CONCURRENT-LANE HOV SAFETY

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ABSTRACT

The purpose of this study is to determine the safety effects, if any, of concurrent-lane HOV implementations, and to recommend, on the basis of safety, one or more of the various measures used to separate HOV lanes from adjacent mainlanes. A literature search was undertaken to ascertain the results of research on various existing projects. The documents reviewed herein where found via database searches, telephone contacts, and references in other documents.

ACKNOWLEDGEMENTS

This report was prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration, and the Virginia Department of Transportation. The contents of this report reflect the views of the Hampton Roads Area MPO. The Commission is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration, the Virginia Department of Transportation, or the Hampton Roads Planning District Commission. This report does not constitute a standard, specification or regulation. FHWA or VDOT acceptance of this report as evidence of fulfillment of the objectives of this planning study does not constitute endorsement/approval of the need for any recommended improvements nor does it constitute approval of their location and design or a commitment to fund any such improvements. Additional project level environment impact assessments and/or studies of alternatives may be necessary.

EXECUTIVE SUMMARY

The key points discovered during the search of literature concerning the safety of concurrent-flow HOV lanes are as follows:

- The addition of capacity through construction of general purpose lanes typically causes accident rates to go down at least 29%.

- *0'-2' Buffer*: Not only have the additions of concurrent HOV lanes with 0'-2' buffers not resulted in the drop in accident rates associated with general purpose lane additions, but these additions have typically caused rates to exceed the pre-HOV rates of the subject freeways.

- *3'-8' Buffer*: Due to the problems inherent in the use of control sections, the data on the project with a 3'-8' buffer is inconclusive.

- *8' Buffer Raised 6"*: After HOV lanes were added with an 8' buffer raised 6", a drop in accident rates occurred which is similar in magnitude to that of the typical general purpose lane addition (29%).

- *13' (Full) Buffer*: Not only did the addition of concurrent HOV lanes with a full buffer (13') not result in the drop in accident rates associated with general purpose lane additions, but this addition caused rates, in the PM peak period, to exceed the pre-HOV rate of the subject freeway.

In summary, the only concurrent-lane HOV design which the available research indicates to be similar in safety to a general purpose lane addition is the 8' buffer raised 6".

Due to the above positive finding concerning the safety of the 8' buffer raised 6" used on Alameda 580, the details on the design, operation, and history of the project should be studied for possible application in Hampton Roads. In addition, due to the fact that the research available on the 3'-8' design was inconclusive, further research on this design should be conducted.

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I. Introduction

The purpose of this study is to determine the safety effects, if any, of concurrent-lane HOV implementations, and to recommend, on the basis of safety, one or more of the various measures used to separate HOV lanes from adjacent mainlanes. A literature search was undertaken to ascertain the results of research on various existing projects. The documents reviewed herein where found via database searches, telephone contacts, and references in other documents.

This report contains three levels of summarization. First, on the highest level of summarization, the accident data from the reviewed reports have been categorized by design type and presented on charts in the body of this report. Secondly, the change in accidents, along with key descriptive variables, are listed by project in Table 1 which comprises Appendix A. And finally, on the most detailed level, pertinent quotations and key data from the reviewed documents are included as Appendix B.

The results of the research on concurrent HOV lanes, categorized by freeway design, can be found below, following a brief discussion of general purpose lanes.

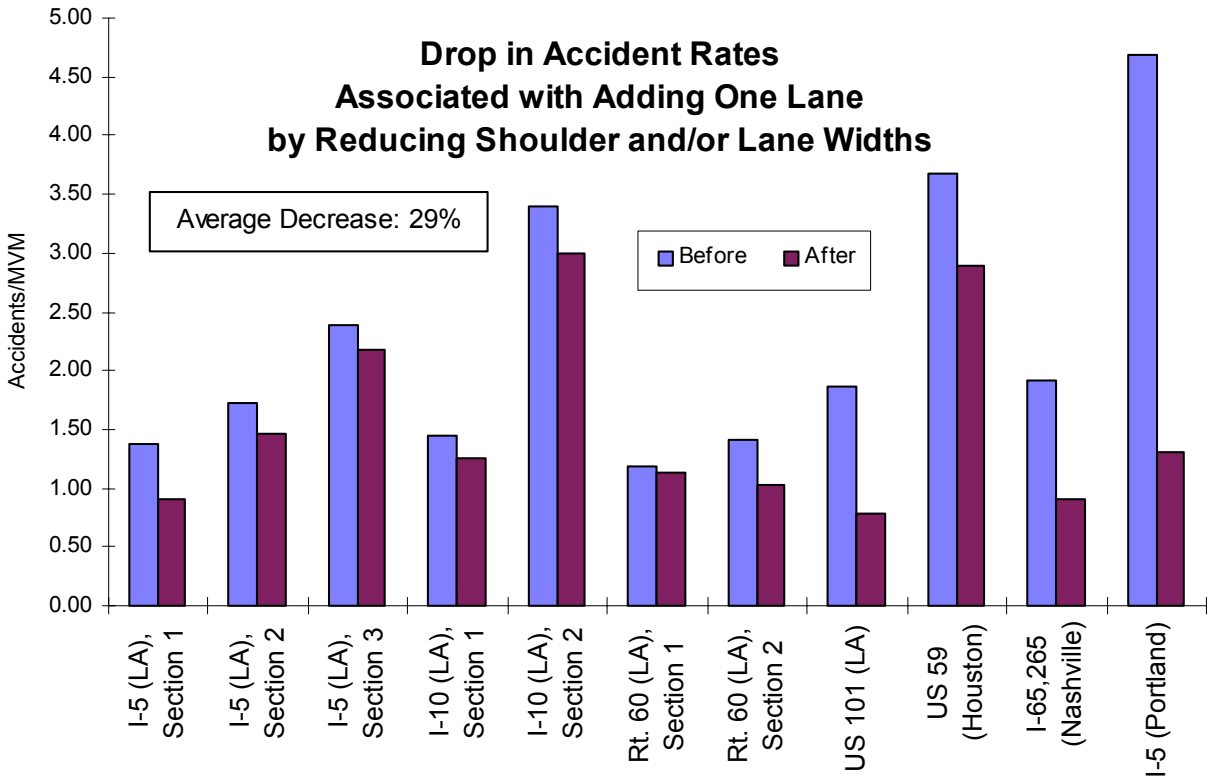
HOV Lane with 0'-2' Buffer

II. Results of Literature Search

A. General Purpose Lane Additions

The addition of general purpose (GP) lanes to a freeway has been shown to consistently decrease accident rates. It is assumed that this decrease results from the lower congestion associated with increased capacity. Figure 1 below indicates that, on average, accident rates drop by 29% after one lane is added. It should be noted that this 29% is based only on lane additions constructed by reducing shoulder and/or lane widths. Because lane additions achieved using standard design widths should reduce accident rates even further, comparing HOV projects to the 29% benchmark conservatively favors the HOV side of the comparison.

FIGURE 1



Source: *Synthesis of Safety Research Related to Traffic Control and Roadway Elements,* Vol. 1 (Washington: Federal Highway Administration, 1982), p. 1-4.

B. Concurrent HOV Lane Additions

For this study, accident research was categorized by freeway design, i.e., the type of separation between HOV and general purpose (GP) lanes for the subject highway, as follows:

- 0'-2' Buffer
- 3'-8' Buffer
- 8' Buffer, 6" High
- 13' Buffer ("Full Buffer")

As shown on the following charts, the data indicates significant differences between the safety of the various concurrent-lane HOV designs. It should be noted that, unfortunately, the results for each of the alternatives to the traditional 0'-2' buffer (the last three of the four above types) are based on only one freeway per type. The results provided below should be interpreted in light of this limitation.

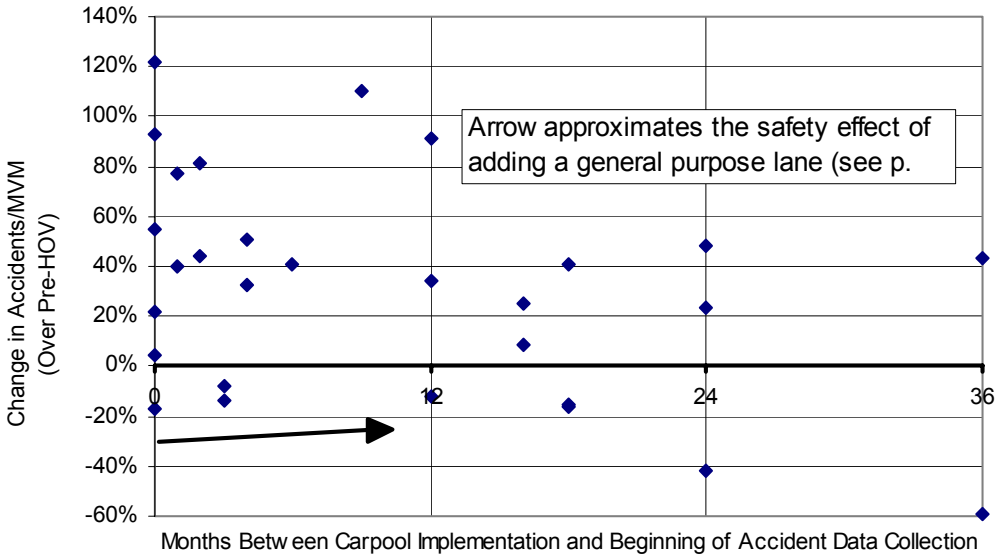
HOV Lane with 4' Buffer

1. 0'-2' Buffer

The accident data of the projects with 0'-2' buffers, listed by project in Appendix A, are summarized in graph form on Figure 2a below. It should be noted that data from two projects, the Southeast Expressway in Boston and the Santa Monica Freeway near Los Angeles, are not included on Figure 2a because these projects did not exist for more than five months. The graph indicates that, at least during the first three years[1] of existence, not only have the additions of concurrent HOV lanes with 0'-2' buffers not resulted in the drop in accident rates associated with general purpose lane additions (indicated by the arrow on the chart),[2] but these additions have typically caused rates to exceed the pre-HOV rates of the subject freeways.

FIGURE 2A

0'-2' Buffer
Concurrent-Lane HOV, Add-A-Lane



Note: This chart contains both peak period and 24 hour rates.
Source: Table 1 (Appendix A).

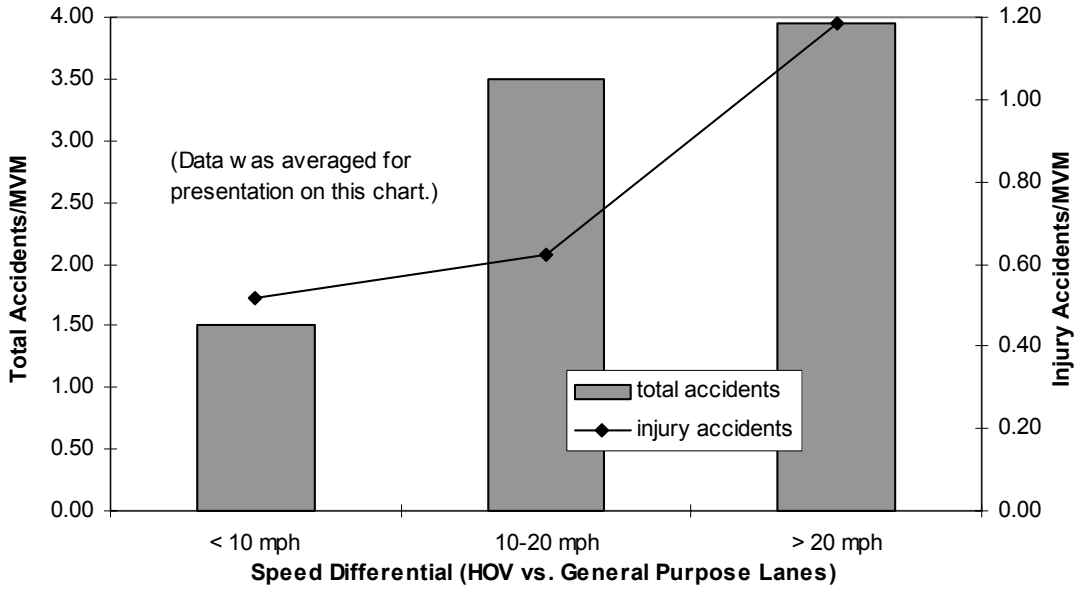
[1] It should be noted that the data points for the third year of existence, for example, are located on the gridline of Figure 2 labeled "24," indicating that the data covers a period *beginning* 24 months after the start of the project.

[2] Note that, for comparing to HOV projects, the safety effect of adding a general purpose lane is represented on graphs in this report by using an arrow which begins with a value of -29% and points slightly upward to reflect the expected rise in rates as the new capacity is met by new demand.

The difference in speeds between the HOV lane and the adjacent general purpose lane, or speed differential, is often mentioned as a possible cause of accident rate increases accompanying concurrent-lane HOV projects. A study of several projects with 0'-2' buffers[3] lends credence to this assertion. Presented in the figure below, data from that study indicates that, for projects with minimal (0'-2') buffers, accident rates increase as speed differential increases.

FIGURE 2B

Effect of Speed Differential with Minimal Buffer (0'-2' Buffer)



Source: Leonard Newman, Cornelius Nuworsoo, and Adolf D. May, "Operational and Safety Experience with Freeway HOV Facilities in California," *Transportation Research Record* 1173 (1988), p. 20.

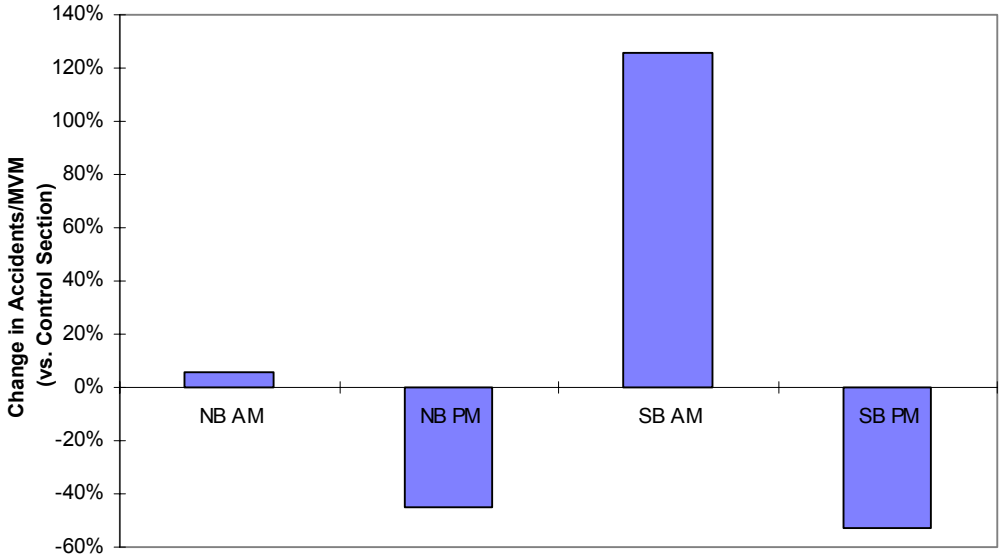
[3]Leonard Newman, Cornelius Nuworsoo, and Adolf D. May, "Operational and Safety Experience with Freeway HOV Facilities in California," Transportation Research Record 1173 (1988), p. 20.

2. 3'-8' Buffer

Figure 3 below summarizes the data, listed in Appendix A, of the only project with a 3'-8' buffer[4] for which safety research is available, I-405 in Orange County, California. Unfortunately the analysis was performed by comparing I-405 accident rates to that of a non-HOV control section. Due to the great variance in accident rates from location to location, such a comparison gives unreliable results[5]. For this project, accident rates in the PM were lower than those of the control section, and AM rates were higher. Even if the AM and PM results were consistent, due to the problems inherent in the use of control sections, data like this is inconclusive.

FIGURE 3

3'-8' Buffer
Concurrent-Lane HOV, Peak Period
I-405 Orange County



Note: Data represents a one-year accident data span beginning two months after implementation.

Source: Edward Sullivan, et al., *High-Occupancy Vehicle Lane Safety* (Sacramento: State of California Department of Transportation, 1992), p. 247.

[4]Over the course of this project, the buffer width varies between 3 and 8 feet.

[5]For further explanation of this unreliability, see Appendix B, p. B-28.

3. 8' Buffer Raised 6"

Figure 4 below summarizes the data, listed in Appendix A, of the only project with an 8' buffer raised 6" for which safety research is available, Alameda 580 near San Francisco, California. After these HOV lanes were added, a drop in accident rates occurred which is similar in magnitude to that of the typical GP lane addition (29%).

FIGURE 4

8' Buffer, 6" High
Concurrent-Lane HOV, Peak Period
Alameda 580

Note: Data points represent one year accident spans.

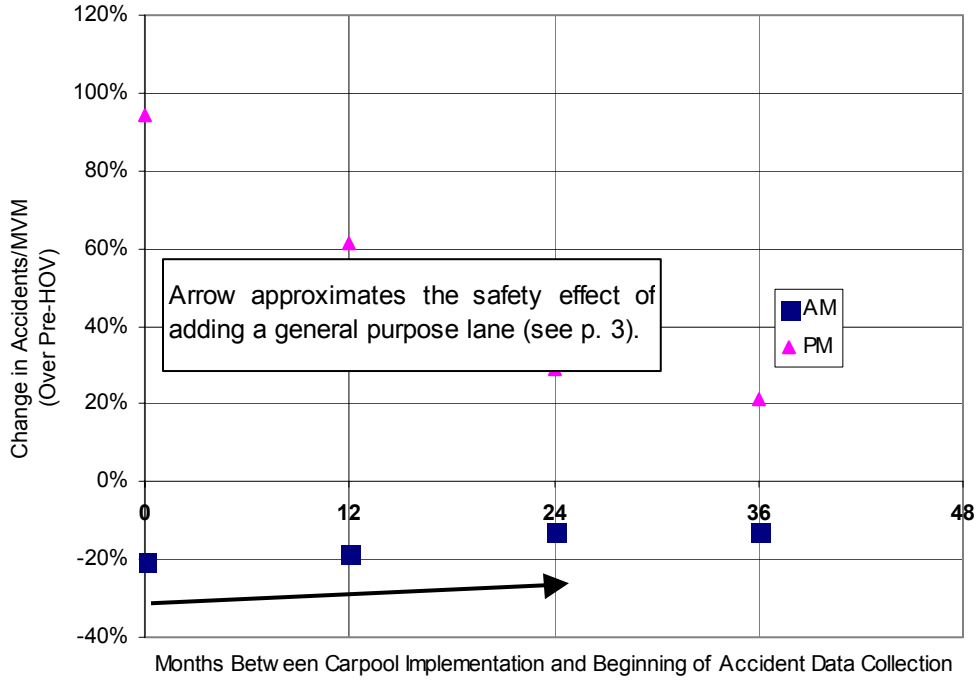
Source: John W. Billheimer, Juliet McNally, and Robert Trexler, *TSM Project Violation Rates,Vol. II, Technical Report* (Los Altos, CA: Systan, Inc., 1981), pp. 4-21, 4-23.

4. Full Buffer (13')

Figure 5 summarizes the data, listed in Appendix A, of the only project with a 13' buffer for which safety research is available, the San Bernardino Freeway near Los Angeles, California. Not only did the addition of concurrent HOV lanes with a full buffer (13') not result in the drop in accident rates associated with general purpose lane additions, but this addition caused rates, in the PM peak period, to exceed the pre-HOV rate of the subject freeway.

FIGURE 5

13' Buffer
Concurrent-Lane HOV, Peak Period
San Bernardino Freeway



Note: Data points represent one year accident spans.

Source: John W. Billheimer, Juliet McNally, and Robert Trexler, *TSM Project Violation Rates, Vol. II, Technical Report* (Los Altos, CA: Systan, Inc., 1981), pp. 4-21, 4-23.

III. Conclusion of Literature Search

The key points discovered during the literature search and discussed above are as follows:

- The addition of capacity through construction of general purpose lanes typically causes accident rates to go down at least 29%.

- *0'-2' Buffer*: Not only have the additions of concurrent HOV lanes with 0'-2' buffers not resulted in the drop in accident rates associated with general purpose lane additions, but these additions have typically caused rates to exceed the pre-HOV rates of the subject freeways.

- *3'-8' Buffer*: Due to the problems inherent in the use of control sections, the data on the project with a 3'-8' buffer is inconclusive.

- *8' Buffer Raised 6"*: After HOV lanes were added with an 8' buffer raised 6", a drop in accident rates occurred which is similar in magnitude to that of the typical GP lane addition (29%).

