www.perseus.com/>).

The survey instrument was distributed in two formats: an e-mail-based text and html-based Netscape file. Respondents with direct Internet access were able to open the Netscape file and submit responses directly. Those respondents without direct Internet access completed the survey in the e-mail text and used reply to send the completed survey. A portion of the survey respondents printed the Netscape file and returned the survey via fax.

3.3 SURVEY RECIPIENTS

The research team sent the opinion survey to members and friends of the Transportation Research Board HOV Systems Committee and members of the American Association of State Highway and Transportation Officials (AASHTO) Task Force for Public Transportation Facilities Design of the AASHTO Subcommittee on Design. These individuals are interested in the topics associated with HOV lanes as evidenced by their involvement in these groups. The

research team felt that these individuals would offer excellent insight into the national experience regarding HOV lane safety as well as professional thoughts and experiences on the topic.

3.4 SURVEY RESPONSES

3.4.1 Respondents

The research team distributed 95 surveys and compiled results from 23 respondents. The response rate was 24 percent. The responses included more than 230 written comments on the various HOV lane safety issues. Individuals responding to the survey represent a mix of backgrounds, experience, and job responsibilities. Although not all the respondents had direct experience operating HOV lanes or in-depth knowledge of safety issues, the responses are of use in defining possible safety concerns with HOV facilities.

3.4.2 States with Buffer-Separated HOV Lanes

Of the 23 respondents, 12 were from states that operate buffer-separated HOV lanes. Information from areas with buffer-separated HOV lanes is particularly important to this research for use in comparison with observations from the Dallas area.

3.5 SURVEY DATA SUMMARY AND ANALYSIS

[Appendix A](#) contains the survey and results. Provided below are selected questions highlighting the opinion survey results and comments. The first half of the survey posed questions specifically related to buffer-separated HOV lanes, and the second half related to barrier-separated HOV lanes.

3.6 GENERAL FINDINGS OF SAFETY ISSUES SURVEY

3.6.1 Buffer-Separated HOV Lanes

[Table 1](#) shows responses given by the transportation professionals surveyed to the following statement: “Based on your experience, please indicate your region or state’s relative concern for any of the following safety issues associated with buffer-separated HOV lanes.”

Table 1. Safety Issues of Buffer-Separated HOV Lanes - Level of Concern.

Issue	High	Medium	Low	No	N/A	No Response	Total
Vehicles Illegally Crossing Buffer	6	5	3	1	5	3	23
Vehicle Merges at Ingress/Egress	3	5	5	1	5	4	23
Lack of, or Reduced Inside Shoulder Width	5	6	5	0	2	5	23
Reduced HOV Lane or Mainlane Widths	0	3	6	5	5	4	23
HOV Lane Used For Disabled Vehicles	4	1	5	5	4	4	23
HOV Lane Used For Evasive Action	3	5	6	1	4	5	23

3.6.2 Barrier-Separated HOV Lanes

Table 2 shows responses given by the transportation professionals surveyed to the following statement: “Based on your experience, please indicate your region or state’s relative concern for any of the following safety issues associated with barrier-separated HOV lanes.”

Table 2. Safety Issues of Barrier-Separated HOV Lanes - Level of Concern.

Issue	High	Medium	Low	No	N/A	No Response	Total
Operational Issues at Ingress/Egress Locations	2	5	6	2	3	5	23
Lack of, or Reduced Inside Shoulder Width	4	3	4	3	3	6	23
Reduced HOV Lane Widths	0	3	5	6	3	6	23
Disabled Vehicles in HOV Lane	3	4	4	4	2	6	23
Wrong Way Movements on HOV Lanes	3	2	3	6	3	6	23

3.7 SPECIFIC ISSUES FROM SAFETY ISSUES SURVEY

3.7.1 Buffer-Separated HOV Lanes

Issues the survey respondents indicated as typically occurring on buffer-separated HOV lanes were separated into the following categories:

- ingress/egress difficulty,
- illegally crossing the buffer,

- speed differential, and
- reduced inside shoulder.

The safety issues at ingress/egress locations result from having extreme congestion in the general-purpose lanes. In this case, a vehicle in the HOV lane desiring to merge into the adjacent congested general-purpose lane is unable to find an acceptable gap in general-purpose lane traffic. Difficulty merging causes the vehicle to slow down or stop in the buffer area or within the HOV lane, possibly blocking other HOV lane traffic from continuing. Traffic queuing in the HOV lane is usually unexpected and may result in rear-end crashes. One survey respondent noted that their experience showed that most of the HOV lane crashes occurred in the vicinity of access points involving heavy merge volumes or weave areas.

The issue of vehicles illegally crossing the buffer involves occupancy violators and non-violators. Occupancy violators will illegally cross the buffer to bypass slowed mainlane traffic and then return across the buffer to the mainlanes when the traffic is moving steadily again. Also, occupancy violators may be familiar with enforcement practices in the area and illegally move back and forth across the buffer area to avoid known enforcement areas.

One survey respondent noted that vehicles crossing the buffer basically “hurt” the entrance to the HOV lanes. Another respondent noted that impatient HOV lane users may cross the buffer or use the access locations and go back to the general-purpose lanes to pass slower HOV lane vehicles.

Some respondents noted that the speed differential between the buffer-separated HOV lanes and the general-purpose lanes can be a safety concern. One survey respondent explained that many years ago transportation professionals realized the safety implications of placing high-speed traffic next to low-speed traffic and how the use of acceleration and deceleration lanes at freeway entrance and exit ramps exist to minimize the speed differential for merging vehicles. In a congested freeway situation, the speed differential between the outside freeway lane and entrance and exit ramps is typically not as substantial as the differential between the HOV lane and the first general-purpose lane. Another survey respondent noted a safety concern related to vehicles stopped in the general-purpose lane attempting to enter the HOV lane where vehicles were traveling at much higher speeds.

Substandard width for the inside shoulder may cause disabled vehicles to stop in the HOV lane, either partially or completely blocking the lane. During uncongested time periods, drivers may be tempted to park a disabled vehicle on the HOV lane. In certain cases, the inside shoulder is either reduced or completely taken away to implement the HOV lane. One survey respondent noted some drivers do not understand that the shoulder has been taken away and simply park their disabled vehicle in the HOV lane.

3.7.2 Barrier-Separated HOV Lanes

Issues that the survey respondents indicated as typically occurring on barrier-separated HOV lanes were restricted mainly to the HOV lane and did not routinely influence the general-purpose lanes. Without a concerted effort of HOV lane enforcement, excessive speed in the lane can create a safety hazard resulting in crashes, particularly at access locations where a potential for queuing exists. Crashes within barriers of an HOV lane can make incident management difficult, particularly if the facility lacks shoulders. Facilities designed without inside shoulders do not provide a location to park disabled vehicles. The ability to pass stalled vehicles is important to the successful operation of barrier-separated HOV lane facilities. Some barrier-separated facilities include breakdown areas in the design to minimize the impact of not having shoulders.

The design of access points for a barrier-separated HOV lane is also noted as being critical in alleviating the number of vehicle crashes. The barrier-separation may create problems with sight distance at access points and horizontal curves, particularly when the HOV lane is operating during non-daylight hours. This situation requires ample signing and illumination to increase the level of safety. Access considerations also apply to getting emergency vehicles into the lane and providing adequate incident response in the event an incident has blocked the HOV lane and caused a long backup of traffic on the lane.

CHAPTER 4: CRASH DATA ANALYSIS

4.1 INTRODUCTION

The research team analyzed available crash data from Dallas, both macroscopically and microscopically. Macroscopically, injury crash rates from each of the HOV lane corridors in the Dallas area were developed to determine whether the corridors experienced an overall change related to crash occurrence in the years after the HOV lanes were implemented in each corridor. Microscopically, locations of individual crashes and crash reports from the Dallas area were reviewed to determine crash characteristics and possible reasons for crash occurrence.

4.2 CRASH RATE ANALYSIS FOR DALLAS, TEXAS

4.2.1 Background

The Dallas area has 54.2 lane-miles of HOV lanes currently in operation on five freeways. The first HOV lane in Dallas opened in October 1991. The IH-30 HOV lane is a barrier-separated contraflow facility using a moveable barrier system. In late 1996, buffer-separated HOV lanes were opened in each direction on IH-35E North, and they operate 24 hours per day. The following year, buffer-separated HOV lanes were opened on IH-635, also serving traffic in each direction of travel and operating 24 hours per day. The latest addition to the Dallas area HOV lane network serves the area south of downtown Dallas as a reversible barrier-separated HOV lane along IH-35E South and buffer-separated and reversible barrier-separated HOV lanes along US-67. These last two corridors were not included in the crash data analysis since the HOV lanes have only been in operation since 2000. There was not enough after data yet available to do a comprehensive crash data analysis on these corridors.

In 2002, TTI completed a multi-year research Project 7-4961, “An Evaluation of Dallas Area HOV Lanes” (4). Although this project focused primarily on the mobility benefits of HOV lanes, it also took a cursory look at crash data from three of the HOV lane corridors in Dallas. The results of the crash data analysis indicated that more in-depth research was needed on the topic to determine why there was an increase in overall injury rates in the two corridors with buffer-separated concurrent flow HOV lanes.

4.2.2 Reliability of Electronic Crash Data

The research team obtained the coded crash data from the Accident Records Bureau of the Texas Department of Public Safety in Austin. Coded crash data refers to crash information contained in the DPS mainframe database, which consists of all the data from the original crash reports (ST-3), with the exception of crash sketches and the exact wording of narratives.

The reader should be aware that crash reporting errors are possible. The main areas of concern for crash reporting errors with regard to this research were the coded location (i.e., lane designation) and severity of a crash within the corridors of interest. The research team made every effort to identify electronic database discrepancies by reviewing a large sample of the original ST-3 reports. The review of the ST-3s supported the information contained in the crash database. Researchers found that DPS personnel made proper corrections to information such as lane designation.

4.2.3 HOV Lane Corridor Injury Crash Rates

A “before” and “after” analysis of injury crash data was performed to evaluate changes in crash occurrence in corridors with the two types of HOV lane facilities available in the Dallas area, barrier- and buffer-separated facilities.

Injury crash rates are an effective means of measuring crash potential based on the concept of vehicle exposure measured in vehicle-miles traveled (VMT). Injury related, two-way crash rates (injury crashes per 100 Million VMT) for the three corridors of interest have been calculated for multiple years using ARB supplied data. Also, TTI had available peak period traffic volumes that could be used to develop peak period injury crash rates for a limited number of years.

Figures 1, 2, and 3 show the typical cross-sections for IH-30 (East R.L. Thornton Freeway), IH-35E North (Stemmons Freeway), and IH-635 (LBJ Freeway), respectively. Each cross-section is followed by a table (Tables 3-5) showing yearly crash rates for the particular corridor. Year 2000 crash data were the most recent data available from the DPS database at the time of this research.

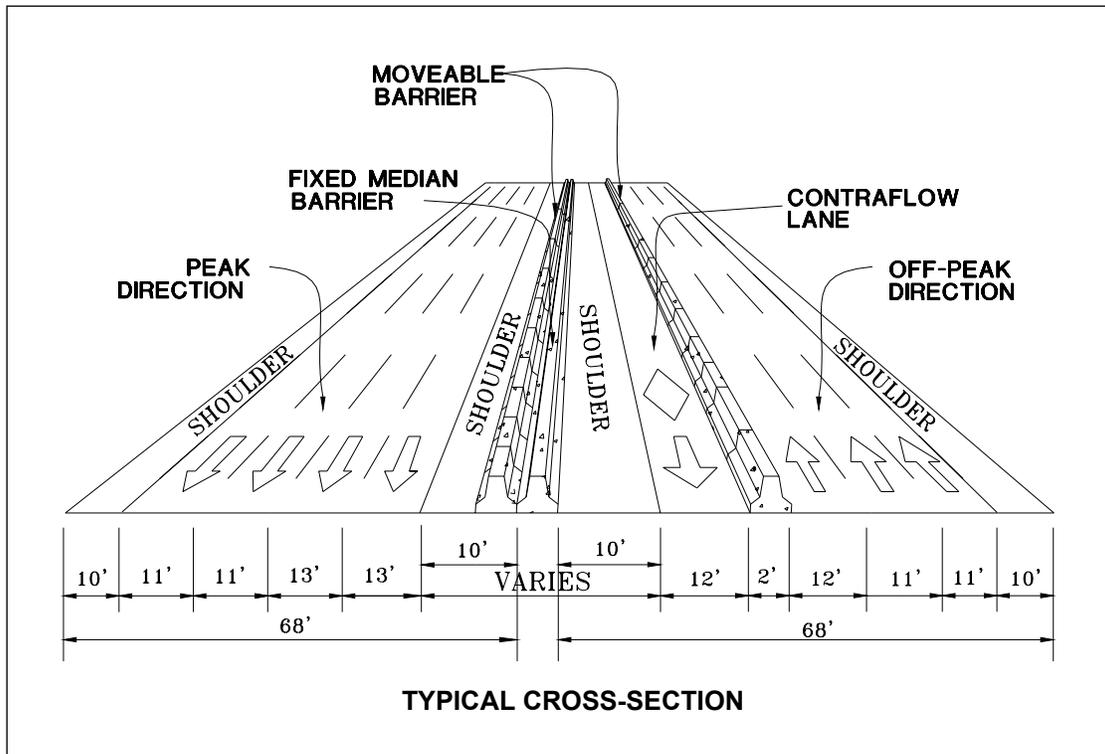


Figure 1. IH-30 (ERLT) Contraflow HOV Lane (Dallas, Texas).

Table 3. IH-30 (ERLT) Freeway Corridor Injury Crash Rates.

IH-30 with Contraflow Barrier-Separated HOV Lane US-75 to Jim Miller Rd. (Control Section: 0009-11 from Milepoint 4.5 to 10.1)								
Injury Related Crashes								
Yr	Total Crashes	Peak Period Crashes	EB/WB	Nonserious/ Serious ¹	Weekday/ Weekend	Vehicle-Miles Traveled (100 Mil VMT) ²	Crash Rate (Crashes/ 100 Mil VMT)	Peak Period Crash Rate ⁷
85	244	-	116/128	212/32	151/93	2.67	91	-
86	276	-	134/142	237/39	190/86	2.91	95	-
87	235	-	125/110	211/24	147/88	2.79	84	-
88	213	-	120/93	192/21	142/71	2.75	78	-
89	204	-	204/102	180/24	133/68	2.75	74	-
90	149 (Const.)	-	69/80	129/20	99/50	2.47	60	-
Construction of HOV Lanes ³								
92 ⁴	182	51	102/80	169/13	124/58	2.46	74	Unavailable ⁶
93 ⁵	201 (Const.)	59	94/107	181/20	142/59	2.46	82	Unavailable ⁶
94	234 (Const.)	68	102/132	219/15	151/83	2.28	103	Unavailable ⁶
95	270 (Const.)	-	159/111	247/23	187/83	2.28	118	-
96	276 (Const.)	-	153/123	255/21	194/82	2.41	115	-
97	232 (Const.)	-	121/111	221/11	156/76	2.67	87	-
98	192	63	91/101	180/12	131/61	2.61	74	63
99	222	76	104/118	200/22	153/69	2.61	84	83
00	230	78	118/112	213/17	154/76	2.66	86	73

Notes:

¹Nonserious = Possible or Non-incapacitating Injury, Serious = Incapacitating Injury or Fatality.

²Yearly corridor VMT calculation for 1992-2000 includes HOV lane vehicles.

³HOV lane construction began 12/90 and ended 9/91.

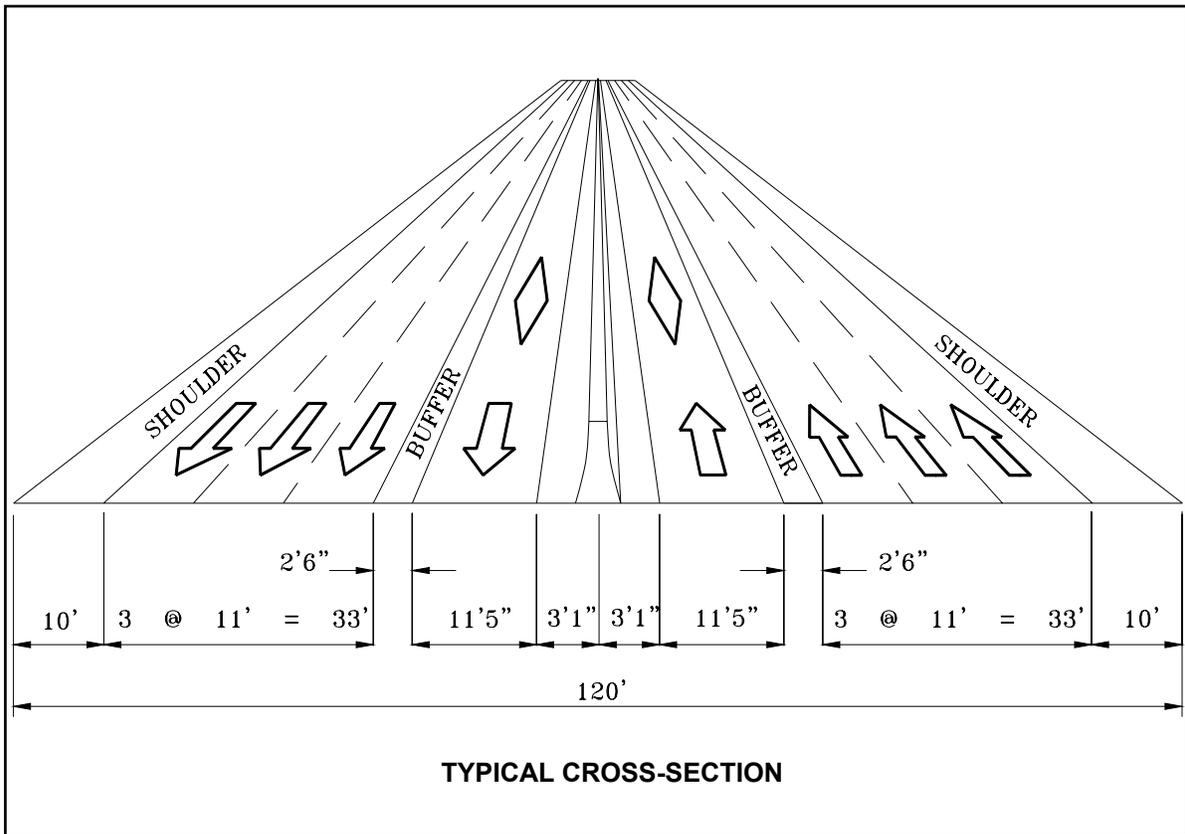
⁴Major roadway reconstruction occurred during five of the first six years of HOV lane operation.