- *13' (Full) Buffer*: Not only did the addition of concurrent HOV lanes with a full buffer (13') not result in the drop in accident rates associated with general purpose lane additions, but this addition caused rates, in the PM peak period, to exceed the pre-HOV rate of the subject freeway.

In summary, the only concurrent-lane HOV design which the available research indicates to be similar in safety to a general purpose lane addition is the 8' buffer raised 6".

IV. Further Study

Due to the above positive finding concerning the safety of the 8' buffer raised 6" used on Alameda 580, the details on the design, operation, and history of the project should be studied for possible application in Hampton Roads. In addition, due to the fact that the research available on the 3'-8' design was inconclusive, further research on this design should be conducted.

Appendix A- Change in Accidents Summarized by Project

The following table contains changes in accident rates, along with key descriptive variables, for the concurrent-lane HOV projects covered in this study. This data has been categorized and analyzed in the body of this report. For the origin of this data and more project details, see Appendix B.

TABLE 1- Change in Accidents Summarized by Concurrent-Lane Project

Freeway	Series	'Before' Average		Units	Add vs. Take(15)	'After' Average	Time of Day (3)	Source (14)	Design Period (13)	Design		Time A (1)	Time B (2)	Time Span	Change (19)
										Access (17)	Separation (18)				
0'-2' Buffer															
Boston- Southeast Expressway		16.7		Accidents	Take	25.0	(16)	2	5/77-6/77	limited	0'; posts	0 months	2 months	2 months	50%
LA Area- Rt. 55 (Orange County)		16.7		Acc's/Mo./AADT (5)	Add	20.4	24 hour	3	12/85-8/86	limited	double yellow	0 months	9 months	9 months	22%
LA Area- Rt. 91		124		Acc's/14 Months (6)	Add	220	2-8pm	4	7/85-8/86	limited	2'	1 month	15 months	14 months	77%
LA Area- Santa Monica Freeway (I-10)	First Month	0.4		Injury Acc's/MVM	Take	2.7	pk. period	5	1976	continuous	regular dash	0 months	1 month	1 month	575%
	2nd & 3rd Months	0.4		Injury Acc's/MVM	Take	1.15	pk. period	5	1976	continuous	regular dash	1 month	3 months	2 months	188%
	4th & 5th Months	0.4		Injury Acc's/MVM	Take	0.75	pk. period	5	1976	continuous	regular dash	3 months	5 months	2 months	88%
Miami- I-95	AM, HOV3+	4.3		Accidents/MVM	Add	3.7	pk. period	1	12/75-5/77	continuous	single stripe	3 months	13 months	10 months	-14%
	AM, HOV2+	4.3		Accidents/MVM	Add	2.9	pk. period	1	12/75-5/77	continuous	single stripe	13 months	17 months	4 months	-33%
	PM, HOV3+	5.1		Accidents/MVM	Add	4.7	pk. period	1	12/75-5/77	continuous	single stripe	3 months	13 months	10 months	-8%
	PM, HOV2+	5.1		Accidents/MVM	Add	2.4	pk. period	1	12/75-5/77	continuous	single stripe	13 months	17 months	4 months	-53%
New Jersey- Garden State Parkway	First 2 Months	1.4		Accidents/MVM	Add	2.7	pk. period	7	12/80-10/81	continuous	regular dash	0 months	2 months	2 months	93%
	Next 9 Months	0.9		Accidents/MVM	Add	1.3	pk. period	7	12/80-10/81	continuous	regular dash	2 months	11 months	9 months	44%
Northern Virginia- I-95	NB Rush Hours, thru 1987	see 'Change' column->			Add (7)	n/a	pk. period	8	9/86-12/87	continuous	(16)	9 months	2 years	15 months	101%
	SB Rush Hours, thru 1987	see 'Change' column->			Add (7)	n/a	pk. period	8	9/86-12/87	continuous	(16)	2 months	17 months	15 months	81%
	NB 24 Hr, 1986	149.2		(8)	Add (7)	209.2	24 hour	9	1986-88	continuous	(16)	1 month	1 year	1 year	40%
	NB 24 Hr, 1987	149.2		(8)	Add (7)	200.0	24 hour	9	1986-88	continuous	(16)	1 year	2 years	1 year	34%
	NB 24 Hr, 1988	149.2		(8)	Add (7)	184.4	24 hour	9	1986-88	continuous	(16)	2 years	3 years	1 year	24%
	SB 24 Hr, 1987	148.6		(8)	Add (7)	209.6	24 hour	9	1986-88	continuous	(16)	0.5 year	1.5 years	1 year	41%
	SB 24 Hr, 1988	148.6		(8)	Add (7)	209.3	24 hour	9	1986-88	continuous	(16)	1.5 years	2.5 years	1 year	41%
Portland- Banfield	First Year	0.81		Accidents/MVM	Add	1.56	(16)	6	1/76-6/77	(16)	(16)	0 months	1 year	1 year	93%
	After First Year	0.81		Accidents/MVM	Add	0.80	(16)	6	1/76-6/77	(16)	(16)	1 year	1.5 years	0.5 year	-1%
San Fran.- US 101 (Marin)- Ph's I&II	AM, Peak Direction	0.845	(4)	(9)	Add	0.776	pk. period	10	1/89-9/90	continuous	0'	(10)	(10)	20 months	-8%
	PM, Peak Direction	0.895	(4)	(9)	Add	1.514	pk. period	10	1/89-9/90	continuous	0'	(11)	(11)	21 months	69%
San Fran.- US 101 (Marin)- Ph I	AM, Peak Dir., 1st Year	1.71		Accidents/MVM	Add	1.42	pk. period	10	1976-80	continuous	0'	0 months	1 year	1 year	-17%
	AM, Peak Dir., 2nd Year	1.71		Accidents/MVM	Add	1.5	pk. period	12	1976-80	continuous	0'	1 year	2 years	1 year	-12%
	AM, Peak Dir., 3rd Year	1.71		Accidents/MVM	Add	1.0	pk. period	12	1976-80	continuous	0'	2 years	3 years	1 year	-42%
	AM, Peak Dir., 4th Year	1.71		Accidents/MVM	Add	0.7	pk. period	12	1976-80	continuous	0'	3 years	4 years	1 year	-59%
	PM, Peak Dir., 1st Year	4.18		Accidents/MVM	Add	9.26	pk. period	12	1976-80	continuous	0'	0 months	1 year	1 year	122%
	PM, Peak Dir., 2nd Year	4.18		Accidents/MVM	Add	8.0	pk. period	12	1976-80	continuous	0'	1 year	2 years	1 year	91%
	PM, Peak Dir., 3rd Year	4.18		Accidents/MVM	Add	6.2	pk. period	12	1976-80	continuous	0'	2 years	3 years	1 year	48%
	PM, Peak Dir., 4th Year	4.18		Accidents/MVM	Add	6.0	pk. period	12	1976-80	continuous	0'	3 years	4 years	1 year	44%
Seattle- I-5	NB, PM; 1st 18 months	1.10	(12)	Accidents/MVM	Add	1.15	pk. period	13	8/83-5/87	continuous	8" solid stripe	0 months	18 months	1.5 years	5%
	NB, PM; Next 27 months	1.10	(12)	Accidents/MVM	Add	0.92	pk. period	13	8/83-5/87	continuous	8" solid stripe	18 months	3.75 years	2.25 years	-16%
	SB, AM; 1st 18 months	0.93	(12)	Accidents/MVM	Add	1.44	pk. period	13	8/83-5/87	continuous	8" solid stripe	0 months	18 months	1.5 years	55%
	SB, AM; Next 27 months	0.93	(12)	Accidents/MVM	Add	0.79	pk. period	13	8/83-5/87	continuous	8" solid stripe	18 months	3.75 years	2.25 years	-15%
Seattle I-5 Southcenter Hill Vicinity	SB, first full year	143		Accidents	Add	189	24 hour	14	1992-1993	continuous	8" solid stripe	4 months	16 months	1 year	32%
	SB, second full year	143		Accidents	Add	155	24 hour	14	1992-1993	continuous	8" solid stripe	16 months	2.3 years	1 year	8%
	NB, first full year	63		Accidents	Add	95	24 hour	14	1992-1993	continuous	8" solid stripe	4 months	16 months	1 year	51%
	NB, second full year	63		Accidents	Add	79	24 hour	14	1992-1993	continuous	8" solid stripe	16 months	2.3 years	1 year	25%
3'-8' Buffer															
LA Area- I-405 (Orange County)	NB AM	1	(4)	Accidents/MVM	Add	1	pk. period	11	7/90-6/91	limited	3-8' buffer	2 months	14 months	1 year	6%
	NB PM	2	(4)	Accidents/MVM	Add	1	pk. period	11	7/90-6/91	limited	3-8' buffer	2 months	14 months	1 year	-45%
	SB AM	0	(4)	Accidents/MVM	Add	1	pk. period	11	7/90-6/91	limited	3-8' buffer	2 months	14 months	1 year	126%
	SB PM	2	(4)	Accidents/MVM	Add	1	pk. period	11	7/90-6/91	limited	3-8' buffer	2 months	14 months	1 year	-53%
8' Buffer (6" high)															
San Francisco- Alameda 580	AM, Peak Dir., 1st Year	2		Accidents/MVM	Add	1	pk. period	12	~3yr life	limited	8' buffer (6" high)	0 months	1 year	1 year	-40%
	AM, Peak Dir., 2nd Year	2		Accidents/MVM	Add	0	pk. period	12	~3yr life	limited	8' buffer (6" high)	1 year	2 years	1 year	-73%
	AM, Peak Dir., 3rd Year	2		Accidents/MVM	Add	0	pk. period	12	~3yr life	limited	8' buffer (6" high)	2 years	3 years	1 year	-87%
	PM, Peak Dir., 1st Year	2		Accidents/MVM	Add	1	pk. period	12	~3yr life	limited	8' buffer (6" high)	0 months	1 year	1 year	-11%
	PM, Peak Dir., 2nd Year	2		Accidents/MVM	Add	1	pk. period	12	~3yr life	limited	8' buffer (6" high)	1 year	2 years	1 year	-46%
	PM, Peak Dir., 3rd Year	2		Accidents/MVM	Add	2	pk. period	12	~3yr life	limited	8' buffer (6" high)	2 years	3 years	1 year	-10%
13' Buffer															
LA- San Bernardino Freeway (I-10)	AM, Peak Dir., 1st Year	2		Accidents/MVM	Add	1	pk. period	12	1976-1980	limited	13'	0 months	1 year	1 year	-20%
	AM, Peak Dir., 2nd Year	2		Accidents/MVM	Add	1	pk. period	12	1976-1980	limited	13'	1 year	2 years	1 year	-19%
	AM, Peak Dir., 3rd Year	2		Accidents/MVM	Add	2	pk. period	12	1976-1980	limited	13'	2 years	3 years	1 year	-13%
	AM, Peak Dir., 4th Year	2		Accidents/MVM	Add	2	pk. period	12	1976-1980	limited	13'	3 years	4 years	1 year	-13%
	PM, Peak Dir., 1st Year	1		Accidents/MVM	Add	2	pk. period	12	1976-1980	limited	13'	0 months	1 year	1 year	94%
	PM, Peak Dir., 2nd Year	1		Accidents/MVM	Add	2	pk. period	12	1976-1980	limited	13'	1 year	2 years	1 year	61%
	PM, Peak Dir., 3rd Year	1		Accidents/MVM	Add	2	pk. period	12	1976-1980	limited	13'	2 years	3 years	1 year	29%
	PM, Peak Dir., 4th Year	1		Accidents/MVM	Add	2	pk. period	12	1976-1980	limited	13'	3 years	4 years	1 year	21%

For speed differential of 10-20 mph, contiguous (0'-2' separation) freeway sections (LA 91, ORA 55, MRN 101, SF 280) had accidents rates averaging 127% higher (source 15) than those with full buffer (13' wide).

TABLE 1 (CONT'D)

Change in Accidents Summarized by Concurrent-Lane Project

Notes:

(1) 'Time A' indicates the amount of time from the HOV implementation to the beginning of the period covered by the "After" average.
(2) 'Time B' indicates the amount of time from the HOV implementation to the end of the period covered by the "After" average.
(3) 'Time of Day' indicates the period (e.g., 24 hour, peak period, etc.) over which statistics apply.
(4) The data shown is for a non-HOV control section.
(5) Accidents/Month/(Annual Average Daily Traffic)*1E-6 (dry weekdays only).
(6) Weekday Accidents/14 Month Period (14:00 to 19:59).
(7) Capacity added via adding shoulder lane and claiming left lane for HOV (simultaneously).
(8) (Accidents*1E8)/(Average Daily Traffic*Length*Days).
(9) Accidents/MVM (excluding accidents occurring under atypical or irrelevant conditions).
(10) Half of the project was 12.5 years old when the 20-month study period began and the other half was 1.5 years old.
(11) Half of the project was 12.5 years old when the 20-month study period began and the other half was 2.5 years old.
(12) Period prior to HOV lane construction (ramp metering was used).
(13) The period in question for knowing the design of the freeway (usually the period analyzed by the study used).
(14) See below for description of data sources.
(15) This column indicates whether the HOV lane was established through adding a lane or taking a lane.
(16) Missing data.
(17) This column indicates whether the HOV lane can be entered and exited anywhere along its length or entered only at designated ingress/egress points.
(18) This column indicates the separation, if any, between the HOV lane and the adjacent general purpose lane.
(19) 'After' vs. 'Before.'

Data Sources:

1- Craig Miller et al., *Safety Evaluation of Priority Techniques for High Occupancy Vehicles* (Washington: Federal Highway Administration, 1979), p. 38.
2- Charles Kalauskas et al., *Southeastern Expressway- Evaluation of the Downtown Express Lane* (Boston: Central Transportation Planning Staff, 1977), p. 55.
3- Thomas F. Golob, Wilfred W. Recker, and Douglas W. Levine, "Safety of Freeway Median High Occupancy Vehicle Lanes," *Accident Analysis & Prevention* 22, no. 1 (1990), pp. 22.
4- Thomas F. Golob, Wilfred W. Recker, and Douglas W. Levine, *Safety of High Occupancy Vehicle Lanes Without Physical Separation* (Irvine, CA: University of California, Irvine, Institute of Transportation Studies, 1988), p. 29.
5- John W. Billheimer, "The Santa Monica Freeway Diamond Lanes," *Transportation Research Record* 663 (1978), p. 7.
6- *Banfield High Occupancy Vehicle Lanes* (Washington: Federal Highway Administration, 1978), p. 84.
7- John C. Powers, "Garden State Parkway HOV Lane," *Transportation Research Record* 906 (1983), p. 55.
8- Bernice H. Strommer, *I-95 HOV/Shoulder Travel Lane Use*, part II (Richmond: Virginia Department of Transportation, 1992), p. 9.
9- *Update of HOV/Shoulder Travel Lane Use on I-95*, Appendix F (Richmond: Virginia Department of Transportation, no date), Table 8.
10- Edward Sullivan et al., *High-Occupancy Vehicle Lane Safety* (Sacramento: State of California Department of Transportation, 1992), p. 166.
11- Edward Sullivan et al., *High-Occupancy Vehicle Lane Safety* (Sacramento: State of California Department of Transportation, 1992), p. 247.
12- John W. Billheimer, Juliet McNally, and Robert Trexler, *TSM Project Violation Rates*, draft final report, vol. II, *Technical Report* (Los Altos, CA: Systan, Inc., 1981), pp. 4-21, 4-23.
13- Kim C. Henry and Omar Mehyar, *Six-Year Flow Evaluation* (Seattle: Washington State Department of Transportation, 1989), pp. 47, 48.
14- Eldon L. Jacobson, *I-5 Southcenter Hill Vicinity Interim HOV Lane Operational Analysis* (Olympia: Washington State Department of Transportation, 1994), pp. A-1, B-1.
15- Leonard Newman, Cornelius Nuworsoo, and Adolf D. May, "Operational and Safety Experience with Freeway HOV Facilities in California," *Transportation Research Record* 1173 (1988), p. 20.

Appendix B- Report Quotes and Data

Pertinent quotes and graphs of data from the documents reviewed for this study are provided in this appendix. The first section of this appendix, labeled "General," covers documents with general comments concerning the safety of concurrent-lane HOV projects. The remainder of this appendix is organized by project. The projects are grouped by geographic location, and the geographic locations are addressed alphabetically. Because data from the latter section has been summarized in both the report body and Appendix A, the reader may wish to use the latter section for reference purposes.

In this appendix, comments by HRPDC staff are included in italics.

TABLE OF CONTENTS FOR APPENDIX B

GENERAL

"Evaluating and Planning HOV Lane Enforcement" by John W. Billheimer, Juliet McNally, and Robert Trexler, *Transportation Research Record* 910 (1983), pp. 56-68.

[*This study contains basically the same information as the* TSM Project Violation Rates *study by same authors (see p. B-30).*]

p. 64 "Long stretches of barrier-free main-line HOV lanes operating next to stop-and-go traffic...can easily cause unacceptable increases in accident rates."

"The Effectiveness of High-Occupancy Vehicle Facilities" by ITE Technical Council Committee 6A-37, *ITE Journal* (February 1988), p. 17-18.

p. 17 "...there is also increasing disagreement about appropriate design standards..."

p. 18 "HOV facilities are surprisingly safe, according to the reported accident rates. Where data were reported for accident rates on HOV lanes, the rates were lower than the rates reported on parallel non-HOV lanes." *No data provided.*

"Design Features of High-Occupancy Lanes" by ITE Technical Council Committee 5C-11, *ITE Journal* (November 1991), p. 10-12.

p. 10 "HOV lanes separated from the general-purpose lanes by a concrete or steel rail barrier or by a substantial (12- to 14-foot-wide) buffer are considered exclusive HOV lanes." *However, for the purposes of this study, lanes with 12- to 14-foot-wide buffers were considered "concurrent."*

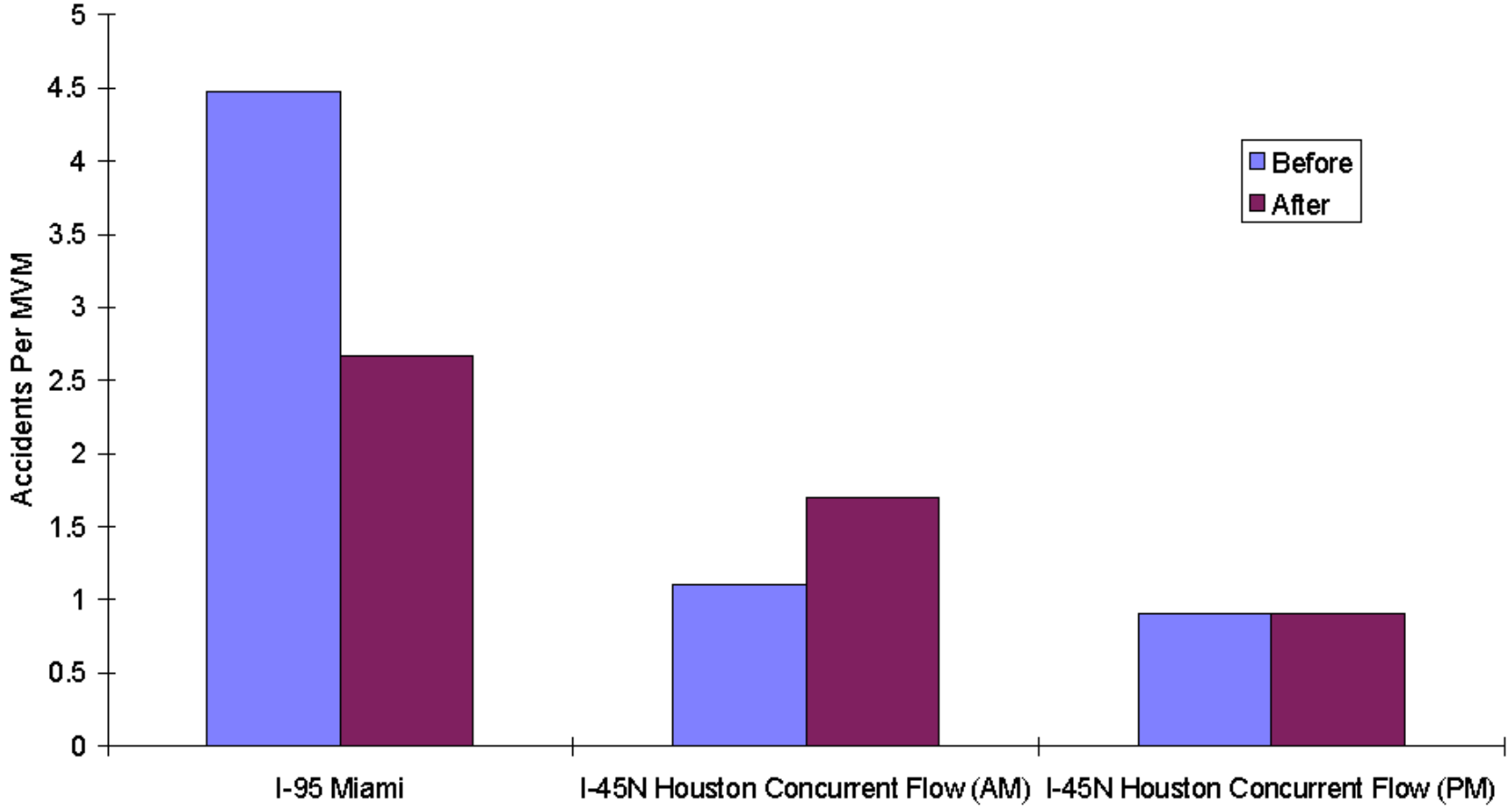
p. 12 "Many operating projects...do not have designs that would be acceptable under the reduced dimensions included in this report."