⁵Reconstruction of Fair Park bridge began 5/93 and ended 2/96.

⁶Due to construction, no peak period data were collected.

⁷TTI collected traffic volumes used.

Table 3 shows higher corridor crash rates between the years 1994-1996. Several major construction projects in the corridor would seem to explain this increase, as the crash rates declined in subsequent years. The injury crash rates prior to implementation of the HOV lane, with the exception of 1990, are generally similar to the crash rates after implementation. The research team could not determine the reason for the low injury crash rate in 1990.



Note: Intermediate ingress/egress is possible at locations where the painted buffer changes to a single skip stripe as shown in the left side of the photo below.



Figure 2. IH-35E North (Stemmons) Freeway HOV Lane (Dallas, Texas).

Table 4. IH-35E North (Stemmons) Freeway Corridor Injury Crash Rates.

IH-35E North with Concurrent Flow Buffer-Separated HOV Lanes IH-635 to Dallas County Line (Control Section: 0196-03 from Milepoint 28.5 to 34.5)									
Injury Related Crashes									
Year	Total Crashes	Peak Period	NB/SB	Nonserious/ Serious ¹	Weekday/ Weekend	Vehicle-Miles Traveled (100 Mil VMT) ²	Crash Rate (Crashes/100 Mil VMT)	Peak Period Crash Rate ⁴	
90	74	-	38/36	69/5	54/20	2.57	29	-	
91	75	-	40/35	67/8	50/25	2.55	29	-	
92	64	-	35/29	52/12	53/11	2.64	24	-	
93	104	37	57/47	95/9	70/34	2.64	39	45	
94	110	35	61/49	94/16	78/32	2.7	40	53	
Construction of HOV Lanes ³							Average Crash Rate	32	49
97	157 (Const.)	-	85/72	150/7	117/40	2.98	53	-	
98	162	54	87/74	145/17	119/43	3.49	46	67	
99	162	65	85/77	155/7	123/39	3.43	47	78	
00	197	73	96/101	185/12	157/40	3.59	55	100	
							Average Crash Rate	50	82

Notes:

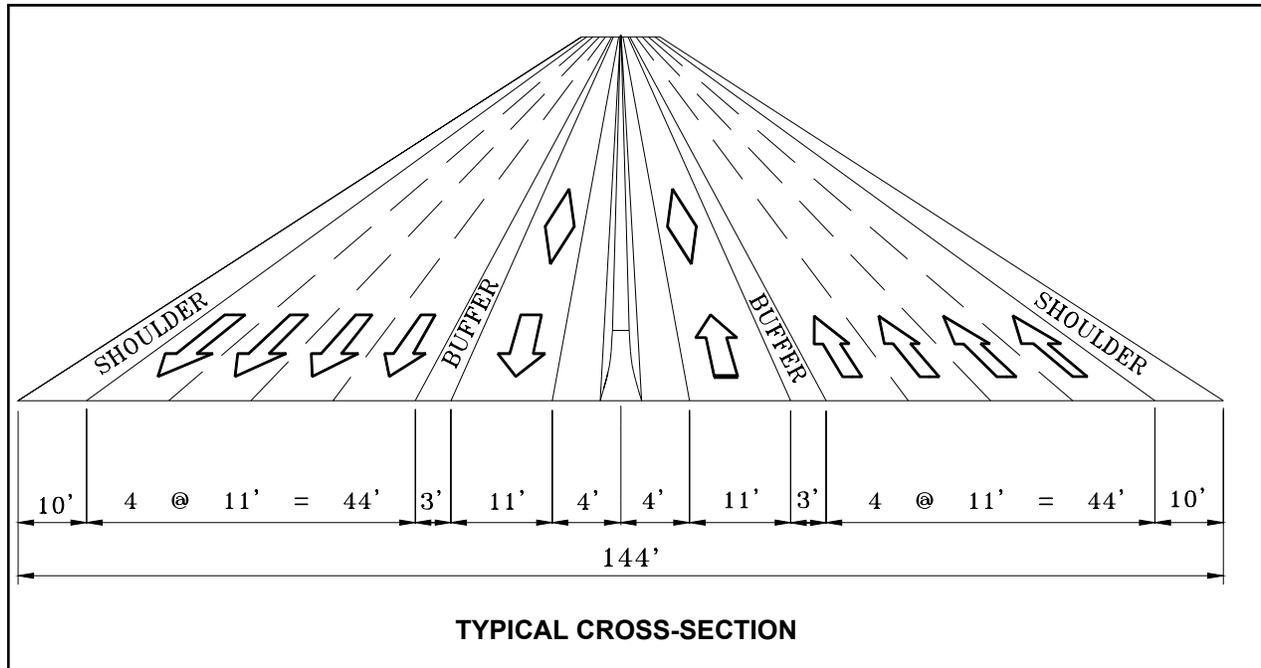
¹Nonserious = Possible or Non-incapacitating Injury, Serious = Incapacitating Injury or Fatality.

²Yearly Corridor VMT calculation for 1997-2000 includes HOV lane vehicles.

³HOV lane construction began 6/95 and ended 9/96.

⁴TTI collected traffic volumes used.

Table 4 shows higher corridor crash rates for the HOV lane operation period from 1997 to 2000. The injury crash rate average from 1997-2000 is 56 percent higher than the 1990-1994 average. Also, the injury crash rates in the “after” condition are higher for peak travel periods. When looking at individual years, the peak period crash rates in the IH-35E North corridor are shown to be higher than the daily crash rates.



Note: Intermediate ingress/egress is possible at locations where the painted buffer changes to a single skip stripe.

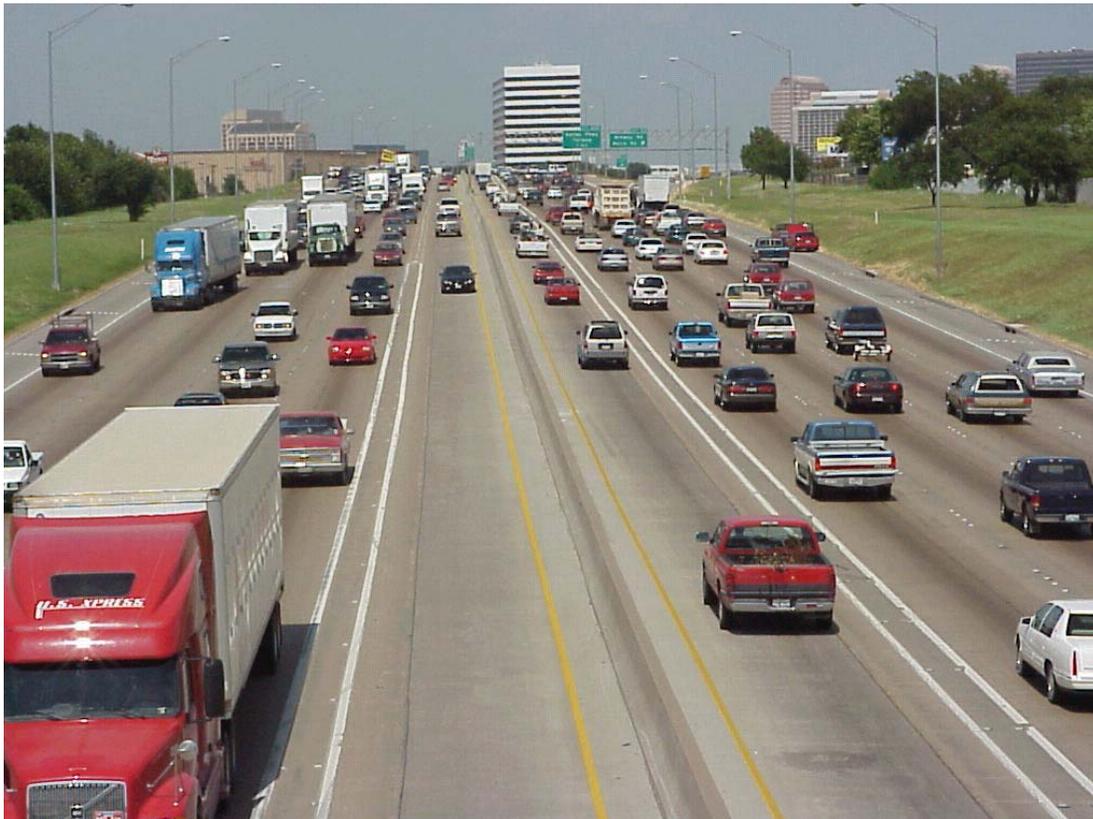


Figure 3. IH-635 (LBJ) Freeway HOV Lane (Dallas, Texas).

Table 5. IH-635 (LBJ) Freeway Corridor Injury Crash Rates.

IH-635 with Concurrent Flow Buffer-Separated HOV Lanes US-75 to IH-35E North (Control Section: 2374-01 from Milepoint 6.5 to 14.5)									
Injury Related Crashes									
Year	Total Crashes	Peak Period	EB/WB	Nonserious/ Serious ¹	Weekday/ Weekend	Vehicle-Miles Traveled (100 Mil VMT) ²	Crash Rate (Crashes/100 Mil VMT)	Peak Period Crash Rate ⁵	
90	264	-	138/126	236/28	193/71	5.48	48	-	
91	282	-	152/130	256/26	186/96	5.95	47	-	
92	245	84	107/138	227/18	176/69	6.06	40	-	
93	241	78	131/110	228/13	181/60	6.06	40	-	
94	283	93	142/141	375/16	216/67	6.60	43	55	
Construction of HOV Lanes ³							Average Crash Rate	44	55
97 ⁴	225	-	118/107	210/15	180/45	3.45	65	-	
98	476	184	242/234	451/25	375/101	7.53	63	94	
99	434	146	218/216	403/31	337/97	7.42	59	77	
00	450	162	223/227	422/28	355/95	7.37	61	88	
							Average Crash Rate	62	86

Notes:

¹Nonserious = Possible or Non-incapacitating Injury, Serious = Incapacitating Injury or Fatality.

²Corridor VMT calculation for 1997-2000 includes HOV lane vehicles.

³HOV lane construction began 6/95 and ended 3/97.

⁴July-December.

⁵TTI collected traffic volumes used.

Table 5 shows higher corridor crash rates for the HOV lane operation period from 1997 to 2000. The injury crash rate average from 1997-2000 is 41 percent higher than the 1990-1994 average. Also, the crash rates in the “after” condition are higher for peak travel periods. When looking at individual years, the peak period crash rates are shown to be higher than the daily crash in this corridor.

4.2.4 Higher Severity Injury Crash Rates

The most severe condition of individuals involved in the crash determines the overall crash severity. The injury severity is typically broken down into four categories:

- Type C - Possible Injury: A person complaining of a sore neck.
- Type B - Non-incapacitating Injury: Obvious scrapes and bruises that would not physically disable a person at the scene.
- Type A - Incapacitating injury: Broken limbs or obvious blood loss.
- Type K – Fatality: Highest severity level.

The injury crash rates that are presented in [Section 4.2.3](#) included injuries of all severity levels. An increase in injury crash rate was shown for both of the buffer-separated HOV lane corridors. The research team is aware that many studies on crash data only focus on injury crashes of the higher severities, that is Types K, A, and B.

Tables 6 and 7 show the distribution of crash severity types as a percentage of the total. Also shown are the injury crash rates by year with the Type C injury crashes excluded from the calculation.

Table 6. IH-35E (Stemmons) Injury Crash Rates by Severity Percentage.

IH-35E (Stemmons) Crash Injury Level of Severity (%)						Injury Crash Rate, Excluding Type C (Crashes/100 Mil VMT)		
	Fatal Type K	Incap. Type A	NonIncap. Type B	Poss Inj. Type C	Total	Crashes, without Type C	100 Mil VMT ¹	Crash Rate
1990	0%	6%	32%	63%	100%	27	2.57	11
1991	3%	7%	38%	52%	100%	35	2.55	14
1992	3%	16%	33%	48%	100%	33	2.64	13
1993	1%	8%	25%	66%	100%	35	2.64	13
1994	1%	12%	33%	53%	100%	49	2.70	18
Average Crash Rate								14
Construction of HOV Lanes ²								
1997	1%	3%	30%	67%	100%	51	2.98	17
1998	1%	9%	26%	64%	100%	57	3.49	16
1999	1%	3%	26%	71%	100%	46	3.43	13
2000	1%	5%	31%	62%	100%	74	3.59	21
Average Crash Rate								17

Notes:

¹Yearly Corridor VMT calculation for 1997-2000 includes HOV lane vehicles.

²HOV lane construction began 6/95 and ended 9/96.

Table 7. IH-635 (LBJ) Injury Crash Rates by Severity Percentage.

IH-635 (LBJ) Crash Injury Level of Severity (%)						Injury Crash Rate, Excluding Type C (Crashes/100 Mil VMT)			
	Fatal Type K	Incap. Type A	NonIncap. Type B	Poss Inj. Type C	Total	Crashes, without Type C	100 Mil VMT ¹	Crash Rate	
1990	3%	7%	30%	61%	100%	101	5.48	18	
1991	0%	9%	35%	56%	100%	122	5.95	21	
1992	2%	5%	26%	67%	100%	81	6.06	13	
1993	1%	4%	24%	71%	100%	70	6.06	12	
1994	2%	4%	23%	71%	100%	80	6.6	12	
Construction of HOV Lanes ²								Average Crash Rate	15
1997	0%	5%	17%	77%	100%	50 ^{Jul-Dec} ³	3.45	14	
1998	0%	5%	26%	69%	100%	144	7.53	19	
1999	1%	6%	27%	66%	100%	145	7.42	20	
2000	1%	5%	27%	67%	100%	150	7.37	20	
								Average Crash Rate	18

Notes:

¹Corridor VMT calculation for 1997-2000 includes HOV lane vehicles.

²HOV lane construction began 6/95 and ended 3/97.

³July-December.

Tables 6 and 7 show that the difference in “before” and “after” injury crash rates is reduced when Type C crashes are excluded from the calculation; but, the injury crash rate average from 1997-2000 is still higher than the 1990-1994 average.

4.2.5 Crash Database Injury Crash Rates Results

A macroscopic look at crash occurrence using injury crash rates for the IH-30 corridor did not indicate anything noteworthy related to the barrier-separated HOV lane. However, both of the buffer-separated HOV lane corridors in Dallas did show higher corridor injury crash rates in the “after” years. The injury crash rate from IH-35E North increased 56 percent. The injury crash rate from IH-635 increased 41 percent. Also, crash rates were shown to be higher during the peak periods in the “after” years.

A microscopic examination of the location of crashes and reported reasons for crash occurrences was studied further to understand crash characteristics and will be discussed in more detail later in this report.

4.2.6 Other Related Research

The research team previously discussed other related research in the [literature findings section](#) of this report. One research study mentioned is particularly interesting given the results of the analysis of injury crash rates for Dallas corridors with buffer-separated concurrent flow HOV lanes.

Research conducted by the Midwest Research Institute studied electronic crash data from California on freeways where the inside shoulder was converted to a travel lane and the other lanes were reduced in width. All of the freeways analyzed statistically are using the additional inside lane as an HOV lane. This type of conversion project is basically what has been done for the two corridors with buffer-separated concurrent flow lanes in the Dallas area.

MRI's analysis indicated that crash frequencies increased after the freeways were changed in this manner. However, the research did not attempt to explain the increase in the number of crashes. MRI's primary data source was the FHWA Highway Safety Information System (HSIS) database ([9](#)).

4.3 INJURY CRASH OCCURRENCE BY LANE IN DALLAS, TEXAS

4.3.1 Daily Injury Crash Occurrence by Lane

Tables 8-10 show the particular lane where crashes occurred for each of the corridors with an HOV lane.

Table 8. IH-30 (ERLT) Freeway Corridor Injury Crashes by Lane.

IH-30 (ERLT) Injury Crashes by Lane Location ²															
Year	Barrier-Separated HOV			Lane 1 (Inside Lane)			Lane 2			Lane 3			Lane 4		
	EB	WB	Total	EB	WB	Total	EB	WB	Total	EB	WB	Total	EB	WB	Total
1985	N/A	N/A	N/A	21	22	43	27	26	53	29	21	50	N/A ⁴	N/A ⁴	N/A ⁴
1986	N/A	N/A	N/A	33	25	58	23	28	51	33	36	39	N/A ⁴	N/A ⁴	N/A ⁴
1987	N/A	N/A	N/A	18	18	36	23	17	40	18	25	43	12	9	21
1988	N/A	N/A	N/A	21	17	38	26	14	40	13	11	23	13	6	19
1989	N/A	N/A	N/A	16	20	36	18	13	21	15	15	30	14	8	22
1990	N/A	N/A	N/A	10	11	21	11	14	25	14	13	27	11	13	24
Construction of HOV Lanes ¹															
1992	2	0	2	21	15	36	20	15	35	17	15	32	16	13	29
1993 ³	1	2	3	23	29	52	18	25	43	15	29	44	10	7	17
1994	5	5	10	22	26	48	17	29	46	16	27	43	15	8	23
1995	2	1	3	47	35	82	31	16	47	34	22	56	13	15	28
1996	1	0	1	42	38	79	31	27	57	22	19	41	25	12	37
1997	3	1	4	24	20	44	20	16	31	22	21	43	16	17	33
1998	1	0	1	20	26	46	13	19	32	13	16	29	18	14	32
1999	1	4	5	19	20	39	23	27	50	12	15	27	22	9	31
2000	1	2	3	18	22	40	20	21	41	35	24	59	17	15	32

Notes:

¹HOV lane construction began 12/90 and ended 9/91.

²Major roadway reconstruction occurred during five of the first six years of HOV lane operation.

³Reconstruction of Fair Park bridge began 5/93 and ended 2/96.

⁴Database code for Lane 4 did not exist prior to 1987. Lanes 3 and 4 are summed together in 1985 and 1986.

Table 8 indicates relatively few crashes are occurring within the barrier-separated HOV lane on IH-30. The increase in injury crashes during the years 1994-1996 reflect the occurrence of several major construction projects in the IH-30 corridor. Lanes 1, 2, and 4 do not indicate anything noteworthy for the most recent years studied. However, the frequency of Lane 3 crashes in the year 2000 is the highest of all previous. As this increase is for only one year, it is unclear whether or not this is a trend. Also, it is not obvious that the increase in Lane 3 crashes effects the injury crash rate for the corridor as seen previously in Table 3.

Table 9 below shows more crashes occurring within the IH-35E North buffer-separated HOV lane than Table 8 showed occurring in the IH-30 barrier-separated HOV lane. Also, there are more crashes occurring in Lane 1 (inside lane) immediately adjacent to the HOV lane. The average injury crash frequency in Lane 1 for the HOV operating period 1997-2000 is 153 percent higher than the 1990-1994 average prior to operation. Lanes 2 and 3 also show an increase but not as substantial.

Table 9. IH-35 (Stemmons) Freeway Corridor Injury Crashes by Lane.

IH-35E (Stemmons) Injury Crashes by Lane Location												
Year	Buffer-Separated HOV			Lane 1 (Inside Lane)			Lane 2			Lane 3		
	NB	SB	Total	NB	SB	Total	NB	SB	Total	NB	SB	Total
1990	N/A	N/A	N/A	7	10	17	9	11	20	6	4	10
1991	N/A	N/A	N/A	7	6	13	9	10	19	4	4	8
1992	N/A	N/A	N/A	5	6	11	6	8	14	6	4	10
1993	N/A	N/A	N/A	10	14	24	11	11	22	18	7	25
1994	N/A	N/A	N/A	9	12	21	17	9	26	15	16	31
Average	N/A	N/A	N/A	8	10	17	10	10	20	10	7	17
Construction of HOV Lanes ¹												
1997	12	6	18	27	18	45	17	10	27	15	11	26
1998	10	12	22	16	15	31	22	12	34	10	15	25
1999	10	10	21	18	25	43	20	9	29	11	14	25
2000	10	8	18	26	28	54	32	13	45	28	12	40
Average	11	9	20	22	22	43	23	11	34	16	17	29

Notes:

¹HOV lane construction began 6/95 and ended 9/96.

Table 10. IH-635 (LBJ) Freeway Corridor Injury Crashes by Lane.

IH-635 (LBJ) Injury Crashes by Lane Location															
Year	Buffer-Separated HOV			Lane 1 (Inside Lane)			Lane 2			Lane 3			Lane 4		
	EB	WB	Total	EB	WB	Total	EB	WB	Total	EB	WB	Total	EB	WB	Total
1990	N/A	N/A	N/A	34	15	49	26	18	44	25	34	59	27	18	45
1991	N/A	N/A	N/A	26	26	52	34	26	60	31	29	60	25	21	46
1992	N/A	N/A	N/A	26	33	59	13	17	30	23	28	51	16	18	34
1993	N/A	N/A	N/A	26	24	50	27	14	41	25	21	46	19	12	31
1994	N/A	N/A	N/A	31	27	48	24	29	53	34	19	53	20	24	44
Average	N/A	N/A	N/A	29	25	52	25	21	46	28	26	54	21	19	40
Construction of HOV Lanes ¹															
1997	19	22	41	84	66	150	29	29	58	24	22	46	32	39	71
1998	26	28	54	81	78	159	29	37	66	31	17	48	31	32	63
1999	26	29	55	73	84	157	22	16	38	32	23	55	31	26	57
2000	33	24	57	57	76	133	23	41	64	26	21	47	35	21	56
Average	26	26	52	74	76	150	26	31	56	28	21	49	32	30	62

Notes:

¹HOV lane construction began 6/95 and ended 3/97.

Table 10 shows more crashes occurring with the IH-635 buffer-separated HOV lane. Also, there are more crashes occurring in Lane 1 (inside lane) immediately adjacent to the HOV lane. The average injury crash frequency in Lane 1 from 1997-2000 is 188 percent higher than the 1990-1994 average. Lanes 2 and 4 also show an increase, but not as substantial. The Lane 3 average has dropped.

4.3.2 Injury Crash Occurrence by Lane during Peak Periods in Dallas, Texas

Tables 11 and 12 show crashes occurring during the peak period for each of the buffer-separated HOV lane corridors. The crashes occurring during the peak periods show the same characteristics as the daily information presented in the previous tables. More crashes occurred in Lane 1 during the years since the HOV lanes were implemented.

Table 11. IH-35E (Stemmons) Freeway Corridor Crashes by Lane During Peak Periods.

IH-35E (Stemmons) Injury Crashes by Lane Location (Peak Periods)												
Year	Buffer-Separated HOV			Lane 1 (Inside Lane)			Lane 2			Lane 3		
	NB	SB	Total	NB	SB	Total	NB	SB	Total	NB	SB	Total
1990	N/A	N/A	N/A	2	6	8	2	6	8	3	1	4
1991	N/A	N/A	N/A	1	4	5	0	4	4	2	2	4
1992	N/A	N/A	N/A	1	5	6	2	2	4	6	4	10
1993	N/A	N/A	N/A	4	8	12	2	6	8	4	4	8
1994	N/A	N/A	N/A	3	6	9	4	4	8	4	5	9
Average	N/A	N/A	N/A	2	6	8	2	4	6	4	3	7
Construction of HOV Lanes ¹												
1997	7	4	11	13	12	25	7	4	11	5	7	12
1998	4	7	11	8	8	16	4	2	6	1	6	7
1999	3	3	6	11	14	25	8	3	11	6	5	11
2000	3	3	6	9	19	28	5	8	13	5	7	12
Average	4	4	9	10	13	24	6	4	10	4	6	11

Notes:

¹HOV lane construction began 6/95 and ended 9/96.

Table 12. IH-635 (LBJ) Freeway Corridor Crashes by Lane During Peak Periods.

IH-635 (LBJ) Injury Crashes by Lane Location (Peak Periods)															
Year	Buffer-Separated HOV			Lane 1 (Inside Lane)			Lane 2			Lane 3			Lane 4		
	EB	WB	Total	EB	WB	Total	EB	WB	Total	EB	WB	Total	EB	WB	Total
1990	N/A	N/A	N/A	9	9	18	11	2	13	8	13	21	5	7	12
1991	N/A	N/A	N/A	5	7	12	6	9	15	13	8	21	9	6	15
1992	N/A	N/A	N/A	8	13	21	3	3	6	11	15	26	8	8	16
1993	N/A	N/A	N/A	13	8	21	8	3	11	8	7	15	5	2	7
1994	N/A	N/A	N/A	15	6	21	11	9	20	12	4	16	6	9	15
Average	N/A	N/A	N/A	10	9	19	8	5	13	10	9	20	7	6	13
Construction of HOV Lanes ¹															
1997	8	13	21	43	32	75	11	11	22	6	6	12	12	16	28
1998	12	11	23	35	32	67	10	10	20	9	6	15	12	4	16
1999	12	8	20	32	31	63	4	3	7	7	6	13	8	7	15
2000	15	9	24	28	33	61	10	8	18	7	4	11	10	5	15
Average	12	10	22	35	32	67	9	8	17	7	6	13	11	8	19

Notes:

¹HOV lane construction began 6/95 and ended 3/97.

4.3.3 Database Injury Crash Occurrence by Lane Results

An increase in crash occurrence is specific to the HOV lane and Lane 1 for both corridors with buffer-separated HOV lanes in the Dallas area. The average number of injury crashes in Lane 1 of IH-35E from 1997-2000 is 153 percent higher than the 1990-1994 average. The average number of injury crashes number in Lane 1 of IH-635 from 1997-2000 is 188 percent higher than the 1990-1994 average. An increase in the other general-purpose lanes was noted for both corridors; but, the increase is not as substantial as the Lane 1 increase.

A more dramatic change in injury crashes has occurred in Lane 1 of the IH-635 (LBJ) corridor as compared to the IH-35E North corridor. Therefore, the research team focused on determining the concentration of crashes in the IH-635 corridor by examining injury crash occurrence by milepoint within the limits of the HOV lane. This analysis is discussed in the [following section](#). The reader should be aware that two intermediate ingress/egress points are available for this corridor. The intermediate ingress/egress points are basically skip striping between the HOV lane and the general-purpose lanes. The remainder of the lane is designated with a “no crossing” paint stripe.

4.4 HOV LANE AND LANE 1 INJURY CRASHES BY MILEPOINT

4.4.1 IH-635 (LBJ) Injury Crashes by Milepoint for Years 1998-2000

The IH-635 (LBJ) corridor has experienced the more dramatic change in crash occurrence in Lane 1 of the two buffer-separated HOV lane corridors. Overall injury crash rate increase is mostly due to the increase in crashes which occurred in the HOV lane and Lane 1 immediately adjacent to the HOV lane. The research team analyzed the crashes by milepoint in the IH-635 (LBJ) corridor to identify specific locations of crash occurrence by direction.

Figures 4 and 5 show a concentration of crashes occurring in the area just prior to an enforcement location for the eastbound direction. This concentration is at a location of considerable congestion within the corridor during peak periods. Unstable traffic flow occasionally causes the operating speeds in the eastbound general-purpose lanes to drop to near zero in the area between Montfort Drive and Hillcrest Road based on available speed profile data

within the corridor as shown in [Figure 6](#). Montfort Drive and Hillcrest Road are indicated by arrows in each of the figures.

Figures [7](#) and [8](#) also show a concentration of crashes occurring in the area just prior to an enforcement location for the westbound direction. Congestion and the resulting unstable traffic flow occasionally causes the operating speeds in the westbound general-purpose lanes to drop to near zero in the area near Marsh Lane based on available speed profile data within the corridor as shown in [Figure 9](#). Marsh Lane is indicated by an arrow in each of the figures. [Table 13](#) shows average speed data developed from speed profiles in the corridor which indicates a substantial difference in the peak hour average speed of the HOV lane compared to the general-purpose lanes.

Table 13. IH-635 (LBJ) Freeways Peak Hour Average Speeds.

Corridor/Time/Direction	Peak Hour Average Speeds (MPH)						Avg. Speed Differential
	1998		1999		2000		
	HOV Lane	GP Lanes	HOV Lane	GP Lanes	HOV Lane	GP Lanes	
IH-635 (LBJ) AM WB	54	27	59	22	60	27	33 MPH
IH-635 (LBJ) AM EB	59	38	56	39	62	38	21 MPH
IH-635 (LBJ) PM WB	66	21	56	24	55	28	35 MPH
IH-635 (LBJ) PM EB	53	19	49	20	50	30	28 MPH

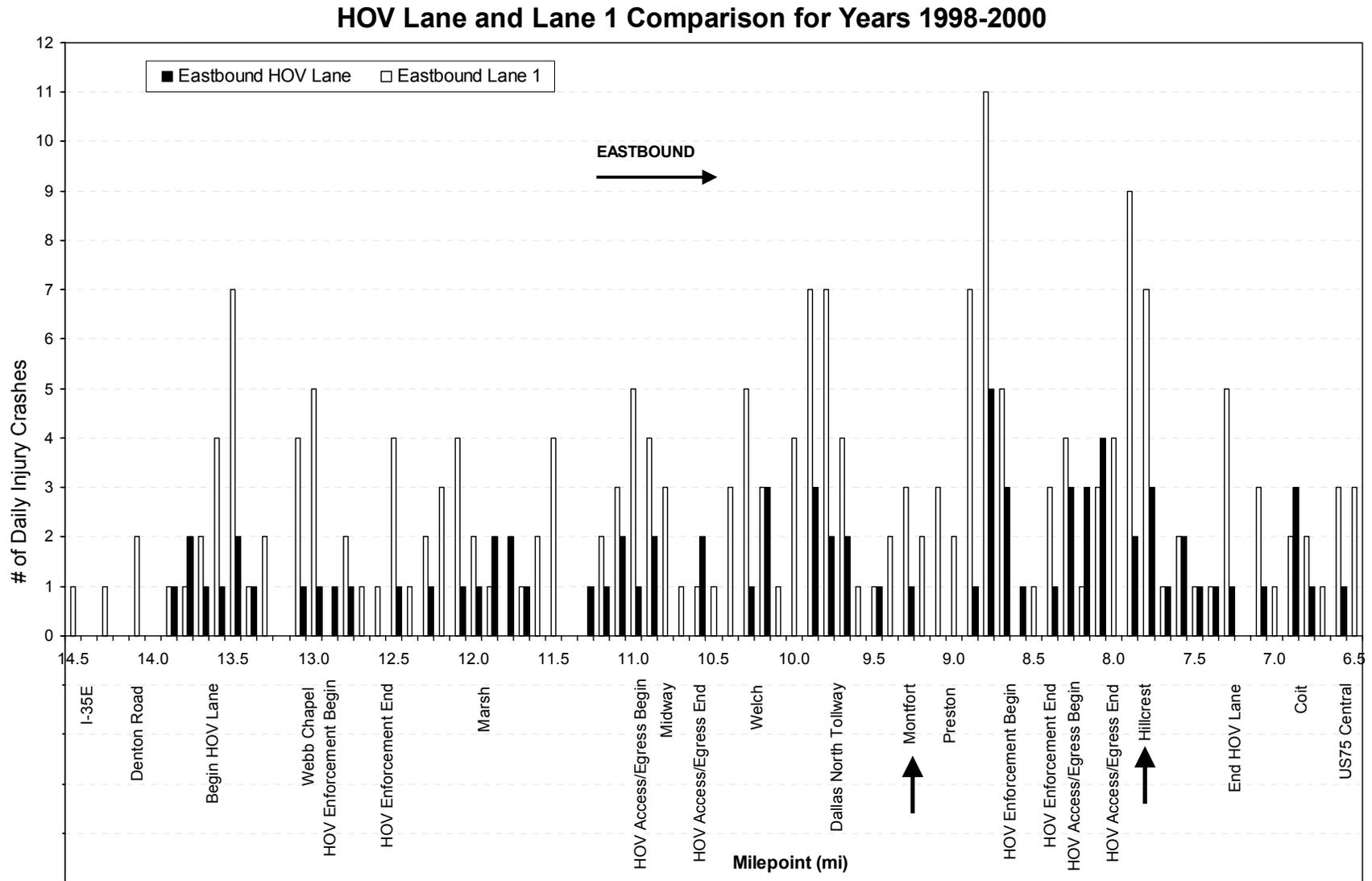


Figure 4. IH-635 (LBJ) Eastbound Injury Crashes by Milepoint – Daily.

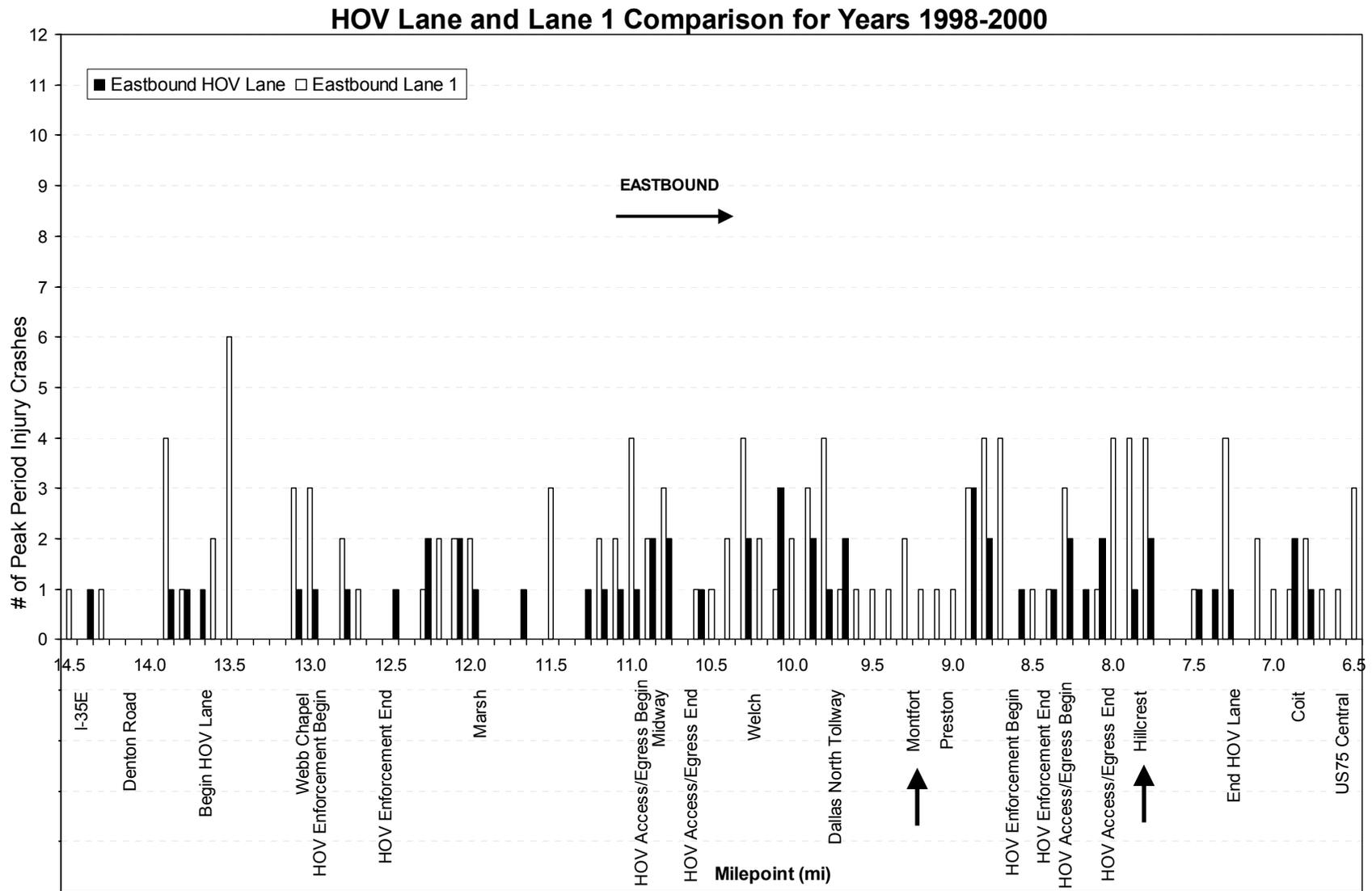


Figure 5. IH-635 (LBJ) Eastbound Injury Crashes by Milepoint – Peak Period.