Study of Current and Planned High Occupancy Vehicle Lane Use: Performance and Prospects by Frank Southworth of Oak Ridge National Laboratory and Fred Westbrook of Camden Corporation (Springfield, VA: National Technical Information Service, December 1985).

p. 3-24 "While limited in its coverage, and subject...to the problem of defining a sufficiently long observation period..., there would seem to be no major increase in accidents as a result of HOV lane operations." *[projects studied:* ***I-95 Miami, I-45N Houston CF Lane, I-66 Virginia****] See Figure 6, following page. Note that these data were not included in Table 1 because no time frame was given.*

FIGURE 6

Oak Ridge Study



Source: Southworth and Westbrook, p. 3-25.

High-Occupancy Vehicle Facilities by Charles Fuhs (New York: Parsons Brinckerhoff, December 1990).

Buffer-Separated (*As Opposed to Barrier-separated*)

p. 4-2-11 "...there appear to be no incremental benefits for a wider buffer."
"A buffer width of between 4 feet and 13 feet is discouraged, as motorists may mistake it for a travel lane."

Nonseparated

p. 4-2-14 "[A nonseparated design] should not be selected as a permanent solution because of its associated operational shortcomings." *["shortcomings" not specified]*

Safety

p. 3-8-1 "One measurable objective is to manage the facility so that the accident rate...equals or betters rates on the adjacent freeway, on a basis of comparative vehicle miles of travel. (A comparison...on a person-mile basis is not appropriate as this promotes a bias against mixed-flow operation.)"

"Studies of projects have generally found that HOV operations were as safe, and in some examples, substantially safer than the adjacent mixed-flow traffic stream." *The author's concurrent-lane project data shows, however, HOV lanes with higher accident rates than mixed-flow lanes (see Figure 7, following page).*

p. 3-8-2 "A substantial buffer (10 or more feet in width) can also offer some of the same advantages [as barrier separation], albeit with some compromise in fully regulating traffic operation."

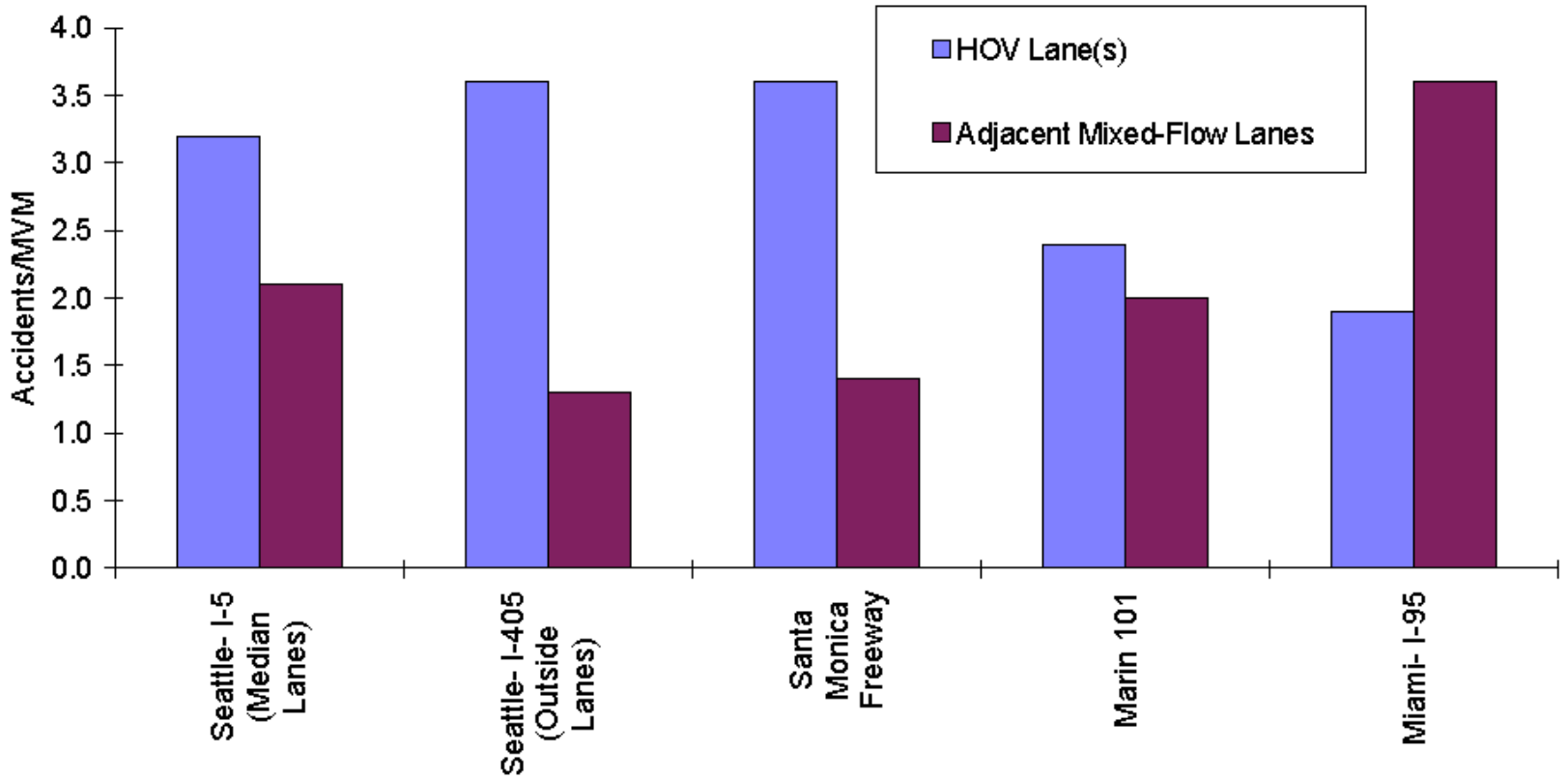
"A wide buffer can serve to substantially separate traffic flows while providing a refuge for vehicle breakdowns, and it can save space over the creation of separate breakdown shoulders for a barrier-separated facility. However, the operation of high-speed traffic on either side of a buffer of any width has posed a concern among some operators and enforcement agencies."

"If the HOV lane is shared with mixed-flow traffic or borrowed from a shoulder, there may be an element of motorist confusion that impairs performance."

"The practice of weaving in and out of an HOV facility...increases the potential for accidents. Designating access locations may alleviate this."

FIGURE 7

Buffer-Separated and Nonseparated High-Occupancy Vehicle Facilities



Source: Fuhs, p. 3-8-1.

"Freeway Concurrent Flow High Occupancy Vehicle Lanes: Basic Considerations" by Robert W. Stokes, Dennis L. Christiansen, and Steven Z. Levine, *Compendium of Technical Papers,* ITE 54th Annual Meeting, San Francisco (Washington: Institute of Transportation Engineers, 1984), pp. 20-21 - 20-25.

p. 21 "...the continuous access feature of the reserved lane may pose serious enforcement and safety problems."

p. 22 "The I-95 project (6.7 mi) in **Miami** [emphasis added] was experiencing a 30% to 40% violation rate and, due to a series of fatal rear-end accidents, it was necessary "to go back in" and add an inside shoulder."

p. 22 "Safety is a concern. A FHWA study [by Beiswenger, Hoch and Associates, 1979] concluded that "concurrent flow HOV lane treatment is potentially one of the most hazardous priority treatments that can be implemented on a limited access facility.""

p. 23 "A speed differential of this magnitude [25 mph] poses potential safety problems for...HOVs, violators or disabled vehicles attempting to enter the HOV lane fro the normal flow lanes."

Conference Proceedings, 1990 HOV Facilities Conference (Transportation Research Circular #366) edited by Katherine F. Turnbull (Washington: Transportation Research Board, December 1990).

Access/Egress and Safety Session

Speaker: Jim Robinson, FHWA

p. 76 "He [Mr. Robinson] noted that many of these comments reflect general observations from individuals associated with the different projects rather than detailed reports."

"With no barrier separation, the potential for accidents is greater. However, most of the available information seems to indicate that the accident rates usually remain relatively constant, or even go down. There are a few examples which seem to indicate that the accident rates have increased. However, it is difficult to tell if the increase is due to the HOV lane or to other changes that have been made in the freeway facility." *No data provided.*

Speaker: Ron Klusza, Caltrans

p. 77 "At this point, there is little information available on the impacts of these different buffer widths on safety concerns."

High-Occupancy Vehicle Project Case Studies: Historical Trends and Project Experiences by Katherine F. Turnbull (College Station, TX: Texas A&M University, Texas Transportation Institute, 1992).

p. 42 "The ongoing monitoring and evaluation of the I-394 interim HOV lane in the **Minneapolis** [emphasis added] area indicated that there were no unique accident problems associated with the project." [*The footnote for the preceding statement refers to a survey of users.*]

Re: *An Analysis of Traffic Safety Relative to the Commuter Lane Projects on SR-91 and SR-55 in Orange and Los Angeles Counties* (Irvine, CA: University of California, Irvine, Institute of Transportation Studies, 1987) *[This study was prepared by the same authors and covers the same freeways as* Safety of High Occupancy Vehicle Lanes without Physical Separation *(see p. B- 24) and* Safety of Freeway Median High Occupancy Vehicle Lanes *(see p. B-21).]*

p. 43 "First, the analysis indicated that the traffic congestion experienced on the freeway overwhelmed all other factors in determining safety. Thus, identifying the impact of the HOV lanes was difficult due to increasing congestion patterns. Second, the study indicated that little change in safety would result if the lanes were general-purpose lanes rather than HOV lanes. Finally, the lack of good accident data from the period before the HOV lanes were implemented was cited as a limiting factor in the analysis."

Safety Evaluation of Priority Techniques for High Occupancy Vehicles by Craig Miller, Robert Deuser, Joseph Wattleworth, and Charles Wallace (Washington: Federal Highway Administration, 1979).

p. 44 "The previous sections have shown that concurrent-flow HOV lane treatment is potentially one of the most hazardous priority treatments that can be implemented on a limited-access facility. On the other hand, it is possible to employ this treatment effectively and safely provided certain precautions are taken."

"Specific recommendations that may improve the safety of a concurrent-flow HOV lane...include the following:"

- "The general recommendation on provision of median shoulders is emphatically reiterated for this priority treatment."

For further discussion of this study, see page B-33.

A Policy on Geometric Design of Highways and Streets (Washington: American Association of State Highway and Transportation Officials, 1990).

p. 236 "...the greater a vehicle deviates from this average speed the greater its chances of becoming involved in an accident."

p. 797 "When undue deceleration or acceleration by leaving or entering traffic takes place directly on the highway traveled way, it disrupts the flow of through traffic, and often is hazardous."

BOSTON- SOUTHEAST EXPRESSWAY

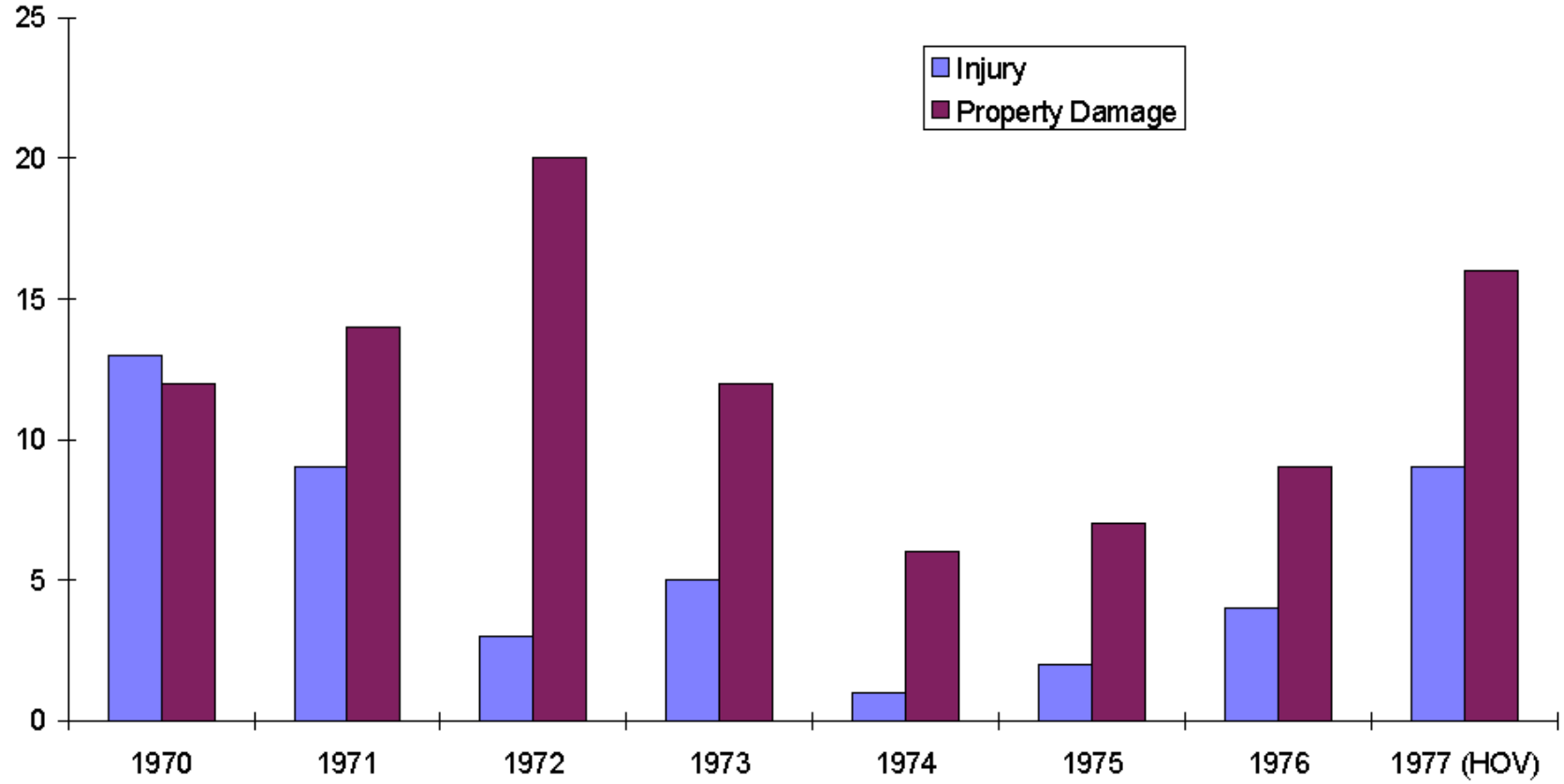
Southeast Expressway- Evaluation of the Downtown Express Lane *CTPS Technical Report 3* by Charles Kalauskas, John Attanucci, Daniel Brand, and Howard Morris (Boston: Central Transportation Planning Staff, December 1977).

p. 56 "Despite improved reporting procedures [police patrols were greatly increased during project life], the figures for both months of Lane operation fall within the range of accident figures reported by the normal police patrols between the years 1970 through 1976. In addition, only two of the May accidents and two of the June accidents occurred in or could be associated with the Express Lane." *[July, August, September, and October not addressed.]*

See Figures 8 and 9, following pages.

FIGURE 8

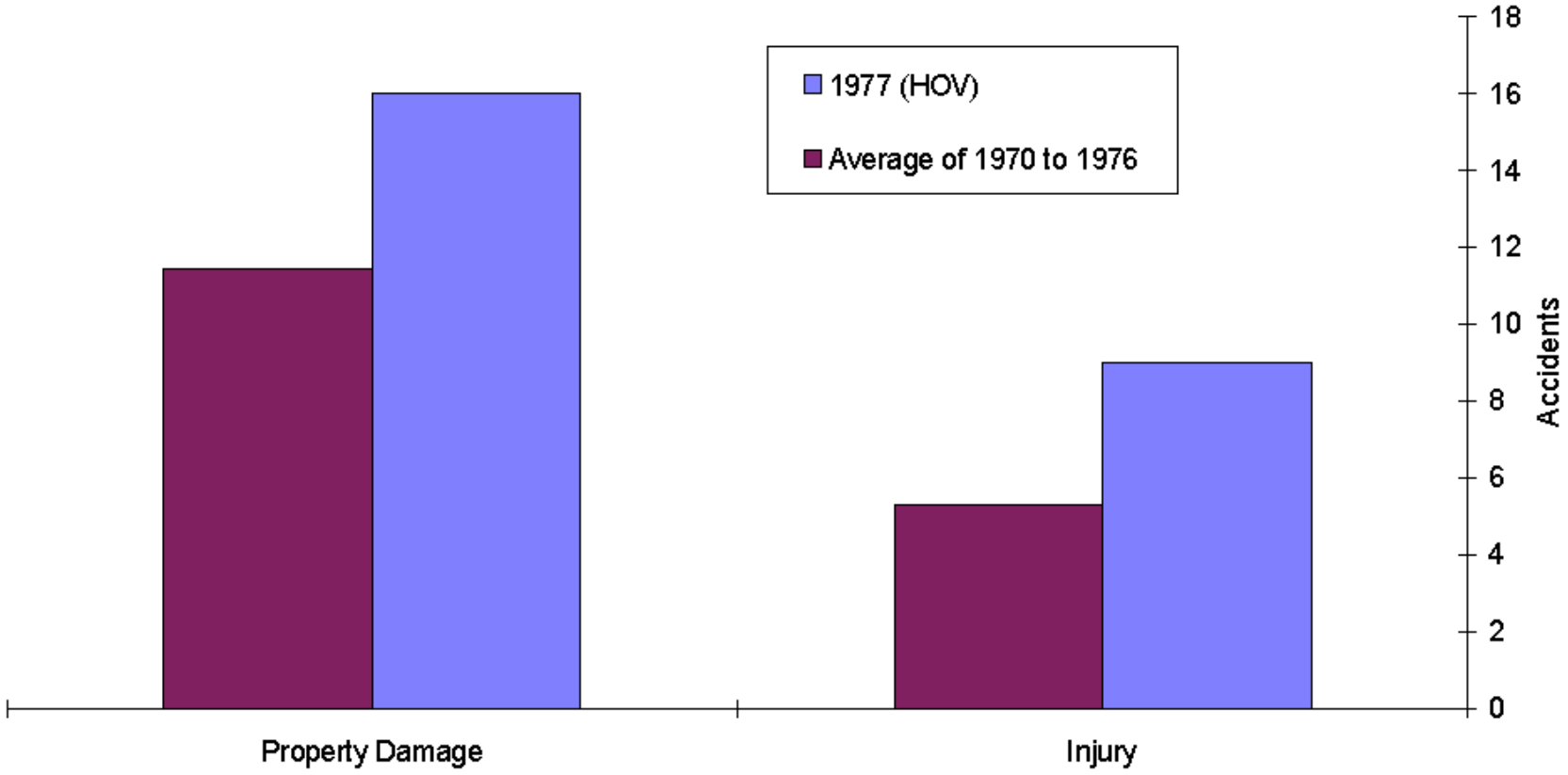
Southeast Expressway
Accidents During May and June



Source: Kalauskas, et al., p. 55.

FIGURE 9

Southeast Expressway
Accidents During May and June Portion of 1977 Implementation



Source: Kalauskas, et al., p. 55.

CALIFORNIA- GENERAL

Decreased Safety and the HOV Lane (unpublished) by Les Berriman (Irvine, CA: Drivers for Highway Safety, undated).

"...all [concurrent-flow HOV lane additions] converted back to general purpose lanes have resulted in...reduced accidents."

"The **Santa Monica** [emphasis added] freeway is the most famous such case -- a 70% reduction in accidents."