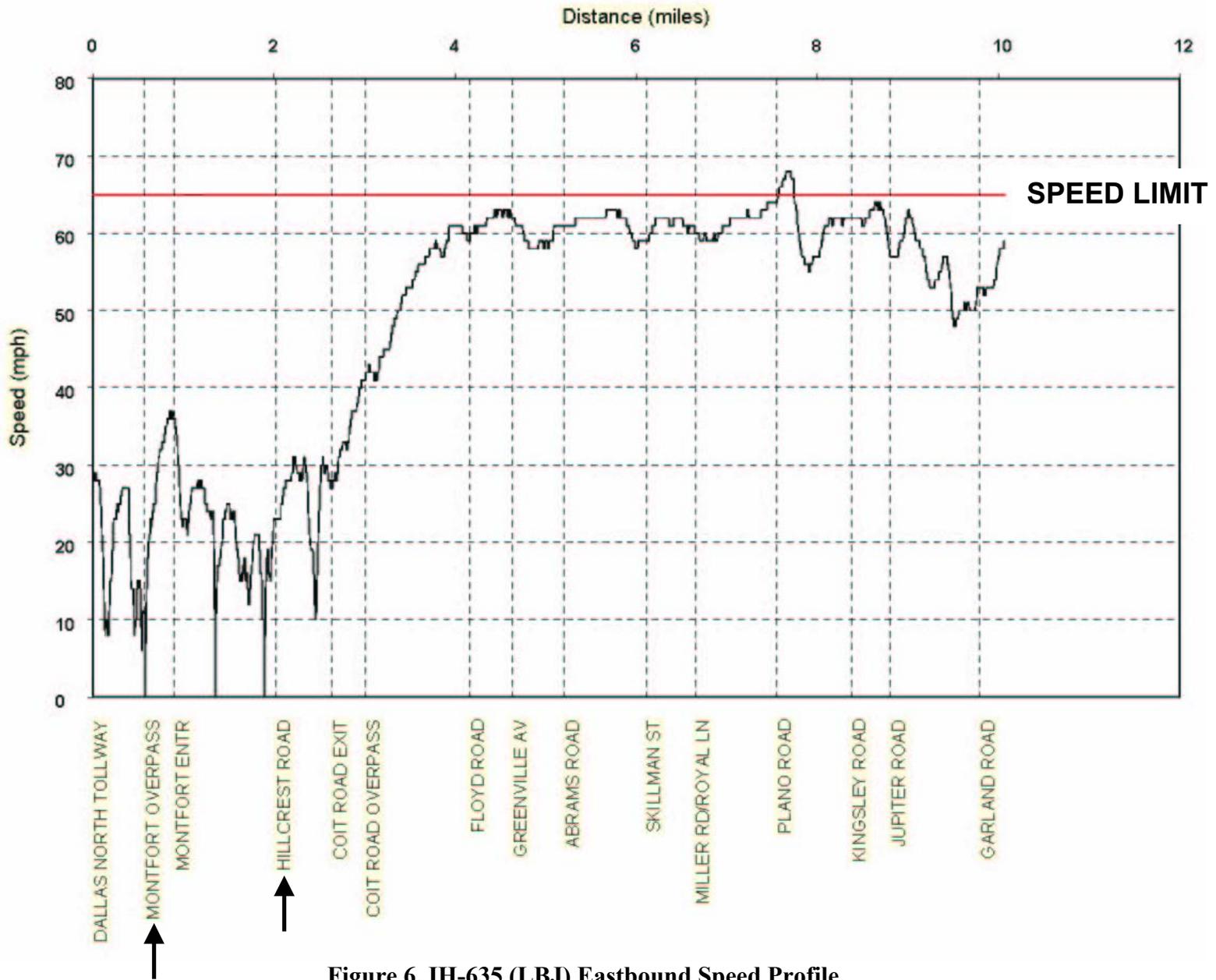


Figure 6. IH-635 (LBJ) Eastbound Speed Profile.

HOV Lane and Lane 1 Comparison for Year 1998-2000

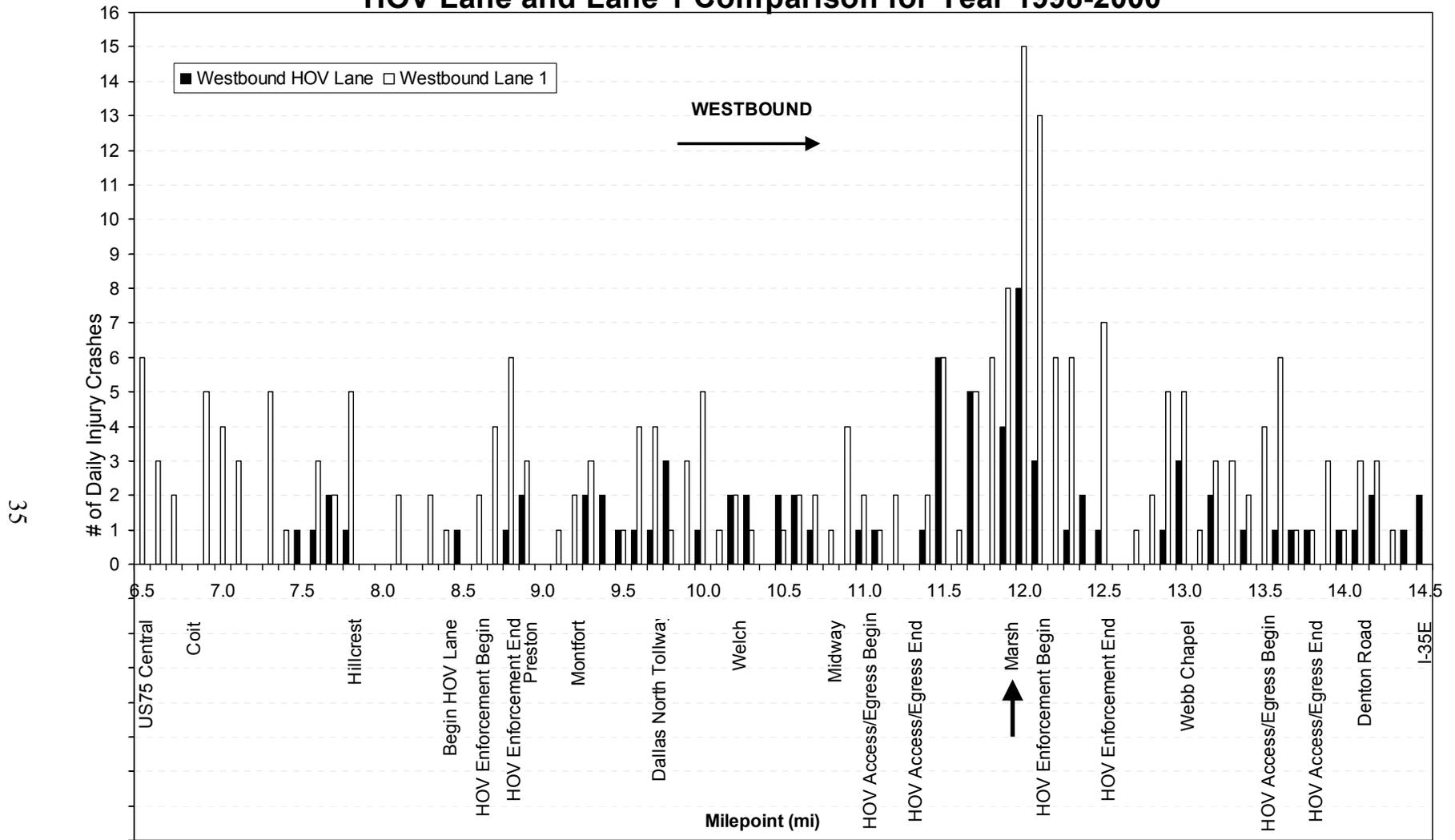


Figure 7. IH-635 (LBJ) Westbound Injury Crashes by Milepoint - Daily.

HOV Lane and Lane 1 Comparison for Year 1998-2000

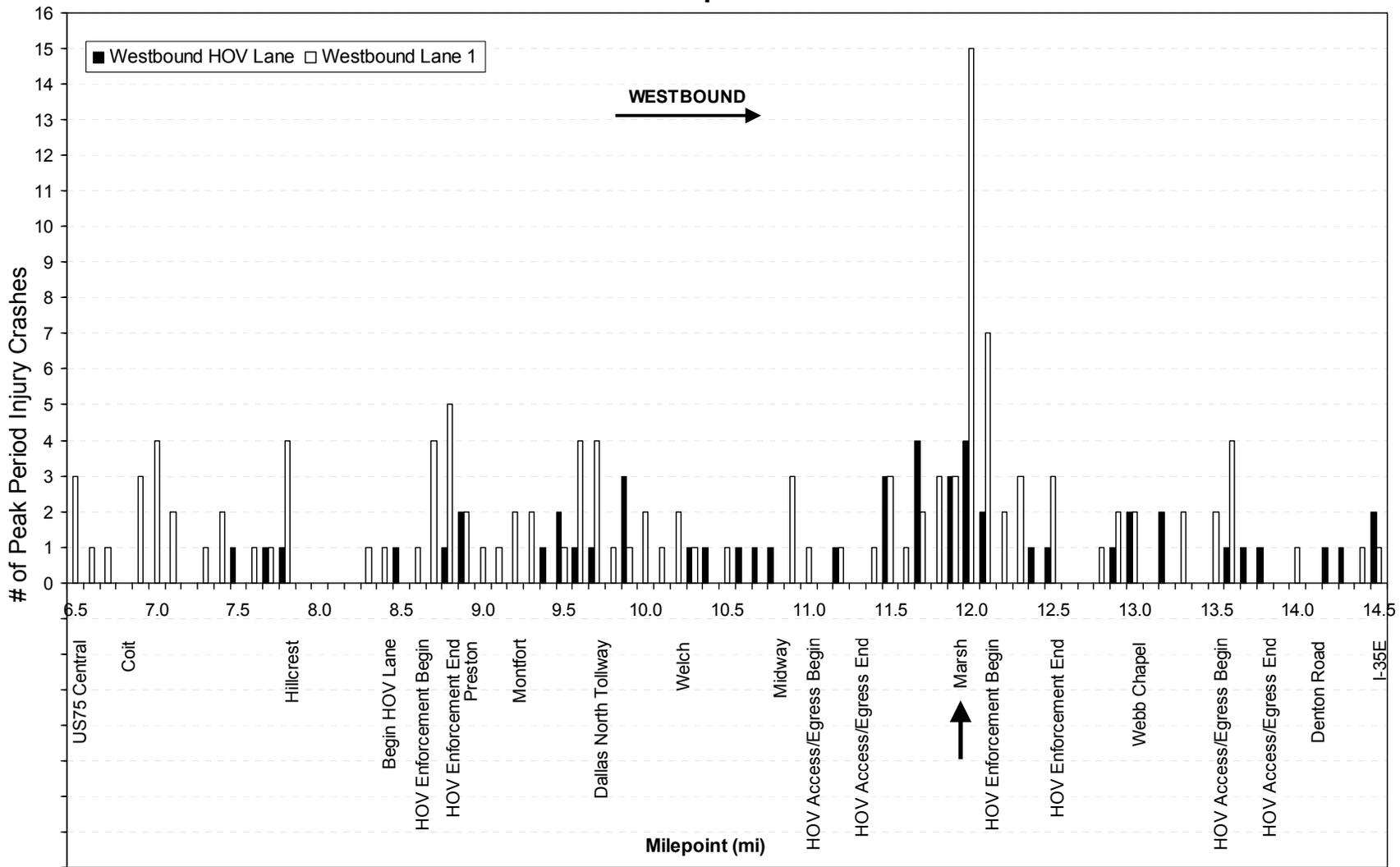


Figure 8. IH-635 (LBJ) Westbound Injury Crashes by Milepoint - Peak Period.

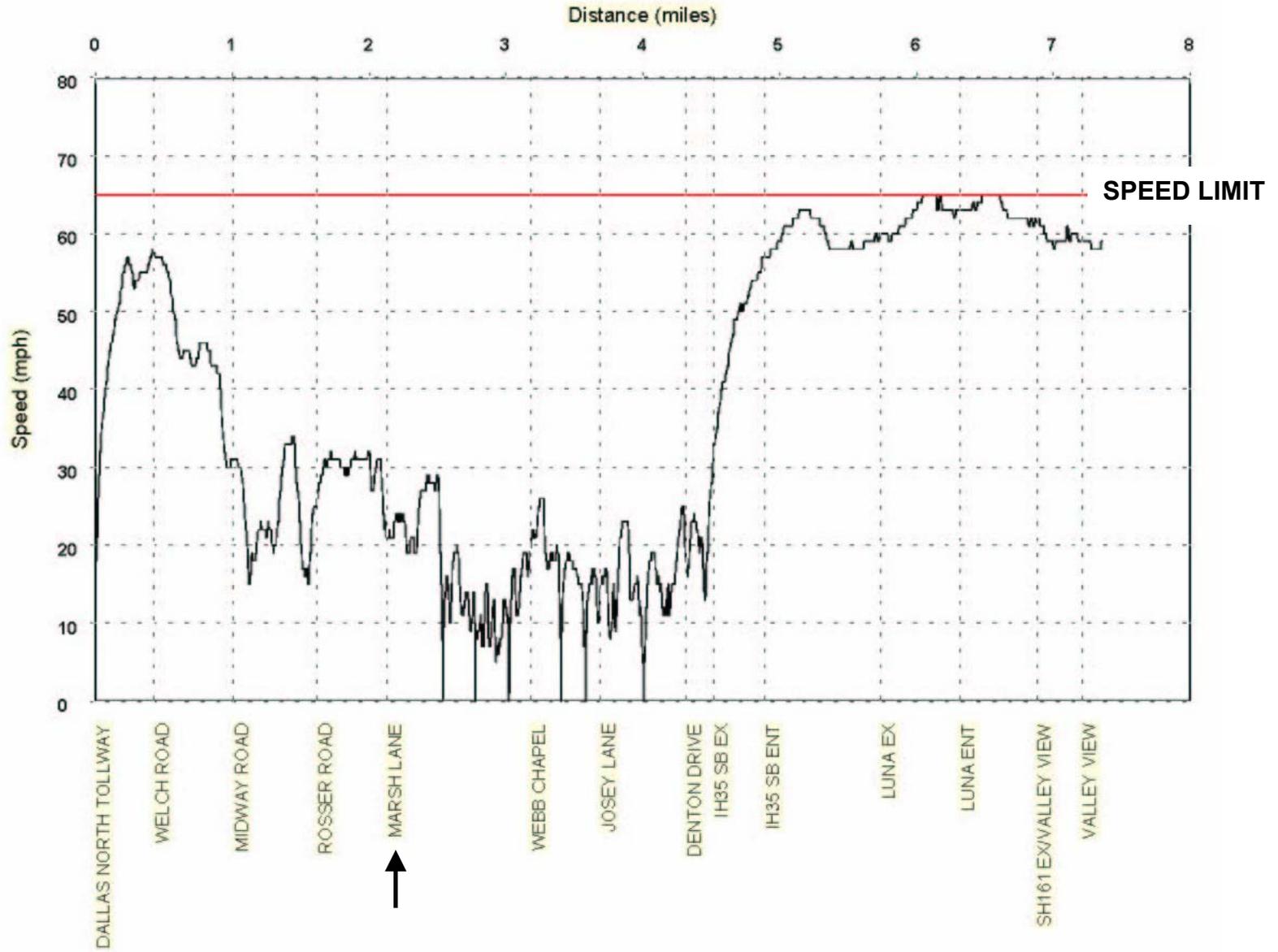


Figure 9. IH-635 (LBJ) Westbound Speed Profile.

4.4.2 Database Injury Crash Occurrence by Milepoint Results

The analysis of injury crashes by milepoint in the IH-635 (LBJ) corridor showed crashes occurring throughout the length of the corridor in both the HOV lane and Lane 1. However, the research team noted a high concentration of injury crashes occurring in the area just prior to the HOV lane enforcement area for both directions of the freeway. These areas are locations of high traffic congestion. The speeds in the general-purpose lanes are known to drop very low during peak travel times. As a result, a speed differential exists between the HOV lane and the general-purpose lanes.