"[**Marin 101**] experienced a doubling in accident rate with addition of an HOV lane. The lane was opened to all traffic during a bus driver's strike and the accident rate dropped 47% to the pre-project level..."

"Compensating for traffic growth...shows the real time increase to be 34% [for the Route 91 freeway]. If the lane had been general purpose accidents should have decreased by about 20%."

"Recent data shows that total accidents (based on dry weekdays) on the **[Route] 55 freeway** [emphasis added], since the HOV lane addition, have increased more than 40% over what they would be if nothing had been done and 90% over what they would be if the lane was general purpose."

"Operational and Safety Experience with Freeway HOV Facilities in California"by Leonard Newman, Cornelius Nuworsoo, and Adolf D. May, *Transportation Research Record* 1173) (1988), pp. 18-24.

<u>Abstract</u>

p. 18 "none of the currently operating facilities was found to contain severe operational or accident problems."

"Although statistically reliable conclusions could not be made, it did appear that certain designs were better than others. The physically separated facility appears to be the safest type because interaction of HOV lane vehicles and mixed flow vehicles is virtually eliminated. Of the facilities that were not physically separated..., the wide buffer (full lane width) facility was clearly superior to the contiguous types." *No projects with buffers greater than 2' and less than 13' wide were studied.*

"The study was unable to differentiate between the various contiguous designs, which were categorized by whether they restrict intermediate access or not."

Body

Types Studied:
Physically separated,
Buffer-separated (13' wide),
Essentially contiguous (0 to 2' buffer)

p. 19 "...the approach to the Bay Bridge was considered too unique to be fairly compared with the others."

Facilities Analyzed:
LA 10 LA 91 ORA 55 MRN 101 SF 280

p. 21 "When speed differentials increase, the contiguous design accident rates went up, but the buffer design accident rates stayed the same." "...the buffer-separated design is likely to be superior to other types, even under varied operating conditions. Considerations of this...conclusion, however, should include the fact that the buffer-separated facility is used on only one freeway. It is also worth noting that no left shoulder is available in the contiguous designs studied..."

"Five cells were determined to be comparable." [the high volume cells in the low and medium speed differential categories] "At the 5-percent level, the differences in mean accident rates between various designs are not statistically significant..."

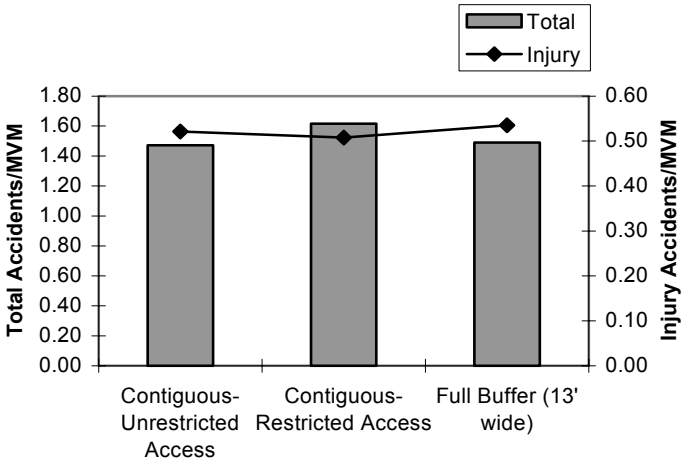
p. 22 "Next, all cells for each type of design were lumped together, and the test was applied between various designs. Analysis of variance indicates that the differences in means between various designs were again not significant..." "...on the basis of available data, one result confirms an earlier opinion, that contiguous HOV lanes were basically the same in safety and effectiveness irrespective of limitations placed or not placed on intermediate access."

p. 23 "A moderate speed differential (10-20 mph) appears to cause as many operational problems as high differential (>20 mph). The high differential usually indicates severe congestion in the mixed flow lanes, whereas the moderate differential usually indicates that the mixed flow lanes are operating at very high flows and are subject to frequent shock waves and sudden queues. This may result in more frequent and sudden changes involving the HOVL."

See Figures 10, 11, 12, 13, and 14 on following pages.

FIGURE 10

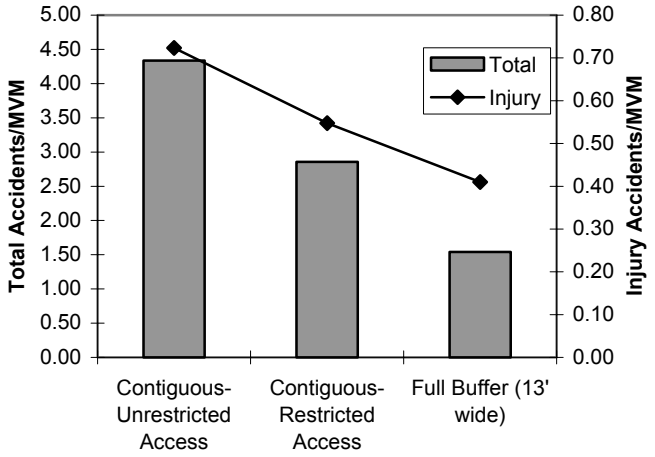
Speed Differential <10 mph



Note: Some of the data from the study has been averaged for presentation here.
Source: Newman, Nuworsoo, and May, p. 20.

FIGURE 11

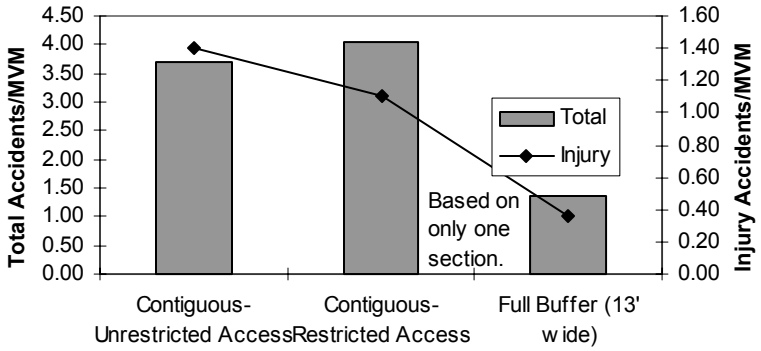
Speed Differential 10-20 mph



Note: Some of the data from the study has been averaged for presentation here.
Source: Newman, Nuworsoo, and May, p. 20.

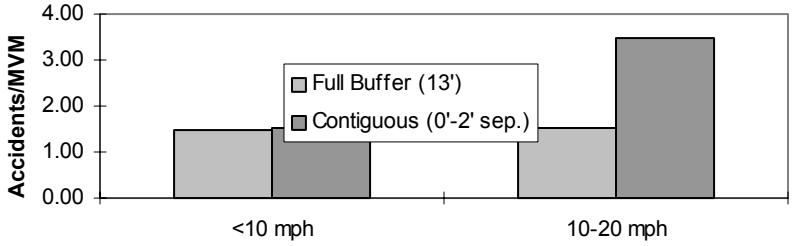
NOTE: Injury rates are subject to low sample size.

FIGURE 12
Speed Differential >20 mph



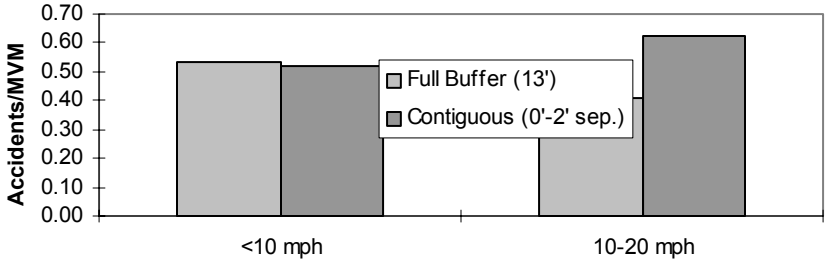
Note: Some of the data from the study has been averaged for presentation here.
Source: Newman, Nuworsoo, and May, p. 20.

FIGURE 13
Five California Concurrent-Flow HOV Freeways
Total Accidents



Note: Some of the data from the study has been averaged for presentation here.
Source: Newman, Nuworsoo, and May, p. 20.

FIGURE 14
Five California Concurrent-Flow HOV Freeways
Injury Accidents



Note: Some of the data from the study has been averaged for presentation here.
Source: Newman, Nuworsoo, and May, p. 20.

NOTE: Injury rates are subject to low sample size.

Synthesis of Safety Research Related to Traffic Control and Roadway Elements, Vol. 1, authors differ by chapter (Washington: Federal Highway Administration [FHWA-TS-82-232], December 1982).

p. 8-11 "The lack of physical separation between HOV and general lanes associated with this measure generally causes operational and safety problems."

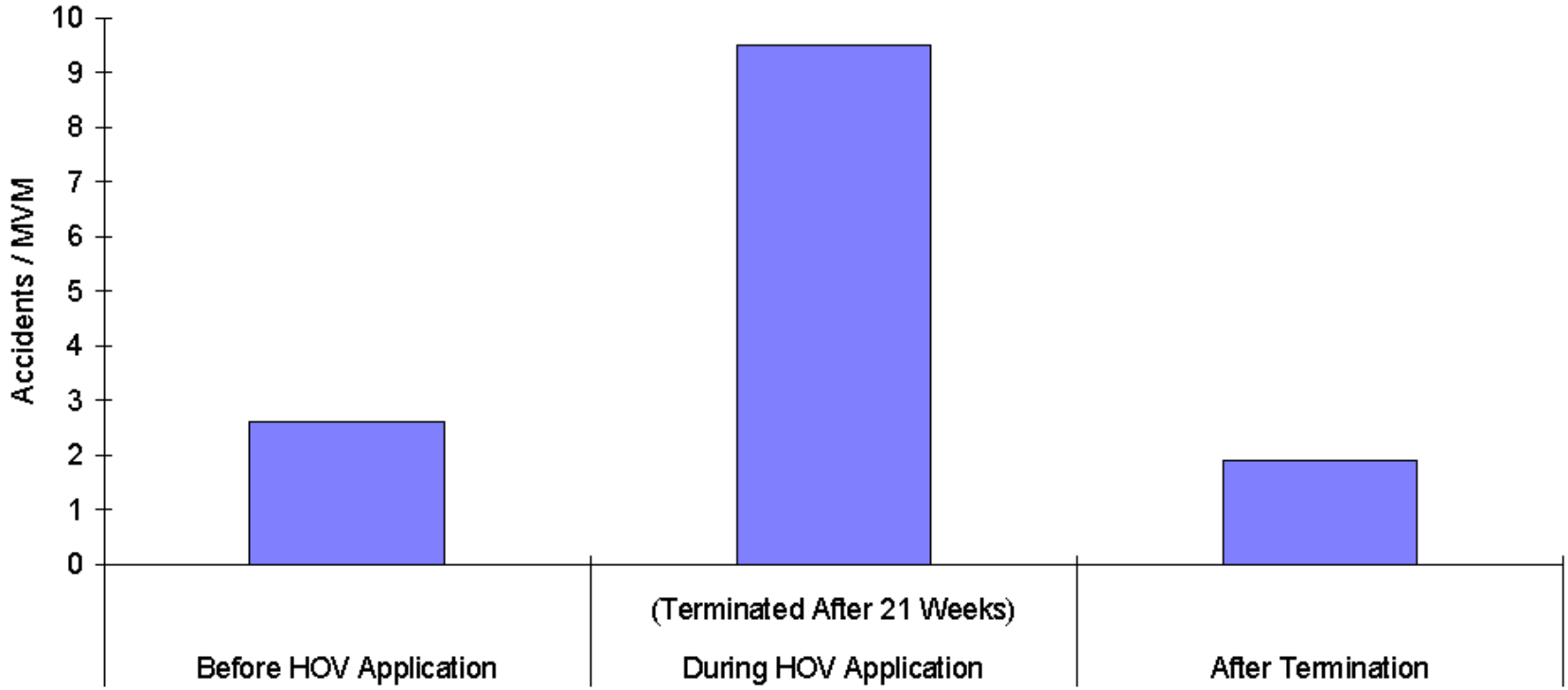
p. 8-14 "The same percentage trend [increase in the percentage of rear-end accidents] was observed on **Route 101 [Marin]** despite the fact that congestion was relieved through increased capacity..."

Route 280- San Francisco [*no data provided, therefore this project is not on following charts]* "Except for the first year of operation, the accident rate has been about the same as it was before the HOV lane was implemented. There has been only one accident involving vehicles in the express lane during 3 years of operation."

See charts on following pages.

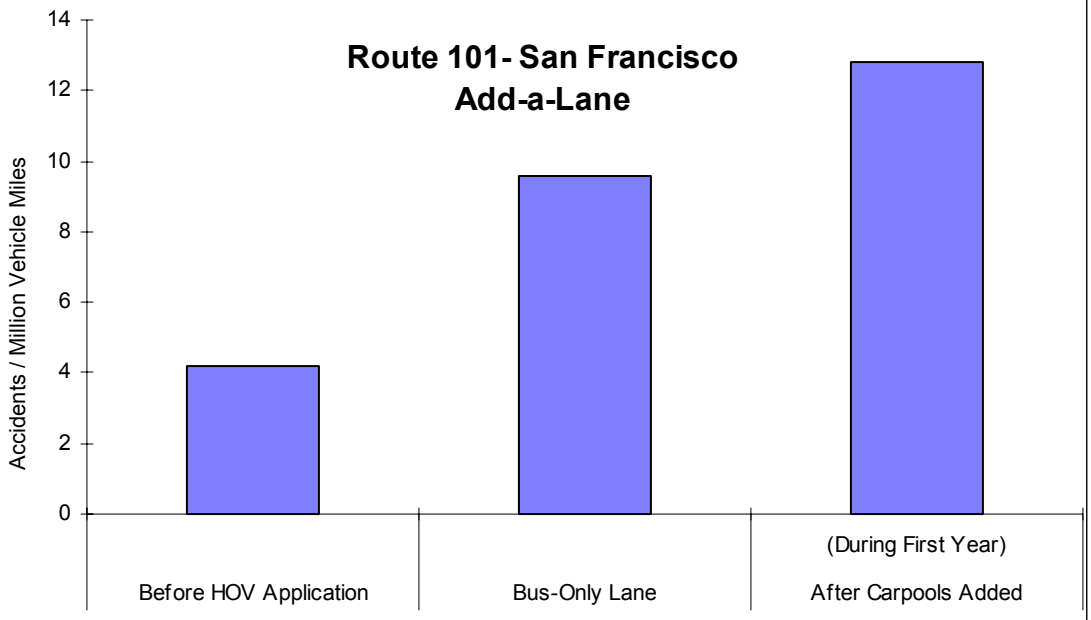
FIGURE 15

Santa Monica Freeway
Take-a-Lane



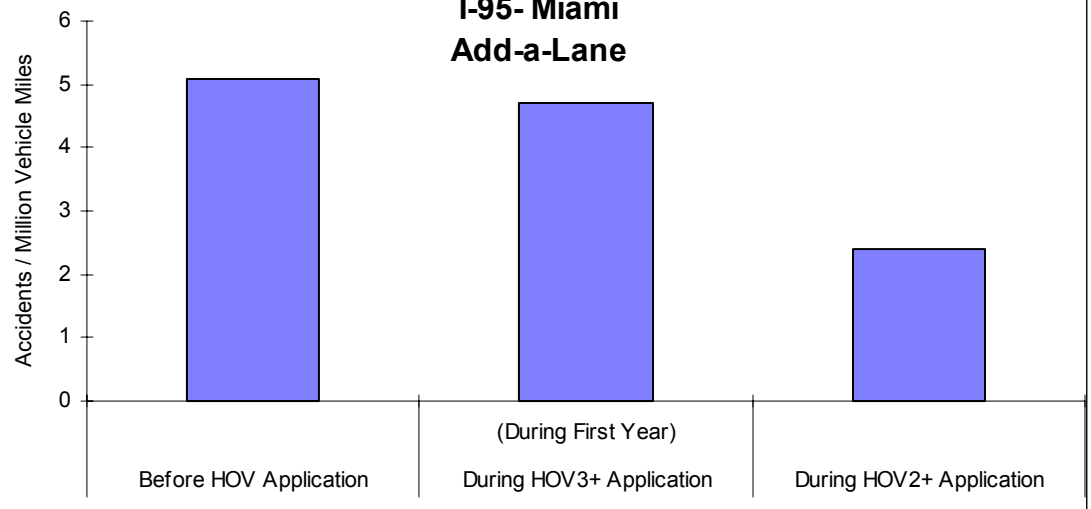
Source: *Synthesis of Safety Research Related to Traffic Control and Roadway Elements* , p. 8-15.

FIGURE 16



Source: *Synthesis of Safety Research Related to Traffic Control and Roadway Elements* , p. 8-15.

FIGURE 17



Source: *Synthesis of Safety Research Related to Traffic Control and Roadway Elements* , p. 8-15.

HOUSTON- I-45N

- *See* Study of Current and Planned High Occupancy Vehicle Lane Use*, p. B-1*.

LA AREA-

SANTA MONICA FREEWAY

- *See* TSM Project Violation Rates*, p. B-30.*
- *See* Decreased Safety and the HOV Lane*, p. B-10*.

High-Occupancy Vehicle Lane Safety by Edward Sullivan, N. Devadoss, James Daly, and Alypios Chatziioanou (Sacramento: State of California Department of Transportation, September 30, 1992).

Referring to a study of the ***Santa Monica Freeway***[6]*:*

p. 405 "First week total number of reported accidents (59) was substantially higher than the pre-project average weekly rate of 11.5 accidents, but dropped to an average of 25 total accidents per week. Prior to project, an average of 2.5 injury accidents were reported per week. In first week of operation, this number jumped to 19 accidents, but subsequently dropped to an average of four injury accidents per week."

For further discussion of this document, see pg's B-28 and B-46.

"The Santa Monica Freeway Diamond Lanes: Freeway Accident Analysis by John W. Billheimer, *Transportation Research Record* 663 (1978), pp. 1-7.

p. 1 "...accidents...increased by a factor of 2.5 times pre-project levels..." "...it appears that the most significant factor was the pronounced speed differential..." "The experiment in Santa Monica raises serious questions about the use of barrier-free preferential lanes."

p. 2 "...decline [in accident rate] was still continuing as the project ended." *[It was, using a straight-line trend, at about 100% above pre-project levels (in accidents per week) at the end.]*

[6]The study referred to is *Diamond Lane Project: Fifteen Week Evaluation Report* (Sacramento: State of California Department of Transportation, 1976).

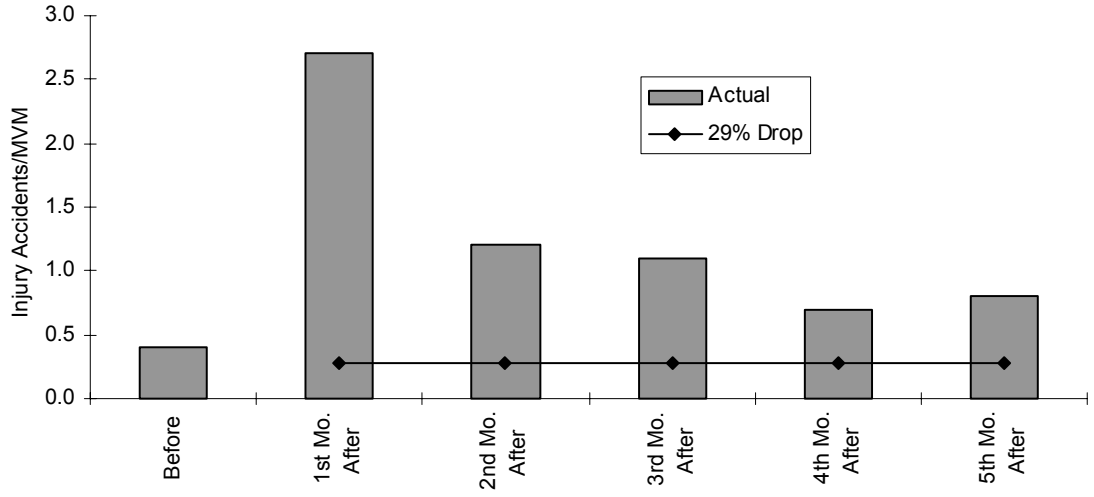
p. 3 "...marked increase of accidents in the Number 2 lane adjacent to the Diamond Lane. The number of accidents in the adjacent lane rose from under two accidents per week prior to the project to 14.8 accidents per week during the Diamond Lane operating hours..." "The average increase in accidents on the entire freeway during project implementation was on the order of 15 accidents per week. Thus, a significant proportion of the overall increase in accidents was concentrated in the Number 2 lane."

p. 5 "After initial increases, freeway accidents in both **Portland [Banfield]** and **Miami [I-95]**, where preferential lanes were created by *adding* [emphasis added] a lane..., dropped below pre-project levels by the second month of operation." *Although the injury accident history of I-95 [see Figure 18d, p. B-20] supports this statement, the injury and total accident histories of the Banfield Freeway [see Figure 18b, following page, and "Portland" section, p. B-44] refutes it.*

See data from this study on the following pages.