4.5 CRASH REPORTS FOR DALLAS, TEXAS

4.5.1 HOV Lane and Lane 1 (Inside General-Purpose Lane) Crash Reports

The crash data analysis noted an increase in the number of injury crashes occurring in the HOV lane and Lane 1. The research team obtained copies of approximately 1,150 crash reports for crashes in the HOV lane or Lane 1 covering the years 1997-2000 for both the IH-35E and IH-635 corridors. The research team conducted a thorough review of the crash reports to better understand the crash characteristics and determine if any recognizable trends existed.

4.5.2 Notable Trends in Crash Characteristics

The research team tried to understand driver intent by reviewing each individual crash report with particular attention given to the crash sketch and narrative. Although it is impossible to determine driver intent and crash causes with absolute certainty, the research team was able to get a general sense of typical crash characteristics.

The following items provide typical information as gathered from the crash reports on IH-35E and IH-635 involving the HOV lane or the adjacent Lane 1 (inside lane) general-purpose lane or both:

- Vehicles in Lane 1 are trying to avoid suddenly stopped general-purpose lane traffic by quickly moving into the HOV lane and are involved in a crash with a fast-moving HOV lane vehicle (See typical example in [Figure 10](#)).

- Vehicles suddenly stopping in Lane 1 and being rear-ended by a following vehicle.
- Vehicles suddenly moving from the HOV lane to Lane 1 and being rear-ended by another vehicle in Lane 1 that is unable to stop.
- Illegal lane changes (i.e., crossing the double white line) from the HOV lane and Lane 1 at locations other than proper access points are causing both rear-end and sideswipe crashes.
- Vehicles in highly congested Lane 1 are attempting to move into the HOV lane while still traveling at low speeds and are involved in a crash with a faster moving vehicle in the HOV lane.
- Stopped traffic in the HOV lane due to a disabled vehicle (e.g., vehicle with flat tire) causes rear-end crashes because fast-moving vehicles in the HOV lane are not expecting to encounter the stopped traffic.

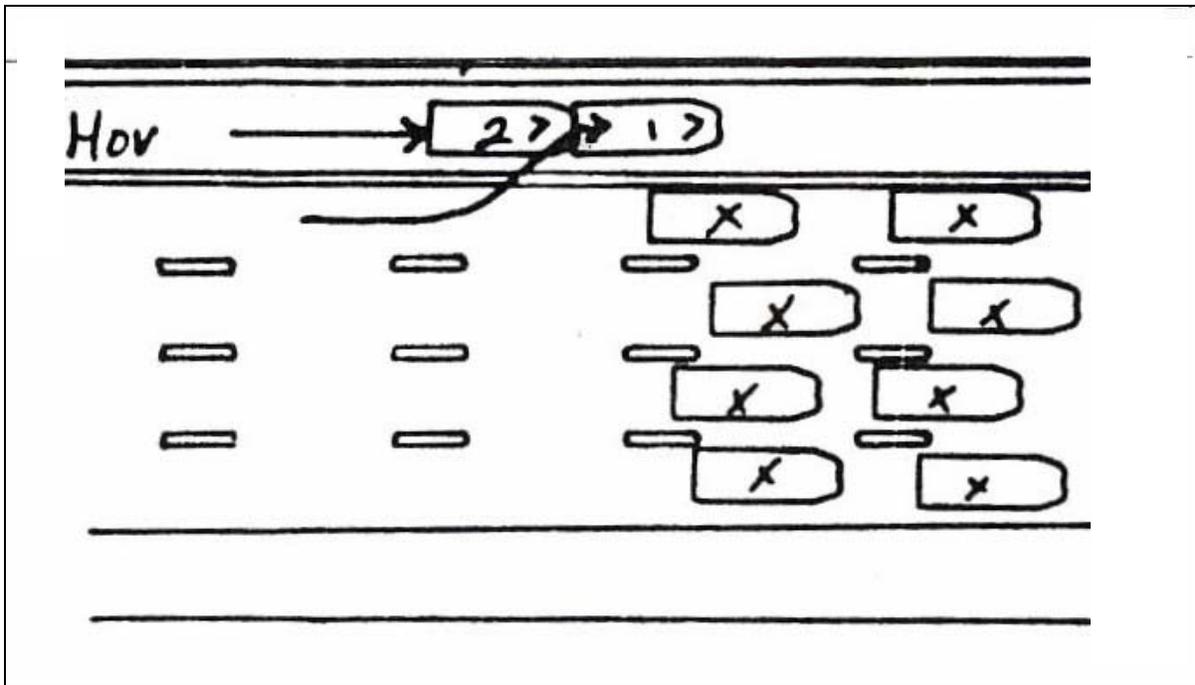


Figure 10. Example of Crash Investigator’s Sketch on IH-635.

4.5.3 Results from Dallas Crash Reports Review

Although it is impossible to determine driver intent and crash causes with absolute certainty, the research team concluded that many of the crashes that occur in the HOV lane or the

adjacent general-purpose lane are related to the substantial speed differential between the two lanes.

In [Chapter 5](#), the research team offers suggestions for corridor characteristics and HOV lane cross-sections to lessen the effect of speed differential for future buffer-separated corridors in the Dallas area.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This report has presented both a macroscopic and a microscopic review of crash data for corridors with HOV lanes in the Dallas area. By using the crash data, the research team was able to draw some general conclusions and provide guidance for future design of freeways with HOV lanes in the Dallas area.

5.2 BARRIER-SEPARATED HOV LANES

The analysis of crash data from the IH-30 corridor indicates that the barrier-separated HOV lanes did not have an effect on injury crash rates. However, the research team has identified the following items for further research based on the analysis:

- A relatively small number of crashes are occurring within the HOV lane, with most occurring at or near access points. It would be of benefit to examine these crashes in more detail along with the access point design.
- Although there are a few crashes related to excessive speed, it would be of benefit to examine possible ways to reduce speed at critical locations.
- Examine whether crashes in the HOV lane may be averted if enough room is available between the median and the moveable barrier so that passing a stalled vehicle is possible.

5.2.1 Recommended Cross-Section for Contraflow Moveable Barrier HOV Lanes

The research team developed the following recommended cross-sections based on the review of electronic crash data for the IH-30 corridor. The corridor characteristics of IH-30 in the Dallas area include limited right-of-way and low traffic in the off-peak direction. [Figure 11](#) shows the desirable cross-section for a contraflow moveable barrier HOV lane. [Figure 12](#) shows the minimum recommended cross-section. The minimum cross-section is currently being used in the IH-30 corridor.

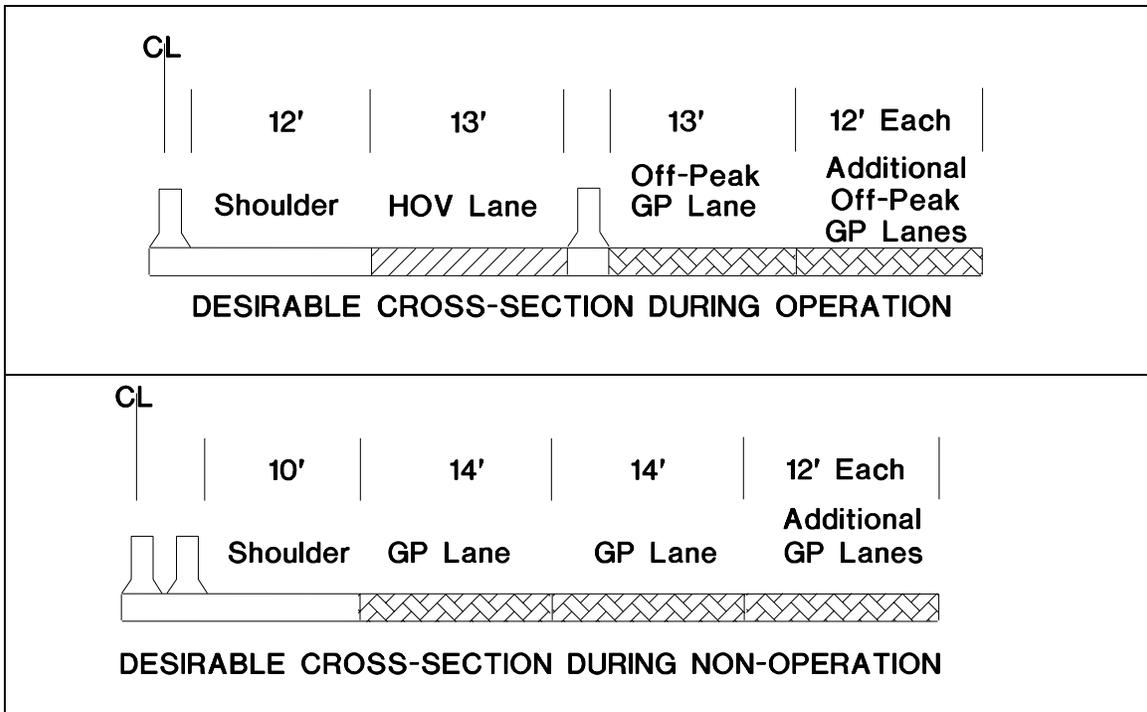


Figure 11. Desirable Cross-Section for Contraflow Moveable Barrier HOV Lanes.

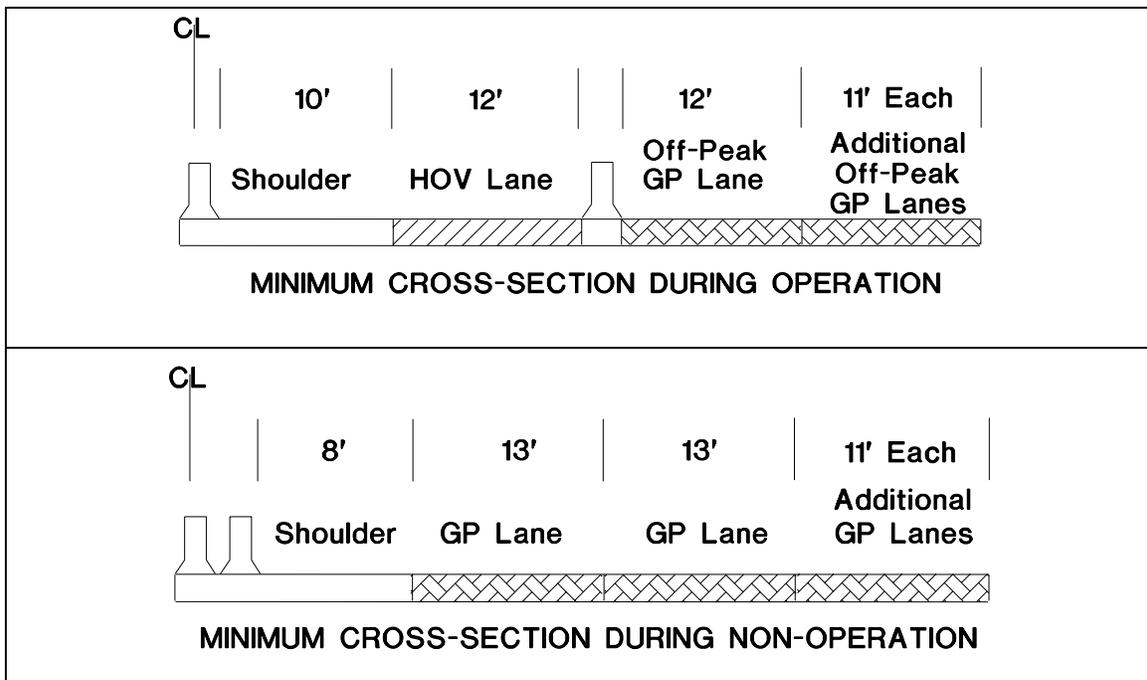


Figure 12. Minimum Cross-Section for Contraflow Moveable Barrier HOV Lanes.

5.3 BUFFER-SEPARATED HOV LANES

A review of electronic crash data from the two corridors with buffer-separated HOV lanes indicated that the crash occurrence has increased since the HOV lanes became operational. Also, the increase is specific to the HOV lane and Lane 1 for both corridors.

With this information, the research team reviewed copies of crash reports from these corridors where crashes were identified as occurring in the HOV lane or in Lane 1. With the knowledge gained as a result of this research, the research team is able to offer the following statement concerning crash occurrence for corridors with buffer-separated HOV lanes in the Dallas area.

The increase in injury crash occurrences in Dallas corridors with buffer-separated HOV lanes is likely due to the speed differential between the HOV lane and the adjacent general-purpose lane.

Table 14, an extension of Table 13 shown previously, shows the average speed differential between the HOV lane and the general-purpose lanes for both of the corridors with buffer-separated HOV lanes.

Table 14. Peak Hour Average Speeds.

Corridor/Time/Direction	Peak Hour Average Speeds (MPH)						Avg. Speed Differential
	1998		1999		2000		
	HOV Lane	GP Lanes	HOV Lane	GP Lanes	HOV Lane	GP Lanes	
IH-35E North AM SB	57	18	59	19	57	32	35 MPH
IH-35E North PM NB	52	30	43	26	52	18	24 MPH
IH-635 (LBJ) AM WB	54	27	59	22	60	27	33 MPH
IH-635 (LBJ) AM EB	59	38	56	39	62	38	21 MPH
IH-635 (LBJ) PM WB	66	21	56	24	55	28	35 MPH
IH-635 (LBJ) PM EB	53	19	49	20	50	30	28 MPH

5.3.1 Recommended Cross-Section for Buffer-Separated HOV Lanes

IH-635 (LBJ) is a highly congested circumferential corridor around northern Dallas serving eastbound and westbound traffic. The traffic characteristics are known to be mostly short trips that cause a great deal of weaving of vehicles from lane to lane. Numerous freeway ramps

and ramp spacing are thought to contribute to the weaving in the corridor. Many of the corridor's freeway ramp-pair combinations have spacing that is at or near the minimum ramp terminal spacing as recommended by AASHTO ([11](#)). A lane change between the HOV lane and the general-purpose lane appears to be relatively difficult when the general-purpose lanes are highly congested, as is the case with IH-635 (LBJ) during peak-periods.

IH-35E North is a highly congested radial corridor serving northbound and southbound traffic. Although the corridor is radial, the level of congestion is similar to that of IH-635, particularly in the area north of the IH-635 interchange. The congestion causes a great deal of weaving of vehicles from lane to lane. Numerous freeway ramps and their ramp spacing are thought to contribute to the weaving. This corridor also has a few freeway ramp-pair combinations with spacing at or near the minimum ramp terminal spacing as recommended by AASHTO ([11](#)).

Based on the freeway characteristics and a review of crash data within each corridor, it appears that the excessive congestion in the general-purpose lanes (i.e., bumper-to-bumper traffic) makes it difficult for vehicles in the HOV lane to find gaps in Lane 1 to easily change lanes. Also, vehicles in the slow moving general-purpose lanes wishing to enter the HOV lane must first change lanes into the HOV lane and then accelerate up to speed. In either situation, the speed differential between the HOV lane and Lane 1 appears to be a factor in crash occurrence. The research team kept these key findings in mind in developing suggested cross-sections for buffer-separated HOV lanes.

[Figure 13](#) shows recommendations for desirable and minimum cross-sections for future buffer-separated HOV lanes in the Dallas area. The minimum cross-section provides enough room for two 8 feet wide vehicles to be in the HOV lane area (inside shoulder, HOV lane, and painted buffer) of the freeway without encroaching on the general-purpose lanes. This is important because it allows two vehicles with a large speed differential to avoid a collision. As mentioned earlier in the report, vehicles in the Dallas buffer-separated HOV lanes experience difficulties moving to the general-purpose lanes due to the high level of congestion. The gaps simply are not available to do this maneuver at high speeds. With at least the minimum cross-section shown below, HOV lane vehicles can slow or stop if necessary to wait for gaps in the general-purpose lanes and enough room remains for another HOV vehicle to pass.

The minimum cross-section also provides enough room for a slow moving vehicle in the general-purpose lanes to move into the HOV lane and accelerate without completely obstructing the HOV lane or Lane 1. Again, a faster moving vehicle in the HOV lane has a better chance of moving past a slower moving vehicle that has not yet gotten up to speed.

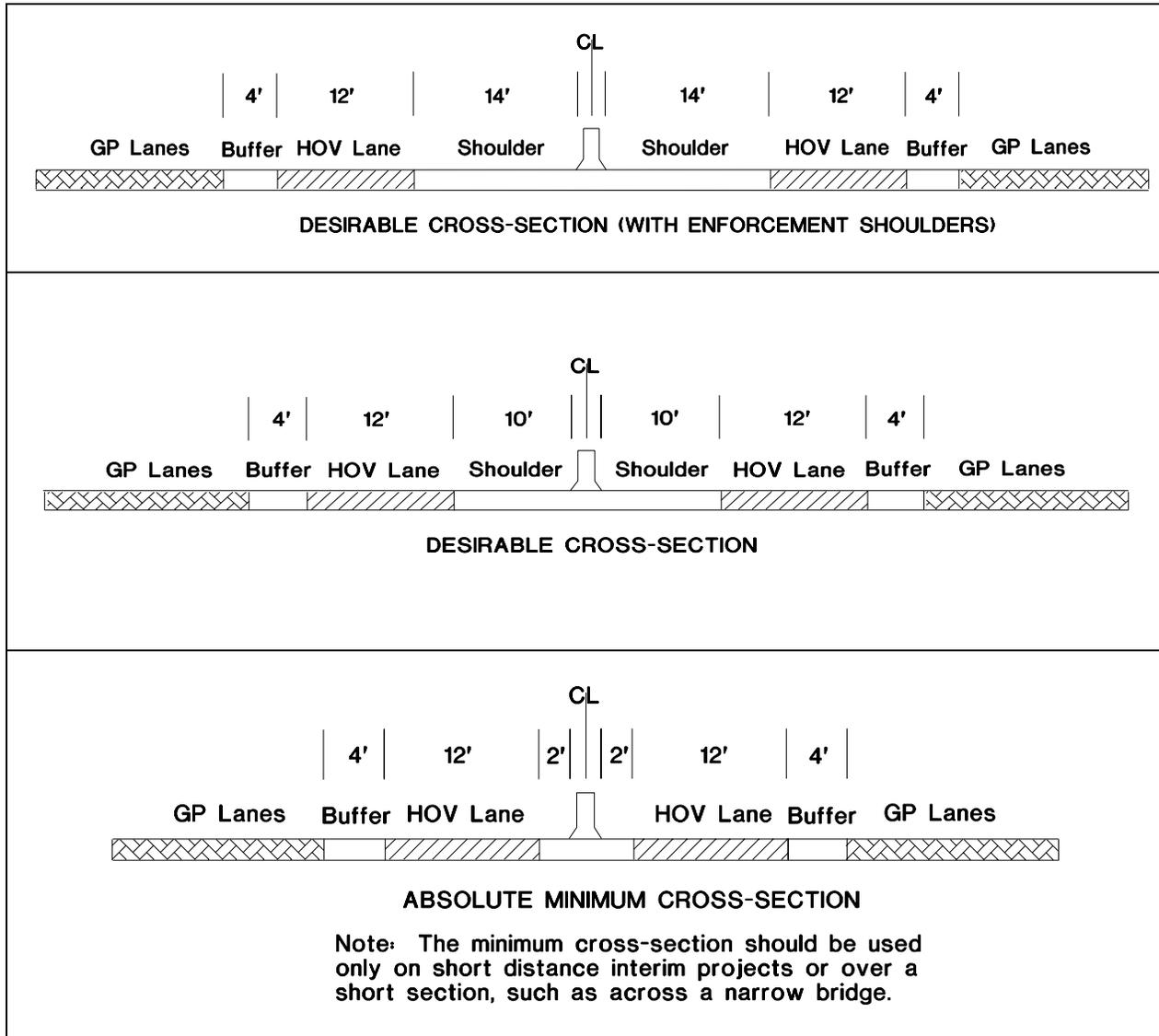


Figure 13. Desirable/Minimum Cross-Section for Buffer-Separated HOV Lanes.

5.4 FUTURE RESEARCH DIRECTION

A comparison of corridor injury crash rates before and after the HOV lanes were implemented showed an increase in both of the buffer-separated corridors in Dallas. The injury crash rates increased by 56 percent in the IH-35E corridor and by 41 percent in the IH-635 corridor.

Higher vehicle speeds and trip reliability in the HOV lane compared to the general-purpose lanes are goals of implementing HOV facilities. However, in the case of buffer-separated HOV lanes, the speed differential also contributes to crash potential. Further research is needed to evaluate innovative safety countermeasures that address this operational issue, while still maintaining the mobility benefits of HOV lanes.

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**APPENDIX A:
HOV LANE SAFETY SURVEY FORM
AND SURVEY RESULTS**

HOV Lane Safety Survey

The Texas Transportation Institute (TTI) is conducting a research project sponsored by the Texas Department of Transportation (TxDOT) concerning the safety of two types of High Occupancy Vehicle (HOV) lanes operating in Texas. These are:

- BUFFER-SEPARATED - buffers of varying widths, with or without delineators, and/or channelizers separating adjacent traffic flow;

and,

- BARRIER-SEPARATED - fixed or moveable concrete barriers separating adjacent traffic flow.

We are seeking information on HOV lane safety issues in your region/state. Any information obtained from this survey is for research purposes only. All individual responses are kept confidential. We are requesting your contact information in the event we need to ask for follow-up questions.

Thank you for participating.

1. Please provide respondent ID information (for internal use only):

Name:

Title:

Agency:

Address:

City:

State:

Phone:

E-mail (required):

A. BUFFER-SEPARATED HOV LANES

Based on your experience, please indicate if your region/state has any of the following safety issues for BUFFER-SEPARATED HOV lanes. Rate the relative concern for each type of safety issue as either "High", "Medium", "Low", "No" concern, or "Not Applicable".

2. Vehicles illegally crossing buffer (e.g. double-white stripe):

- High
- Medium
- Low
- No
- Not Applicable

2a. Comments on illegally crossing buffer:

3. Vehicle merges at access/egress locations:

- High
- Medium
- Low
- No
- Not Applicable

3a. Comments on merges at access/egress:

4. Lack of, or reduced, inside shoulder width:

- High
- Medium
- Low
- No
- Not Applicable

4a. Comments on inside shoulder width:

5. Reduced HOV lane widths and /or main lane widths:

- High
- Medium
- Low
- No
- Not Applicable

5a. Comments on reduced HOV lane widths:

6. HOV lane used for disabled vehicles:

- High
- Medium
- Low
- No
- Not Applicable

6a. Comments on HOV lane used for disabled vehicles:

7. HOV lane used for evasive action:

- High
- Medium
- Low
- No
- Not Applicable

7a. Comments on HOV lane used for evasive action:

8. Explain the safety issue that concerns you the most from Questions 2 -7. Why does it concern you?

9. Provide any OTHER safety issues or concerns in your region/state related to BUFFER-SEPARATED HOV lanes.

10. Based on your experience, please rank the top three most important safety issues associated with BUFFER-SEPARATED HOV lanes. (Use those mentioned in Questions 2-7, or issues you have added)

First

Second

Third

11. Have any measures or policy changes been implemented in your area or state to address these BUFFER-SEPARATED HOV lane safety issues or concerns (e.g. adding delineators, modifying pavement markings, etc.)?

- Yes
- No
- Not Applicable

12. If Yes to Question 11, please explain.

B. BARRIER-SEPARATED HOV LANES

Based on your experience, please indicate if your region/state has any of the following safety issues for BARRIER-SEPARATED HOV lanes. Rate the relative concern for each type of safety issue as either a "High", "Medium", "Low", "No" concern, or "Not Applicable".

13. Operational issues at access/egress locations to/from HOV lane:

- High
- Medium
- Low
- No
- Not Applicable

13a. Comments on operational issues at access/egress locations:

14. Lack of, or reduced, inside shoulder width:

- High
- Medium
- Low
- No
- Not Applicable

14a. Comments on lack of, or reduced, inside shoulder width:

15. Reduced HOV lane widths:

- High
- Medium
- Low
- No
- Not Applicable

15a. Comments on reduced HOV lane widths:

16. Disabled vehicles in HOV lane:

- High
- Medium
- Low
- No
- Not Applicable

16a. Comments on disabled vehicles in HOV lane:

17. Wrong way movements on HOV lanes:

- High
- Medium
- Low
- No
- Not Applicable

17a. Comments on wrong way movements on HOV lanes:

18. Explain the safety issue that concerns you the most from Questions 13 -17. Why does it concern you?

19. Please provide ANY OTHER safety issues or concerns in your region/state related to BARRIER-SEPARATED HOV lanes.

20. Based on your experience, please rank the top three most important safety issues associated with BARRIER-SEPARATED HOV lanes. (Use the those mentioned in Questions 13-17, or issues you have added.)

First

Second

Third

21. Have any measures or policy changes been implemented in your region/state to address these BARRIER-SEPARATED safety issues or concerns? (e.g. modified signing, changes in operating hours, etc.)

- Yes
- No
- Not Applicable

22. If Yes to Question 21, please explain.

C. Final Comments

23. Have there been any studies or analysis in your region/state regarding these or any other safety issues or concerns?

- Yes
- No
- Not Applicable

24. If Yes to Question 23, please list and/or explain.

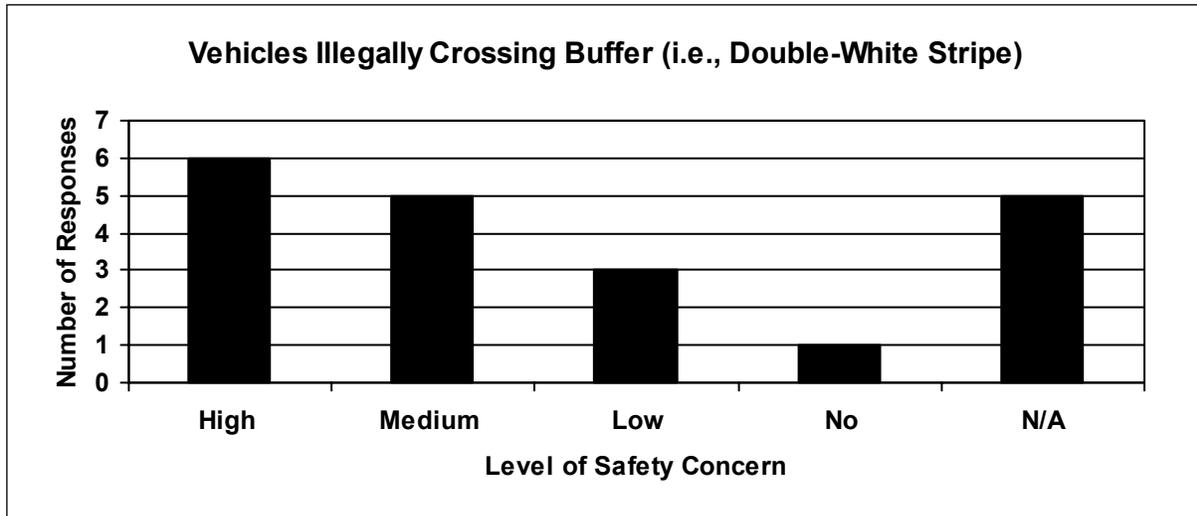
25. Please provide any additional comments or concerns that may be related to HOV lane safety, or this survey.

Thank you for your time and cooperation in this research effort.

Revised 12/18/2002

Buffer-Separated HOV Lanes

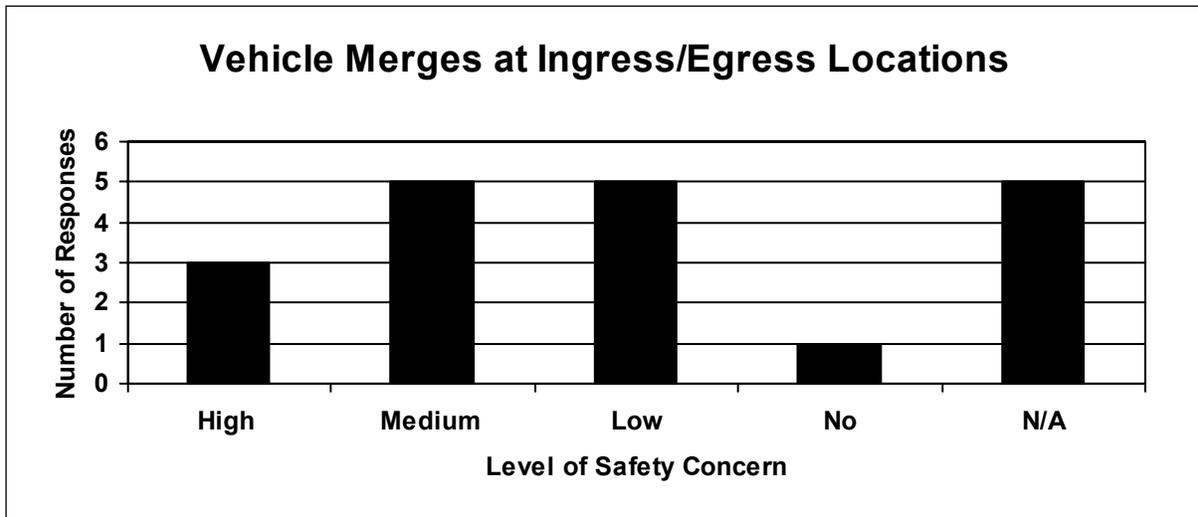
Based on your experience, please indicate if your region/state has any of the following issues for BUFFER-SEPARATED HOV lanes. Rate the relative concern for each type of safety issue as either “High,” Medium,” “Low,” “No concern,” or “Not Applicable.”



Comments on illegally crossing buffer (10 responses):

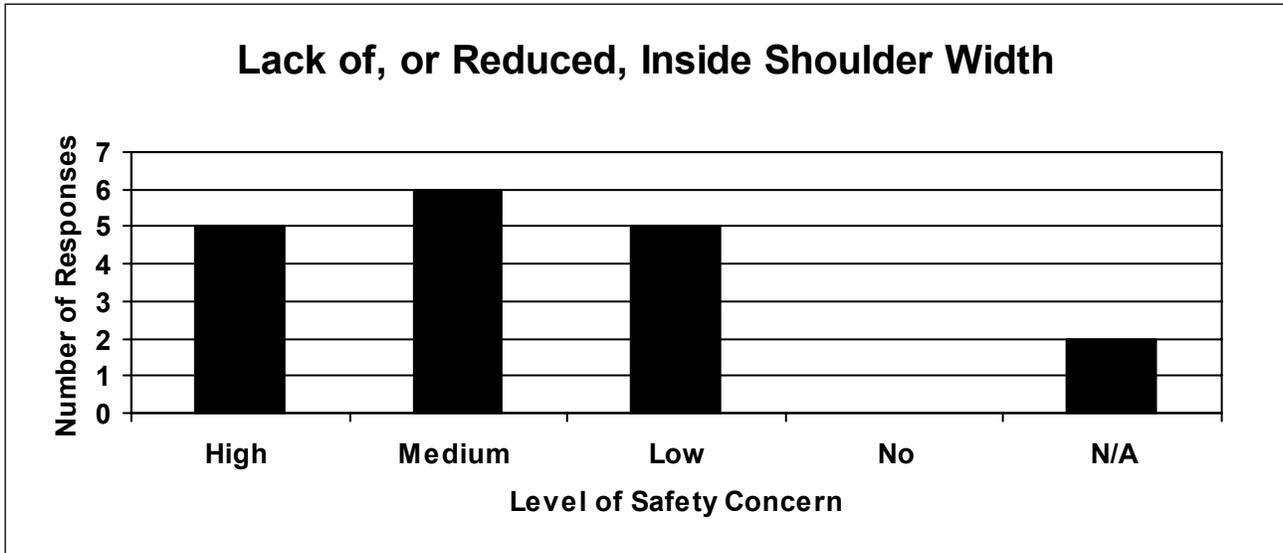
- [Our DOT]uses single white stripe.
- This really hurts entrance of our concurrent-flow HOV lanes. Especially if the non-HOV lanes are severely congested.
- Moderate violation rate.
- In 1995, a study on accident rates from more than a dozen HOV facilities found that in most cases, instead of lowering accident rates (the addition of conventional lanes lowers accident rates by an average of 29 percent), the addition of HOV lanes increased accident rates significantly.
- Buffer violations are not rampant in California and controlled by a steep minimum violation fine of \$271 including a moving violation point on the motorist's insurance.
- Addressed by rigorous enforcement.
- Highest on those portions of the HOV system where there is inadequate enforcement areas.
- Buffer area collects debris. This debris is launched by cars illegally crossing causing problems to vehicles in the left lane of the highway. They have to take evasive action that at times causes crashes.

- We use a narrow buffer, less than 3 to 4 feet.
- Buffers are very narrow and not easily distinguishable from standard pavement markings. Drivers are not routinely stopped and cited for crossing over the buffer, and no significant safety hazard has been presented as a result of these violations.



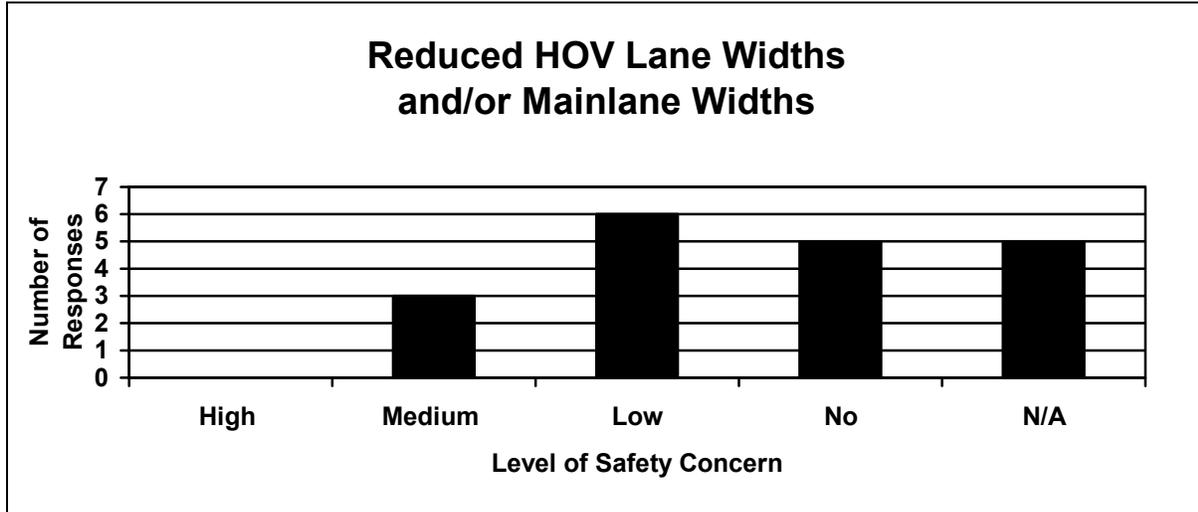
Comments on merges at ingress/egress (9 responses):

- Speeding at the HOV ingress and egress locations may pose a safety hazard for HOV and mainline traffic.
- Buses must weave across two GP lanes to access the HOV lane.
- There tends to more conflicts at egress points when lanes are open to all traffic.
- There has not been conclusive evidence that heightened crash rates occur at HOV ingress/egress.
- We allow unlimited access into and out of the concurrent flow HOV lanes so the access and egress is spread out. Concentrating the merge and diverge maneuvers makes it more difficult for drivers to make the maneuvers and forces unsafe behavior during congested operation -- especially if the mainlanes are congested and the HOV is not, or vice versa.
- Not a problem. Design provides for access areas separate from egress areas, both also have speed-change lanes.
- Drivers in the HOV lane have a blind spot when merging into the general-purpose lanes. They must rely on vehicles to move over to the right to allow them to enter.
- HOVs are on high-volume freeways.
- Access zones are typically long enough to allow for adequate merging. Some lane terminations are too abrupt and need to be lengthened to promote smoother flow. Higher crash incidences are evidenced at lane transitions/terminations.