FIGURE 18A

Santa Monica Freeway

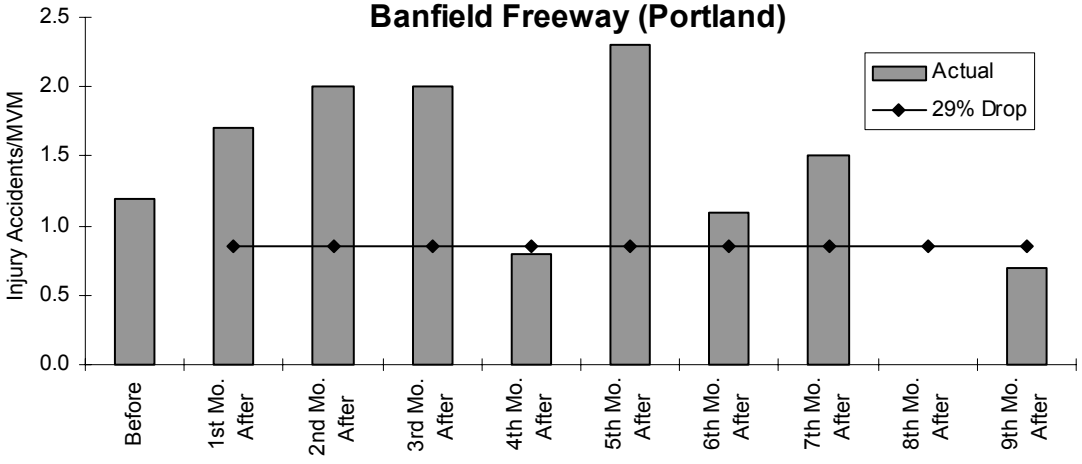


Note: "29% drop" has been added; see p. 3.

Source: John W. Billheimer, "The Santa Monica Freeway Diamond Lanes," p. 7.

FIGURE 18B

Banfield Freeway (Portland)

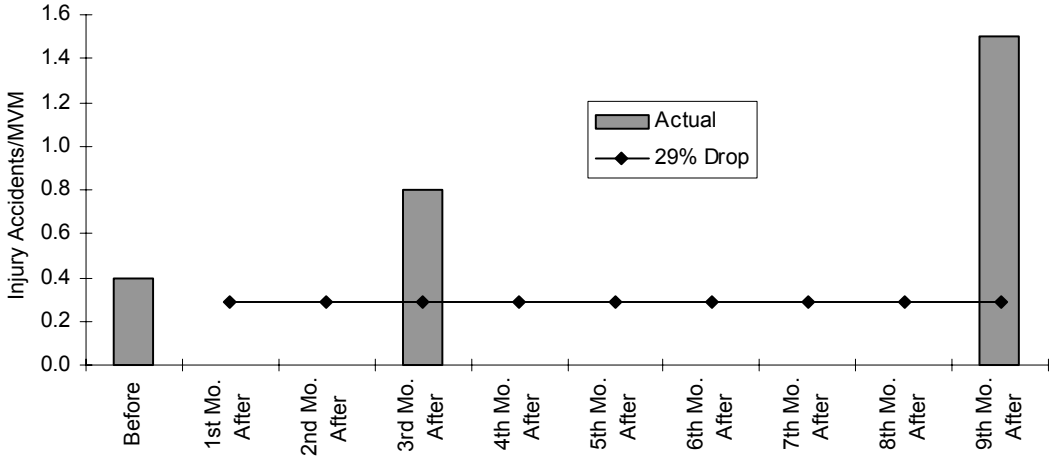


Note: "29% drop" has been added; see p. 3.

Source: John W. Billheimer, "The Santa Monica Freeway Diamond Lanes," p. 7.

FIGURE 18C

Marin 101

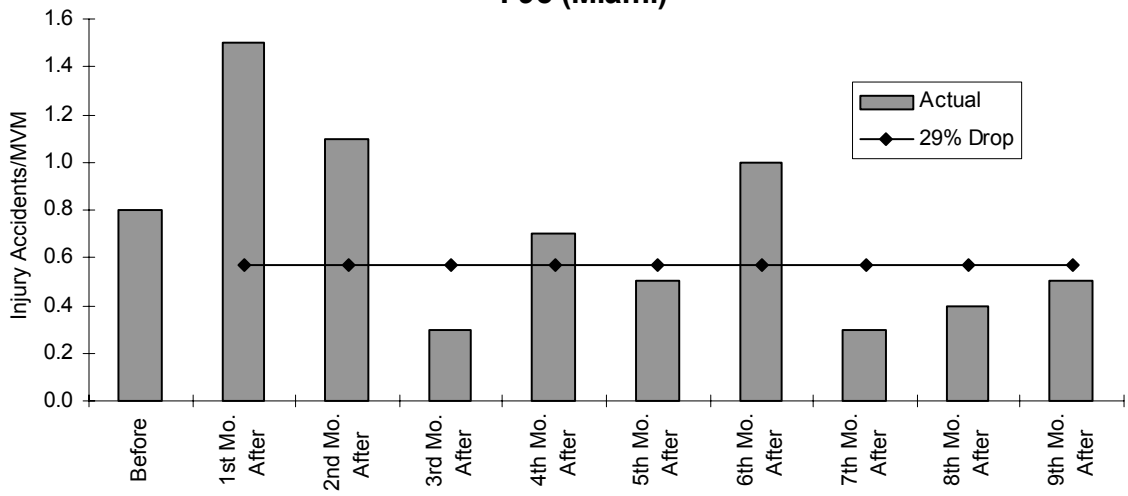


Note: "29% drop" has been added; see p. 3.

Source: John W. Billheimer, "The Santa Monica Freeway Diamond Lanes," p. 7.

FIGURE 18D

I-95 (Miami)



Note: "29% drop" has been added; see p. 3.

Source: John W. Billheimer, "The Santa Monica Freeway Diamond Lanes," p. 7.

LA AREA (CONT'D)-

ROUTE 55 (ORANGE COUNTY)

- *See* Decreased Safety and the HOV Lane*, p. B-10, and* Operational and Safety Experience with Freeway HOV Facilities in California*, p. B-10.*

- *See* High-Occupancy Vehicle Project Case Studies*, p. B-6*.

"Commuter Attitudes Toward Proposed High-Occupancy-Vehicle Lanes in Orange County, California" by Sharon M. Greene and Kenneth L. Barasch, *Transportation Research Record* 1081 (1986), pp. 19-25.

This is a survey concerning proposal of adding a lane in "the area between the center divider and the [existing] left traffic lane" of Route 55.

p. 22-23"On **Route 55** [emphasis added], there was concern that the new lanes would be 'unsafe without the median for emergencies' (34 percent) and 'unsafe for lane changing and getting on/off the lane' (17 percent)."

"Safety of Freeway Median High Occupancy Vehicle Lanes: A Comparison of Aggregate and Disaggregate Analyses" by Thomas F. Golob, Wilfred W. Recker, and Douglas W. Levine, *Accident Analysis and Prevention*, 22, no. 1 (1990) pp. 19-34.

p. 19 "...political success requires community consensus that the HOV strategy is both appropriate and safe." "In its most extreme form, a low-cost HOV lane can be created simply by restriping and converting part or all of the existing median (or left) shoulder for use as a traffic lane. Although low-cost projects are attractive when comparing capital costs,...they have some significant operational disadvantages, including safety and enforcement."

p. 24 "The conclusion from the time series analysis is that the HOV lane has no adverse effect on safety." [*Did not account for effect of added capacity; see Figure 19, page B-23.*]

p. 31 "...within seven months of the implementation of the added lane, extremely heavy congestion has returned to most of the length of **northbound SR-55** [emphasis added] over most of the 2:30 p.m. to 6:45 p.m. time period." [*It is significantly less than it was, however.*]
[*southbound SR-55: congestion increased June '85 (pre) to January '86 (post) and then returned (June '86) to June '85 level*]

p. 31 [This article's figure 14 (northbound) appears to indicate that the effect of congestion is greater with HOV; its figure 15 (southbound) does not indicate a change.]

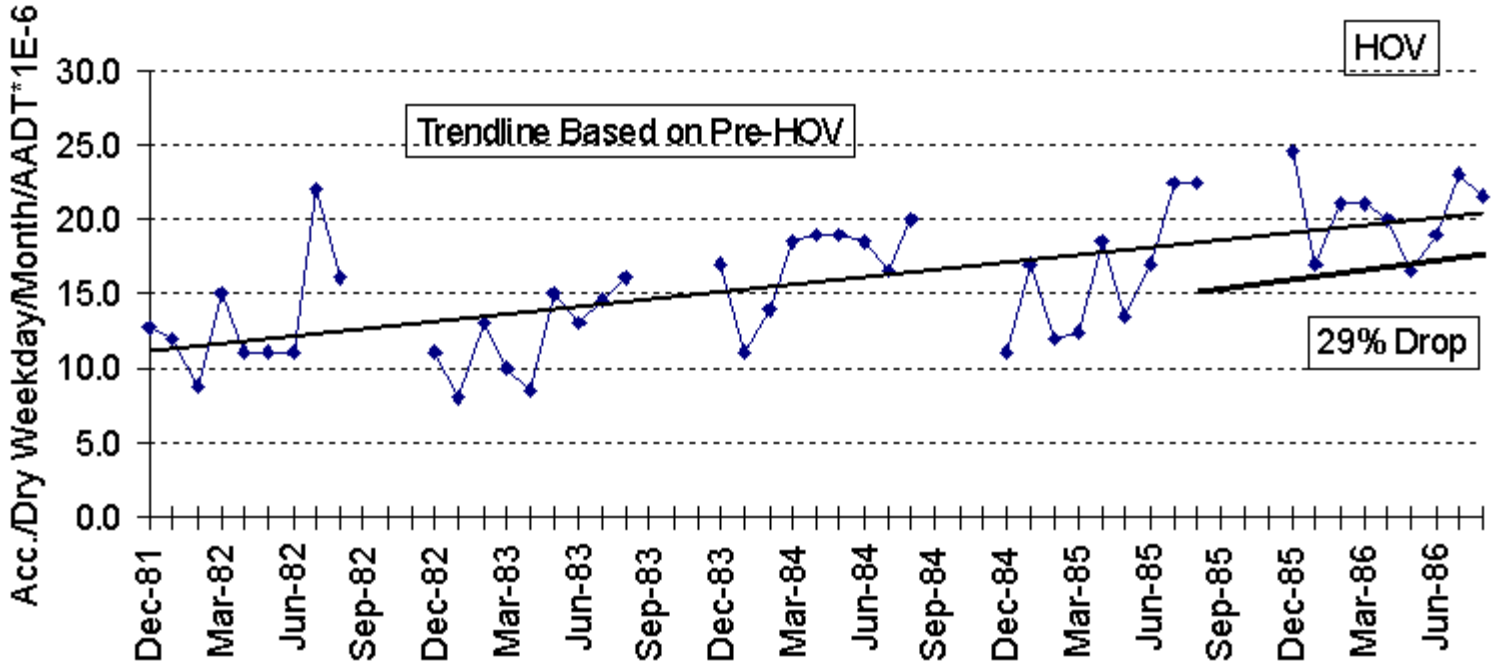
p. 33 "...it may not be possible to determine the effects on traffic safety of an HOV lane installed in a freeway median using aggregate accident history information alone."
"...there are up to approximately 2% more accidents on SR-55 resulting from HOV

operation of the added lane, as opposed to mixed-flow operation. There is no way to place a confidence bound on this estimate."

See figure on following page.

FIGURE 19

Route 55



Note: "29% drop" added; see p. 3.

Source: Golob, Recker, and Levine, "Safety of Freeway Median High Occupancy Vehicle Lanes," p. 22.

LA AREA (Continued)-

LA- ROUTE 91 (LA COUNTY)

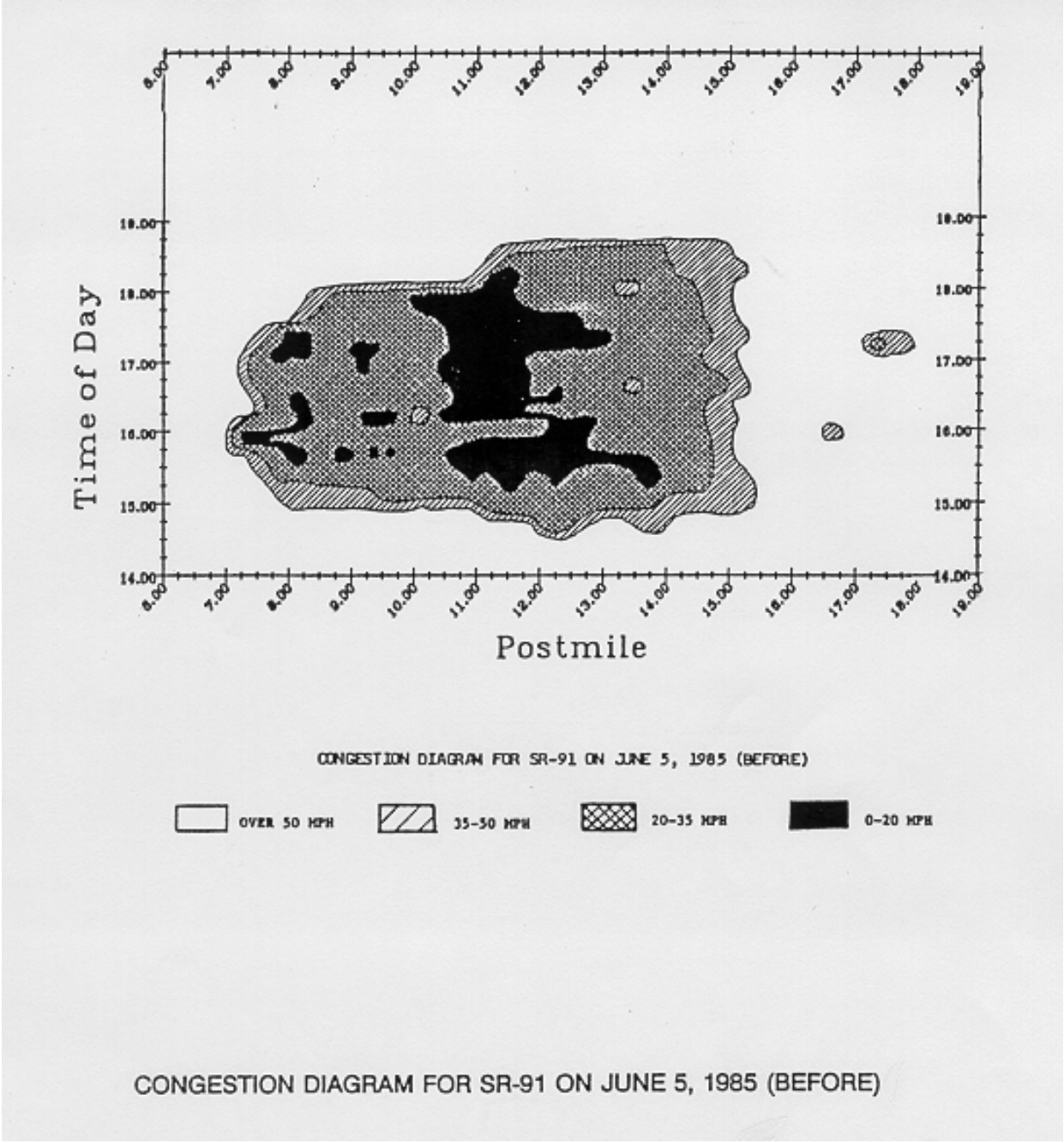
- *See* High-Occupancy Vehicle Project Case Studies*, p. B-6.*
- *See* Operational and Safety Experience with Freeway HOV Facilities in California*, p. B-10*.

Safety of High Occupancy Vehicle Lanes without Physical Separation by Thomas F. Golob, Wilfred W. Recker, and Douglas W. Levine (Irvine, CA: University of California, Irvine, Institute of Transportation Studies, 1988).

p. 37 "All of the changes in the patterns of reported accidents on SR-91 can be attributed to changes in the location and timing of traffic congestion." *Yet the report's congestion diagrams (see following pages) show that total congestion decreased, as one would expect with a lane addition.*

For accident history, see Figure 20, p. B-27.

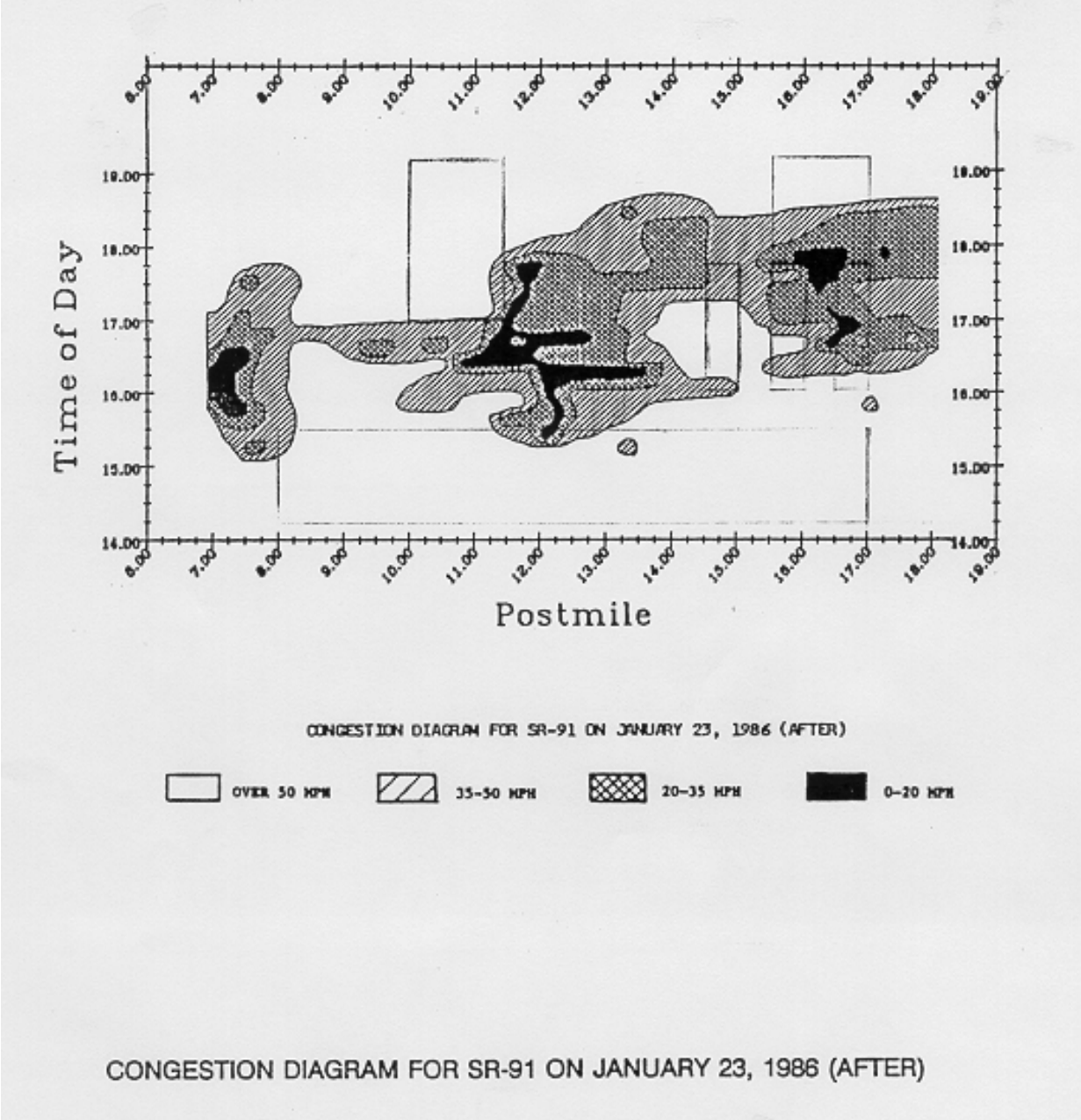
INSERT A
CONGESTION DIAGRAM FOR SR-91 ON JUNE 5, 1985 (BEFORE)



CONGESTION DIAGRAM FOR SR-91 ON JUNE 5, 1985 (BEFORE)

Source:
Safety of High Occupancy Vehicle Lanes without Physical Separation
by Thomas F. Golob, Wilfred W. Recker, and Douglas W. Levine
p. 16

INSERT B
CONGESTION DIAGRAM FOR SR-91 ON JUNE 5, 1985 (AFTER)

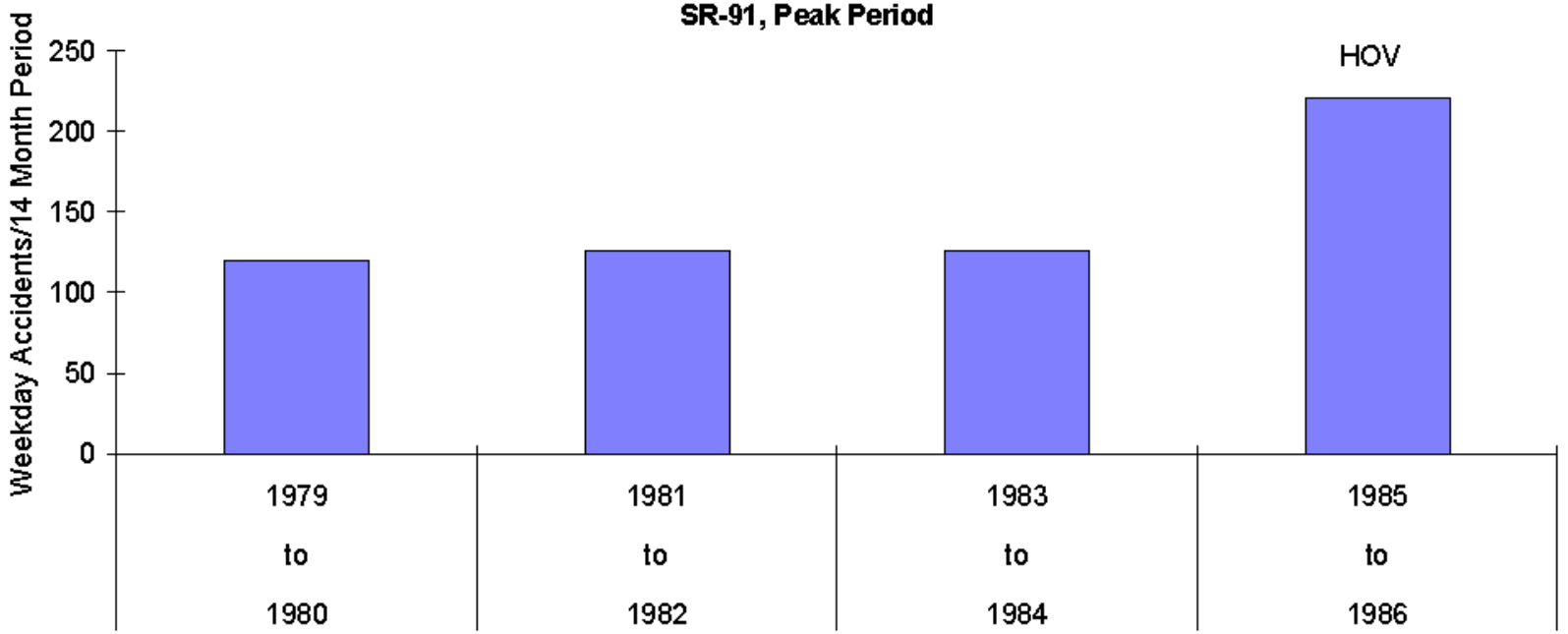


CONGESTION DIAGRAM FOR SR-91 ON JANUARY 23, 1986 (AFTER)

Source:
Safety of High Occupancy Vehicle Lanes without Physical Separation
by Thomas F. Golob, Wilfred W. Recker, and Douglas W. Levine
p. 17

FIGURE 20

SR-91, Peak Period



Source: Golob, Recker, and Levine, *Safety of High Occupancy Vehicle Lanes Without Physical Separation*, p. 29.

LA AREA (Continued)-

I-405 (ORANGE COUNTY)

High Occupancy Vehicle Lane Safety by Edward Sullivan, N. Devadoss, James Daly, and Alypios Chatziioanou (Sacramento: State of California Department of Transportation, 1992).

p. 323 "...no major systematic differences in accident characteristics...could be attributed directly to the presence of the HOV lanes."

P. 15 "It should be emphasized that this study addresses cross-sectional comparisons (an HOV section against one or more control/non-HOV section(s)) rather than before and after comparisons of HOV facility implementation. Although imperfect, the cross-sectional approach was chosen to avoid the influence of changes in traffic volumes and other underlying conditions over time. Resources did not permit both cross-sectional and before-after comparisons..."

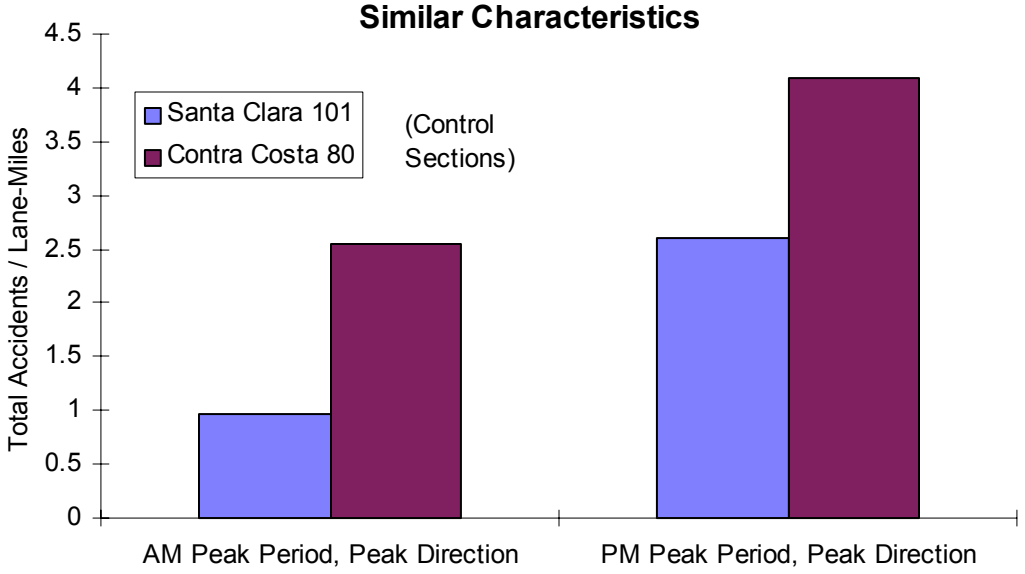
p. 11 "The control sections were selected based on their traffic flow and geometric features being similar to the HOV facility." *Accident rates vary significantly even between facilities with similar "traffic flow and geometric features." In fact, the two control sections (San Mateo 101 and Contra Costa 80) used for comparison to one of the HOV projects studied (Santa Clara 101) had significantly different accident rates (see Figure 21a, following page). Therefore the results of this study are inconclusive.*

See data for I-405 on Figure 21b, following page.

For further discussion of this document, see pg's B-17 and B-46.

FIGURE 21A

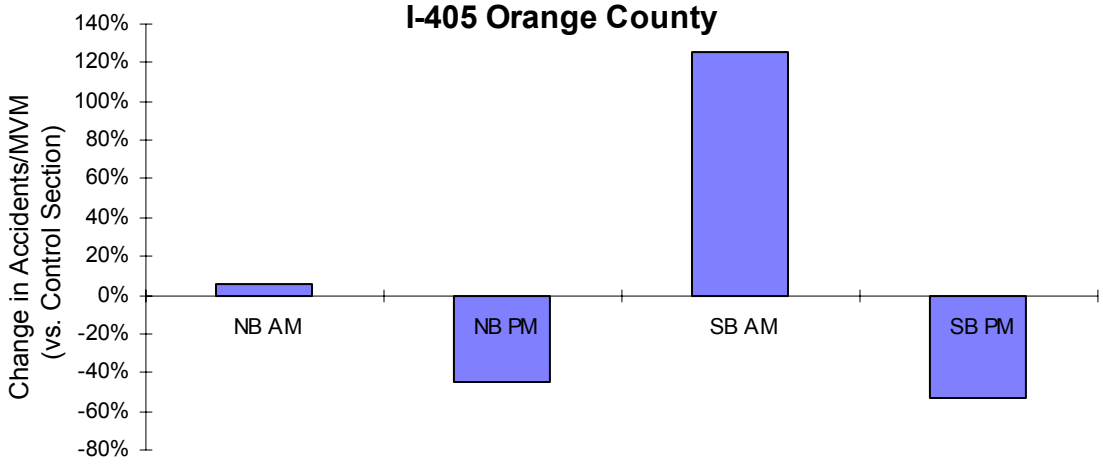
Differing Accident Rates Between Projects with Similar Characteristics



Source: Sullivan, et al., p. 111.

FIGURE 21B

3'-8' Buffer
Concurrent-Lane HOV, Peak Period
I-405 Orange County



Note: Data represents a one year accident data span beginning two months after implementation.
Source: Sullivan, et al., p. 247.

LA AREA (Continued)-

SAN BERNARDINO FREEWAY (I-10)

See "full buffer" data in Operational and Safety Experience with Freeway HOV Facilities in California*, pg's B-10 through B-13. All of the full buffer data in that study is based on sections of the San Bernardino Freeway (I-10).*

TSM Project Violation Rates, draft final report, vol. II, *Technical Report* by John W. Billheimer, Juliet McNally, and Robert Trexler (Los Altos, CA: Systan, Inc., October 1981).

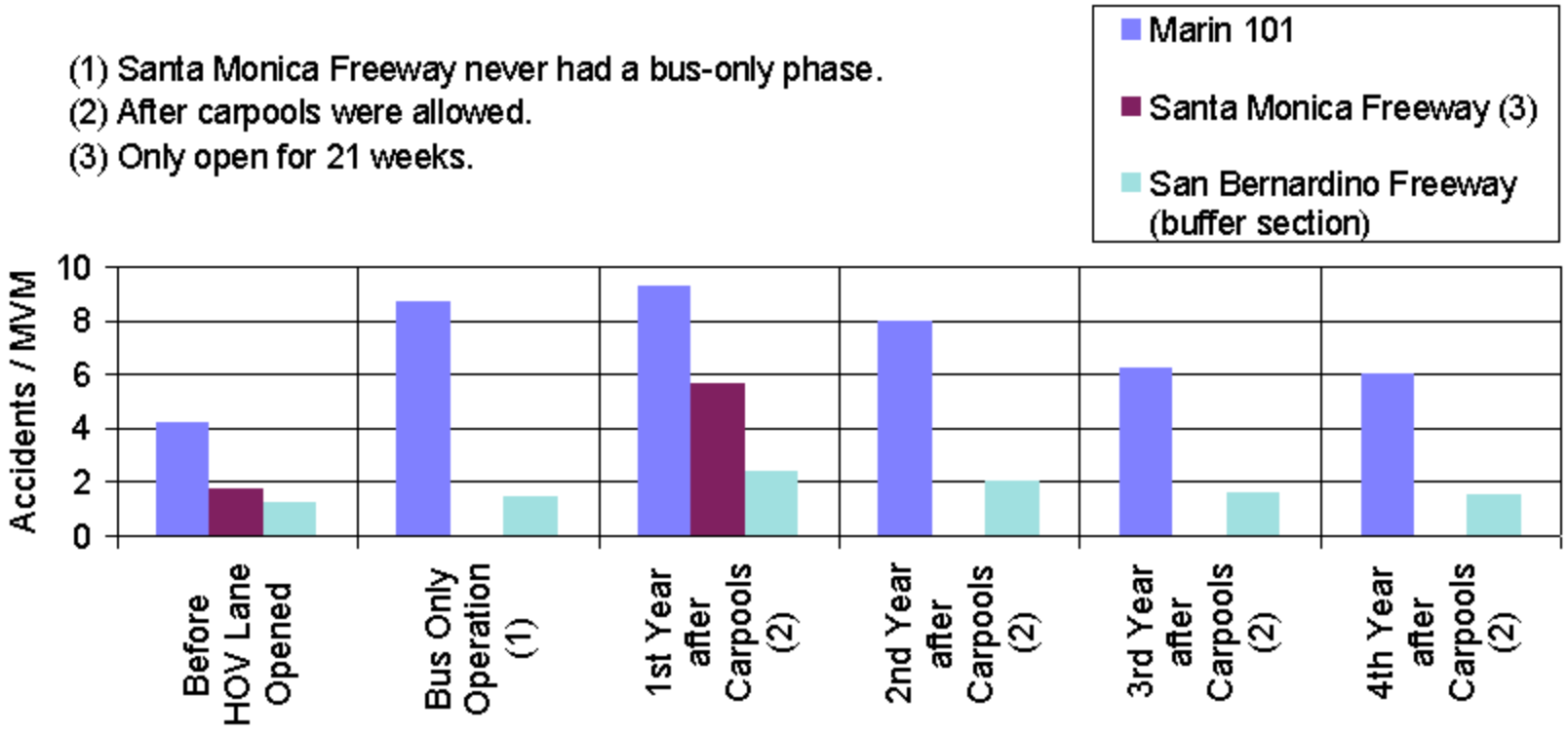
See data from this study, for this and other projects, on following pages.

For further discussion of this study, see page B-46.

FIGURE 22

AM Peak Period, Peak Direction

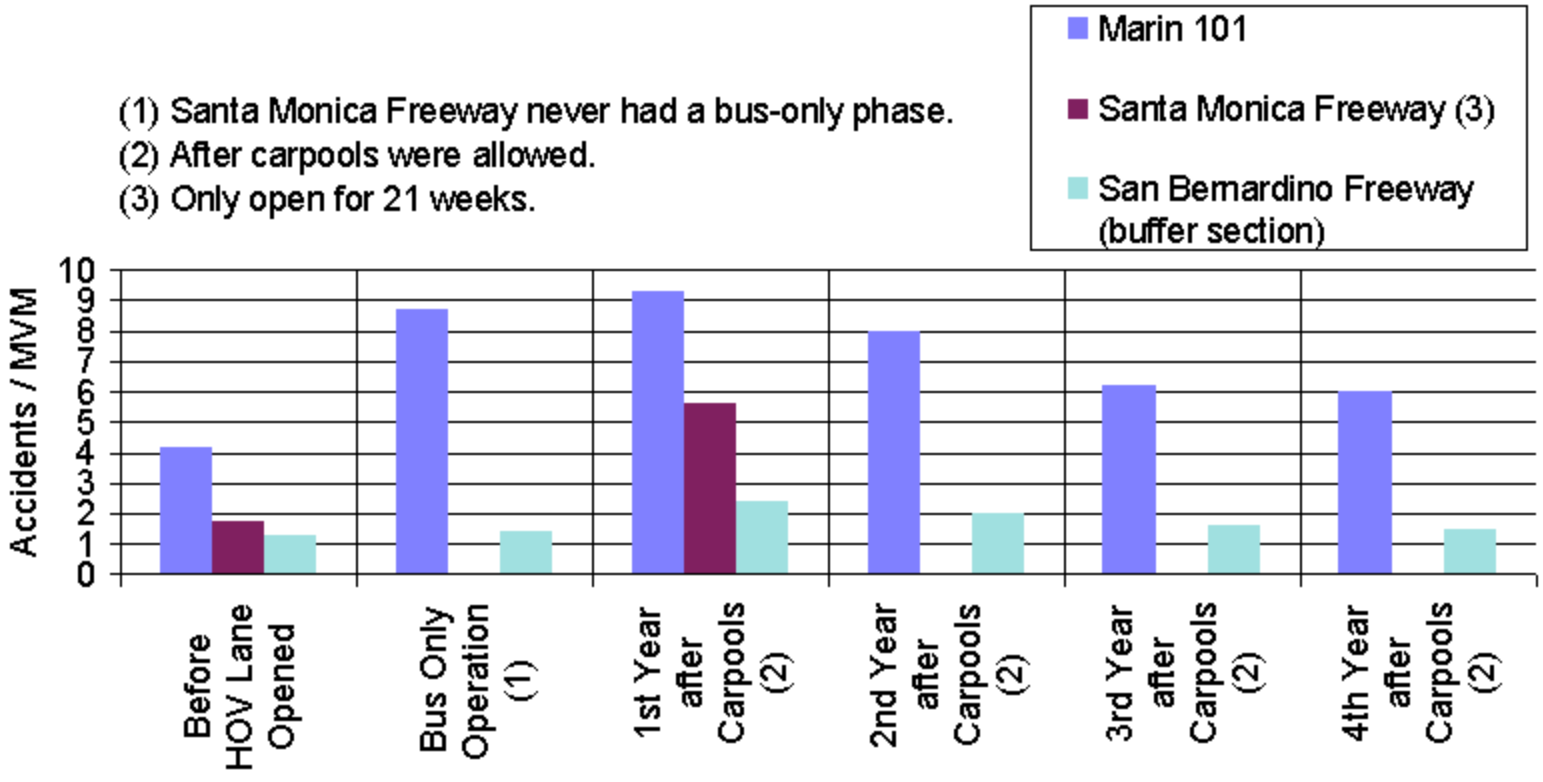
(1) Santa Monica Freeway never had a bus-only phase.
(2) After carpools were allowed.
(3) Only open for 21 weeks.



Source: Billheimer, McNally, and Trexler, pp. 4-21 & 4-23.

FIGURE 23

PM Peak Period, Peak Direction



Source: Billheimer, McNally, and Trexler, pp. 4-21 & 4-23.

MIAMI- I-95

- *See "Freeway Concurrent Flow High Occupancy Vehicle Lanes," p. B-5*.
- *See* Study of Current and Planned High Occupancy Vehicle Lanes, *p. B-1*.
- *See* High-Occupancy Vehicle Facilities, *p. B-3*.
- *See* The Santa Monica Freeway Diamond Lanes, *p. B-17*.

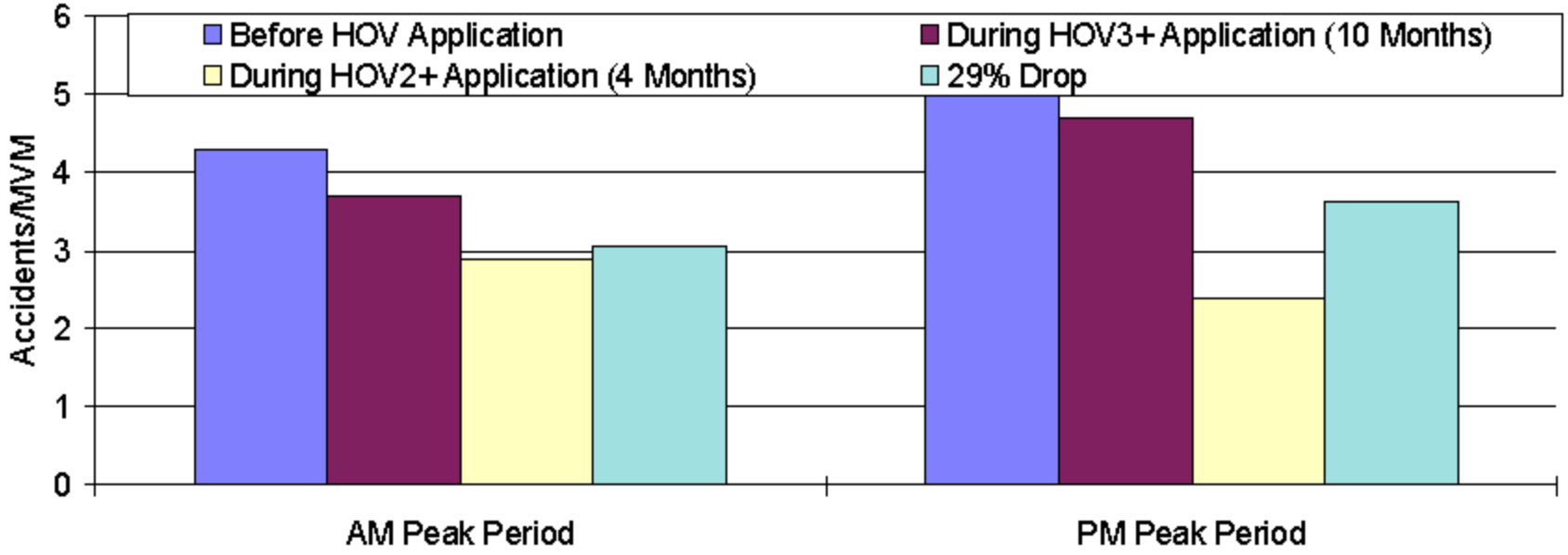
Safety Evaluation of Priority Techniques for High Occupancy Vehicles by Craig Miller, Robert Deuser, Joseph Wattleworth, and Charles Wallace (Washington: Federal Highway Administration, 1979).