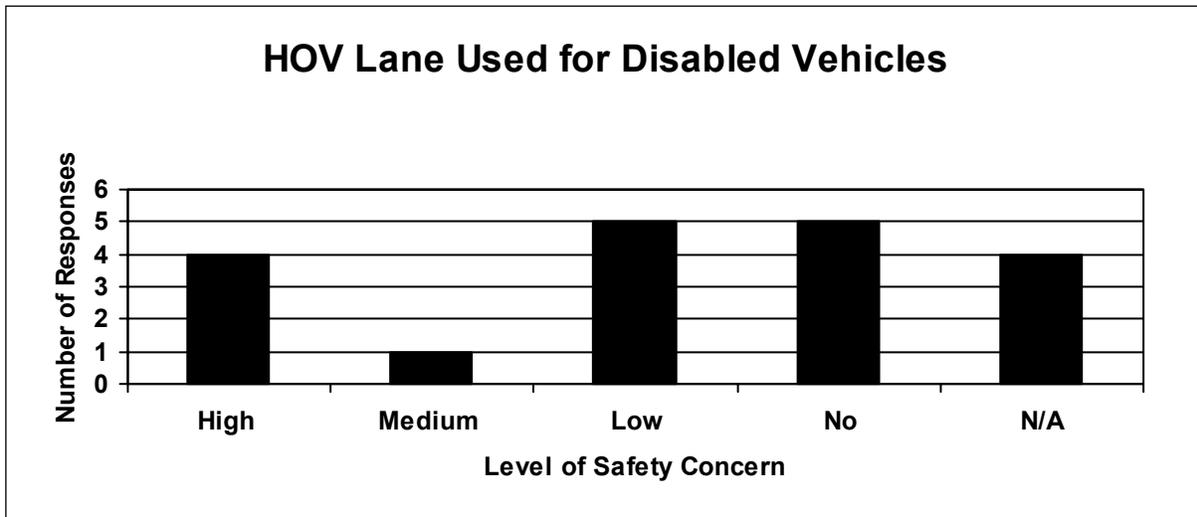
Comments on inside shoulder width (8 responses):

- Incident management is difficult with the lack of shoulders in the HOV lane.
- Only 2 feet in older section. Reconstructed section has 10 feet.
- In general, our concurrent-flow HOV lanes have a decent left-side shoulder. However, not wide enough for shelter. Wide enough for HOV enforcement by state police.
- No place to store disabled vehicles.... hence they block the HOV lane.
- Not of particular high risk although we always try to accommodate full inside shoulder width whenever we can.
- Where there is lack of a full-width inside shoulder, it is an issue for enforcement. However, there is no evidence that reduced inside shoulder width has caused crashes.
- One third of the crashes on the HOV lanes result in a vehicle striking the median barrier.
- If the shy distance to barrier is less than 18 inches, there is reluctance in trucks using inside lanes and there may be a higher incidence of drivers feeling uncomfortable driving next to the barrier. There does not appear to be as much problem in observed traffic flow when the inside lane has at least 2, and preferably 4 ft. separation from median barrier. There is negligible difference in accidents between buffer-separated and barrier-separated designs.



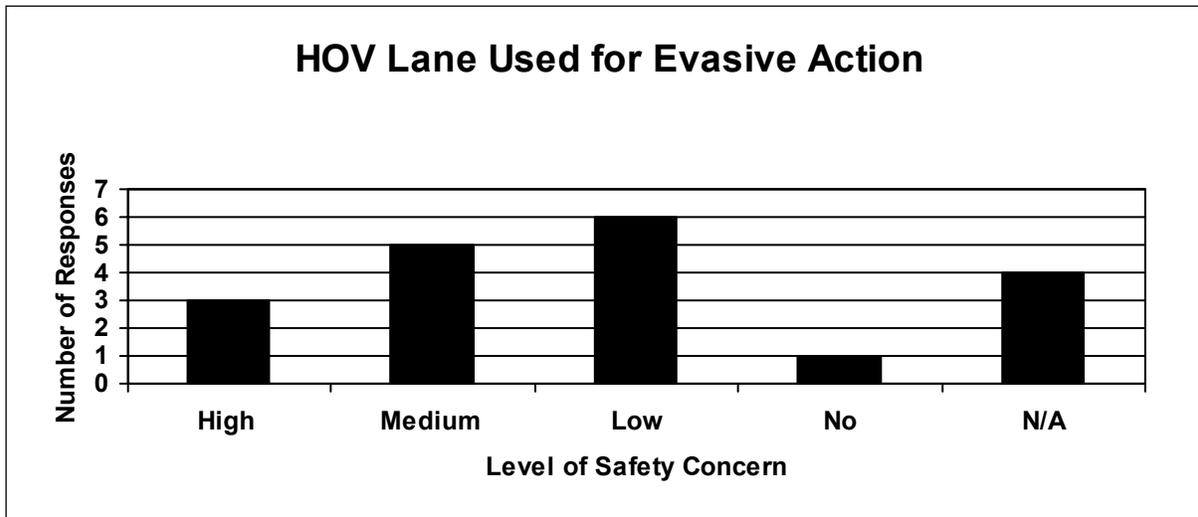
Comments on reduced HOV lane widths (4 responses):

- Incident management is difficult because of the reduced lane width inside the HOV lane.
- Although 10-foot lane widths are rare, evidence of heightened crash rates at these locations is not evident.
- No problem identified.
- No real issue with reduced lane widths so long as 1) there is no reduction below 11 feet, and 2) there are at least one or more outside lanes reserved at 12 feet width for large trucks. Some HOV lanes are 11 feet, but include a 2-4 ft. buffer that is constructed as part of the HOV lane "envelope." This reduces the overall driver perception that the HOV lane is narrower.



Comments on HOV lane used for disabled vehicles (5 responses):

- Disabled vehicles often make their way off the traveled way and into a shoulder or refuge before becoming fully disabled. The only time this issue became of significant concern was twenty or more years ago when part-time HOV shoulders were used.
- Rarely used for disabled vehicles.
- Not a problem. Most cars pull into the buffer area.
- In most cases, inside shoulder has been removed to implement HOV and some drivers do not understand and park in the lane.
- Experience dating from the 70s shows that if an HOV lane is used as a breakdown shoulder in off-peak periods, drivers confuse its function in the peak hours when it is supposed to be operational.



Comments on HOV lane used for evasive action (4 responses):

- Highway Patrol through the TMC has the authority to open the HOV lane to everyone in the event of a "major" crash, hazardous spill or other emergencies. The public has accepted this rare practice because the benefits of getting around the hazard are very clear.
- Such use occurs rarely when general-use traffic is backed up; however, potential exists for severe crashes.
- Concern at accident sites where mainline traffic merges with faster moving HOV traffic.
- May cause more crashes, but no definitive evidence. Certainly, the potential for this event when GP lanes are stop-and-go is one reason why HOV lane speed differential in most areas seldom exceeds 20-25 mph over adjacent GP traffic speed. The presence (or lack of) and adjacent median breakdown shoulder can perhaps influence the likelihood that such incidents can be averted by HOVs.

Explain the safety issue that concerns you the most from the above questions concerning BUFFER-SEPARATED HOV lanes. Why does it concern you? (15 responses)

- Speeding in the HOV lane may create a safety hazard for vehicles using the HOV lane and for vehicles traveling in the general-purpose lanes. Violation of the speed limit in the HOV lane can be dangerous due to reduced inside lane width and the potential for sudden queuing at the merge locations.
- (1) There are crashes that result when violators (and to a lesser extent, non-violators) illegally change lane into concurrent-flow HOV. (2) In general, we do not limit ingress/egress to concurrent-flow HOV and maybe we should.
- Vehicles illegally/suddenly crossing buffer.
- Decades ago, the dangers of placing two traffic streams, one high-speed and one low-speed, next to each other led to the construction of acceleration and deceleration lanes on every interstate highway. In the 1990s using HOV lanes to place high-speed traffic next to low-speed conventional lane traffic was shown to be significantly less safe than the addition of conventional lanes (see Question 2a).
- Two are inter-related-- substandard inside shoulder widths which cause use of HOV lane for disabled vehicles. Using the HOV lane for disabled vehicles is a concern because of the items listed. It is not only a safety concern, but operationally it reduces the effectiveness of the HOV lane. This is primarily a result of reduced inside shoulder widths.
- Perhaps ingress/egress location and length. Weaving is of concern and reducing the potential for safety related concerns in making the best choices in location, etc.
- Shoulder width or (lack of) seems like the most important issue since vehicles will pull off on the inside shoulder, and with free-flow and high-speed conditions along HOV, there have been and will be dangerous conflicts.
- Biggest concern is over disabled vehicles stopped in the HOV lane, especially during uncontested time periods. Traffic is moving fast and not expecting a disabled vehicle.
- Potential for buffer crossing to cause a serious crash. Enforcement is key to reduced crash potential.
- Vehicles crossing buffer (in or out) at illegal locations pose safety hazard.
- Speed differentials between HOV and general-purpose lanes make illegal crossing a concern.
- Cross over from mainline to HOV and HOV to mainline. Concerned because debris is kicked up and move to mainline causes panic/evasive action.
- HOV lanes used by disabled vehicles.

- Experience suggests that the highest accident locations for GP traffic (heavy merge and weave areas close to major interchanges) are also the locations where most HOV lane crashes occur. So access transitions, and particularly lane drops and project terminations) cause the greatest potential for safety concerns. Where HOV lanes overload, this problem can manifest itself in a high incidence of rear-end accidents upstream of the lane drop. Also, lane drops caused by two HOV lanes coming together (found at the termini of fwy/to/fwy connectors) are similar locations where this problem is evidenced. As HOV lane volumes have grown, the same types of problems experienced on congested freeways manifest themselves on HOV facilities.
- Differential in speed and lateral offset.

Provide any OTHER safety issues or concerns in your region/state related to BUFFER-SEPARATED HOV lanes (7 responses).

- Differential speed between HOV and adjacent GP lane separated only by a single white stripe. Vehicles stopped in GP lanes attempt to enter the HOV lane.
- Impatient HOV drivers cross buffer or illegally use ingress and egress areas to pass other HOVs.
- Safety issues regarding buffer-separated lanes are not well understood. Several lanes have caused accident rates to increase following installation, while others have not. Reasons for these differences have not been explored adequately.
- Effective enforcement is also an issue.
- When buffer area is used for enforcement/maintenance traffic backs up. Also, illegal users (15 percent) and aggressive drivers.
- Need to more clearly delineate the buffer area. [The state] is not currently in compliance with the desired wider pavement markings recommended in the latest MUTCD. A higher and more visible marking would help delineate the HOV lane as a different part of the roadway reserved and managed for HOVs.
- Signage placement and overload-with narrow shoulders and median barrier, the placement of signs for informational and regulatory purposes can infringe on the needed area for operations. Signs alerting drivers to exit in the skip areas to get to the proper SOV exit are also an issue- are they far enough in advance for the HOV vehicle to exit the lane and weave over to the gore/exit ramp while fighting for position.

Based on your own experience, please rank the top three most important safety issues associated with BUFFER-SEPARATED HOV lanes. (Use those mentioned above, or issues you have added.)

Ranked First (16 responses):

- Speeding
- Speed differential with no buffer
- Illegal access
- Illegally crossing buffer
- Differential speeds (see Questions 2a and 8)
- Use of HOV lane for disabled vehicles
- Weave distance per lane
- Shoulder
- Use by disabled vehicles
- Crossing buffer
- Lane changes (legal or illegal) from slow moving lane to fast moving lane, or vice versa
- Speed differentials
- Cross-overs
- Use by disabled vehicles
- Design treatment at lane drops and designated access locations
- Shoulder-width sight distances

Ranked Second (15 responses):

- Merge locations
- Buses weaving to enter
- Mainline merge points

- Reduced inside shoulder width
- Sub-standard inside shoulder width
- Ingress/egress length & location
- Merges
- Reduced inside shoulders
- Reduced inside shoulder width
- Lack of adequate inside shoulder width
- Weaving
- Maintenance - road debris
- Ingress/egress points
- Good horizontal sight distance for design speed
- Crossing buffer

Ranked Third (13 responses):

- Queuing at the HOV merge with general-purpose lanes
- Increased speed differential
- Reduced HOV lane widths
- Inside shoulder width
- Crossing buffer
- Concentrated ingress/egress points
- Aggressive driving/speeding/tailgating in HOV lanes
- HOV lane used for evasive action
- Weaving and bottlenecks where the barrier-separated lanes and diamond lanes converge as well as where the diamond lanes begin/end
- Speed disparity

- Vehicles crossing buffer
- Availability of median breakdown shoulder
- Disabled vehicle usage

Have any measures of policy changes been implemented in your area or state to address these buffer-separated HOV lane safety issues or concerns (e.g., adding delineators or modifying pavement markings)?

YES: 7 responses

NO: 6 responses

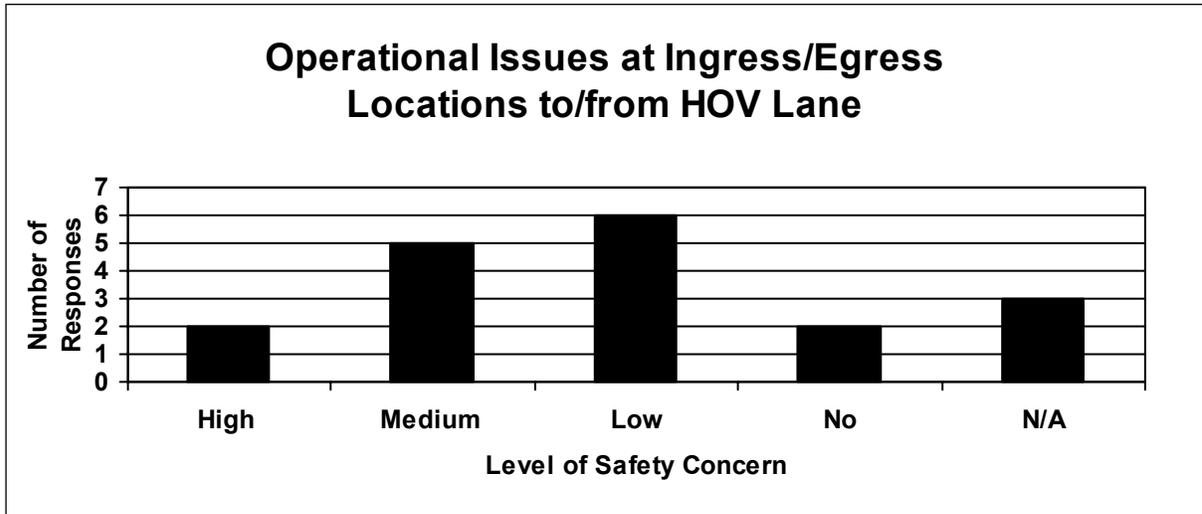
N/A: 5 responses

If Yes to the above question, please explain (7 responses):

- [Our DOT] has striped the southbound concurrent-flow HOV with a double white line for about 1 or 2 miles.
- [The DOT] is revising the HOV Guidelines for Planning, Design and Operation to include a greater weave distance per lane.
- We have no part-time HOV, part-time shoulder facilities. Policy is that we have a minimum 7 feet inside shoulder, and preferably a full 12 feet shoulder to facilitate enforcement.
- A rigorous enforcement program funded entirely by DOT has been part of the operation of the HOV lanes since they were first opened.
- Enforcement by marked and unmarked police units.
- We do not have buffer-separated HOV lanes. We do have concurrent HOV lanes separated by pavement markings. Our safety record with those lanes has been good. The most common safety issues that have been associated with these lanes have been at bottlenecks, at significant weaving sections and where roadway geometry has varied from our usual desirable level of construction. We have developed some countermeasures to address these problems including use of rumble strips, enhanced signing, incident response measures, use of Traveler Information Systems and improved roadside design.
- Signage addition and striping changes from a continuous double skip to a skip/solid pattern restricting HOV ingress/egress locations - need further coordination with vertical alignment.

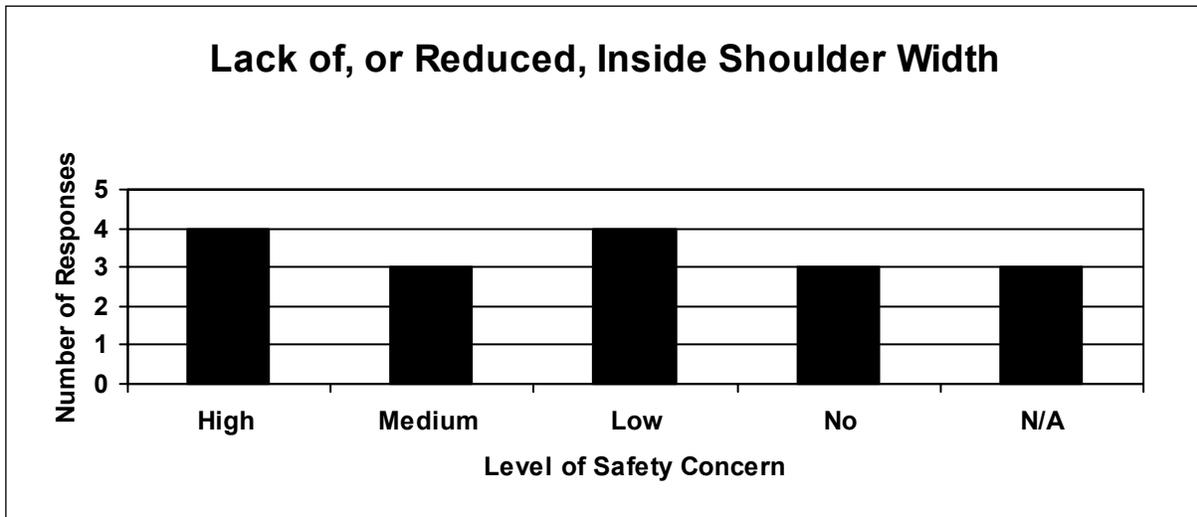
Barrier-Separated HOV Lanes

Based on your experience, please indicate if your region/state has any of the following safety issues for BARRIER-SEPARATED HOV lanes. Rate the relative concern for each type of safety issue as either “High,” “Medium,” “Low,” “No concern,” or “Not Applicable.”