See data from this study, for the I-95 project, on following page.

For further discussion of this study, see page B-6.

FIGURE 24

I-95 Miami



Note: "29% drop" has been added; see p. 3.

Source: Miller, et al., p. 38.

MINNEAPOLIS- I-394

➢ *See* High-Occupancy Vehicle Project Case Studies, *p. B-6*.

I-394 Interim HOV Lane: A Case Study (phase I report) by Strgar-Roscoe-Fausch, Inc (St. Paul, MN: Minnesota Department of Transportation, October 1987).

p. 14 "The I-394 HOV lane appears to be operating very safely. Accident data is very spotty, but conversations with enforcement agencies indicate that the only accidents which have occurred in the HOV lane have been minor accidents related to adverse winter weather conditions or drunk drivers hitting the entrance gates at night."

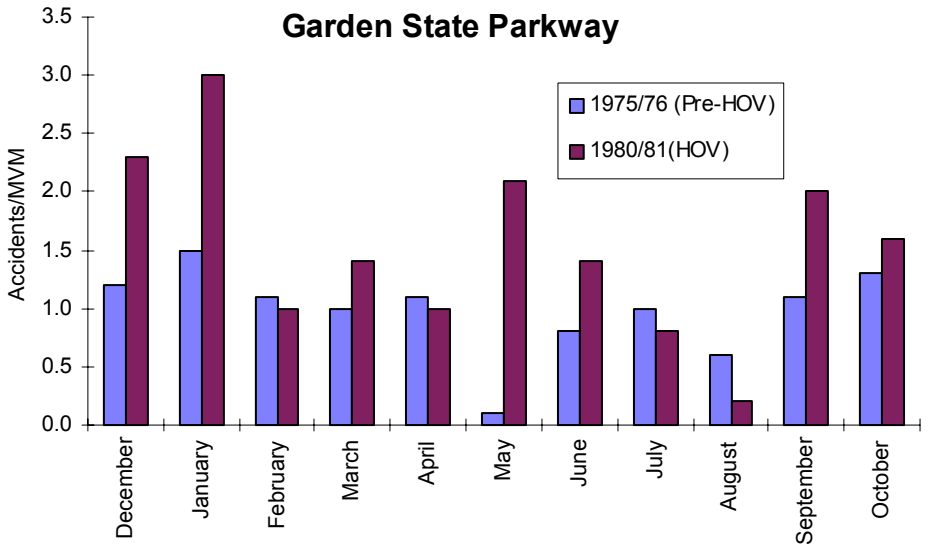
NEW JERSEY- GARDEN STATE PARKWAY

"Garden State Parkway HOV Lane" by John Powers, *Transportation Research Record* 906 (1983), pp. 54-56.

p. 56 "The peak-period accident rates in the HOV lane section increased by as much as 100 percent to 2.97 accidents/million vehicle miles during the first two months of operation in comparison with a rate of 1.49 accidents/million vehicle miles for the same time of year in the before period of 1975-1976. Initial increases of this type have been observed on other highways where HOV lanes have been implemented."

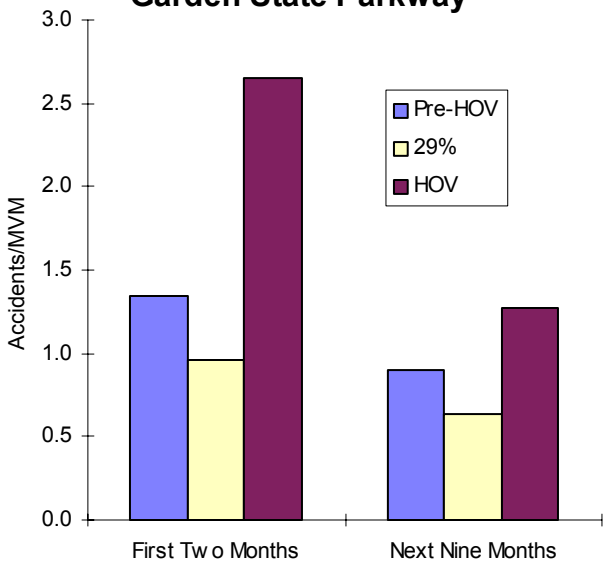
"After January, peak-period accident rates in the HOV lane section declined..." "Such a drop to pre-construction rates has been observed in successful HOV lane operations elsewhere." [*The rates still tended to be somewhat higher; see following page.*]

FIGURE 25



Source: Powers, p. 55.

FIGURE 26



Source: Powers, p. 55.

NORTHERN VIRGINIA-

I-95

I-95 HOV/Shoulder Travel Lane Use, Part II by Bernice H. Strommer (Richmond: Virginia Department of Transportation, January 1992).

p. 9 "The findings of an earlier study dated May, 1988 suggest that shoulder travel use combined with HOV operation does pose a safety threat. *[No mention of whether this threat is due to shoulder or HOV lane or both.]* More accidents occurred during the HOV/shoulder travel lane operation (September, 1986 through December 1987) [*NB operation began 12/85; SB began 7/86*] than during the control period (September, 1984 through December, 1985). The proportion of rear-end accidents during rush hour northbound and southbound HOV/shoulder travel lane operation, however, did not increase from that during the control period. Accident rates during HOV/shoulder travel lane operation rose above the interstate accident rate for the entire Northern Virginia District and the rates for northbound and southbound during the rush hours increased **101 and 81 percent** [emphasis added], respectively from that of the control periods."

"Monitor of accidents on HOV I-95 continued...and studies were completed in November, 1989 and July, 1990. The findings indicated that the number of accidents for total vehicles as well as total vehicle accident rate had stabilized for northbound direction in 1986, 1987, and 1988. HOV/shoulder travel lane use started September, 1986. [*No, NB operation began 12/85 and SB began 7/86, but the analysis period did start September, 1986.*] Reduced speed and work zone surveillance could account for the lower accident rates in 1985. *[But in the Banfield study (see Figure 29, p. B-45) construction made accidents go up.]* This section of I-95 underwent construction from September 1985 through June, 1986."

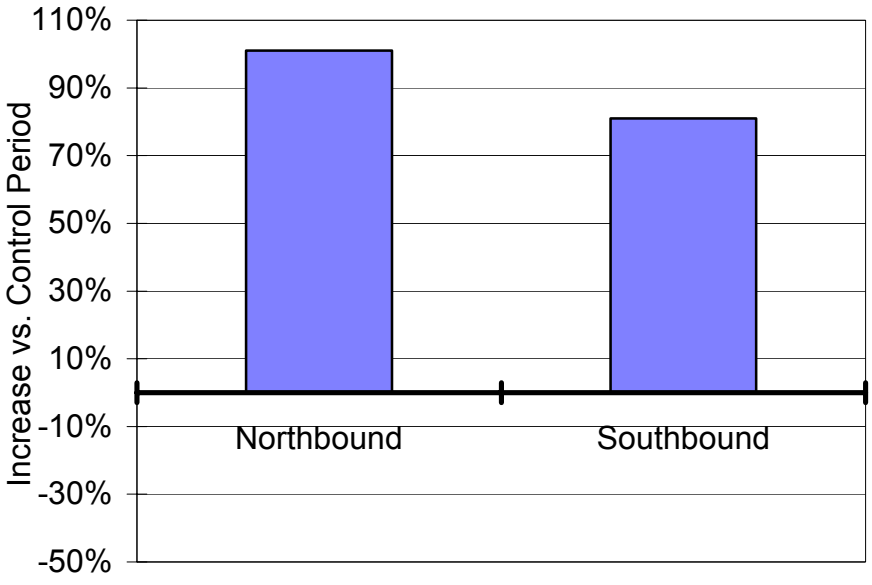
<u>Conclusions</u>

p. 24 "Accident rates on the HOV portion of I-95 initially rose when shoulder usage was adopted and have stabilized at double the interstate accident rate for the entire Northern Virginia District."

See data from this study on following page.

FIGURE 27

Northern Virginia - I-95
Peak Period



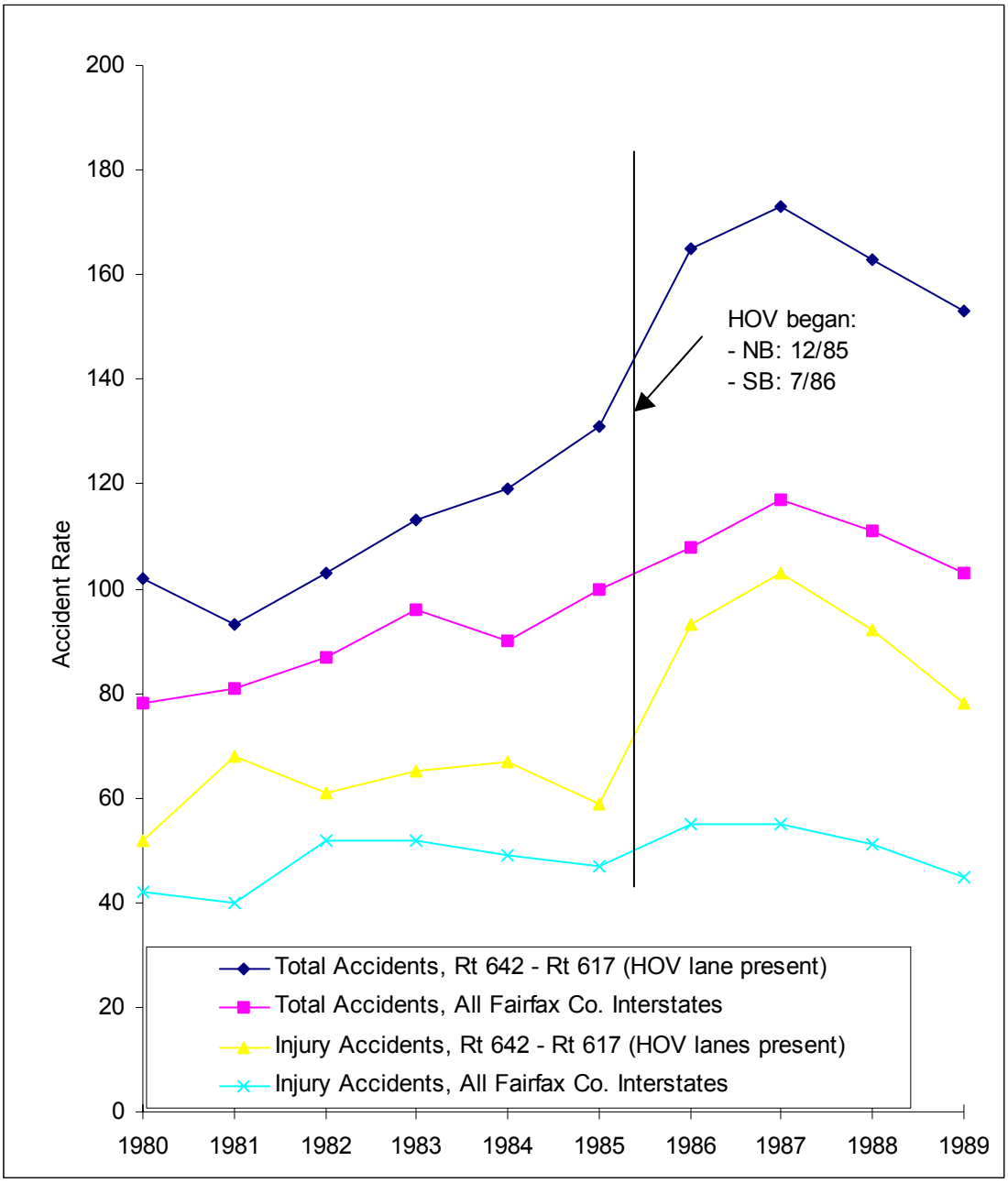
Source: Strommer, p. 9.

High Occupancy Vehicle (HOV)/Shoulder Travel Lane Use on Interstate Route 95 in Northern Virginia (Richmond: Virginia Department of Transportation, May 1991, revised December 1991).

Appendix D "...there appears to be a significant increase [in accident rates] after 1985." [Tom Jennings, FHWA] *The chart on the next page followed his comments.*

"Accident rates [for I-95] have generally gone up on HOV sections compared with the non-HOV control section." [J. L. Butner] *See charts, p. B-41*.

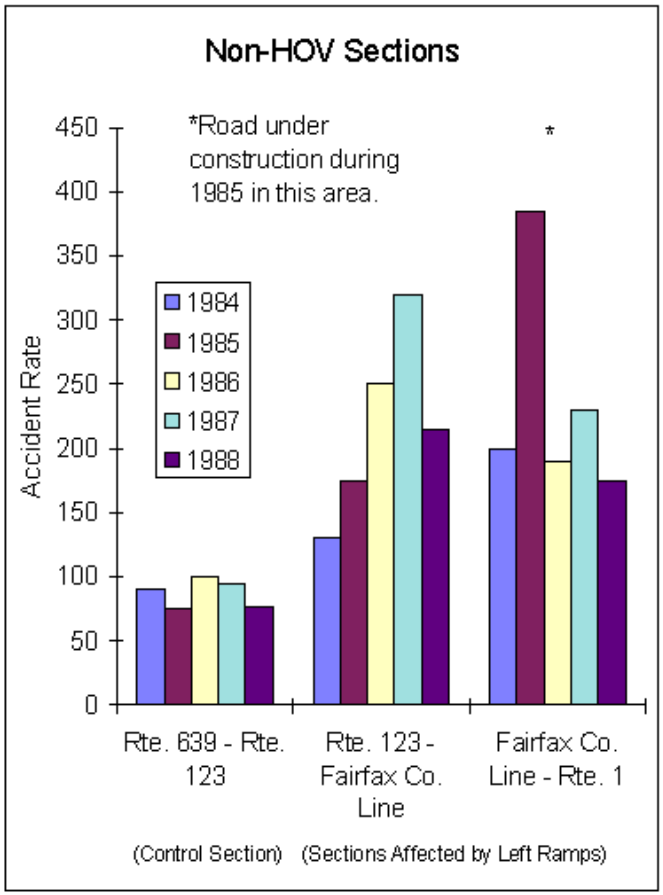
INSERT C
SECTION OF I-95 WITH HOV VS. ALL FAIRFAX CO. INTERSTATES

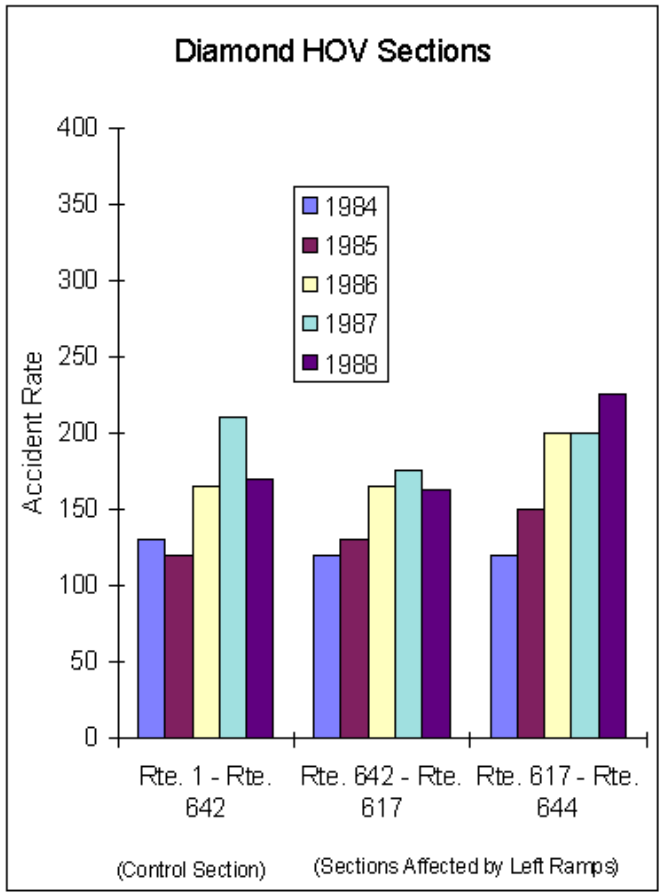


Source: *High Occupancy Vehicle (HOV);/Shoulder Travel Lane Use on Interstate Route 95 in Northern Virginia*, p. D-4

INSERT D

I-95 ACCIDENT DATA BY YEAR





Note: Some limits of study sections were illegible on original charts; the limits shown have been ascertained with the aid of the FHWA.

Source: *High Occupancy Vehicle (HOV)/Shoulder Travel Lane Use on Interstate Route 95 in Northern Virginia*, p. D-12.

Assessment of Accidents and HOV/Shoulder Travel Lane Use on I-95 from Route 644 to Route 1 North of Woodbridge in Fairfax County*, Update with Supplement on Left-hand Exits and Entrances* (Richmond: Virginia Department of Transportation, July 1990).

p. 1 "The accident rate...increased from 159 (per 100 mvm) for the control period [9/84 to 12/85] to 222 during the HOV/shoulder travel lane operation [evaluated from 7/86 to 12/87]. This is a 40 (39.6) percent rise. This increase is attributed to the conditions both in the northbound and southbound directions [*conditions unspecified*]."

p. 2 "For the morning peak, the accident rate for the northbound direction [experienced] a 101 percent increase. For the evening peak, the accident rate for the southbound direction [experienced] an 81 percent increase."

p. 3 "The findings of the initial evaluation suggest that shoulder travel lane use combined with HOV operation pose a safety threat."

Fact Sheet about I-95 HOV/Shoulder Travel Operation (Richmond: Virginia Department of Transportation, undated).

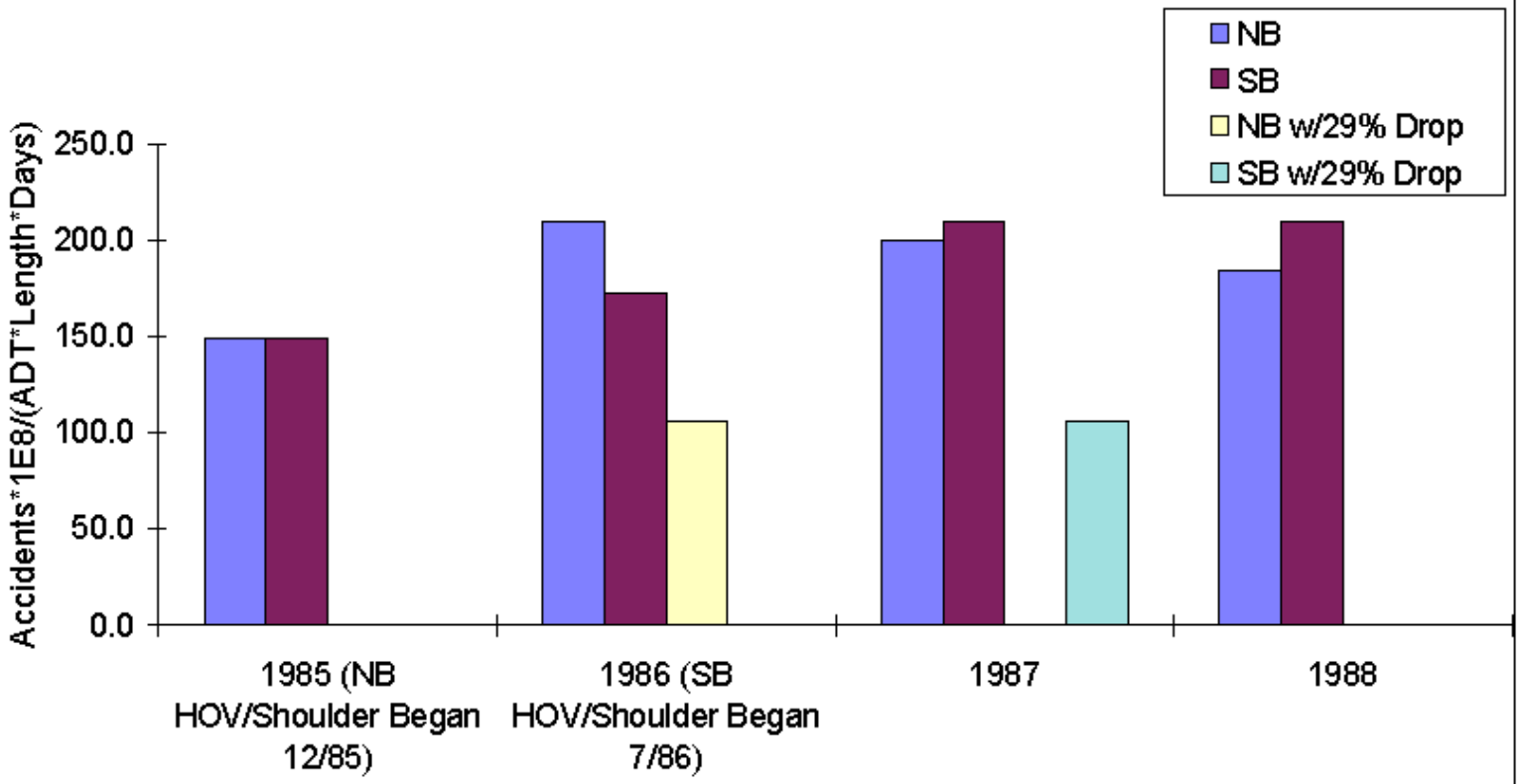
"...the substantial increase in accidents experienced with shoulder travel lane [and HOV] operation during the rush..."