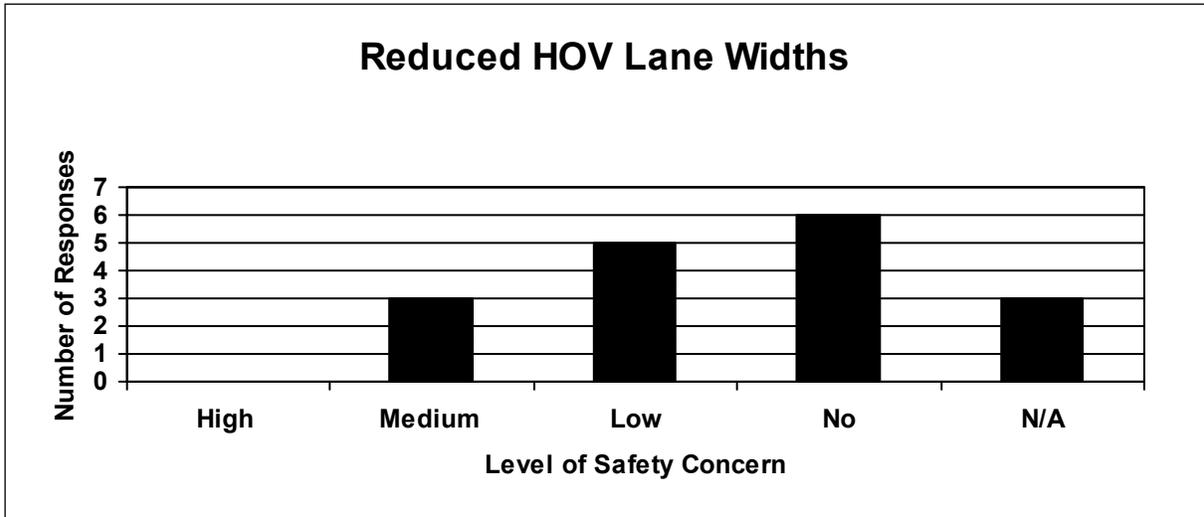
Comments on operational issues at ingress/egress locations (9 responses):

- Speeding at the ingress and egress locations may create a safety hazard for HOV and mainline traffic.
- Dual HOV reversible lanes narrow to accommodate entry/exit slip ramps. Transition to GP at end of HOV lacks sufficient transition length.
- Generally no problems if signed appropriately.
- The HOV lanes operate as mixed use lanes outside HOV hours. Many drivers will queue up just before HOV expires.
- There tends to be slow downs at merge points when lanes are open to all traffic.
- [The state] has very few barrier-separated HOV lanes due to the amount of right-of-way required for full standard geometric elements.
- Weaving and bottlenecks where the barrier-separated lanes and diamond lanes converge (one-lane entry and exit constraints of the two-lane reversible facility).
- Sight distance is often restricted, weave distances are substandard for the intended volumes of vehicles using the access area, and illumination and signing/markings are poor in some cases.
- Access points are one of the more likely places for conflict, bottleneck and collisions.



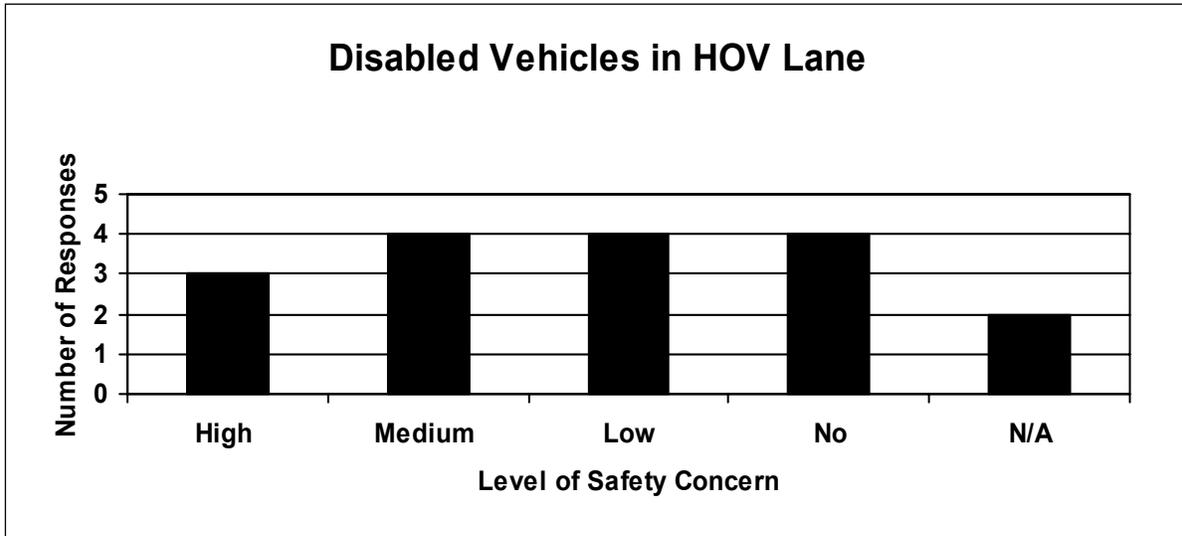
Comments on lack of, or reduced, inside shoulder width (6 responses):

- Incident management can be difficult with the lack of shoulders in the HOV lane. However, four breakdown areas are located along the lane so disabled vehicles can avoid blocking the lane.
- All barrier-separated HOV lanes in [the state] have full standard inside shoulder widths.
- Motorists do not drive within striped lanes (i.e., drive within barriers on both sides).
- If a typical incident like a stalled vehicle cannot be negotiated, the traffic stream is trapped, making incident response difficult and operational reliability jeopardized. This is potential fatal flaw if the lack of a breakdown area exists for more than about 1000 feet. This is perhaps the most critical fatal flaw in some reversible HOV facilities.
- Shoulders narrower than 4 feet typically have more run off the road accidents.
- Sight distances, esp. at horizon curves.



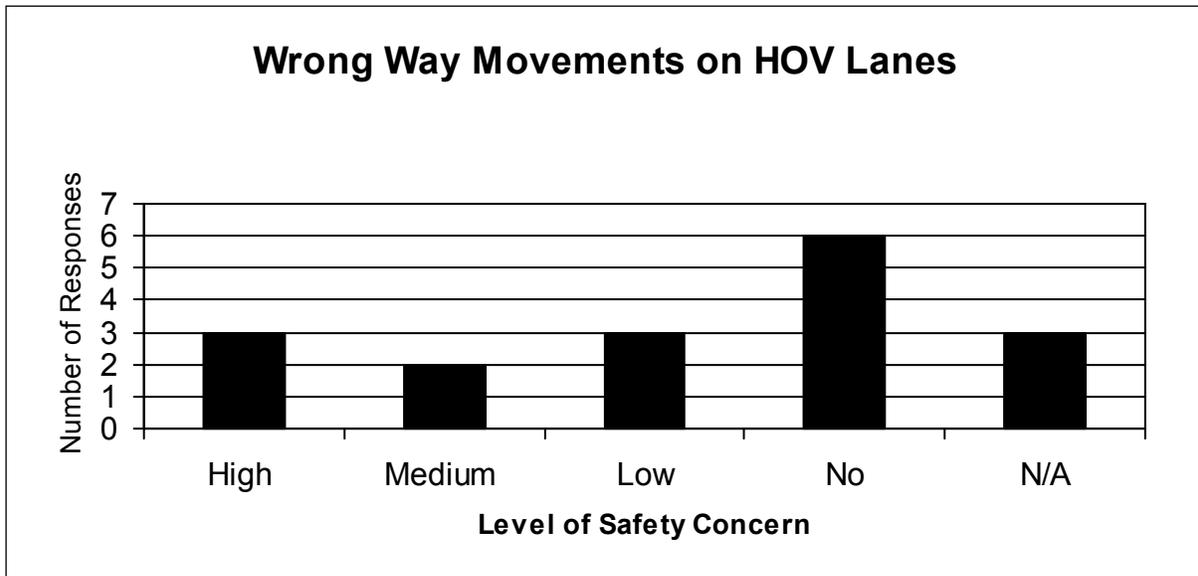
Comments on reduced HOV lane widths (3 responses):

- Incident management can be difficult with reduced lane width inside the HOV lane.
- All have full standard if not greater than standard lane widths.
- Not critical if the entire HOV envelope allows for bypassing stalled vehicles.



Comments on disabled vehicles in HOV lane (7 responses):

- Disabled vehicles can temporarily disrupt traffic operations in the HOV lane. Queuing sometimes occurs in the HOV lane until the disabled vehicle is cleared. [The DOT] maintains an integrated system to detect and respond to accidents and breakdowns in the HOV lane. Traffic detectors, pole-mounted video cameras, and roving patrols of State Police officers relay information to the lane's operation center. TMC personnel monitor traffic and dispatch tow trucks, police, fire, and ambulance as needed. Two radio-dispatched trucks are stationed in the lane during the entire operation period. Four breakdown areas are located along the lane so that disabled vehicles can avoid blocking the lane. In addition, if an incident occurs in the lane, variable message signs approaching the entrance to the lane will alert drivers of a problem. The HOV lane will be closed temporarily if a serious incident creates major congestion and re-opened as soon as the lane is cleared.
- Our one facility is a two lane reversible, so not an issue. The one section with single lane (19 feet envelope) has potential for problems, but the volumes are relatively low and few incidents reported.
- With barrier-separated facilities, we always have space for disabled vehicles on one side or the other, if not both.
- Ongoing need to make certain that disabled vehicles are removed from the barrier-separated segment when changing directions.
- Potentially high if occurring in combination with issue above. If ample shoulder exists to bypass a stalled vehicle, then this is not an issue.
- Our database shows more vehicles moving to the right because largely the shoulder is more likely to be full on the right and that is typical motorist behavior.
- Accident management required.



Comments on wrong way movements on HOV lanes (7 responses):

- The contraflow design of the HOV lane essentially eliminates the potential for wrong way movements on the HOV lane. The contraflow approach involves converting an off-peak general-purpose lane to a peak-direction HOV lane.
- Gates are effective.
- Potential for this to occur without good signing and positive lane controls.
- We had troubles with rare wrong-way movements in our Express Lanes (not exclusive HOV). The results of wrong way movements can be tragic. Nets, like those used to "catch" jets on aircraft carriers are used at the mainline access.
- The gate system virtually eliminates this problem but always a concern.
- Again, this is ONLY an issue typically encountered on a reversible HOV lane. Redundancy in the design of barriers, gates and signs are absolutely required, and there is no compromising on this traffic control feature. Some of the most serious crashes involved multiple fatalities on any HOV lanes have occurred due to wrong way movements on reversible lanes.
- Low experience but high level of concern. State Patrol provides some special emphasis patrols. We have special procedures for [state DOT] staff working in the lanes when they are closed to traffic to improve safety if there are illegal entries and we have used unique equipment to stop wrong way vehicles.

Explain the safety issue that concerns you the most from the above questions. Why does it concern you (10 responses)?

- Speeding in the HOV lane may create a safety hazard for vehicles using the HOV lane and for vehicles traveling in the general-purpose lanes. Violation of the speed limit in the HOV lane can be dangerous due to reduced inside lane width and the potential for sudden queuing at the merge locations.
- Transition to GP and short weave from a northbound entrance ramp, forcing unsafe weaving.
- Making sure the facility ingress and egress points are well signed.
- Access to accidents or disabled vehicles is difficult due to limited shoulder widths in the contraflow express lane (one side is a fixed concrete barrier and the other is a movable barrier). Also, movable barrier is hit often from the opposite direction due to reduced shoulder widths.
- Wrong way movements, although rare, cause tragic results.
- Wrong-way traffic: Usually fatal and almost always high-profile, even though they occur rarely. (As compared with much more frequent accidents on barrier-separated lanes.)
- Restrictions and entry/exit points and the problems associated with accidents that can occur inside the barrier-separated segment.
- Inadequate total space in a barriered facility to pass a stalled vehicle, not because this is the most serious from a safety standpoint (wrong way movements win this title but rarely happen), but because this shortcoming keeps the HOV facility from ever being able to be a reliable alternative, and unnecessarily exposes incident management personnel to more likelihood of being victims in secondary events.
- Access point design can have the highest number of accidents.
- Inside shoulder width/sight distances.

Please provide ANY OTHER safety issues or concerns in your region/state related to BARRIER-SEPARATED HOV lanes (3 responses):

- Excessive speed--55 mph limit is largely ignored.
- Lack of adequate weave/merge distances at ingress/egress zones, both for at-grade and grade-separated designs. The existing treatments were not designed for the level of use they are getting.
- Access for emergency vehicles and provision of incident response.

Based on your own experience, please rank the top three most important safety issues associated with BARRIER-SEPARATED HOV lanes. (Use those mentioned above, or issues you have added)

Ranked First (12 responses):

- Speeding
- Inadequate transitions
- Signing
- Lane width
- Reduced shoulders
- Wrong way
- Reduced shoulder widths
- Wrong way travel
- Crashes/incidents on barrier-separated HOV lanes
- Lack of bypass capability (breakdown shoulder)
- Roadway geometry
- Shoulder width

Ranked Second (11 responses):

- Reduced HOV lane width
- Excessive speed
- Shoulder availability
- Shoulder width
- Disabled vehicles
- Disabled
- Wrong way movements

- Restrictions at the entrance/exit points
- Wrong way movements (primarily reversible lanes)
- Bottleneck/operation design
- Wrong way movements

Ranked Third (10 responses):

- Merge locations
- Sight distance
- Ingress/egress
- Ingress/egress
- Shoulders
- Disabled vehicles in HOV lanes
- Clearing accidents
- Adequate sight and merge distance at exits
- Incident response
- Stalled vehicles-removal

Have any measures of policy changes been implemented in your area or state to address these barrier-separated HOV lane safety issues or concerns (e.g., modified signing or changes in operating hours)?

YES: 5 responses

NO: 6 responses

N/A: 3 responses

If Yes to Question 21, please explain (5 responses):

- It is difficult to construct a barrier-separated HOV lane in [our state] without meeting full standard geometric criteria. In fact, all barrier-separated HOV lanes are to full standard.
- Policy to have full shoulder widths. Must request a design deviation if full width can't be designed. Systems to reduce wrong way movements.

- Improved signing and entry/exit barriers
- Ongoing monitoring and a new gate system is planned.
- Our safety record with those lanes has been good. The most common safety issues that have been associated with these lanes have been at bottlenecks, at significant weaving sections and where roadway geometry has varied from our usual desirable level of construction. We have developed some countermeasures to address these problems including use of rumble strips, enhanced signing, incident response measures, use of Traveler Information Systems and improved roadside design.

Have there been any studies or analysis in your region/state regarding these or any other safety issues or concerns?

YES: 9 responses

NO: 7 responses

N/A: 1 response

If Yes to Question 23, please list and/or explain (8 responses):

- Several years ago the [state DOT] conducted studies in the past on whether to buffer-separate with designated ingress/egress, or operate a continuous access lane separated by a paint stripe only (which is what they have).
- A number of studies were done in the past; however, there is a need to revisit the issues. The FHWA administered HOV Pooled Fund Study proposes to investigate various safety issues.
- The on-going evaluation includes safety. Also, any high accident locations are determined every two years and steps are taken to reduce the collisions.
- 1976: Study of Santa Monica Diamond Lanes by John Billheimer of SYSTAN. Early 1990s: Study of Safety Issue on HOV Lanes by Ed Sullivan of Cal Poly.
- Mn/DOT completed a study titled the "Twin Cities HOV Study" in February 2002. This study contained safety related information concerning the possible impacts to opening the HOV lanes to all traffic. Mn/DOT is currently preparing an operations management plan for the region's HOV system. This plan will include changes for making the HOV system safer and more efficient.
- In the past there have been studies undertaken, particularly to address wrong way movements, and changes in designs were made.
- An in-depth study of off peak hours of operation and safety. An in-depth study of the effects of varied roadway cross-section on accident experience.

- Striping and access needs for buffer separated.

Please provide any additional comments or concerns that may be related to HOV lane safety, or this survey (5 responses):

- Do 4 feet buffers have a better safety record than narrow paint stripes?
- Orange County Transportation Authority contracted with Parsons Brinckerhoff last summer (2002) to conduct an evaluation comparing buffer-separated HOV lanes with designated ingress/egress locations with HOV lanes with continuous access operations. Safety was one of the factors considered in the evaluation.
- Issue is one of the most serious facing HOV planners, and it is one of the least well understood. As such, it is worthy of a serious research effort.
- There is an overall lack of consistent crash data for HOV facilities, and because accident forms do not tabulate accidents related to HOV lanes, no easy ability to get such data. Recommendations are needed nationwide on how accidents are recorded, and forms developed to allow coding by type of facility/lane.
- We need to have more work on implementing safety measures on urban roadways with reduced design standards.