Supplemental Study, Update of HOV/Shoulder Travel Lane Use on I-95, *Appendix F* (Richmond: Virginia Department of Transportation, undated).

See data from this study on following page.

FIGURE 28

Northern Virginia - I-95
24 Hour Rates



Note: "29% Drop" data was added; see p. 3.

Source: "Supplemental Study, Update of HOV/Shoulder Travel Lane Use on I- 95," Table 8.

NORTHERN VIRGINIA (Continued)-

I-66

- *See* Study of Current and Planned High Occupancy Vehicle Lane Use, *p. B-1*.

PORTLAND- BANFIELD FREEWAY

- *See* The Santa Monica Freeway Diamond Lanes, *p. B-17*.

Banfield High Occupancy Vehicle Lanes (Washington: Federal Highway Administration, March 1978).

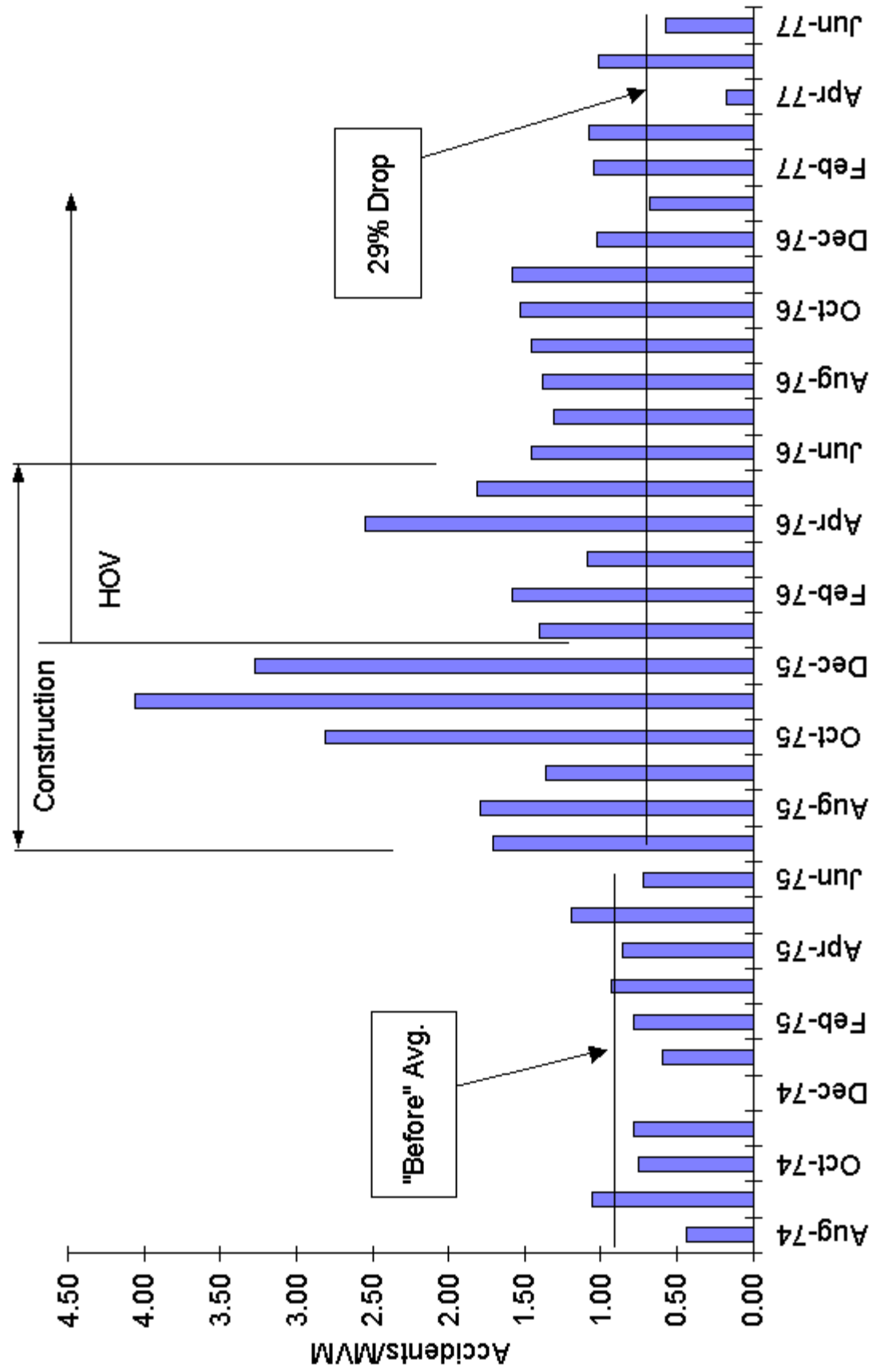
p. 82 "The difference in peak period travel speed between the faster moving HOV traffic and the congested normal traffic has...proven not to be a problem." "The HOV motorists tend to adjust their speed to the adjacent traffic flow so as to allow sufficient stopping time in emergency situations."

p. 83 "...accident rate per million vehicle miles...traveled has returned to pre-HOV lane levels."

See data from this study on following page.

FIGURE 29

Banfield Freeway



SAN FRANCISCO-

MARIN 101

- *See* Decreased Safety and the HOV Lane, *p. B-10*.
- *See* Operational and Safety Experience with Freeway HOV Facilities in California*, p. B-10*.
- *See* Synthesis of Safety Research Related to Traffic Control and Roadway Elements, *p. B-14*.

TSM Project Violation Rates, draft final report, vol. II, *Technical Report* by John W. Billheimer, Juliet McNally, and Robert Trexler (Los Altos, CA: Systan, Inc., October 1981).

p. 4-17 "Accidents decreased moderately in the AM but increased by 81% in the PM period on Marin 101." *For data see Figures 22 and 23, pg's B-31 and B-32.*

p. 4-25 "The increases in accident rates accompanying barrier-free preferential lanes raises serious questions regarding the suitability of this design in certain settings."

For further discussion of this study, see page B-30.

High Occupancy Vehicle Lane Safety by Edward Sullivan, N. Devadoss, James Daly, and Alypios Chatziioanou (Sacremento: State of California Department of Transportation, September 30, 1992).

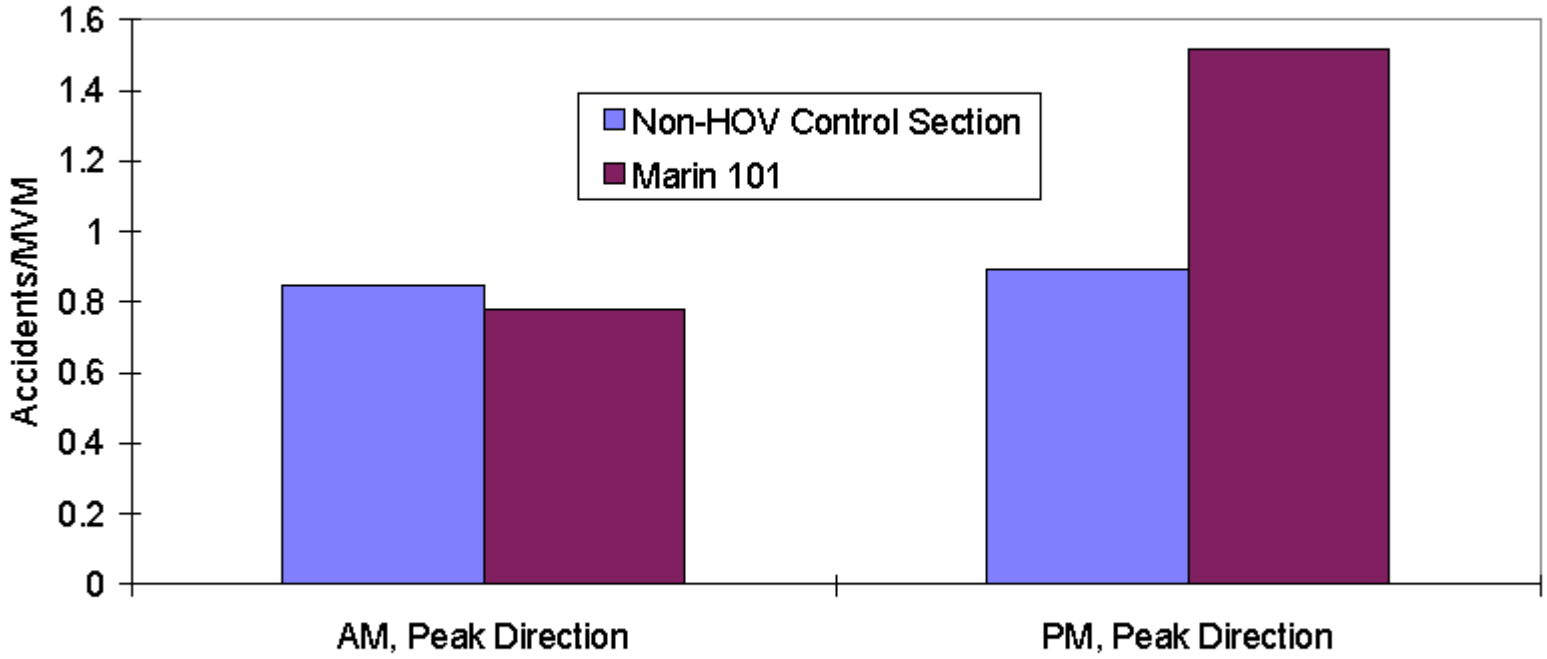
p. 323 "...no major systematic differences in accident characteristics...could be attributed directly to the presence of the HOV lanes."

See data for Marin 101 from this study on following page.

For further discussion of this study, see pg's B-17 and B-28.

FIGURE 30

Marin 101



Note: Excluding accidents occuring under "atypical" or "irrelevant conditions."

Source: Sullivan, et al., p. 166.

SAN FRANCISCO (Continued)-

I-280

- *See* Operational and Safety Experience with Freeway HOV Facilities in California, *p. B-10*.
- *See* Synthesis of Safety Research Related to Traffic Control and Roadway Elements, *p. B-14*.

ALAMEDA 580

- *See Figure 4, p. 8*.

SEATTLE- VARIOUS PROJECTS

Task 2.4 Safety and Enforcement Improvements Assessment *HOV Pre-Design Studies: Puget Sound Region* by JHK & Associates (Olympia, WA: Washington State Department of Transportation, dates provided below).

Working Paper 1: Existing Conditions (August 20, 1994)

p. 2 "...HOV lane accidents were classified as those which occurred either in an HOV lane or in the shoulder adjacent to an HOV lane."

of the five segments having charts showing accidents per 100,000 vehicles:

> *For 3 segments, the HOV rate looks approximately equal to the general purpose (GP) rate;*
>
> *For 2 segments, the HOV rate looks significantly higher than the GP rate.*

Working Paper 2: Conceptual Solutions (November 1, 1994)

p. 3 "The presence of a buffer zone (typically a two- to four-foot striped and/or textured strip between GP and HOV lanes) increases the sight distance and available stopping time of vehicles wishing to enter the HOV lane from a GP lane. Buffer zones also act as access restrictions (to cross them is a violation) in most existing applications."

Working Paper 3: Evaluation of Conceptual Solutions (January, 1995)

p. 12 "This solution entails the placement of a permanent New Jersey barrier...for the purpose of preventing the lane changes which appear to be causing the existing safety deficiencies at this location."

p. 13 "This solution was suggested to...reduce the high HOV/GP speed differential which appears to be contributing to the extremely high HOV accident rates in the 130th/145th area."

Evaluation of Seattle's South I-5 Interim HOV Lanes (preprint from Transportation Research Board, 72nd Annual Meeting, 1993) by Gary Farnsworth and Cyrus G. Ulberg (Washington: Transportation Research Board, 1993).

p. 8 "The average number of accidents in the left hand lanes of the facility increased from 2 per month to 7 per month, after the HOV lanes were installed." "This added congestion would not have occurred if these lanes were continuous with the highway or had ended at unobtrusive termination points."

I-5 North High-Occupancy Vehicle Lane 2+ Occupancy Requirement Demonstration Evaluation, *Working Paper* by Cy Ulberg, et al. (Olympia, WA: Washington State Department of Transportation, February 1992).

[Examines change from 3+ to 2+ only:]

p. xiii "No discernible trends were identified associated directly with the change [3+ to 2+]. However, the areas downstream from both the northbound and southbound HOV lane reflect an increasing accident rate, which started before the implementation of the demonstration."

Design Criteria for HOV Facilities, Section 1050 (memorandum) by D. C. Jackson (Olympia, WA: Washington State Department of Transportation, January 5, 1994).

p. 11 "Buffer widths between...4 and 8 ft are not considered desirable since they may be mistakenly used as a refuge area for which they would be inadequate."

p. 4 "...the ease of access [of concurrent flow lanes] also can create...higher potential for conflicts, particularly considering the speed differential between the HOV lane and the mixed traffic lanes. These operational shortcomings can be alleviated somewhat by the use of a buffer between the HOV lane and the general-purpose lanes."

Six-year Flow Evaluation by Kim C. Henry and Omar Mehyar (Seattle, WA: Washington State Department of Transportation, January 1989).

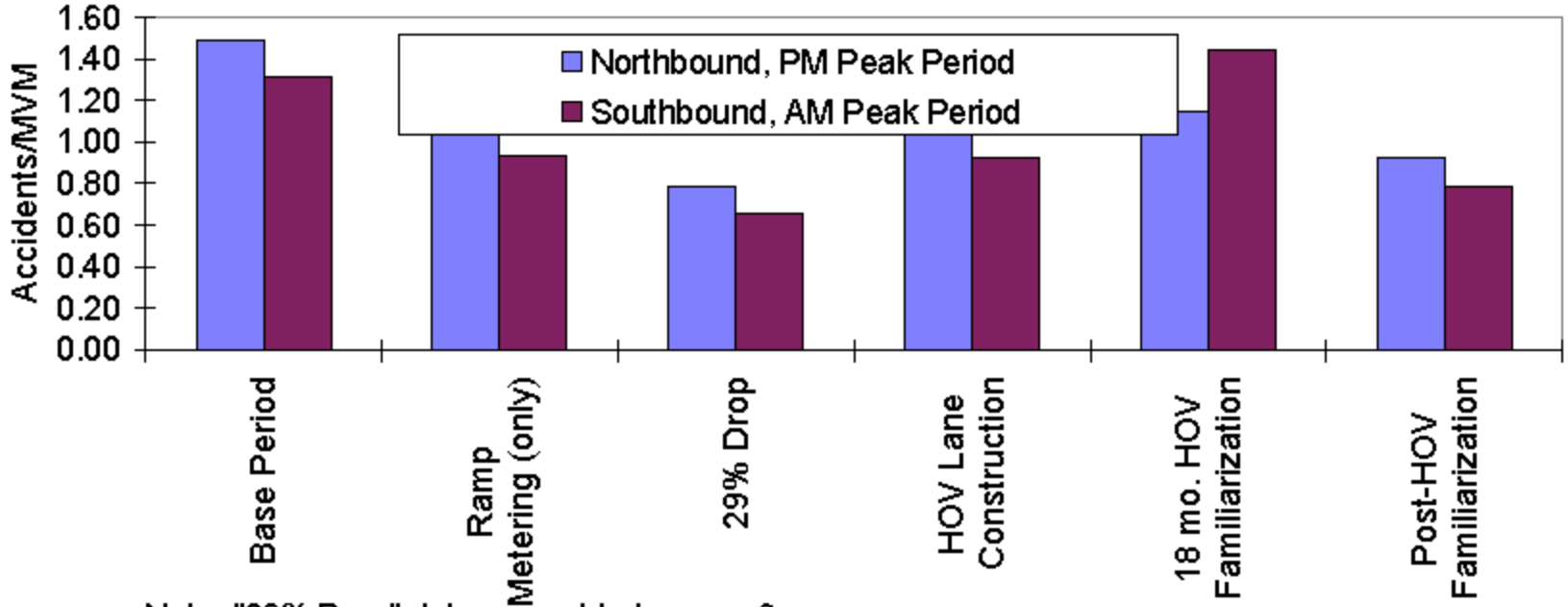
See data from this study on following page.

I-5 Southcenter Hill Vicinity Interim HOV Lane Operational Analysis, *draft,* by Eldon L. Jacobson (Olympia, WA: Washington State Department of Transportation, June 1994)

See data from this study on page 51.

FIGURE 31

Seattle- I-5

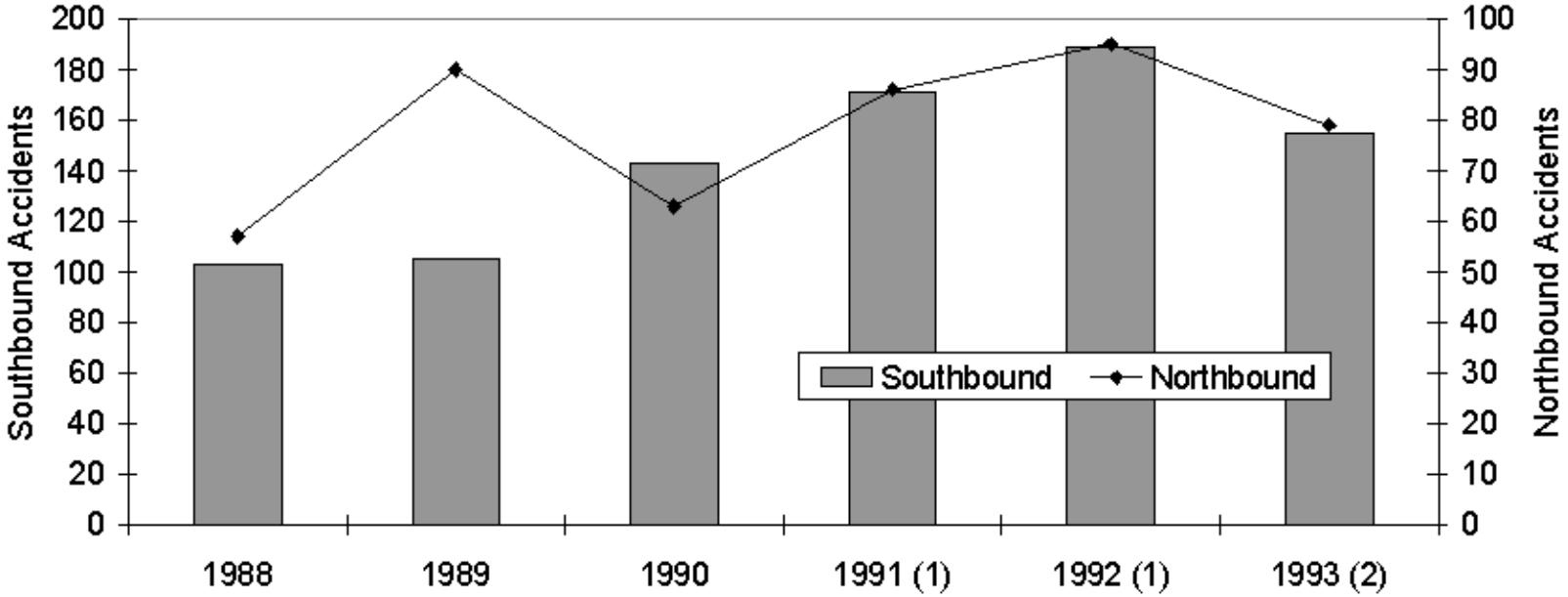


Note: "29% Drop" data was added; see p. 3.

Source: Henry and Mehyar, pp. 47, 48.

FIGURE 32

I-5 Interim HOV Lanes, Southcenter Hill Vicinity (Seattle)



(1) HOV lanes openned 8-19-91.

(2) Southbound restriping and southbound and northbound changed from 3+ to 2+ 12-92.

Source: Jacobson, p. 1 (Appendix A), p. 1 (Appendix B).